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VIA HAND DELIVERY

City of Riverside
Planning Division
Attn: Diane Jenkins, AICP, Principal Planner
3900 Main Street, Third Floor
Riverside, CA 92522

RE: Draft EIR Crystal View Terrace/ Green Orchard Place/ Overlook Parkway Project (P11-0050) for the City of Riverside, California (SCH No. 2011021028)

Greetings:

On behalf of the Stop the Overlook Parkway Connection, I hereby submit these comments on the Draft EIR for, and in opposition to, the Crystal View Terrace/ Green Orchard Place/ Overlook Parkway Project.

General Comments/Summary:

The California Environmental Quality Act (CEQA) was adopted as a disclosure and transparency document. The theory is that by providing a document that adequately describes the environmental consequences of a project to decision makers and the public, the decision makers will make a rational decision based upon the true environmental consequences of the project and if they do not, the electorate can hold them accountable for their decisions. The core of this statutory structure is the adequacy of the document as an informational document.

ANALYSIS

Unfortunately, the Draft EIR for this Project fails as an informational document. While the EIR states that the four scenarios are being considered equivalently as potential alternatives, this is obviously not the case. The Draft EIR is also often conclusory and does not provide the analysis

or examination required by CEQA to inform the public and decision makers of the analytical pathway taken from facts to conclusions.

A specific plan evaluating multiple options for a connection from Overlook Parkway to SR-91, as well as the permanent removal of Overlook Parkway from planning documents, should be prepared, and impacts to the circulation system as a whole considered, as intended in the General Plan. This EIR fails to provide the broad planning level of scrutiny intended by the General Plan's policies and, as a result, fails to evaluate impacts to the circulation system as a whole and provide decision-makers with potential alternatives for successful development.

PROJECT DESCRIPTION AND SUMMARY

For Scenarios 3 and 4, two segregable bridges will be built. The bridges will not be span bridges, but will each have one, 7-foot diameter support column in the Arroyo as seen in Figure 2-11 and -12.

The look of the bridge, fill, and Proposed C Street are not well detailed in the EIR. To quote a portion of the Land Use/General Plan Consistency Analysis, "The proposed improvement plans for both the bridge and fill sections of Overlook Parkway do not include adequate detail to ensure consistency with its General Plan 2025 classification, as a designated 'parkway' and Policy LU-11.1; therefore, secondary impacts to aesthetics and community character could occur." The Project Description should be updated with further detail or depictions of the planned roadways.

BASELINES

There is often no rhyme or reason to the use of the "gates open" versus "gates closed" baseline in the EIR. The EIR does not apply these baselines equally and to all scenarios and impacts, but rather only to "traffic dependant issues." (EIR p. S-4) It is difficult to see that any impact from this *road* project could be traffic *independent*, though it is my understanding that the two baselines are only used when a traffic *count* was relied upon. Nevertheless, the result of the use of two baselines only *sometimes* creates an often confusing EIR.

Conclusions are made based on only one of the two baselines without explanation or without reasoning. For instance, the evaluation of indirect growth inducing impacts from new roadways with Scenarios 3 and 4are found to be less than significant analyzed against a "gates open" baseline; however, no evaluation of impacts to a "gates closed" baseline is in evidence. (EIR p. 5-4)[1]

[1] In fact, growth inducing impacts may be regionally significant from a "gates closed" baseline by providing an alternative cut-through option to the existing roadways. The EIR does not evaluate or disclose this potential impact. The EIR must be amended and recirculated to use both baselines equally so that apples-to-apples comparisons of scenarios and impacts may be made by the public and decision-makers.

In Table S-1, the summary of significant environmental analysis results, is often unclear as to which baseline was applied. This should be remedied. If the analysis is the same with either baseline, this should likewise be made apparent.

CUMULATIVE EFFECTS

The EIR also misleads decision makers and the public as to the extent and severity of the Project's environmental impacts. For instance, the EIR fails to consider cumulative effects from outside of the City such as impacts to the loss of agriculture in nearby areas including Moreno Valley. There is seemingly no basis for limiting the cumulative impact analysis to the limit in the EIR to the "approximately 7,500-acre Project vicinity," approximately 11.7 square miles.

SEGMENTATION

The EIR wrongly segregates consideration of environmental effects, particularly with regards to Scenario 4. CEQA requires that an EIR consider the "whole of an action" rather than piecemeal consider the effects of each element of a project. (CEQA Guidelines § 15378, *San Joaquin Raptor/Wildlife Rescue Center v. County of Stanislaus* (1994) 27 Cal.App. 4th 713, 729-730) With respect to Scenario 4, the EIR repeatedly segregates consideration of impacts from the Proposed C Street from the remainder of the project, rather than considering the totality of impacts from the connected Overlook Parkway and Proposed C Street. The effect of this piecemeal consideration of impacts is that effects traffic, air quality, biological, land use/planning, and other effects can be written off as individually insignificant. As with *San Joaquin Raptor/Wildlife Rescue Center v. County of Stanislaus* (1994) 27 Cal.App. 4th 713, 729-730, the EIR's failure to consider the whole Scenario 4 project results in the "fallacy of division" and causes the EIR to overlook the Scenario's overall impact "by separately focusing on isolated parts of the whole." In this manner the EIR particularly understates Scenario 4's project effects.

The EIR also fails to evaluate the project scenarios as a larger part of the circulation system.

ALTERNATIVES

The Alternatives Analysis is quite flawed and biased in favor of Scenario 4. The EIR designates Scenario 2, the "gates open" baseline, as the "No Project Alternative" and environmentally superior. There is no reason that Scenario 2 was chosen over Scenario 1, particularly where the "gates closed" baseline represents the legal existing physical condition. Both Scenarios 1 and 2 should be evaluated as no project alternatives in the EIR. Regardless, both Scenarios 1 and 2 satisfy most, if not all, project objectives and significantly reduce project impacts when compared to Scenarios 3 and 4. At the least, these environmentally superior scenarios must be implemented in lieu of Scenarios 3 and 4.

MITIGATION

CEQA also requires that where feasible mitigation exists which can substantially lessen the environmental impacts of a project, **all feasible mitigation** must be adopted. In this way CEQA goes beyond its informational role to require that projects substantively lessen their negative effects on the environment. It is critical to proper drafting of an EIR that all feasible mitigation measures be required of a project. This has not been done with this Project. For instance, no mitigation is proposed for noise impacts or impacts to GHGs, among others.

Moreover, all mitigation measures required in the EIR must be fully enforceable and certain to occur. This Project fails to ensure that all feasible mitigation will occur with this Project and instead provides vague, uncertain, and unenforceable mitigation measures. For instance, mitigation for paleontological impacts are uncertain and vague, as detailed herein.

Further shortcomings of the EIR are detailed below.

Summary:

The EIR considers the following four project alternatives termed "scenarios":

- Scenario 1: Gates Closed to Through Traffic, No Connection of Overlook Parkway:
  Under Scenario 1, both Crystal View Terrace and Green Orchard Place gates would remain in place and be closed until Overlook Parkway is connected to the east across the Alessandro Arroyo, to Alessandro Boulevard, and a connection westerly of Washington Street is built to get the traffic to SR-91.
- Scenario 2: Gates Removed, No Connection of Overlook Parkway:
  Under Scenario 2, the gates at both Crystal View Terrace and Green Orchard Place would be removed, and there would be no connection of Overlook Parkway across the Alessandro Arroyo. Overlook Parkway and required connection to the SR-91 would remain on the General Plan 2025 Master Plan of roadways for future buildout.
- Scenario 3: Gates Removed, Overlook Parkway Connected:
  Under Scenario 3, the gates at Crystal View Terrace and Green Orchard Place would be removed, and Overlook Parkway would be connected between Via Vista Drive and Sandtrack Road with construction of a fill crossing and over the Alessandro Arroyo with a bridge crossing, allowing for a through connection to Alessandro Boulevard. The connection to the SR-91 would not be considered and would be removed from the Master Plan of Roadways in the General Plan 2025.
- Scenario 4: Gates Removed, Overlook Parkway Connected, and the Proposed C Street Constructed West of Washington Street:
  Under Scenario 4, both Crystal View Terrace and Green Orchard Place gates would be removed and Overlook Parkway would be connected east across Alessandro Arroyo and to Alessandro Boulevard. In addition, a roadway (the Proposed C Street) would also be extended west of Washington Street to provide a connection to SR-91.

Agricultural Resources

The people adopted Proposition R, the "Taxpayer's Initiative to Reduce Costly Urban Sprawl by Preserving Riverside's Citrus and Agricultural lands, Its Unique Hills, Arroyos and Victoria Avenue." The two main features of Proposition R relate to: (1) preservation of agriculture through application of the RA-5-Residential Agricultural Zone to two specific areas of the City of Riverside (City), and (2) protection of hillside areas through application of the RC-Residential Conservation Zone to areas of the City based on slopes over 15 percent.

The people also adopted Measure C, an amendment to Proposition R, entitled "Citizens' Rights Initiative to Reduce Costly Urban Sprawl, to Reduce Traffic Congestion, to Minimize Utility Rate Increases and to Facilitate Preservation of Riverside's Citrus and Agricultural Lands, its Scenic Hills, Ridgelines, Arroyos and Wildlife Areas." Measure C amended Proposition R to promote agriculture by adding the following as official City policy:

> "It is hereby declared to be the policy of the City of Riverside to promote and encourage agriculture as an essential industry and a desirable open space use. The Greenbelt and La Sierra Lands are important agricultural lands because of their high soil quality, favorable climate and low water costs. It is further declared to be the policy of the City to retain, wherever feasible, agricultural lands in private ownership and to encourage and assist the maintenance and formation of family farms, especially for farmers who live on their land."

Measure C promotes the preservation of agricultural uses in these areas by:

- Ensuring that the Gage Canal water is reserved for agricultural uses as the highest priority;
- Protecting the Arlington Heights Greenbelt from heavy traffic;
- Minimizing the extension of City services and urban infrastructure into agricultural land areas affected by Measure C, except as needed for agricultural purposes;
- Developing and implementing public service and infrastructure standards compatible with and appropriate for agricultural lands; and
- Planning and implementing wherever feasible in the Arlington Heights Greenbelt, in the La Sierra Lands, in the Sycamore Canyon Park area, and in other appropriate areas for recreational opportunities for biking, equestrian and hiking uses consistent with farming needs, agricultural uses, and wildlife protection.

The EIR finds that impacts to Agriculture with all Scenarios would be less than significant or no impact. This finding is not supported with respect to, at least, Scenario 4 due to the conflict with Proposition R and Measure C, direct conversion of 11.73 acres of farmland, and indirect conversion of farmland due to urban development pressures. The EIR fails to evaluate this conversion of 11.73 acres of farmland considering Proposition R and Measure C. The Greenbelt and La Sierra Lands are declared with Prop. R to be "important agricultural lands because of their high soil quality, favorable climate and low water costs." Policy is to retain these important agricultural lands in private ownership. Scenario 4's conversion of these important and unique agricultural lands should be deemed significant in light of these adopted laws and policies.

The evaluation of agricultural impacts from Scenario 4 also fails to discuss indirect conversion of farmlands with respect to Measure C. Measure C contains an implicit understanding that heavy traffic and urban infrastructure in agricultural areas will detrimentally impact the Greenbelt and other agricultural uses. Given that voters passed this measure, Scenario 4's conflict therewith should be considered a significant impact under significance thresholds one and three.

Cumulative agricultural impacts are not adequately evaluated without consideration of impacts outside of the City. This issue is discussed further in the cumulative impact section of this letter.

Mitigation for agricultural impacts must be adopted with Scenario 4. Such mitigation should include:

1. Limitations on use of Proposed C Street including large truck prevention except for agricultural uses.
2. Implementation of traffic control measures on Proposed C Street, such as speed humps, chicanes, chokers/curb extensions, street islands, speed humps, round-abouts, one-way streets, limited access barriers, etc. to the extent compatible with the agricultural use of the Greenbelt.
3. Requirement of a permanent agricultural conservation easement on land of at least 2:1 of equal quality and to compensate for the direct and growth inducing/ cumulative loss of agricultural land by one of the following methods:
    a. The outright purchase of easements, or
    b. donation of mitigation fees to a local, regional, or statewide organization that provides for acquisition and stewardship of agricultural conservation easements.
4. Require the implementation of the CA Department of Conservation's 30 conservation tools, available from the CA Dept. of Conservation upon request.
5. Noise reduction measures along Proposed C Street such as noise barriers/walls, vegetation, quieter pavement design, lowered road, etc.

Air Quality

Construction

Scenario 4 would construct the Proposed C Street and the Overlook Parkway Bridge. The EIR assumes that these construction activities would not occur at the same time, and thus fails to provide a total "worst case scenario" for air quality emissions. The below table shows that if the the Proposed C Street and Overlook Parkway are constructed at the same time in either 2012 or 2013 with Scenario 4, construction emissions would be significant for NOx.

Pollutant	2012	2013	2013 C St.	2013 total if C St. concurrent construction	2012 total if C St. concurrent construction	Threshold
ROG	9.22	8.49	11.95	20.44	21.17	75
NOx	67.44	62.67	97.6	160.27	165.04	100
CO	40.42	39.71	54.18	93.89	94.6	550
SOX	.08	.08	.1	.18	.18	150

PM10	4.95	4.52	11.15	15.67	16.1	150
PM2.5	4.55	4.12	7.92	12.04	12.47	55

The EIR must either consider the impacts from construction of Scenario 4 as a whole or condition Scenario 4 to prohibit concurrent construction of the Proposed C Street and Overlook Parkway.

The EIR also fails to quantify the construction emissions anticipated offsite and, again, assumes that such activities would not occur simultaneously with the other construction activities. Scenarios 3 and 4 would include as traffic mitigation quite a bit of restriping, paving, adding turn lanes, and modifying/ adding signalization. Mitigation measures proposed for Scenario 3 would modify twelve intersections, and measures for Scenario 4 would modify fourteen. These changes are not demonstrably minimal or short term and must be evaluated in the EIR. Additionally, as above, the EIR must either provide total construction emissions with these off-site improvements or condition the project to prohibit concurrent construction of off-site improvements.

The estimated number of dump trucks for the fill crossing is severely underestimated in the Air Quality Analysis. According to the EIR, the fill crossing will require export of 1,000 cubic yards of soil. (EIR p.2-32) The Air Quality Analysis assumes that only two dump truck trips will be required for the fill crossing construction. (Air Quality Analysis p. 39) If a cubic yard of earth weighs approximately 1.35 tons, and the typical weight capacity of a dump truck is 15 tons/truck, the assumption in the Air Quality Analysis of 2 trucks is short about 88 trucks. The EIR does not demonstrate that the relied upon two trucks is sufficient. As a result, the construction air quality analysis and traffic analysis are flawed, and the analyses must be updated to account for soils export from the fill crossing.

The EIR does not estimate the amount of soils to be imported/exported with bridge construction, but assumes a much higher demand for dump trucks (50 trucks for abutment construction). The EIR fails in its informational role by omitting this information.

Construction Equipment emissions are also underestimated because use assumptions are limited to 5 days a week, 8 hours a day, despite the fact that construction may occur up to 12 hours per day and 6 days a week. The EIR fails to provide a "worst-case" construction emissions scenario, as claimed, by this and the other errors stated above.

Scenarios 3 and 4 fail to incorporate all feasible mitigation for construction air quality emissions which, as detailed above, may be significant. The following additional mitigation measures should be incorporated into construction for Scenarios 3 and 4:

1. Gravel pads must be installed at all access points to prevent tracking of mud onto public roads.
2. Install and maintain trackout control devices in effective condition at all access points where paved and unpaved access or travel routes intersect (e.g. Install wheel shakers, wheel washers, and limit site access.)
3. Require a dust control plan for earthmoving operations.
4. When materials are transported off-site, all material shall be covered, effectively wetted to limit visible dust emissions, and at least six inches of freeboard space from the top of

the container shall be maintained.

5. All streets shall be swept at least once a day using SCAQMD Rule 1186 certified street sweepers utilizing reclaimed water trucks if visible soil materials are carried to adjacent streets.
6. The contractor or builder shall designate a person or persons to monitor the dust control program and to order increased watering, as necessary, to prevent transport of dust offsite.
7. Post a publicly visible sign with the telephone number and person to contact regarding dust complaints. This person shall respond and take corrective action within 24 hours.
8. Any vegetative cover to be utilized onsite shall be planted as soon as possible to reduce the disturbed area subject to wind erosion. Irrigation systems required for these plants shall be installed as soon as possible to maintain good ground cover and to minimize wind erosion of the soil.
9. Any on-site stockpiles of debris, dirt or other dusty material shall be covered or watered three times daily.
10. Any site access points within 30 minutes of any visible dirt deposition on any public roadway shall be swept or washed.
11. A high wind response plan shall be formulated for enhanced dust control if winds are forecast to exceed 25 mph in any upcoming 24-hour period.
12. Implement activity management techniques including a) development of a comprehensive construction management plan designed to minimize the number of large construction equipment operating during any given time period; b) scheduling of construction truck trips during non-peak hours to reduce peak hour emissions; c) limitation of the length of construction work-day period; and d) phasing of construction activities.*
13. Require high pressure injectors on diesel construction equipment.*
14. Restrict truck operation to "clean" trucks, such as a 2007 or newer model year or 2010 compliant vehicles.*
15. Require the use of CARB certified particulate traps that meet level 3 requirements on all construction equipment.*
16. Utilize only CARB certified equipment for construction activities.*
17. Require all contractors to turn off all construction equipment and delivery vehicles when not in use and/or idling in excess of 3 minutes.*
18. Restrict engine size of construction equipment to the minimum practical size.*
19. Substitute gasoline-powered for diesel-powered construction equipment.*
20. Require use of alternatively fueled construction equipment, using, e.g., compressed natural gas, liquefied natural gas, propane, or biodiesel.*
21. Install catalytic converters on gasoline-powered equipment.*
22. Electrical powered equipment shall be utilized in-lieu of gasoline-powered engines where technically feasible.*
23. All forklifts shall be electric or natural gas powered.*
24. Suspend use of all construction equipment operations during second stage smog alerts.*
25. Provide temporary traffic controls such as a flag person, during all phases of construction to maintain smooth traffic flow.*
26. Reroute construction trucks away from congested streets and sensitive receptor areas.*
27. Configure construction parking to minimize traffic interference.*

28. Prior to the issuance of a grading and building permit, the applicant shall submit verification that a ridesharing program for the construction crew has been encouraged and will be supported by the contractor via incentives or other inducements.*
29. Minimize construction worker trips by requiring carpooling and providing for lunch onsite. *
30. Provide shuttle service to food service establishments/commercial areas for the construction crew.*
31. Provide shuttle service to transit stations/multimodal centers for the construction crew.*
32. Require the use of Zero-VOC paints, coatings, and solvents.

(* Would reduce impacts to GHGs as well)

Operation

Operational air quality impacts will be less than significant under all scenarios under existing traffic volumes and default parameters provided by the emission factors model for Riverside County.

Health Risks

The Air Quality Analysis is severely lacking in its evaluation of health risks from diesel PM. First, the air quality health risk assessment claims that because traffic will not be created but merely redistributed, no health risks would occur. While Scenarios 3 and 4 may not generate diesel trucks, they have the potential to *attract* such pass-through traffic as an alternative route. The EIR wrongly dismisses this potential by looking at the distribution of trips in the County as a whole, but PM impacts occur in a localized area and disperse with distance. For local health risk impacts to sensitive receptors, such as nearby residences, this redistribution may result in significant effects.

Second, the assessment claims that the only health risks associated with diesel particulate matter are those related to long –term exposures. This is simply not true. Acute short-term and immediate health risks including headache, dizziness, nausea, coughing, eye nose and throat irritation, increase in allergies, etc. are well documented and known to occur. Exposure to diesel exhaust also causes inflammation in the lungs, which may aggravate chronic respiratory symptoms and increase the frequency or intensity of asthma attacks.

Third, the Air Quality Analysis and EIR fail to conduct any calculations or make any attempt to quantify or evaluate whether health risks from diesel PM may occur from increased cut-through traffic with Scenarios 2-4. By failing to analyze and evaluate potential health risk impacts to sensitive receptors along Victoria Avenue and Gage Canal and in the seven impacted residential communities of Alessandro Heights, Canyon Crest, Casa Blanca, Arlington Heights, Hawarden Hills, Presidential Park, and Victoria, the EIR fails as an informational document. A finding that health risk impacts will be less than significant is unsupported.

Diesel PM health risks are not to be taken lightly. Diesel PM is known to cause immune system effects; reproductive, developmental, and endocrine effects; nervous system effects; and lung health problems, as recognized by the County in the General Plan. Immune system effects

include increased allergic inflammatory responses and suppression of infection fighting ability. Diesel PM has also been associated with reproductive effects such as decreased sperm production, changes in fetal development, low birth weight and other impacts. Diesel PM exposure may also cause impairment to the central nervous system. (*The Health Effects of Air Pollution on Children*, Michael T. Kleinman, Ph.D, Fall 2000, <http://aqmd.gov/forstudents/health_effects_on_children.html#WhyChildren>; *See also, Diesel and Health in America: the Lingering Threat*, Clean Air Task Force, February 2005, <http://www.catf.us/resources/publications/files/Diesel_Health_in_America.pdf>)

With regards to respiratory and cancer effects of diesel PM, SCAQMD has stated the following:

> "Diesel particles consist mainly of elemental carbon and other carbon-containing compounds… Diesel particles are microscopic…Due to their minute size, diesel particles can penetrate deeply into the lung. There is evidence that once in the lung, diesel particles may stay there for a long time.
>
> In addition to particles, diesel exhaust contains several gaseous compounds including carbon monoxide, nitrogen oxides, sulfur dioxide and organic vapors, for example formaldehyde and 1,3-butadiene. Formaldehyde and 1,3-butadiene have been classified as toxic and hazardous air pollutants. Both have been shown to cause tumors in animal studies and there is evidence that exposure to high levels of 1,3-butadiene can cause cancer in humans…
>
> Diesel emissions may also be a problem for asthmatics. Some studies suggest that children with asthma who live near roadways with high amounts of diesel truck traffic have more asthma attacks and use more asthma medication.
>
> Some human volunteers, exposed to diesel exhaust in carefully controlled laboratory studies, reported symptoms such as eye and throat irritation, coughing, phlegm production, difficulty breathing, headache, lightheadedness, nausea and perception of unpleasant odors. Another laboratory study, in which volunteers were exposed to relatively high levels of diesel particles for about an hour, showed that such exposures could cause lung inflammation." (*The Health Effects of Air Pollution on Children, supra*; *See also, Mira Loma Commerce Center EIR No. 450, Air Quality, Section 4.*)

Furthermore, infants, children, and the elderly are more susceptible to diesel PM and its associated health impacts. With regards to infants and children, increased susceptibility to TACs and diesel PM exists for a variety of reasons. Children are generally more active than adults, have higher respiration rates, and inhale more pollutants deeper into the lung. Children also have more lung surface area in proportion to their body size and inhale more air pound for pound when compared to adults, taking in 20 to 50 percent more air and associated air pollutants than adults. When compared to adults, children spend more active time outdoors in polluted air environments and exert themselves harder than adults when playing outside. Importantly, this exposure to high pollutant levels in children occurs while their lungs are still developing, and therefore has more severe impacts on this sensitive group. (*The Health Effects of Air Pollution on Children, supra.*)

This increased susceptibility to air pollutant emissions for children has resulted in the California EPA Office of Environmental Health Hazard Assessment ("OEHHA") weighting cancer risk by a factor of 10 for exposures to carcinogens from birth to two years old, and by a factor of 3 for exposures from 2 years old to 15 years old. (*Technical Support Document for Cancer Potency Factors: Methodologies for derivation, listing of available values, and adjustments to allow for early life stage exposures*, California EPA OEHHA Air Toxicology and Epidemiology Branch, April 2009, p. 3. <http://www.oehha.ca.gov/air/hot_spots/pdf/TSDCPFApril_09.pdf.>) It is unclear that these increased risks were accounted for in the EIR. Additionally, recent studies conducted by SCAQMD's Brain and Lung Tumor and Air Pollution Foundation have found a specific connection between exposure to diesel PM and brain cancer in children. (Annual Meeting of the Brain & Lung Tumor and Air Pollution Foundation, April 2, 2010, <http://www.aqmd.gov/hb/2010/April/100425a.htm>)

In addition to an increased risk of cancer, the effects of diesel PM on children include slowed lung function and growth, increased emergency room visits, increased incidences of asthma and bronchitis, crib death, asthma respiratory infections, allergic symptoms, and asthma hospitalizations. (*Diesel and Health in America: the Lingering Threat*, *supra*.)

The County of Riverside has recently acknowledged that due to poor air quality in the County:

- In 2005, the greatest percentage of asthma-related hospitalizations were among those under age 18 (38%) followed by those over 65 (19%). Blacks experienced the greatest rate of hospitalizations in 2005 at 225.7 per 100,000 population, versus 99.5 and 81.2 for Hispanics and whites, respectively.
- Risk of Cancer from Diesel Soot and Other Toxic Air Pollutants: Whereas the regional risk of cancer from diesel soot and other toxic air pollutants dropped by 8 percent between 1998 and 2005, the cancer risk in Riverside County increased by 2 percent.
- Poor air quality costs Riverside and San Bernardino around ***$6.3 billion annually*** in health care expenses.

If Scenarios 3 or 4 are adopted, additional mitigation for these potential risks must be incorporated. Such measures may include enforcing a weight limit on Overlook Parkway and the Proposed C Street and installing traffic calming measures such as additional speed humps, chicanes, chokers/curb extensions, street islands, speed humps, round-abouts, one-way streets, limited access barriers, etc. to deter use of by diesel trucks. These traffic calming measures should likewise be considered to deter use by *all cut-through* traffic.

Biology

The bridges will not be span bridges, but will each have one, 7-foot diameter support column in the Arroyo as seen in Figure 2-11 and -12. The impact of these columns does not appear to have been considered in the EIR or Biological Technical Report.

There is disconnect between the impact to jurisdictional waters detailed in the Biological

Technical Report and the EIR. The Biological Technical Report considering the whole area (Scenario 4?) found that a total 1.56 acres of wetlands would be permanently impacted, requiring mitigation at a 2:1 ratio.

Considering the whole Scenario 4 in the EIR, impacts will be significant to only 1.52 (1.49+.03) acres of wetland. The EIR provides that Scenario 3 would impact 1.28 (.02 +.32+.76) acres temporarily and slightly less than 0.21 (.05 + .15+ <.01) acres permanently for a total of 1.48-1.49 acres impacted. This impact to the Arroyo from the fill crossing and bridge is significant. MM-Bio-2 is incorporated to mitigate for impacts from Scenario 3 and 4 for only 1.48 acres. Mitigation for Scenario 4 must mitigate for the loss of 1.56 acres of wetland at a 2:1 ratio as recommended in the Biological Technical Report.

The EIR also fails in its informational role by wrongly segmenting impacts from construction of the Proposed C Street from the remainder of the project when considering biological impacts from Scenario 4. (CEQA Guidelines § 15378 [Project means "the whole of an action"]) The EIR finds temporary and permanent impacts to wetland habitat and jurisdictional resources to be significant "from the construction of a fill crossing and a roadway bridge," but impacts from the Proposed C Street would be less than significant. The EIR wrongly requires no additional mitigation for Scenario 4's impacts to an additional 0.02-0.03 acres at the Proposed C Street location (NOTE: 0.04 acres per the Biological Technical Report). Additional mitigation for Scenario 4 must be required so that all wetland impacts of Scenario 4 are mitigated: either 1.52 or 1.56 acres depending on whether the EIR of Biological Technical Report is the accurate document.

Construction impacts to nesting birds may not be mitigated by reliance on MM-BIO-1. Construction of the Overlook Parkway bridge is anticipated to last approximately 9 months beginning in September. *(See, Air Quality Assessment)* A grading permit will thus likely issue and construction begin without conducting a pre-construction nesting survey, as this survey is only to be conducted "prior to the issuance of a grading permit." If nesting birds later occupy the site during the nesting season from February- June, there is no requirement for later surveys or nest avoidance. Mitigation must be incorporated providing for nest avoidance if nests are discovered once construction has begun and surveys after any substantial breaks in the construction schedule or areas under construction.

Cultural Resources

The Cultural Resource Survey of the EIR fails to evaluate impacts from the operation of Scenario 4, that is, additional traffic to Victoria Avenue and over the Gage Canal. The assessment instead only considers impacts from the *physical alterations* including road construction, signals, etc. Without accounting for changes to the characteristics of Victoria Avenue caused by operation and increased traffic into these important historical areas, the EIR fails as to provide the public and decision-makers with an accurate accounting of Scenario 4's

impact to these cultural resources. While the EIR nevertheless finds impacts to Victoria Avenue significant and unmitigated, the scope of these impacts remains undisclosed.

Along those same lines, 118 cultural resources were recorded within one mile of the survey areas; however those survey areas only include areas where road construction/bridge construction will occur. The survey area is *not* the study area. Even accounting for off-site impacts, neither the EIR nor the Cultural Resource Survey considers impacts to cultural resources in the study area where vehicular traffic will increase because of the project, but *no construction* will occur. Impacts may be caused by the project's alteration of the circulation system without construction or similar physical alterations. For instance, impacts to Victoria Avenue may occur from increased traffic by changing its atmosphere; impacts to the Gage Canal may occur by changing the integrity of feeling and design or function. Cultural impacts in the entire study area must be evaluated for effects from changes in the circulation system in the EIR.

Regarding paleontological impacts, MM-CUL-4 is insufficient to mitigate for impacts where any monitor may only halt grading temporarily and within 50 feet of such a find. At least 100 feet must be permitted. Moreover, if it is possible to avoid the resource rather than "salvage" it, avoidance must be made a consideration.

Land Use/ Planning

The land use and planning consistency analysis is fatally flawed and fails to accurately depict the scenarios inconsistency with the General Plan.

To first note a typographical error, Table 4.1-1, the Land Use/ General Plan Consistency Analysis (Appendix H) is mislabeled on the even pages as Balboa Park Master Plan-Project Consistency.

The following deficiencies with the Consistency Analysis (Appendix H) are carried through to the EIR and render the conclusions of the EIR unsupported:

- Policy CCM-2.2: the Consistency Evaluation finds Scenarios 2-4 "consistent" with balancing traffic flow with economic realities, environmental, and aesthetic considerations. Scenarios 2 and 4 will have significant impacts to delays and Scenario 3 will significantly increase delays. There is no discussion at all of economic or aesthetic considerations. The finding of consistency is unsupported.

- Policy CCM-2.4: The Consistency Evaluation for Scenario 3 finds the project consistent despite the fact that the scenario would add one additional LOS F failing roadway segment in 2035. This conclusion is not supported by any evidence.

- Policy CCM-2.8: This policy objective is to "Design street improvements considering the effect on aesthetic character and livability of residential neighborhoods, along with traffic

engineering criteria." Scenarios 3 and 4 are acknowledged to increase traffic in Crystal View Terrace. Scenario 3 is acknowledged to significantly impact Victoria Ave even with mitigation. With regards to Scenario 4, there is no discussion of impacts to Victoria Ave., the Gage Canal, or Casa Blanca neighborhoods from development of Overlook Pkwy or the Proposed C Street. There is also no discussion of impacts on any other roadways or neighborhoods which will be impacted by cut-through traffic to use these connections. Overall, the findings that these Scenarios are consistent with this Policy are not supported by any evidence or reasoning. At the least, Scenarios 3 and 4 should be deemed inconsistent.

- Policy CCM-2.9: This policy concerns designing streets to consider pedestrian walkways, bike lanes, equestrian pathways, etc. Many commenters on the Notice of Preparation noted that there are no sidewalks along many of the "cut-through" streets, creating a safety hazard for pedestrians. Others commented that additional traffic along the Gage Canal would hinder its use as a recreational path and negatively affect pedestrian and bike safety. With regards to the Proposed C Street and additional traffic in the Greenbelt area, commenters noted and it should be considered in the EIR that equestrian uses would be rendered unsafe due to the traffic and noise that would arise with this four-lane arterial. It is thus unlikely that the City would deem equestrian improvements "appropriate," effectively nullifying this use in the area and creating further inconsistencies with Policy CCM-2.9. None of these issues were considered in the consistency evaluation of the EIR. Without consideration of these issues the consistency finding is unsupported.

- Policy CCM-2.11: This Policy recommendation is that the City "consider the use of special design traffic control devices. Rather than considering or listing traffic control devices that *would* be used or *may successfully be implemented* with each project Scenario, the Consistency Analysis merely states that the "City would consider" the use of the control devices "as necessary and appropriate." There is no support for this claim and no demonstration that the Scenarios would be consistent with this policy as concluded. Some traffic control devices which may be implemented are listed above and may include: enforcing a weight limit local streets or installing additional speed humps, chicanes, chokers/curb extensions, street islands, speed humps, round-abouts, one-way streets, limited access barriers, etc. Also, it does not appear that the entire Scenario was considered in the consistency evaluation of Scenario 4, but rather only the Proposed C Street was considered. (Consistency Analysis p. 5) As noted above, this segmentation is impermissible under CEQA.

- Policy CCM-2.14: This policy addresses improvements on Victoria Avenues, with the objective that the City, "Allow only the minimum necessary improvements in recognition of Victoria Avenue's historic character." The Consistency Evaluation does not make a

distinction between the level of impacts for all scenarios, where Scenario 4 would have a much greater impact on Victoria Avenue than the other scenarios. The conclusion that Scenario 4 is consistent with this Policy is not supported by the fact that the other Scenarios, and alternatives not considered in the EIR, would not require the same high level of improvement to Victoria Avenue as Scenario 4.

- Policy CCM-4.2: This policy provides, "The connection of Overlook Parkway across the Alessandro Arroyo shall not be completed until a detailed specific plan analyzing potential connection routes between Washington Street and the SR-91 has been adopted. Analysis of the fore mentioned connection route should, at a minimum, include the area bounded by Mary Street, Adams Street, Dufferin Street, and SR-91." The EIR apparently ignores the language of this policy in finding all scenarios consistent therewith. No specific plan was prepared for this Project. Neither the public nor decision-makers have had the opportunity to analyze various potential connection routes. To the contrary, the decision-makers are given only one option with this project for a connection route between Washington Street and the SR-91: Proposed C Street. Alternatively, decision-makers may remove policy CCM-4.2 from the General Plan, as part of Scenario 3. Without preparation of a specific plan analyzing various connection routes, all scenarios are inconsistent with this policy.

- Policy CCM-4.4: This policy prohibits removal of the gates until the Overlook Parkway Bridge is constructed. The consistency evaluation for Scenario 2 finds the project consistent in spite of the fact that the actions of Scenario 2 specifically conflict with the policy. While Scenario 2 may be consistent in the future, after amendment of the General Plan to omit this policy, compared to the existing baseline Scenario 2 is inconsistent.

- Policy CCM-7.1: "Discourage and/or prevent regional cut-through traffic in residential neighborhoods through the employment of traffic calming measures within Riverside." The Consistency Analysis finds all Scenarios consistent with this policy despite the fact that some 90% of traffic using these streets was, is and will be cut through, hence the previously instituted requirement of the gates. The City has repeatedly recognized the likelihood of cut-through traffic using this route and the EIR nowhere states traffic calming measures to be employed to prevent such traffic. Scenario 3 consistency evaluation concludes without any facts, means, or evidence, that the scenario will minimize cut-through traffic because cut through traffic will use Overlook Parkway. The traffic still must get to and from Overlook Parkway, which will cut-through residential neighborhoods. Moreover, by providing a more efficient route, Overlook will *cause,* not alleviate, cut-through traffic. The evaluation is fatally flawed. The evaluation of Scenario 4 is flawed for the same reason. Scenario 4 also fails to consider impacts from cut-through traffic to the Casa Blanca neighborhood. All consistency evaluation sections only consider those streets on which construction will occur and do not appear to

consider general circulation impacts/changes on nearby roadways in the seven effected neighborhoods.

- Policy HP-1.2: The Consistency Analysis finds all scenarios consistent with protecting the City's cultural resources. This conclusion is unsupported where impacts to Victoria Avenue will be significant after mitigation.

- Policy LU-5.1: "Minimize public and private development in and in close proximity to any of the City's arroyos." All scenarios are determined to be inconsistent with this policy including Scenarios 3 and 4 which would specifically develop in the Alessandro Arroyo and attract additional traffic to the arroyo area. The finding of consistency is utterly unsupported.

- Policy LU- 5.3: This policy states, "Encourage that any crossings of the City's major arroyos are span bridges or soft bottom arch culverts…" The Consistency Analysis for Scenarios 3 and 4 finds the development of the bridges over the Alessandro Arroyo consistent with this policy despite the fact that the bridges *will not be span bridges* but will each have a seven foot support column in the Arroyo. The consistency finding is again unsupported.

- Policy LU-6.1: "Enforce and adhere to the protections for agricultural areas set forth in Proposition R and Measure C." The Consistency Analysis finds all scenarios consistent with this policy. The Consistency Analysis again fails to consider impacts from additional traffic to the Greenbelt area for Scenarios 3 and 4 with the construction of Overlook Parkway and the Proposed C Street (for Scenario 4).

  Measure C was adopted to protect Greenbelt streets from heavy traffic and minimize the extension of urban infrastructure into agricultural lands except as needed for agricultural purposes. Scenario 4 instead provides for the building of streets and urban infrastructure in the Greenbelt, impacting ~ 12 acres of designated farmland. (EIR p. 3.1-14)

  Proposition R was adopted to preserve Riverside's citrus and agricultural lands, unique hills, arroyos, and Victoria Avenue. Scenario 4 instead expands urban roads into these agricultural areas, resulting in the direct conversion of ~ 12 acres of farmland and likely indirect conversion of additional farmland due to increased urbanization and traffic pressures. Scenario 4 also builds a non-span bridge over (and in) the Alessandro Arroyo; modifies the Gage Canal; and requires significant changes to, and otherwise significantly impacts, Victoria Avenue. The finding of consistency is utterly unsupported and countered by all evidence.

- On the basis of the Consistency Analysis, the EIR finds that Scenario 4 is consistent with Proposition R and Measure C by "providing a new roadway west of Washington Street to

facilitate vehicles traveling to the SR-91 that would avoid directing vehicles further into the Greenbelt." (EIR p. 3.9-43) Again, this consistency conclusion is not supported by evidence for the above reasons. The argument that vehicles would not be directed *further* into the Greenbelt is in essence an argument that a worse route could have been selected. It does not demonstrate that this route is consistent with Prop R or Measure C.

- Policy LU-11.2: This policy concerns recognizing certain streets as part of the City's parkway landscape network and components of Riverside Park. The evaluation for Scenario 4 recognizes that not enough information or detail is provided to ensure consistency with the General Plan "parkway" designation, yet finds the scenario consistent nonetheless. This conclusion is undermined by the lack of detail and design elements provided. The Project Description should provide the necessary detail, or this Scenario should be deemed inconsistent. The same applies to Scenario 3, where this lack of detail is not discussed.

- Policy LU-13.2: This policy again requires the preparation of a specific plan for Overlook Parkway between Alessandro Blvd. and SR-91. "The specific plan shall address the crossing of the Alessandro Arroyo, traffic calming measures necessary to protect local streets in the area and the extension of Overlook Parkway westerly of the Washington Street/Overlook Parkway intersection....[A]ll improvements shall be designed to sensitively reflect Victoria Avenue's historic character." Again, no specific plan was prepared. The EIR for this project is not equivalent to specific plan consideration of these issues. Traffic calming measures are not evaluated or incorporated in local streets, alternative extensions of Overlook Parkway are not available for review by the public and decision-makers, and overall the EIR does not achieve the intent of this policy. Again, consistency findings are not supported by reasoning or evidence.

- Policy N-4.1: This policy is to *ensure* that noise impacts from vehicles are *minimized* through noise reductions features. The Consistency Analysis finds all Scenarios consistent despite the fact that noise reduction features were merely *considered* and will not be *implemented*. New noise attenuation structures sufficient to minimize noise will not be built. This policy requires more than consideration for consistency; it requires assurance that noise impacts are minimized. A consistency finding is unsupported.

- Policy OS-1.1: "Protect and preserve open space and natural habitat wherever possible." The Consistency Analysis regarding Overlook Parkway (Scenarios 3 & 4) contends that the bridges will preserve open space and habitat in the arroyo because each has only one support column so as to "not impede the open space value of the arroyo." This contention is undermined by Policies LU-5.1 and LU-5.3 to prevent development near arroyos and, if a bridge is needed, build a span bridge. Open space and natural habitat is not preserved here, and a consistency finding is unsupported.

- Policy OS-4.1: Scenarios 2-4 are inconsistent with the policy, "Continue to implement Proposition R and Measure C" for the reasons detailed above. The reasoning in the Consistency Analysis is flawed and countered by all evidence in the EIR and its Appendices.

- Policy OS-6.3: "Preserve the integrity of Riverside's arroyos and riparian habitat areas through the preservation of native plants." The Consistency Analysis for Scenarios 3 and 4 find that the Scenarios are consistent with this policy as impacts to sensitive habitat would be mitigated. However, mitigation does not equate to *preservation* and may occur off-site though the purchase of mitigation credits. This should be considered in any consistency evaluation.

- Policy AQ-1.1: This policy concerns "Equitable Decision-Making." It states, "Ensure that all land use decisions, including enforcement actions, are made in an equitable fashion to protect residents regardless of age, culture, ethnicity, gender, race, socioeconomic status, or geographic location, from the health effects of air pollution." The Consistency Analysis finds all Scenarios consistent on the basis that any scenario would require a public hearing. *The Consistency Analysis does not actually evaluate any issues of equity that may arise with this project.* The failure to consider issues and inequitable distribution of health effects from air pollution is surprising where many commenters on the NOP expressed concern from the diversion of additional traffic to the lower income, hispanic Casa Blanca neighborhood. Any consistency finding with this policy is completely unsupported without consideration of health risks to effected neighborhoods.

- Policy AQ-1.2: This policy concerns environmental justice. It states, "Consider potential environmental justice issues in reviewing impacts (including cumulative impacts)." Here, the evaluation for Scenario 4 acknowledges that, "greater impacts would occur to the north along Madison Street within the Casa Blanca Community Plan area…" The evaluation nevertheless concludes that the Scenario is consistent as it is a "buildout condition associated with the planned circulation network." The Consistency Analysis in essence claims that Scenario 4 is not causing the traffic. This is a fallacy because Scenario 4 *will* bring traffic to the Casa Blanca area now, not perhaps at a later time, perhaps in a different area. Adoption of Scenario 4 will be a specific land use decision causing an inequitable impact to the Casa Blanca community. This environmental justice issue should be given great consideration in the EIR.

- Arlington Heights Policy LU-39.1: "Ensure that Victoria Avenue and its cross streets remain accessible to a wide variety of users, emphasizing pedestrian and bicycle access as well as automotive use." The Consistency Analysis finds all scenarios consistent with the policy despite the fact that Scenario 4 will result in LOS E-F on Victoria Avenue and additional traffic to Victoria Avenue may hinder pedestrian and bicycle access and safety.

Impacts to safety and genuine ability to maintain these uses are not, and must be, considered beyond the mere requirement for bike access and cross walks.

Aesthetics

Aesthetic impacts are combined in the "Land Use" category. As with much of the remainder of the EIR, the Aesthetic portion fails to support with evidence the conclusion that impacts will be less than significant. Scenario 3 is found not to have a substantial adverse effect on a scenic vista, substantially damage scenic resources, or substantially degrade the existing visual character of the site where 1) the aesthetics of the bridge are unknown; 2) the bridge will not be a span bridge as preferred in the General Plan; 3) the bridge will add much traffic and development to an arroyo. This impact should be considered potentially significant until evidence is presented which supports the insignificance finding.

Aesthetic impacts from Scenario 4 are also deemed less than significant despite the fact that Proposed C Street will, in addition to the above impacts from Overlook Parkway, alter the scenic elements of Victoria Avenue in a manner that results in significant adverse cultural impacts. This impact should be considered potentially significant.

Noise

Noise impacts may be significant for operation at sensitive receptors not considered in the Noise Technical Report or EIR. The Noise Technical Report considered exceedences of the noise threshold only where the project scenarios also increased noise by at least 1 db. Hence, there is the potential that undisclosed sensitive receptors could, as a result of the project, experience noise levels in exceedance of the noise threshold but where project increases accounted for only 0.9 db. The EIR does not obviously disclose all significant noise impacts by this omission.

A 50 ft to the centerline distance is relied on for noise impact calculations of the existing noise environment on the basis that such a distance is the "average." This is demonstrated to be untrue in the Table 3 provided and photographic evidence which show the sensitive receptors to be much nearer to traffic noise sources, as near as 17 feet. It is also unclear if these measurements were taken to the property line of these residences. Nevertheless, the use of the 50 foot distance is not supported by evidence in the EIR and results in noise estimates lower than those actually experienced. Likewise, the predicted project noise on roadways was normalized to this 50 foot distance. The actual noise experienced at sensitive receptors may be significantly higher if closer than 50 feet from the source, resulting in significant noise impacts at a greater number of sensitive receptors than disclosed in the EIR.

It is unclear why noise measurements were not taken in a manner which accounted for the existing walls. Instead, the Noise Technical Report assumes flat-site conditions and assumes that the walls will reduce noise at residences by 5dB. It should be clarified why these measurements were not taken. Also, any factors which would reduce the efficacy of these walls to reduce noise should be disclosed.

The noise analysis also assumes that the vehicle mix with for all scenarios will be identical to those experienced in 2011 with the gates open. This assumption ignores changes caused as pass-through traffic redirects to these streets which are presently out of the way for most motorists.

The impact analysis for ***permanent ambient noise increases*** is substantially lacking and consists of only *one paragraph* total for all scenarios. (EIR p. 3.10-47 -48.) While the tables detail noise increases (e.g. Tables 3.10-4, -5, -6, -7, -8, -9), the EIR must analyze these increases above existing, particularly as increases may be well above 20dBA. The EIR wrongly concludes that increases will be significant for Scenarios 3 and 4 without explaining or evaluating the data collected. With regards to Scenarios 1 and 2, the EIR wrongly concludes that impacts will be less than significant because they will be less than the residential standard. This analysis ignores the threshold question which pertains to permanent ambient *noise increases above existing levels,* not exceedences of the noise standard. In fact, Scenario 2 may increase noise by up to 18.5 dB compared to the gates closed baseline (e.g. Overlook Parkway and Kingdom Drive). Scenario 2's impacts are significant and unmitigated.

Additionally, the EIR and Noise Technical Report wrongly apply the noise nuisance level as the threshold of significance/noise standard for construction noise impacts. The threshold of significance at sensitive receptors exterior areas is stated as 55 dBA during the day at residential uses. The different project scenarios would exceed 55 dBA at most evaluated sensitive receptors, a significant effect. (*See, e.g. Table 15 of Noise Technical Report*) The Noise Technical Report and EIR, however, instead apply City Municipal Code § 7.25.010 (A)(5), which states when noise is *unlawful*, it does not provide the City's noise standards for CEQA purposed. On the basis of Section 7.25.010 (A)(5), the Noise Technical Report and EIR find that construction noise impacts are insignificant unless they exceed 75 dBA (20 dBA above the standard), which would not occur at any of the scenarios. The EIR must be amended to state that construction noise impacts are significant where noise will exceed the 55dBA noise standard of the Riverside Municipal Code Title 7 and the 65 CNEL standard of the General Plan 2025. Mitigation is essential.

It also appears that *total* noise levels at sensitive receptors with construction are not considered; rather only the construction-based noise (equipment) and distance are used in the modeling. Levels actually experienced may be much higher than disclosed in the EIR if construction noise *and the existing noise environment* are considered.

As with permanent noise increases, there is no evaluation of the increase in construction noise over existing noise in either the Noise Technical Report or EIR. Instead, the EIR provides *one paragraph* stating that because construction would be limited to daytime and not exceed 75 dBA, noise impacts would be less than significant for Scenarios 3 and 4. (EIR p. 3.10-48) This determination ignores the threshold question concerning temporary *increases* in ambient noise over existing levels. No quantification of these increases is provided. Moreover, the existing noise levels of the receivers evaluated for construction noise impacts are not disclosed in the EIR, preventing an apples-to-apples comparison by the public or decisionmakers. Construction noise impacts should be found significant with respect to this significance threshold and the EIR must be amended and recirculated with a noise assessment that discloses these impacts.

There is no mitigation for noise impacts, either construction or operational. The Noise Analysis and EIR both conclude, without any obvious consideration of *any* mitigation measures, that all mitigation for noise impacts is infeasible. The following mitigation measures must be adopted:

6. Temporary noise barriers must be installed during project construction.
7. Where technically feasible, utilize only electrical construction equipment
8. During construction, the developer shall require that all contractors turn off all construction equipment and delivery vehicles when not in use and prohibit idling in excess of 3 minutes.
9. Provide upgraded windows with a minimum Sound Transmission Class (STC) rating of 34 for all significantly impacts sensitive receptors, and/or provide double-paned windows.
10. Maintain quality pavement conditions that are free of bumps, pot holes, pavement cracks, differential settlement in bridge approaches or individual pavement slabs, etc. Require prompt resolution (i.e. within one week) of reported roadway surfacing issues.
11. Ban heavy trucks near vibration sensitive uses; enforce weight limits on, at least, Overlook Parkway and Proposed C Street.

Traffic/ Transportation

The EIR does not consider impacts to the highways, including SR-91, but only the on- and off-ramps. Impacts to the highway segments must be considered in the EIR.

The EIR wrongly fails to consider increased hazards due to sharp curves, dangerous intersections, etc. where Scenarios 2-4 will *add traffic to existing hazardous conditions*. The EIR instead only considers hazards from street improvements, development, and the bridge. By failing to consider hazardous conditions from changes in the circulation system, adding traffic to hazardous and dangerous roads, the EIR fails as an informational document. It should be noted that many commenters on the NOP cited dangerous conditions for cut-through traffic that would be exacerbated by Scenarios 2-4.

The EIR concludes with respect to Scenario 4 that no hazards will be created with the Proposed C Street. This conclusion is unsupported where a purpose of the Greenbelt area was to prevent incompatible uses such as farm equipment and a busy roadway, or equestrian uses and a busy roadway. This impact should be deemed significant.

With regards to emergency access and safety, the concern with the closed gates Scenario 1 condition expressed by area residents and the Project Objectives revolves almost entirely around this issue. MM-S1-ES-1 easily resolves this concern with the automation of permanent gates. With this measure in place there is virtually no *local* benefit of the other Scenarios 2-4 but rather only to cut-through traffic. Scenario 1 with this mitigation measure should be adopted.

This mitigation measure could be taken a step further to resolve other issues of concern as well: the gates may be automated for area residents. This would resolve trip length/VMT, issues of air

quality, keep noise levels low, and allow easy emergency access. This mitigation measure for Scenario 1 should be considered in the EIR.

Cumulative Impacts

The EIR fails to consider cumulative effects from outside of the City. With regards to the loss of agriculture in nearby areas, 15 projects in the City were considered, all in developed areas. This analysis excludes impacts from nearby urbanizing areas, such as the City of Moreno Valley, which is converting much agricultural land quite near the Project area.

Cumulative impacts to Victoria Avenue would be significant for Scenario 4. Again, this solidifies Scenario 4's inconsistency with the General Plan, Prop. R and Measure C.

Alternatives

The EIR fails to consider a reasonable range of Project alternatives. There is no alternative which considers removing the Overlook Parkway connection from the Master Plan of Roadways in the General Plan 2025 and keeping the gates closed in perpetuity. Scenario 1 still considers and foresees a connection of Overlook Parkway at sometime in the future with the gates closed until that point in time.

Where there is an environmentally superior alternative that significantly decreases the significant impacts of the Project then that alternative must be approved rather than the Project if that alternative is feasible, even if the alternative would impede to some degree the attainment of the project objectives, or would be more costly. [(PRC§ 21002; *Uphold Our Heritage v. Town of Woodside* (2007) 147 Cal.App.4th 587, 597, State CEQA Guidelines § 15126.6(b)]

In this case, as stated in the EIR, ***"All of the scenarios meet the project objectives to a degree."*** (EIR p. 8-19.) This is because the Project objectives are essentially to evaluate potential options and choose one after consideration. Scenario1 would greatly reduce impacts when compared with the Scenarios 3 and 4. Likewise, Scenario 2 would greatly reduce impacts when compared with the Scenarios 3 and 4. One of these alternatives *must* therefore be approved instead of Scenarios 3 or 4 pursuant to CEQA's above substantive mandate.

Project objectives are identified as: "to evaluate and resolve the General Plan 2025 goals and policies relative to the status of the gates, the connection to Overlook Parkway, and a connection from Washington Street to the SR-91 freeway. The project objectives address:

- Public safety concerns related to both emergency vehicle access and increased traffic volumes within residential neighborhoods associated with the gates on Green Orchard Place and Crystal View Terrace;

- Traffic patterns related to the Overlook Parkway connection and the connection westerly

of Washington Avenue consistent with the General Plan 2025;

- Comprehensive circulation system, including multiple modes of transportation such as bikeways and pedestrian routes consistent with the General Plan 2025;

- Historic integrity of Victoria Avenue and the Gage Canal as well as designations which protect the Arlington Heights Greenbelt, and Proposition R and Measure C consistent with the General Plan 2025."

The Comparison of Project Objectives and Scenarios is unreasonably prejudiced in favor of Scenarios 3 and 4 where Scenarios 1 and 2 would equally address Project Objectives.

Scenario 2 "Open Gate": The analysis of Scenario 2 finds that it would only "partially" address public safety concerns derived primarily as a result of the time added from opening the closed gate. There is no reasoning or basis in support of the claim that Scenario 2 would only partially address Objective 1 by allowing unimpeded access by emergency vehicles and emergency evacuation by residents.

Growth Inducement

The consideration of Scenario 4's impact on growth inducement segregates the growth inducing impact of the connection of Overlook Parkway and that of the Proposed C Street. While one or the other may not be growth inducing, the completed route leading from I-215/SR-60 along Alessandro to the Overlook Pkwy Route and SR-91 may be growth inducing by providing an alternative pass through route to that highway.

Additionally, the EIR states that no additional growth would occur as, "In order for additional growth to occur within the Greenbelt area, both Proposition R and Measure C would need to be repealed, which would require a vote by popular referendum." As discussed above, however, Scenario 4 conflicts with Measure C protecting Greenbelt streets from heavy traffic and minimizing the extension of urban infrastructure into agricultural lands except as needed for agricultural purposes. Scenario 4 also conflicts with Proposition R, to preserve Riverside's citrus and agricultural lands, unique hills, arroyos, and Victoria Avenue. Scenario 4 adds growth in the Greenbelt area without repealing these laws, so what is to prevent further, similar intrusion?

Policy Considerations in Opposition to an Overlook Parkway Connection

In addition to the CEQA concerns with the EIR, policy considerations favor rejecting Scenarios 3 and 4 in favor of maintaining Scenario 1- "Closed Gates" and automating those gates so as not to impede emergency access. The gates installed on Green Orchard Place and Crystal View Terrace were installed ***specifically to "prevent cut-through traffic" on two residential subdivisions.*** Removal of the gates will have the opposite effect, subjecting the residential subdivisions in these areas and five other residential neighborhoods to increased traffic and associated impacts.

Furthermore, *major* traffic concerns arise if Scenarios 3 or 4 are implemented particularly from "cut-through" traffic from Moreno Valley along Alessandro Blvd. Moreno Valley is becoming/ has quickly become notorious as the Inland Empire center of "logistics", aka distribution warehouses, and associated truck traffic. A comment letter provided by the City of Riverside to the City of Moreno Valley on a draft EIR for the "RPT Centerpointe West" Project in November 2012 succinctly stated the problem now conveniently overlooked with the Overlook Parkway connection:

> "[T]he DEIR needs to be revised to adequately evaluate regional impacts, including:
> - Assessments of traffic impacts generated by passenger vehicles and delivery trucks (those that would normally travel west along State Route 60 toward the Interstate 215/ State Route 91 interchange) that will find the 'path of least resistance' when the freeways are congested and take routes on City of Riverside arterials such as Van Buren Boulevard and Alessandro Boulevard to access State Route 91."
> - ...this project is expected to generate a percentage of vehicle trips that will utilize Alessandro Boulevard or Van Buren Boulevard to access State Route 91 Freeway. As a result, the DEIR needs to fully evaluate this spill-over effect on streets within the City of Riverside."

The problem is therefore evident and acknowledged by the City of Riverside: cars and trucks from Moreno Valley and the region will find the "path of least resistance" and cut through the Overlook Parkway Connection (if developed) from I-215 and SR-60 to reach SR-91. The traffic impacts stated in this EIR are thus underestimated without considering the immense potential for cut through.

Moreover, if such cut-through traffic is predominantly trucks from Moreno Valley, impacts to sensitive receptors in the Overlook Parkway Connection Area in terms of noise and health risks may be significant and well above the impacts disclosed in the EIR. Night-time noise may become a real problem not evaluated or disclosed in the EIR. Victoria Avenue and the Gage Canal may be more severely adversely impacted not only by the additional traffic but potentially by an above average amount of truck traffic and associated impacts (diesel PM, noise, air quality, etc.). The Arroyo may also be more severely impacted, with greater biological impacts arising from increased truck noise and runoff impacting water quality. Any traffic problems alleviated by the Overlook Parkway connection are likely to be multiplied and exacerbated by providing a path of least resistance to cut-through traffic through historically and culturally important areas (Victoria Avenue and Gage Canal); residential communities (Alessandro Heights, Canyon Crest, Casa Blanca, Arlington Heights, Hawarden Hills, Presidential Park, and Victoria), and a biologically important habitat (Alessandro Arroyo and Eastern Survey areas)

Rather than moving forward with an Overlook Parkway Connection to ease traffic *from outside the City*, the City would likely be better served by continuing to participate in regional planning efforts; encouraging nearby municipalities, such as Moreno Valley and the County of Riverside, to consider the City of Riverside's traffic plans and policies in their

planning efforts; and enforcing the use of designated truck routes for those purposes.

Thank you for your consideration of these comments and the attached and/or referenced material.

Sincerely,

Raymond W. Johnson
JOHNSON & SEDLACK

Attachments and Electronic Citations

(1) *The Health Effects of Air Pollution on Children*, Michael T. Kleinman, Ph.D, Fall 2000, <http://aqmd.gov/forstudents/health_effects_on_children.html#WhyChildren>

(2) *Diesel and Health in America: the Lingering Threat*, Clean Air Task Force, February 2005, <http://www.catf.us/resources/publications/files/Diesel_Health_in_America.pdf>

(3) Annual Meeting of the Brain & Lung Tumor and Air Pollution Foundation, April 2, 2010, <http://www.aqmd.gov/hb/2010/April/100425a.htm>

(4) *Technical Support Document for Cancer Potency Factors: Methodologies for derivation, listing of available values, and adjustments to allow for early life stage exposures*, California EPA OEHHA Air Toxicology and Epidemiology Branch, April 2009, p. 3. <http://www.oehha.ca.gov/air/hot_spots/pdf/TSDCPFApril_09.pdf.>

(5) California Air Pollution Control Officers Association. (January 2008) *CEQA & Climate Change: Evaluating and Addressing Greenhouse Gas Emissions from Projects Subject to the California Environmental Quality Act.*

(6) U.S. Department of Transportation, Federal Highway Administration. (August 2006) *Construction Noise Handbook, Chapters 3, 4, and 9* <http://www.fhwa.dot.gov/environment/noise/construction_noise/handbook/index.cfm>

(7) Electronic Library of Construction Occupational Safety and Health (November/December 2002) *Construction Noise: Exposure, Effects, and the Potential for Remediation; A Review and Analysis.*

(8) U.S. Department of Housing and Urban Development. (March 1985) *The Noise Guidebook.*

(9) Suter, Dr. Alice H., Administrative Conference of the United States. (November 1991) *Noise and Its Effects.*

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City Planning:

Current Planning

- Two years principal planner, Lenexa, Kansas (consulting)
- Two and one half years principal planner, Lee's Summit, Missouri
- One year North Desert Regional Team, San Bernardino County
- Thirty years subdivision design: residential, commercial and industrial
- Thirty years as applicants representative in various jurisdictions in: Missouri, Texas, Florida, Georgia, Illinois, Wisconsin, Kansas and California
- Twelve years as applicants representative in the telecommunications field

General Plan

- Developed a policy oriented Comprehensive Plan for the City of Lenexa, Kansas.
- Updated Comprehensive Plan for the City of Lee's Summit, Missouri.
- Created innovative zoning ordinance for Lenexa, Kansas.
- Developed Draft Hillside Development Standards, San Bernardino County, CA.
- Developed Draft Grading Standards, San Bernardino County.
- Developed Draft Fiscal Impact Analysis, San Bernardino County

Environmental Analysis

- Two years, Environmental Team, San Bernardino County
  - Review and supervision of preparation of EIR's and joint EIR/EIS's
  - Preparation of Negative Declarations
  - Environmental review of proposed projects
- Eighteen years as an environmental consultant reviewing environmental documentation for plaintiffs in CEQA and NEPA litigation

Representation:

- Represented various clients in litigation primarily in the fields of Environmental and Election law. Clients include:
  - Sierra Club
  - San Bernardino Valley Audubon Society
  - Sea & Sage Audubon Society
  - San Bernardino County Audubon Society
  - Center for Community Action and Environmental Justice
  - Endangered Habitats League
  - Rural Canyons Conservation Fund
  - California Native Plant Society
  - California Oak Foundation
  - Citizens for Responsible Growth in San Marcos
  - Union for a River Greenbelt Environment
  - Citizens to Enforce CEQA
  - Friends of Riverside's Hills
  - De Luz 2000
  - Save Walker Basin
  - Elsinore Murrieta Anza Resource Conservation District

Education:

- B. A. Economics and Political Science, Kansas State University 1970
- Masters of Community and Regional Planning, Kansas State University, 1974
- Additional graduate studies in Economics at the University of Missouri at Kansas City
- J.D. University of La Verne. 1997 Member, Law Review, Deans List, Class Valedictorian, Member Law Review, Published, Journal of Juvenile Law

Professional Associations:

- Member, American Planning Association
- Member, American Institute of Certified Planners
- Member, Association of Environmental Professionals
- Member, U.S. Green Building Council, LEED GA

Johnson & Sedlack, Attorneys at Law
26785 Camino Seco
Temecula, CA 92590
(951) 506-9925

12/97- Present

Principal in the environmental law firm of Johnson & Sedlack. Primary areas of practice are environmental and election law. Have provided representation to the Sierra Club, Audubon Society, AT&T Wireless, Endangered Habitats League, Center for Community Action and Environmental Justice, California Native Plant Society and numerous local environmental groups. Primary practice is writ of mandate under the California Environmental Quality Act.

Planning-Environmental Solutions
26785 Camino Seco
Temecula, CA 92590
(909) 506-9825

8/94- Present

Served as applicant's representative for planning issues to the telecommunications industry. Secured government entitlements for cell sites. Provided applicant's representative services to private developers of residential projects. Provided design services for private residential development projects. Provided project management of all technical consultants on private developments including traffic, geotechnical, survey, engineering, environmental, hydrogeological, hydrologic, landscape architectural, golf course design and fire consultants.

San Bernardino County Planning Department
Environmental Team
385 N. Arrowhead
San Bernardino, CA 92415
(909) 387-4099

6/91-8/94

Responsible for coordination of production of EIR's and joint EIR/EIS's for numerous projects in the county. Prepared environmental documents for numerous projects within the county. Prepared environmental determinations and environmental review for projects within the county.

San Bernardino County Planning Department
General Plan Team
385 N. Arrowhead
San Bernardino, CA 92415
(909) 387-4099

6/91-6/92

Created draft grading ordinance, hillside development standards, water efficient landscaping ordinance, multi-family development standards, revised planned development section and fiscal impact analysis. Completed land use plans and general plan amendment for approximately 250 square miles. Prepared proposal for specific plan for the Oak Hills community.

San Bernardino County Planning Department
North Desert Regional Planning Team
15505 Civic 6/90-6/91
Victorville, CA
(619) 243-8245

Worked on regional team. Reviewed general plan amendments, tentative tracts, parcel maps and conditional use permits. Prepared CEQA documents for projects.

Broadmoor Associates/Johnson Consulting
229 NW Blue Parkway
Lee's Summit, MO 64063
(816) 525-6640 2/86-6/90

Sold and leased commercial and industrial properties. Designed and developed an executive office park and an industrial park in Lee's Summit, Mo. Designed two additional industrial parks and residential subdivisions. Prepared study to determine target industries for the industrial parks. Prepared applications for tax increment financing district and grants under Economic Development Action Grant program. Prepared input/output analysis of proposed race track Provided conceptual design of 800 acre mixed use development.

Shepherd Realty Co.
Lee's Summit, MO 6/84-2-86

Sold and leased commercial and industrial properties. Performed investment analysis on properties. Provided planning consulting in subdivision design and rezoning.

Contemporary Concepts Inc.
Lee's Summit, MO 9/78-5/84
Owner

Designed and developed residential subdivision in Lee's Summit, Mo. Supervised all construction trades involved in the development process and the building of homes.

Environmental Design Association
Lee's Summit, Mo.
Project Coordinator 6/77-9/78

Was responsible for site design and preliminary building design for retirement villages in Missouri, Texas and Florida. Was responsible for preparing feasibility studies of possible conversion projects. Was in charge of working with local governments on zoning issues and any problems that might arise with projects. Coordinated work of local architects on projects. Worked with marketing staff regarding design changes needed or contemplated.

City of Lee's Summit, MO
220 SW Main
Lee's Summit, MO 64063
Community Development Director 4/75-6/77

Supervised Community Development Dept. staff. Responsible for preparation of departmental budget and C.D.B.G. budget. Administered Community Development Block Grant program. Developed initial Downtown redevelopment plan with funding from block grant funds. Served as a member of the Lee's Summit Economic Development Committee and provided staff support to them. Prepared study of available industrial sites within the City of Lee's Summit. In charge of all planning and zoning matters for the city including comprehensive plan.

Howard Needles Tammen & Bergendoff
9200 Ward Parkway
Kansas City, MO 64114
(816) 333-4800 5/73-4/75
Economist/Planner

Responsible for conducting economic and planning studies for Public and private sector clients. Consulting City Planner for Lenexa, KS.

Conducted environmental impact study on maintaining varying channel depth of the Columbia River including an input/output analysis. Environmental impact studies of dredging the Mississippi River. Worked on the Johnson County Industrial Airport industrial park master plan including a study on the demand for industrial land and the development of target industries based upon location analysis. Worked on various airport master plans. Developed policy oriented comprehensive plan for the City of Lenexa, KS. Developed innovative zoning ordinance heavily dependent upon performance standards for the City of Lenexa, KS.

SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

THE HEALTH EFFECTS OF AIR POLLUTION ON CHILDREN

Fall 2000

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Introduction

Air pollution has many effects on the health of both adults and children. The purpose of this article will be to examine what is known about how air pollution affects health, especially children's.

Over the past several years the incidence of a number of diseases has increased greatly. Asthma is perhaps the most important disease with an increasing incidence, but other diseases, such as allergic reactions, bronchitis and respiratory infections also have been increasing. The cause of these increases may be due at least in part to the effects of air pollution. This review will address the following questions:

1. Why are children more susceptible to the effects of air pollution than adults?
2. Which air pollutants have the greatest impact on the health of children and adults?
3. What can be done to reduce the effects of air pollution on children's health?

Why are Children More Susceptible to Air Pollution Than Adults?

In many health effects research studies, children are considered as if they were small adults. This is not really true. There are many differences between children and adults in the ways that they respond to air pollution. For example, children take in more air per unit body weight at a given level of exertion than do adults. When a child is exercising at maximum levels, such as during a soccer game or other sports event, they may take in 20 percent to 50 percent more air -- and more air pollution -- than would an adult in comparable activity.

Another important difference is that children do not necessarily respond to air pollution in the same way as adults. Adults exposed to low levels of the pollutant ozone will experience symptoms such as coughing, soreness in their chests, sore throats, and sometimes headaches. Children, on the other hand, may not feel the same symptoms, or at least they do not acknowledge them when asked by researchers. It is currently not known if children actually do not feel the symptoms or if they ignore them while preoccupied with play activities.

This probably does not mean that children are less sensitive to air pollution than adults. There are several good studies that show children to have losses in lung functions even when they don't cough or feel discomfort. This is important because symptoms are often warning signals and can be used to trigger protective behavior. Children may not perceive these warning signals and might not reduce their activities on smoggy days.

Children also spend more time outside than adults. The average adult, except for those who work mostly outdoors, spends most of their time indoors -- at home, work, or even at the gym. Children spend more time outside, and are often outdoors during periods when air pollution is at its highest.

The typical adult spends 85 percent to 95 percent of their time indoors, while children may spend less than 80 percent of their time indoors. Children may also exert themselves harder than adults when playing outside.

Perhaps the most important difference between adults and children is that children are growing and developing. Along with their increased body size, children's lungs are growing and changing, too.

The Lung's Important Role in Health
The lung is an extremely complex organ. While most organs in your body are made up of a few different types of cells, the lung contains more than 40 different kinds of cells. Each of these cells is important to health and maintaining the body's fitness.

Air pollution can change the cells in the lung by damaging those that are most susceptible. If the cells that are damaged are important in the development of new functional parts of the lung, then the lung may not achieve its full growth and function as a child matures to adulthood. Although very little research has been conducted to address this extremely important issue, this review will discuss the information that is available.

USC Children's Health Study
Recent results from the Children's Health Study, conducted by investigators at the University of Southern California, suggest that children with asthma are at much greater risk of increased asthma symptoms when they live in communities with higher levels of ozone and particles and participate in three or more competitive sports. Having said all this, the purpose of this review is not to discourage children or adults from normal daily activities and outdoor exercise. Exercise has very important, beneficial outcomes. Appropriate exercise and prudent exposures of children and adults should be encouraged even in an environment that may always contain some amount of air pollution.

Which Air Pollutants Have the Greatest Impact on the Health of Children and Adults?

Ozone

Ozone is one of the most important air pollutants affecting human health in regions like Southern California.

Ozone (O_3) is a molecule built of three atoms of oxygen linked together in a very energetic combination. When ozone comes into contact with a surface it rapidly releases this extra force in the form of chemical energy. When this happens in biological systems, such as the respiratory tract, this energy can cause damage to sensitive tissues in the upper and lower airways.

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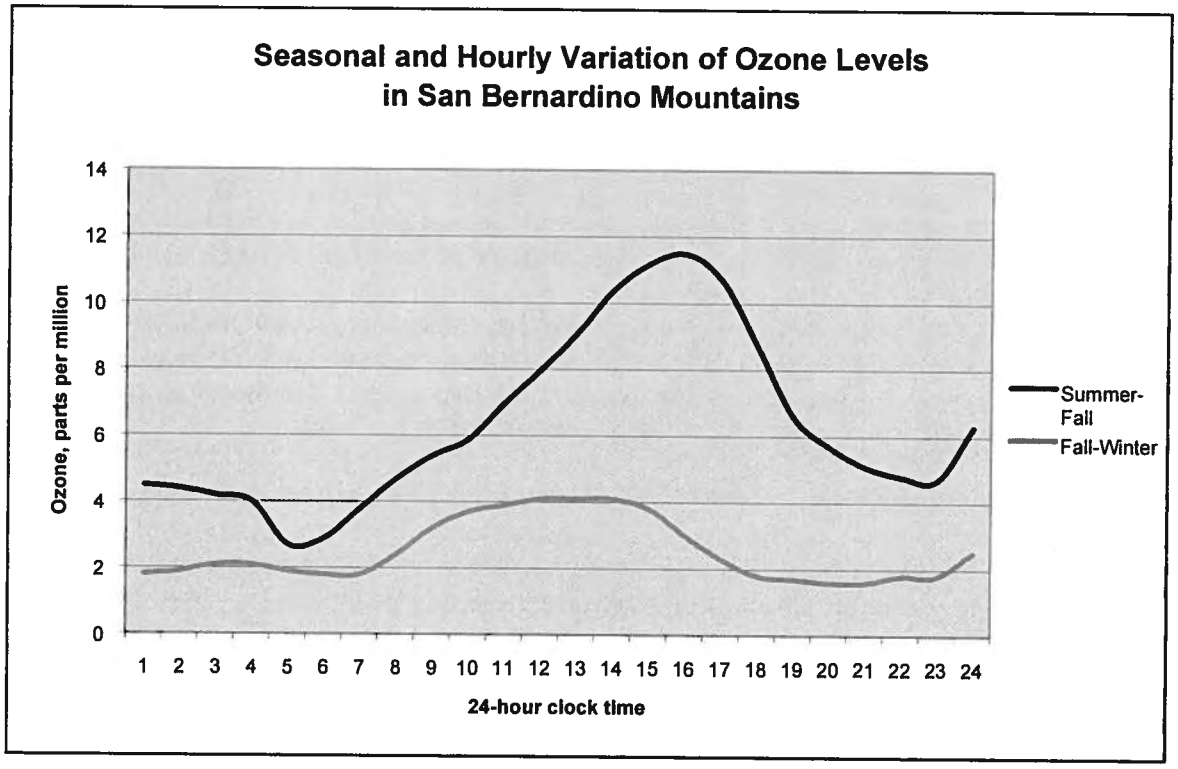
Ozone formation

Because ozone forms as a product of solar energy and photochemical reactions of pollutants, it is not surprising that the highest concentrations of ozone in the atmosphere occur when sunlight is most intense. Thus, ozone generally reaches peak levels during the middle of the day in the summer months. These types of air pollution patterns are called diurnal and seasonal variations. The following graph shows that ozone levels in the San Bernardino Mountains are highest in the summer and fall, and peak in the late afternoon.



Ozone Air Quality Standards

Federal and state agencies have set air quality standards for ozone. An ozone level greater than 0.08 parts per million (ppm) averaged over eight hours is considered unhealthful. This level has been set because both laboratory and community studies have demonstrated measurable effects of ozone at or above that threshold.

The effects of ozone on people include:

- irritation of the nose and throat;
- increased mucus production and tendency to cough;
- eye irritation and headaches for some; and
- during severe episodes, chest pain and difficulty taking a deep breath without coughing.

How Ozone Damages Lungs

What happens when you breathe air that is contaminated with ozone? Like oxygen, ozone is soluble in the fluids that line the respiratory tract. Therefore some ozone can penetrate into the gas-exchange, or alveolar, region of the deep lung.

The following photos show how ozone affects the sensitive tissue in the deep lung. The pictures are from the lungs of rats exposed to ozone in a laboratory under carefully controlled conditions. The human lung is similar --although not identical -- to the rat's lung in terms of the types of cells and the overall structure of the alveolar region.

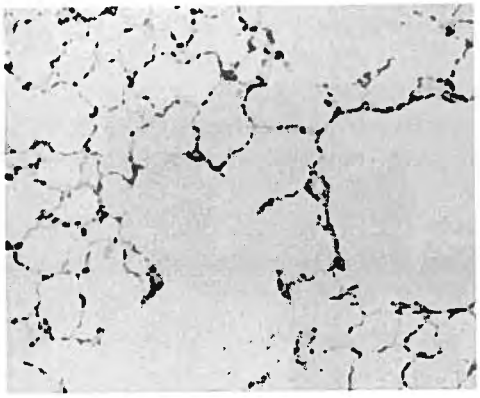


Figure 1

Figure 1 shows a magnified view of the structure of the normal gas-exchange region of the lung. It is called the gas-exchange region because oxygen inhaled from the air is transferred to the hemoglobin in blood in small blood vessels located inside the thin walls separating the alveolar air spaces.

At the same time, carbon dioxide, produced by normal metabolism and dissolved in the blood, is excreted into the air and expired when you breathe out.

The walls of a normal alveolus are very thin. There are only two layers of cells and a thin interstitial matrix separating the air in the alveolar space, or lumen, from the fluid inside the blood vessels. The cells that line the healthy alveoli are mostly very broad and very thin, and are called Type I lung cells or Type I pneumocytes. This provides a very large surface area across which gases can be efficiently transported.

Figure 2 shows the effects of breathing 0.2 ppm ozone for 4 hours. In Southern California air pollution levels can approach 0.2 ppm -- a Stage 1 ozone alert -- during the smoggiest summer days. The photo shows evidence of additional cells, called macrophages, and some material that may be fragments of ozone-injured alveolar wall cells inside the alveolar space.

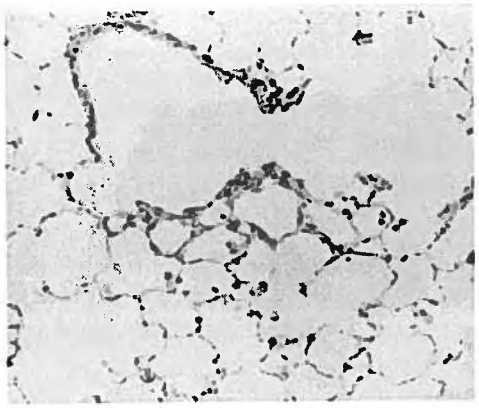


Figure 2

Macrophages are immune system cells that respond to the injury of the delicate cells that line the alveolar lumen. These macrophages play important roles in protecting the lungs from inhaled bacteria,

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fungi and viruses, and are also important in helping to repair lung tissue injury caused by inhaled pollutants.

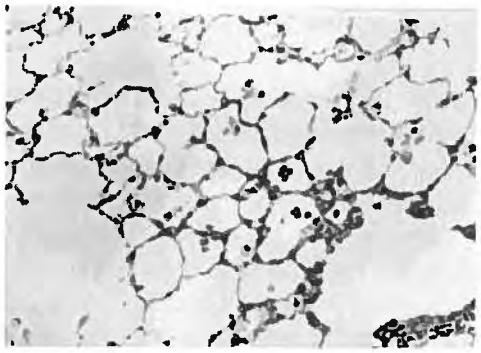

Figure 3

Figure 3 shows more extensive damage following exposure a higher concentration of ozone, 0.6 ppm. The alveolar walls are thicker and there is evidence of cells infiltrating within the walls. There are more macrophages in the alveolar spaces and the thin, Type I cells have been damaged and replaced with thicker Type II, almost cube-shaped cells that are more resistant to the toxic effects of ozone. All of these changes occurred within 48 hours after exposure. If exposure continues for more than three days, the evidence of cell injury seems to be reduced, except for the continuing presence of the Type II cells.

Is Ozone-Related Lung Damage Permanent?
People actually report that the symptoms they feel when first exposed to ozone seem to go away, even though their exposure continues.

Following ozone injury, if the lung is not exposed to ozone for approximately five to seven days, it can for the most part repair itself provided the injury is not too extensive. However, long-term studies with laboratory animals have shown that there may be residual and in some cases permanent damage. This damage might be thought of as accelerated aging of the lung. Thus, frequent exposures to ozone can cause transient damage. The lung's defenses can repair most but probably not all of that damage within a relatively short time in most healthy individuals.

Research and Air Quality Standards
Health scientists probably know more about the effects of ozone on human health than about any other pollutants. This is because ozone is pervasive in the environment. Also there are excellent methods of measuring ozone so the pollutant can be studied using epidemiological methods. The findings of these epidemiological studies can be verified using well-controlled laboratory studies with human volunteers and laboratory animals. Thousands of scientific papers on the health effects of ozone have been published and these have been critically reviewed in documents that provide the scientific basis for National and State Ambient Air Quality Standards. (Ambient refers to outdoor air.)

These so-called Criteria Documents are important because they are extensively reviewed by scientists, public agencies, industry representatives, environmental groups such as the American Lung Association and the Natural Resources Defense Council,

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and the public. National and state ambient air quality standards set the goals for healthy air quality in Southern California and across the country.

Based upon the most recent studies, it is now apparent that ozone plays an important role in causing acute health effects, such as heightening asthma symptoms and developing bronchitis symptoms.

The role of ozone in producing long-term or chronic effects is less clear, at least from the available epidemiological studies. However, laboratory animal studies suggest that there can be long-term consequences.

How to Reduce Ozone Exposure
The U.S. Environmental Protection Agency (EPA) has recommended that ozone should not exceed 0.08 ppm averaged over an 8-hr period. When ozone exceeds this level, active children and adults, those with respiratory disease such as asthma, and other people with unusual susceptibility to ozone should limit prolonged outdoor exposure.

Incidentally, personal tobacco smoking during periods of high ozone exposure doubled the risk of asthmatic individuals needing to go to the emergency room for treatment of asthma symptoms.

Carbon Monoxide

Carbon monoxide (CO), a colorless, odorless gas, is a byproduct of combustion.

When inhaled, carbon monoxide reacts very rapidly with hemoglobin in the blood, preventing uptake and transport of oxygen. Because carbon monoxide readily and firmly attaches to hemoglobin, it stays in the blood for a relatively long time. Thus, during an exposure carbon monoxide concentrations in blood can rise in a matter of minutes, then stay high for hours.

Who is Most Sensitive to the Health Effects of Carbon Monoxide?
Most of the health effects directly associated with carbon monoxide are most likely due to decreases in oxygen delivery to vital organs such as the heart and the brain.

People with heart disease may be especially sensitive to the effects of carbon monoxide. In addition, people with lung diseases that limit efficient use of inhaled oxygen, such as asthma and emphysema, may also be susceptible. Even in people without heart or lung diseases, reduced delivery of oxygen to skeletal muscles, especially during exercise, can reduce the ability to perform strenuous work.

At high levels of carbon monoxide exposure, impaired delivery of oxygen to the central nervous system can reduce the ability to respond quickly to external stimuli. After exposures that convert 5 percent to 10 percent of the circulating hemoglobin to carboxyhemoglobin (COHb), people's ability to recognize and react to flashes of light in a test system are reduced. At 10 percent to 30 percent carboxyhemoglobin, nausea,

headaches, unconsciousness, and sometimes death can result. The severity of symptoms increases with the concentration of carboxyhemoglobin.

Air Quality Standards for Carbon Monoxide
Both the EPA and the State of California have set air quality standards for carbon monoxide based on the results of epidemiological and laboratory findings. Ambient levels of carbon monoxide should not exceed 9 ppm, when averaged over an 8-hour interval, and should not exceed 20 ppm in any one-hour period. (The USEPA has a slightly higher 1-hour standard of 35 ppm).

Sources of Carbon Monoxide
The major sources of carbon monoxide pollution are automotive exhaust and emissions from large industrial combustion sources such as electrical power plants. Because these sources produce many contaminants in addition to carbon monoxide -- such as fine particles and nitrogen oxides -- it is often difficult to isolate the health effects of ambient carbon monoxide from those of other pollutants.

In addition to carbon monoxide generated outside, there are also important indoor sources of the pollutant. The most important of these are combustion sources such as gas ovens, gas burners, water heaters, and heating systems. However, in most cases emissions from well-maintained and vented gas appliances are small.

Tobacco smoking is a more significant source of carbon monoxide. Tobacco smoke can contain very high concentrations of carbon monoxide (1,000 ppm to 50,000 ppm). Carbon monoxide levels in the homes of children whose relatives smoke tobacco products can be higher than the carbon monoxide levels outdoors.

Health Effects of Carbon Monoxide
There are hundreds of cases per year of deaths or severe illness due to carbon monoxide poisoning from faulty appliances, indoor emissions of automobile exhaust and industrial exposures. These cases show that carbon monoxide poisoning causes symptoms very similar to those of the flu. In fact, the true number of cases is not really known because many people may have been poisoned slightly and thought that they were just fighting off a cold or the flu. Thus it is very important to make sure that home appliances are well-maintained and that all combustion sources are properly vented to the outdoors.

Epidemiological studies have shown significant association between several health effects and carbon monoxide, although as mentioned earlier it is difficult to completely isolate carbon monoxide's effects from those of other air pollutants.

For example, asthmatic children in Taiwan who were exposed to high levels of traffic-related air pollution -- using carbon monoxide and nitrogen dioxide as marker compounds-- reported more respiratory symptoms than children with lower exposures.

A study of physician office visits in London showed associations between air pollution and doctor visits for asthma and other lower respiratory disease. For children, levels of nitrogen dioxide, carbon monoxide, and sulfur dioxide were associated with increased numbers of medical consultations. However, in adults, the only consistent association was with levels of airborne particles. This suggests that children and adults might respond differently to pollution exposures.

Prenatal Effects of Carbon Monoxide

Carbon monoxide may also have prenatal effects. Pregnant women who were exposed to high levels of ambient carbon monoxide (5 ppm to 6 ppm) were at increased risk of having low birth-weight babies. It has long been known that women who smoke cigarettes during pregnancy have low birth-weight babies, but this is the first study of similar findings in women exposed to environmental carbon monoxide.

Babies exposed to carbon monoxide during the maturation of their organs may suffer permanent changes to those organs. Studies using newborn rats showed that carbon monoxide exposure could cause changes in the heart muscle tissue. This is turn could increase the severity of effects of artery constrictions when they became adults. Other animal studies have shown that long-term carbon monoxide exposure can contribute to a disease called ventricular hypertrophy, in which the cells of the heart's ventricle chambers are enlarged and possibly weakened.

Airborne Particles

Particles, including nitrates, sulfates, carbon[1] and acid aerosols[2] are a complex group of pollutants.

Unlike ozone, which has a specific chemical composition, airborne particles vary in size and composition depending on time and location. Although the components of particles may have common sources, the types and amounts of particles collected at any one time and location may be unique.

To add to the problem, gaseous pollutants including ozone, sulfur dioxide, nitrogen dioxide and carbon monoxide often are present in the atmosphere at the same time as are particles. It is not always possible to clearly differentiate between the health effects of the gases, the particles, and possibly the combination of particles and gases. This complexity presents a tremendous challenge to the scientific community and to public in trying to understand how inhaled particles affect human health.

The Challenge of Measuring Particle Pollution

Precisely measuring particulate pollution is more difficult and labor intensive than measuring gaseous pollutants such as ozone. For this reason, particle concentrations are not measured on a daily basis in most communities. Frequently, they are measured once every six days.

[1] Both elemental and organic. Elemental carbon is pure carbon from combustion sources, including diesel particulate. Organic carbon is a semi-volatile hydrocarbon from combustion and some evaporative sources.
[2] Aerosol is the scientific term used to describe particles suspended in a fluid, such as air.

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Particle samples are collected on filters that are then weighed. Particle concentrations are reported in terms of micrograms of particles per cubic meter ($\mu g/m^3$) of collected air.

Originally, the particle samples were relatively indiscriminate with respect to particle size and often contained very large particles. These large particles contributed a great deal to the weighed particle mass, but might not have been very important with respect to lung health. This is because most of the particles were too large to penetrate through the nasal and head airways to reach the lung. A more health-related sample was needed.

After a great deal of scientific consideration it was decided that particulate matter with aerodynamic diameters[3] less than or equal to 10 microns (µm) should be collected. Ambient air quality standards were developed for this material, which is called PM_{10}.

Sources of Particle Pollution

Researchers noted that the sources of relatively large-size particles (greater than 3 microns in aerodynamic diameter) were quite distinct from the sources of particles less than 1 micron in diameter.

The larger, so-called "coarse" particles are mostly produced by mechanical processes, such as automobile tire wear on the road, industrial cutting, grinding and pulverizing processes and re-suspension of particles from the ground or other surfaces by wind and human activities. The chemical composition of coarse particles may be somewhat similar to the chemical composition of soil in that area, along with industrial compounds from activities such as mining or smelting operations. The coarse fraction of urban aerosols also contains bits of plants, molds, spores and some bacteria. Thus the characteristics of the coarse particles may vary greatly in different communities.

In contrast, the smaller or so-called "fine" particles in the urban aerosol come from combustion sources, such as power plants, automobile, truck, bus and other vehicle exhaust or from the reactions that transform some of the pollutant gases into solid or liquid particles. These distinctions may be important because the current air pollution health effects literature suggests, although not with certainty, that for some key health effects the fine particles are more important than the coarse particles. These findings have led EPA to propose a new nationwide $PM_{2.5}$ standard that would reduce exposure to particles that are 2.5 microns or less in diameter.

Historic Air Pollution Disasters

Epidemiological studies have consistently associated adverse health effects with exposures to particulate air pollution. Early studies implicated particulate and sulfur dioxide pollution in the acute illnesses and premature deaths associated with extremely

[3] Aerodynamic diameter is used to define particles' size. Particle deposition on a surface, or in the lung, depends on the particle's aerodynamic and diffusion characteristics. A particle's aerodynamic characteristics depend on its density, shape, actual size, and velocity while its diffusion characteristics are functions of its size and the density of the air in which it is suspended.

severe pollution episodes in Donora, Penn., London, and New York in the 1940s, 1950s, and 1960s. The particle levels in a four-week pollution disaster in London in 1955 were more than 50 times higher than the California standard.[4] Twenty percent of that aerosol was composed of acid sulfates -- probably sulfuric acid. The number of people hospitalized for lung or heart-related diseases was extraordinarily high, but more importantly there were more than 4,000 premature, or "excess," deaths in the London population.

Fortunately, major efforts by government agencies, the public, and industries have made it very unlikely there will ever be a similar episode in modern urban communities. However, the lessons learned from these disasters are still relevant. Despite the fact that our levels of airborne particles are much lower than those that occurred during the disasters, EPA estimates that there are still more than 6,000 excess deaths in the United States that could be associated with inhaled particles.

Health Effects of Particulate Pollution

Current ambient levels of PM_{10} -- 30 to 150 micrograms per cubic meter -- are associated with increases in the numbers of people that die daily from heart or lung failure. Most of these deaths are among the elderly. However there is a strong body of evidence that some children are also adversely affected by particulate matter.

The American Thoracic Society's Environmental and Occupational Health Assembly reviewed current health effects literature. They report that daily fluctuations in PM_{10} levels have been related to:

- acute respiratory hospital admissions in children;
- school and kindergarten absences;
- decreases in peak lung air flow rates in normal children; and
- increased medication use in children and adults with asthma.

The USC Children's Health Study suggests that children with asthma living in a community with high particle concentrations may have suppressed lung growth. After children moved into cleaner cities their lung growth returned to the normal rate, but they did not recover the lost potential growth, according to John Peters, the study's principle investigator.

It is difficult to positively assign a quantitative risk associated with particulate matter because nearly all studies of its health effects find other pollutants present that may account for some of the effects.

Part of the problem is due to the nature of the data being collected. The levels of particulate matter vary during the course of the day and peak values can be quite high. Few studies have evaluated the effect of these short-term "spikes." However, at least one epidemiological study of children with asthma suggested that changes in symptoms

[4] The California standard for particulate matter (PM_{10}) is 50 micrograms per cubic meter averaged over 24 hours

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and lung function correlate more strongly with 1-hour peaks than with 24-hour average concentrations.

Other studies, primarily with laboratory animals, suggest that the chemical composition[5] and surface areas of the particles may be more important than particle mass. Scientists are continuing to study the health effects of particles and are developing better methods for measuring the important constituents. It may be possible in the near future to more accurately assess the effects of inhaled particles on human health.

Nitrogen Oxides

Nitrogen oxides are produced during most combustion processes. Mobile sources and power plants are the major contributors in Southern California.

About 80 percent of the immediately released nitrogen oxide is in the form nitric oxide (NO). Small amounts of nitrous oxide (N_2O) are also produced. Nitrous oxide is a "greenhouse" gas that is suspected of playing an important role in global warming.

Nitric oxide reacts with oxygen in the air to produce nitrogen dioxide (NO_2). Further oxidation during the day causes the nitrogen dioxide to form nitric acid and nitrate particles. In the dark, nitrogen dioxide can react with ozone and form a very reactive free radical. The free radical then can react with organic compounds in the air to form nitrogenated organic compounds, some of which have been shown to be mutagenic and carcinogenic.

Health Effects of Nitrogen Dioxide

Nitrogen dioxide is the most important nitrogen oxide compound with respect to acute adverse health effects. Under most chemical conditions it is an oxidant, as is ozone. However, it takes about 10 times more nitrogen dioxide than ozone to cause significant lung irritation and inflammation.

Nitrogen dioxide differs from ozone in that it suppresses the immune system to a much greater degree. As discussed below, some epidemiological studies have shown that children exposed to high levels of ambient nitrogen dioxide may be at increased risk of respiratory infections. Studies with laboratory animals have indeed shown that if mice are exposed first to nitrogen dioxide and later to bacteria at a level that would not infect a healthy control animal, their normal lung defense mechanisms are suppressed and the bacteria are able to infect the host.

[5] The idea that all particles are equally toxic is not scientifically justified. There are many good examples that can be taken from studies of particles in the workplace. For example, certain types of particles that contain quartz --a natural mineral composed of silicon dioxide but with a specific crystal structure -- are very potent lung irritants. Repeated exposures to this material can lead to a serious, permanent lung disease called lung fibrosis. Other mineral particles that are fibrous, such as specific forms of asbestos, can cause lung cancer. Other particles such as titanium dioxide do not seem to cause occupational diseases.

Average levels of nitrogen dioxide in the United States range from 0.02 to 0.04 ppm. Levels in major urban areas in Southern California may be higher, but the region has not exceeded the federal standard[6] for nitrogen dioxide since 1991.

During the 1970s, one of the first studies relating respiratory illnesses and changes in lung function to ambient nitrogen dioxide concentrations reported that children living in areas with high nitrogen dioxide concentrations had greater incidences of lung-related illness than children living in areas with lower concentrations. Since then, other epidemiological studies have suggested that children with asthma are more likely than children without asthma to have reduced lung function and symptoms of respiratory irritation, such as cough and sore throat, when outdoor average nitrogen dioxide concentrations exceed about 0.02 ppm.

Some studies also have suggested that children younger than five years old may be more severely affected by nitrogen dioxide than older children. Several epidemiological studies have suggested that for children, the most important effect of ambient exposure to nitrogen dioxide might be increased susceptibility to respiratory infections and increased severity of responses to inhaled allergens.

Although many epidemiological studies show significant associations between outdoor nitrogen dioxide concentrations and adverse health outcomes, some studies do not corroborate these effects. In part, this is because it is often difficult to fully account for the influences of indoor sources of nitrogen dioxide.

Improvements in Nitrogen Dioxide Measurements

More recent studies have used special devices, called passive dosimeters, that can be worn by children to collect nitrogen dioxide for later analysis. These measurements give epidemiologists the ability to better assess a child's total nitrogen dioxide exposure over the course of the day. These studies show that there can be a great deal of individual variation in exposures, even for children living in the same communities. Thus, it is not surprising that epidemiological studies that do not estimate a nitrogen dioxide dose may reach different conclusions.

However, laboratory studies involving controlled exposures of human volunteers and laboratory animals have demonstrated plausible effects of nitrogen dioxide on human health. For example, if one exposes rats or other animals to nitrogen dioxide, and then examines their respiratory tract tissues, it is very evident that the pollutant can cause short-term injury similar to that seen after ozone exposure.

Long-term exposures to high concentrations of nitrogen dioxide can produce chronic damage to respiratory tract tissue that resembles the lung disease emphysema.

The pollutant's suppression of immune system functions reduces the ability of the host to fight off bacterial and viral infections. Human volunteers who inhaled weakened

[6] 0.053 ppm as an annual average

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influenza virus after being exposed to nitrogen dioxide in laboratories were more susceptible to the infection than a control group that did not inhale nitrogen dioxide.

Other studies show that nitrogen dioxide decreases the body's ability to generate antibodies when challenged by pathogens, and may reduce the ability of the respiratory system to remove foreign particles such as bacteria and viruses from the lung.

Lead

People can be exposed to lead (Pb) through air, food and water. Lead is a toxic heavy metal that causes nerve damage and impairs the body's ability to make hemoglobin, leading to a form of anemia.

Sources of Lead Pollution

Large amounts of lead were emitted to the atmosphere when it was used as a gasoline additive.[7] The emitted lead could be inhaled. In addition, lead fallout from the air caused widespread contamination of soil, plants, food products, and water.

Lead is often measured in children's blood as an index of environmental exposure. Even low levels[8] of lead in the blood of children aged 6 to 7 are linked to measurable changes in intelligence quotient and certain perceptual-motor skills. Higher levels of lead exposure can also result in kidney damage and may be related to high blood pressure in adults.

Sulfur Oxides

Most manmade emissions of the gas sulfur dioxide (SO_2) come primarily from the combustion of fossil fuels such as coal, oil, and diesel fuel.

Most of the sulfur in fossil fuel is converted sulfur dioxide, but a small amount is also converted to sulfuric acid. In the atmosphere, gaseous sulfur dioxide can also be converted to sulfuric acid and sulfate-containing particles. Thus, atmospheric concentrations of sulfur dioxide are often highly associated with acidic particles, sulfuric acid particles and sulfate particle concentrations.

The current National Ambient Air Quality Standards for sulfur dioxide are 18 micrograms per cubic meter averaged annually, and 365 micrograms per cubic meter averaged over 24 hours. Southern California does not exceed the national air quality standard because its industries primarily burn low-sulfur fuels such as natural gas. Much of the sulfur oxide air pollution in Southern California is likely to be associated with diesel emissions.

[7] Lead in the form of tetraethyl lead was added to gasoline in the United States in large amounts from the 1950s until it was banned in the mid-1970s.

[8] 10 to 30 micrograms per 100 milliliters

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Sulfur dioxide is a very water-soluble gas and therefore most of the sulfur dioxide that is inhaled is absorbed in the upper respiratory tract and does not reach the lung's airways. However, the small amount of sulfur dioxide that does penetrate into the airways can provoke important health effects, primarily in individuals with asthma.

For those with asthma, even relatively short-term, low-level exposures to sulfur dioxide can result in airway constriction leading to difficulty in breathing and possibly contribute to the severity of an asthmatic attack.

A number of epidemiological studies have shown associations between ambient sulfur dioxide and rates of mortality (death) and morbidity (illness). However, because sulfur dioxide is often strongly correlated with fine particles and especially sulfate-containing particles, it is difficult to separate the effects of sulfur dioxide from those of the particle compounds.

A study in France found an increase of 2.9 visits to the emergency room for every 20 micrograms per cubic meter increase in atmospheric sulfur dioxide. The results pertained to days when the average sulfur dioxide levels were above 68 micrograms per cubic meter but below the U.S. health standard.

In London, asthma and other lower respiratory diseases in children were most significantly associated with exposures to nitrogen dioxide, carbon monoxide, and sulfur dioxide. In adults the only consistent association was with particulate matter.

Hospital admissions for children with asthma may increase by 20 percent following acute exposure to ozone peaks and possibly with sulfur dioxide. Chronic exposure to increased levels of fine particles, sulfur dioxide, and nitrogen dioxide may be associated with up to threefold increase in nonspecific respiratory symptoms. Thus, recent literature suggests that sulfur dioxide affects adults and children differently and that chronic and acute effects may also be different.

Diesel Emissions

Diesel fuel is burned to power buses, trucks, road-building equipment, trains, boats and ships and electricity-generating equipment. When diesel fuel is burned, the exhaust includes both particles and gases. Diesel emissions are important constituents of ambient air pollution.

What's in Diesel?

Diesel particles consist mainly of elemental carbon and other carbon-containing compounds. Hundreds of compounds have been identified as constituents of diesel particles. These include polycyclic aromatic hydrocarbons (PAHs) and other compounds that have been associated with tumor formation and cancer. In 1998, the California Air Resources Board designated diesel particulate a cancer-causing toxic air contaminant.

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Diesel particles are microscopic. More than 90 percent of them are less than 1 micron in diameter. Due to their minute size, diesel particles can penetrate deeply into the lung. There is evidence that once in the lung, diesel particles may stay there for a long time.

In addition to particles, diesel exhaust contains several gaseous compounds including carbon monoxide, nitrogen oxides, sulfur dioxide and organic vapors, for example formaldehyde and 1,3-butadiene. Formaldehyde and 1,3-butadiene have been classified as toxic and hazardous air pollutants. Both have been shown to cause tumors in animal studies and there is evidence that exposure to high levels of 1,3-butadiene can cause cancer in humans.

AQMD's recent landmark research project, the Multiple Air Toxics Exposure Study II, found that diesel particulate is responsible for about 70 percent of the total cancer risk from all toxic air pollution in the greater Los Angeles metropolitan area.

Diesel emissions may also be a problem for asthmatics. Some studies suggest that children with asthma who live near roadways with high amounts of diesel truck traffic have more asthma attacks and use more asthma medication.

Some human volunteers, exposed to diesel exhaust in carefully controlled laboratory studies, reported symptoms such as eye and throat irritation, coughing, phlegm production, difficulty breathing, headache, lightheadedness, nausea and perception of unpleasant odors. Another laboratory study, in which volunteers were exposed to relatively high levels of diesel particles for about an hour, showed that such exposures could cause lung inflammation.

Thus current epidemiological and laboratory evidence suggests that at typical urban concentrations, diesel exhaust may contribute significantly to the health effects of air pollution.

What Can Be Done to Reduce the Effects of Air Pollution on Children's Health?

After reviewing the literature on how children's exposures differ from those of adults, it is evident that:

- children are outdoors more hours per day than most adults;
- they exert themselves to a greater degree while they are outside than most adults; and
- they participate in more organized activities than adults.

There are definite health benefits to having children participate in outdoor activities. However, scientific evidence also suggests that air pollution exposures can injure children's lungs and other organs.

Air quality information in the form of health reports and air quality advisories are now a regular part of life in California. One logical step is to reduce strenuous activities during pollution episodes and try to take advantage of those hours when airborne pollutant levels are lower.

At the public level there is a long-standing commitment to improve air quality. When you look at the air pollution levels in California today you can see that a great deal of progress has been made. There has been a cost for this progress. For instance, some products are more expensive. In return, the lower levels of pollutant exposure compared to 20 years ago should decrease the adverse effect of air pollution on the long-term health of our developing children.

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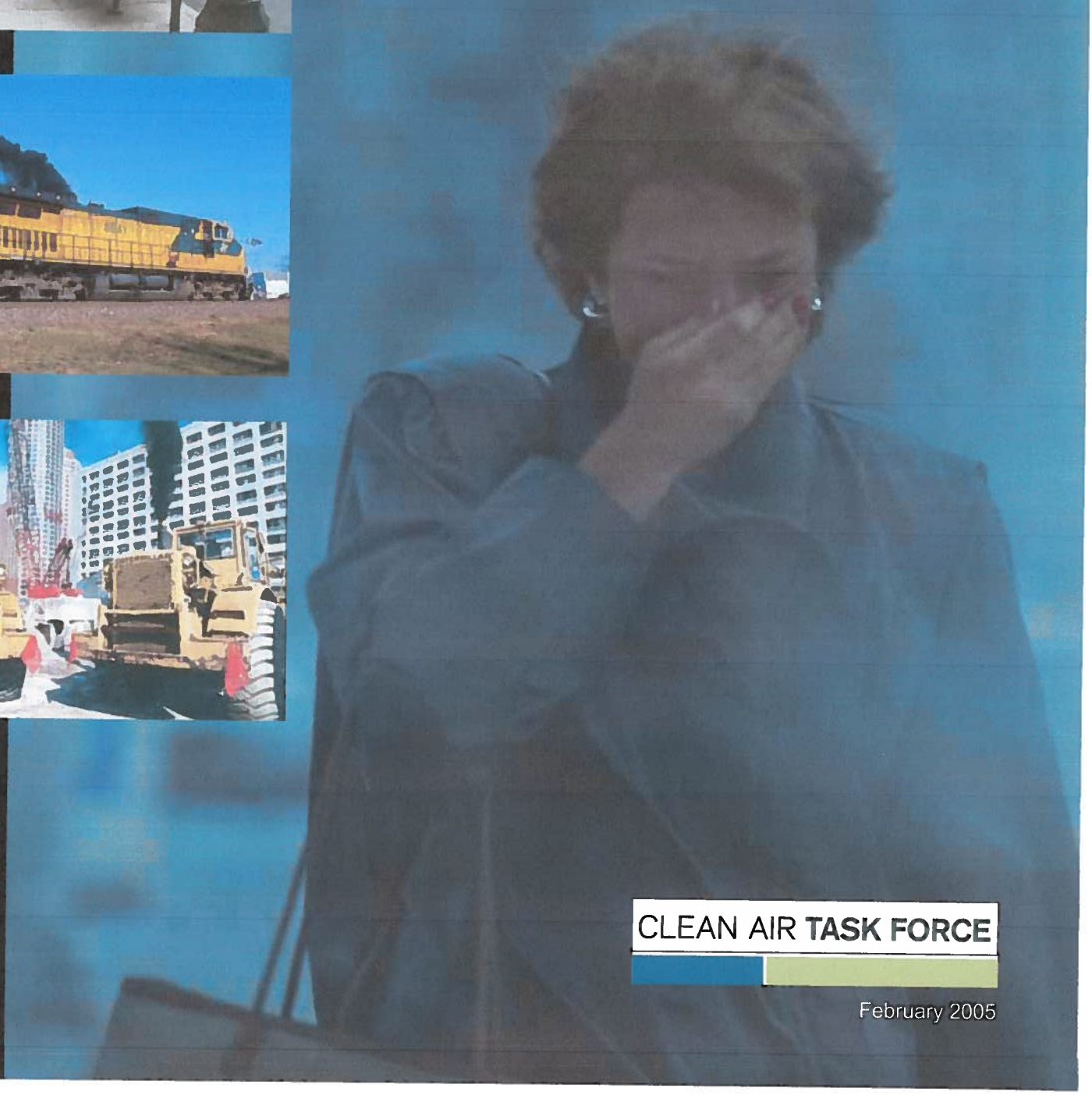
Diesel and Health in America:
The Lingering Threat

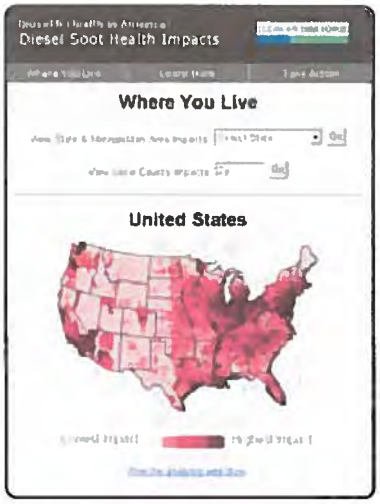


CLEAN AIR **TASK FORCE**

February 2005

Find out about the risks of breathing diesel exhaust *where you live*:

www.catf.us/goto/dieselhealth



CLEAN AIR **TASK FORCE**

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February 2005

Foreword

Scientists have been examining relationships between air pollution and death and disease for decades but only now are we beginning to understand the impacts of one of the most toxic sources of emissions today – the diesel engine. Diesels churn out a hazardous mix of gaseous and particle pollutants. What's more, diesel exhaust is emitted at ground level – where we breathe it – by trucks and buses around us in traffic, at school and transit bus stops, and by heavy construction or agricultural equipment. Diesel exhaust contains numerous dangerous compounds, ranging from respiratory irritants to carcinogens including a host of air toxics, particulate matter, carbon monoxide and nitrogen oxides.

While scientists have concluded that combustion-related particulate matter from all combustion sources is associated with premature death from heart attacks and cancer, we also are finding that carbon particles from mobile sources may be particularly unhealthy. These particles adsorb other metals and toxic gases produced by diesel engines – such as cancer causing-PAH (polycyclic aromatic hydrocarbons) – onto their surfaces making them even more dangerous. Furthermore, research on personal exposures demonstrates that these small particles easily penetrate our indoor environment where they may be trapped for days when ventilation is poor.

This report presents for the first time estimates of the health toll from diesel vehicle pollution. Using methodology approved by the U.S. Environmental Protection Agency's Science Advisory Board (SAB), the analysis finds that approximately 21,000 people die prematurely each year due to particulate matter pollution from diesels. Other serious adverse health impacts include tens of thousands of heart attacks, asthma attacks, and other respiratory ailments that can lead to days missed at work and at school.

Using more highly time-resolved studies we are increasingly able to understand the inflammation mechanism by which particles can lead to atherosclerosis, heart attacks, strokes and ultimately, untimely deaths. From all we know today, we can confidently say that reducing diesel exhaust in our environment will mean improving public health, and as this report demonstrates, reducing preventable premature deaths. We do not need to wait. Technology is available today that can reduce particulate matter emissions by up to 90 percent. Now is the time to clean up our old trucks, buses, heavy equipment and locomotives to provide a cleaner future for us and our children.

Howard Frumkin, M.D., Dr.P.H., FACP, FACOEM
Professor and Chair, Department of Environmental and Occupational Health
Emory University, Rollins School of Public Health

Executive Summary

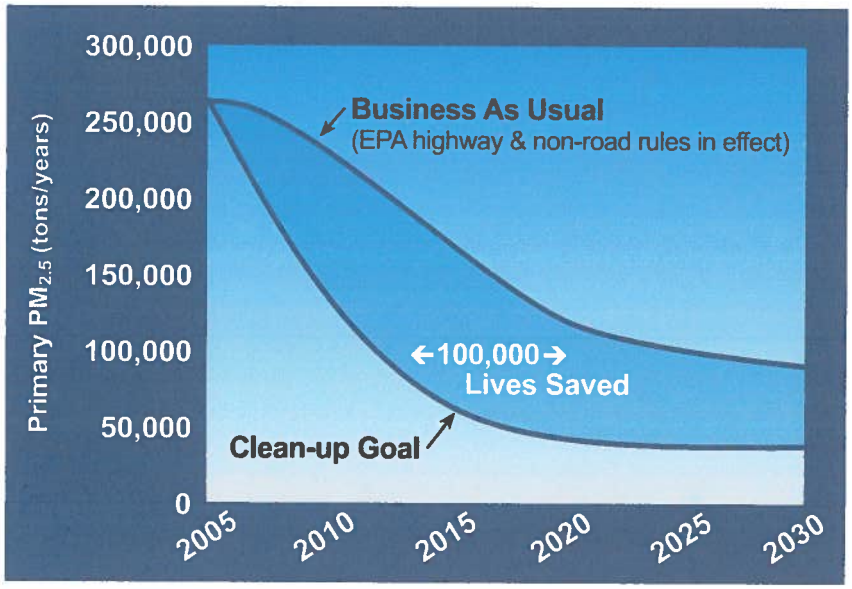
Everyone has experienced it: getting hit right in the face by a cloud of acrid diesel smoke. Perhaps you were standing on a street corner when a bus or truck whizzed by. Or maybe you were standing at a bus stop or stuck behind a dump truck grinding up a hill. But breathing diesel exhaust isn't just unpleasant. It is hazardous to your health. In fact, health research indicates that the portion of the exhaust you can't see may be the most dangerous of all. Asthma attacks, respiratory disease, heart attacks, and even premature death – all of these are among the most serious public health problems linked to emissions from the nation's fleet of diesel vehicles. The good news is that the technology exists right now to clean up emissions from these engines, so that most of the adverse health impacts can be prevented.

Today in the U.S. more than 13 million diesel vehicles help to build our cities and towns, transport our food and goods, and take us to and from work. More than three quarters of all Americans live near intersections, bus stops, highways, bus and truck depots, or construction sites with heavy equipment – all of which are concentrated sources of diesel exhaust. In rural areas, those who live near heavy diesel agricultural equipment suffer their share of exposure to diesel as well.

The U.S. Environmental Protection Agency has issued important regulations that will require dramatic reductions in emissions from new diesel vehicles starting in 2007 – but only the new ones. These regulations, to be phased in over the next quarter century, apply only to ***new*** engines. What about the diesels on the road today? The lifespan of the

average diesel vehicle is nearly 30 years. Many diesels are driven over a million miles. Because of this longevity, we will be left with the legacy of pollution from dirty diesel vehicles for decades to come. That is, ***unless*** we take action to reduce emissions from vehicles currently on the road. We don't have to wait. Control technologies exist right now that can significantly reduce deadly fine particle emissions from diesel vehicles, in some cases by upwards of 90 percent.

American know-how, witnessed by the success of the manufacturers of engines, control devices, and fuel refiners in developing innovative solutions for reducing diesel exhaust, provides a lifesaving opportunity we can seize today. Pollution from dirty diesels on the road now can be dramatically reduced using a combination of cleaner fuels, retrofit emission controls, rebuilt engines, engine repowerings, and accelerated purchase of new, cleaner vehicles. Unlike so many other vexing environmental issues, these affordable solutions present a highly unusual opportunity to actually address a major risk to public health and the environment. In fact, we could virtually eliminate this problem if diesel manufacturers, fleet owners, environmentalists, concerned citizens, and government regulators make the commitment to work together.



An Aggressive Program to Reduce Diesel Emissions Could Save About 100,000 Lives between Now and the Year 2030.

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What are the health impacts of these dirty diesel vehicles? What benefits will we realize if we act now to clean them up? The Clean Air Task Force commissioned Abt Associates, an highly-respected consulting firm that U.S. EPA and other agencies rely upon to assess the benefits of national air quality policies, to quantify for the first time the health impacts of fine particle air pollution from America's diesel fleet. Using this information, we were able to estimate the expected benefits – in lives saved – from an aggressive but feasible program to clean up dirty diesel buses, trucks, and heavy equipment across the U.S.

This report summarizes the findings of the Abt Associates study. It then reviews the degree to which diesel vehicles increase the level of fine particle pollution in the air we breathe, and recommends reduction measures that will save thousands of lives each year.

Key findings include:

- Reducing diesel fine particle emissions 50 percent by 2010, 75 percent by 2015, and 85 percent by 2020 would save nearly 100,000 lives between now and 2030. These are additional lives saved above and beyond the projected impact of EPA's new engine regulations.
- Fine particle pollution from diesels shortens the lives of nearly 21,000 people each year. This includes almost 3,000 early deaths from lung cancer.
- Tens of thousands of Americans suffer each year from asthma attacks (over 400,000), heart attacks (27,000), and respiratory problems associated with fine particles from diesel vehicles. These illnesses result in thousands of emergency room visits, hospitalizations, and lost work days. Together with the toll of premature deaths, the health damages from diesel fine particles will total $139 billion in 2010.
- Nationally, diesel exhaust poses a cancer risk that is 7.5 times higher than the ***combined*** total cancer risk from all other air toxics.
- In the U.S., the average lifetime nationwide cancer risk due to diesel exhaust is over 350 times greater than the level U.S. EPA considers to be "acceptable" (i.e., one cancer per million persons over 70 years).
- Residents from more than two-thirds of all U.S. counties face a cancer risk from diesel exhaust greater than 100 deaths per million population. People living in eleven urban counties face diesel cancer risks greater than 1,000 in a million – one thousand times the level EPA says is acceptable.
- People who live in metropolitan areas with a high concentration of diesel vehicles and traffic feel their impacts most acutely. The risk of lung cancer from diesel exhaust for people living in urban areas is three times that for those living in rural areas.

The vast majority of the deaths due to dirty diesels could be avoided by an aggressive program over the next 15 years to require cleanup of the nation's existing diesel fleet. Practical, affordable solutions are available that can achieve substantial reductions in diesel risk. The only thing that stands between us and dramatically healthier air is the political will to require these reductions and the funding to make it a reality.

What We Must Do to Protect Public Health from Today's Dirty Diesels.

Although the EPA has mandated the phase-in of cleaner new engines and fuels beginning in 2007 for highway vehicles and heavy equipment, EPA has limited authority to mandate emissions controls on the fleet of existing diesel vehicles. To date, EPA has adopted a "voluntary" approach. Nevertheless, in order to meet the new ambient air quality standards for fine particles, states and cities must require controls to reduce diesel emissions. Diesel cleanup is also an important next step in areas that are having difficulty meeting existing and new ambient air quality standards for ozone such as Houston and Dallas, Texas.

States can enact legislation requiring diesel cleanup as some, such as California and Texas, have already begun to do. States should also consider measures to require early engine retirement and speed fleet turnover. For vehicles like long-haul trucks, ships, and locomotives that are engaged in interstate transport, federal regulations, federal legislation, or both may be needed. Funding for such initiatives may pose a challenge for public fleets (school buses, transit vehicles, garbage trucks, etc.), so support for expanded state and federal funding to help the cleanup of fleets owned by cash-strapped states and cities will be necessary. Local and state budget writers will need a strong commitment to come up with the necessary appropriations or bonds to fund the local share.

Particle filters combined with the use of Ultra Low Sulfur Diesel (ULSD) fuel have been found to reduce diesel particles and particle-bound toxics from diesel exhaust by up to 90 percent. Under the new engine rules, ULSD will be available for highway vehicles nationwide starting in 2006. It is already available in cities in 21 states. Not all vehicles can be retrofitted with a particle filter, but there are a variety of options available for the cleanup of every vehicle regardless of make or model year.

Cities and states should:

- Establish ambitious goals for reducing risk to their citizens by cleaning up existing diesels;
- Identify priority geographic areas and diesel "hotspots" for immediate attention;
- Adopt a package of options for reducing diesel exhaust including:
  - Retrofits accomplished by replacing mufflers with an optimal mix of filters or oxidation catalysts depending on vehicle age and type;
  - Requiring Ultra Low Sulfur Diesel and cleaner alternative fuels;
  - Closed crankcase ventilation systems to eliminate engine exhaust from penetrating the cabin of vehicles such as school and transit buses;
  - Engine rebuild and replacement requirements;
  - Truck stop electrification programs to give long-haul truckers a way to power their rigs overnight without running their engines;
  - Contract specifications requiring cleanup of trucks and construction equipment used in public works projects.
- Adopt diesel cleanup measures as federally-enforceable requirements in State Implementation Plans (SIPs) for the attainment of the fine particle and ozone air quality standards;
- Create and fund programs, such as California's "Carl Moyer" and the Texas Emission Reduction Plan (TERP) program, which provide funding for diesel equipment owners to replace or rebuild high-polluting diesel engines;
- Adopt and enforce anti-idling ordinances and legislation.

The Federal government should:

- Pass legislation providing funding for the cleanup of municipal and state fleet vehicles;
- Explore regulatory options for reducing emissions from existing interstate fleets such as long-haul trucks, shipping, and locomotives;
- Retain and enforce the tighter new engine and cleaner fuel standards for highway and non-road diesels.

NESCAUM

Retrofits are effective in reducing particle emissions from heavy equipment. The tractor on the left is retrofitted with a particle emissions control device.

New Findings

While numerous medical studies have linked diesel exhaust to a host of serious adverse health outcomes, no single study has yet quantified the death and disease attributable to diesel across America – until now. Researchers estimate that as many as 60,000 people in the U.S. die prematurely each year because of exposure to fine particles from all sources.[1] And some researchers believe that this figure may even underestimate the total number of particle-related deaths.[2] A reanalysis of the major particle mortality study in over 150 cities suggests that particles from motor vehicles may be more toxic than average.[3]

We know that diesel exhaust is a hazardous mixture of gases and particles including carcinogens, mutagens, respiratory irritants or inflammatory agents and other toxins that cause a range of diverse health effects. Diesel particles act like magnets for toxic organic chemicals and metals. The smallest of these particles (ultrafine particles) can penetrate deep into the lung and enter the bloodstream, carrying with them an array of toxins.[4] Diesel exhaust can contain 40 hazardous air pollutants as listed by EPA, 15 of which are listed by the International Agency for Research on cancer (IARC) as known, probable or possible human carcinogens.[5] Thousands of studies also have documented that fine particles are associated with respiratory and cardiovascular diseases and death. Additional studies have documented effects in infants and children such as Sudden Infant Death syndrome (SIDS) and retarded lung development.[6]

Now, for the first time, this report reveals the staggering toll of death and disease from diesel exhaust in our air – and the dramatic benefits of requiring the cleanup of the nation's existing diesel fleet. Abt Associates, using peer-reviewed, state-of-the-art research methodology employed by U.S. EPA in assessing the national benefits of proposed

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National Annual Diesel Fine Particle Health Impacts[7]

Annual Cases in the U.S., 2010	
Premature Deaths	21,000
Lung Cancer Deaths	3,000
Hospital Admissions	15,000
Emergency Room Visits for Asthma	15,000
Non-fatal Heart Attacks	27,000
Asthma Attacks	410,000
Chronic Bronchitis	12,000
Work Loss Days	2,400,000
Restricted Activity Days	14,000,000

rules and legislation, finds that nearly 21,000 people will die prematurely in 2010 in the U.S. as a result of exposure to fine particle emissions from mobile diesel sources (i.e., all on-and non-road engines such as highway, construction, rail, and marine engines). The average number of life-years lost by those who die prematurely from exposure to fine particles is 14 years.[8]

The deaths from diesel fine particle pollution equal or exceed the death toll from other causes commonly understood to be major public policy priorities. For instance, drunk driving causes more than 17,000 deaths per year.[9] There are more than 20,000 homicides in the U.S. each year.[10] Moreover, the approximately 15,000 premature deaths per year that could be avoided by achieving a 75 percent diesel-risk-reduction target exceed the 11,000 automobile fatalities avoided each year through the use of safety belts.[11]

The Abt Associates analysis further shows that hundreds of thousands of Americans suffer from asthma attacks, cardiac problems, and respiratory ailments associated with fine particles from diesels. These health damages result in thousands of respiratory and cardio-pulmonary related hospitalizations and emergency room visits annually as well as hundreds of thousands of lost work days each year. For instance, the study finds that diesel pollution leads to 27,000 heart attacks and 400,000 asthma attacks each year.[12]

You can find the adverse health impacts from diesel for your state, metropolitan area, and county on the web at: **www.catf.us/goto/dieselhealth**.

The risk from diesel exhaust can be virtually eliminated by the application of emissions control strategies available today. For example, an aggressive but feasible program to reduce diesel particle emissions nationwide 50 percent by 2010, 75 percent by 2015, and 85 percent by 2020 would save about 100,000 lives between now and 2030 – beyond those lives that will be saved under EPA's new engine regulations.[13] Indeed, in the year 2000, the State of California set a Diesel Risk Reduction goal of a 75 percent reduction in diesel risk by 2010 and 85 percent by 2020 and the California Air Resources Board over the past few years has begun to issue regulations to achieve it.[14]

Cancer Risk

CATF has calculated the national average lifetime excess cancer risk posed by diesel. We base these estimates on 1999 modeled directly-emitted diesel fine particle concentrations and by applying both the EPA range of individual risk estimates and the California Air Resources Board (CARB) diesel risk factor for lung cancer over the U.S. population.[15] Although EPA has found diesel exhaust to be a "likely" human carcinogen, EPA has not adopted a risk factor but has, instead, provided a range of lung cancer risk.[16] Based on the national average diesel particulate matter concentration, we find average lung cancer risk ranges from 12 to 1210 per million people over a 70-year lifetime using EPA's range of lung cancer risk.[17] Using the same methodology, CATF finds that, based on the single CARB risk factor, the nationwide average lifetime cancer risk posed by diesel exhaust is over 350 times greater than EPA's "acceptable" level of one cancer in a million.

For comparison, according to EPA's 1999 NATA assessment, the combined risk from all other air toxics is 48 per million.[18] Therefore, diesel exhaust presents a lung cancer risk that is 7.5 times higher than the cancer risk of all other air toxics – ***combined!***[19] In addition, CATF has calculated the cancer risk posed by diesel for residents of each U.S. county. Residents of over two-thirds of U.S. counties experience a cancer risk greater than 100 in a million from diesel exhaust. Moreover, residents of eleven urban U.S. counties face a diesel cancer risk equal to 1,000 new cases of cancer in a population of one million.

People who live in metropolitan areas with a high concentration of diesel vehicles and traffic feel their impacts

most acutely. For example, the estimated risk of lung cancer from diesel in metropolitan areas is much higher than in areas with fewer diesels. In the rural counties we estimate a risk of 142 cancers per million based on the CARB unit risk, but three times that rate, 415 cancer per million, in urban counties. Therefore, the risk of lung cancer for people living in urban areas is three times that for those living in rural areas.[20]

You can find the community cancer risk from diesel for your state, metropolitan area, and county on the web at: **www.catf.us/goto/dieselhealth**. Personal risk varies with location and lifestyle. For example, if you live near a bus, truck, or train terminal, highway, construction site, or warehouse, or commute to work on congested roadways, your exposure may be higher than indicated by the county-wide average estimated here.

The Economic Toll of Health Effects

Respiratory distress severe enough to require a trip to the emergency room can be a terrifying experience for patients and their families. Victims of asthma attacks say that during an attack they wonder if and when their next breath will come. In addition to its serious physical and emotional costs, air pollution also takes a large monetary toll. Emergency room and hospital treatment costs can cripple a family financially, with the average stay for a respiratory ailment lasting about a week.[21] Bouts of respiratory illness and asthma attacks mean lost workdays and lost productivity. Although life is priceless, the government often monetizes loss of life when setting policies related to health and environmental protection. Using accepted valuation methodology employed by EPA in recent regulatory impact analyses, Abt Associates finds that the total monetized cost of the U.S. diesel fleet's fine particle pollution is a staggering $139 billion in 2010.

Pollution from motor vehicles, including diesels, can obscure city vistas such as illustrated in this split view of Dallas, Texas.

State and Metropolitan Area Findings

Using modeled concentrations of directly-emitted diesel fine particles throughout the lower 48 states, Abt Associates developed health impact estimates for every state and major metropolitan area in 1999, the latest year for which EPA's best emissions inventory for diesel fine particles is available.[22] Not surprisingly, heavily populated states with concentrated urban areas and significant diesel traffic fared the worst. Conversely, rural areas with a lower concentration of diesel vehicles fared much better. Similarly, metropolitan areas with large populations and heavy concentrations of diesel vehicles feel the impacts of diesel pollution most acutely.[23] In such large metropolitan areas, many hundreds of lives are shortened every year. However, because these state and metropolitan-area health estimates include only fine particles that are ***directly emitted*** from diesels – excluding any secondarily-formed particles from diesel emissions of nitrogen or sulfur oxides – they significantly understate the total adverse impact of diesel-related particles on public health.[24] Moreover, these estimates exclude any health impacts due to diesel's contribution to ozone smog.

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States: Health Impacts from Diesel Fine Particles (1999)

Rank	State	Deaths	Cancer Deaths	Heart Attacks	Asthma Attacks	Chronic Bronchitis	Work Loss Days	Restricted Activity Days
1	New York	2,332	169	3,692	51,251	1,499	318,532	1,827,525
2	California	1,784	144	2,263	49,499	1,356	292,622	1,683,642
3	Pennsylvania	1,170	103	1,660	19,021	575	110,404	643,926
4	New Jersey	880	77	1,382	17,926	535	107,364	620,975
5	Texas	879	83	1,070	25,348	664	148,394	854,045
6	Illinois	878	76	1,193	19,162	539	112,205	649,445
7	Florida	805	77	980	13,926	438	81,462	474,601
8	Ohio	769	72	1,002	14,464	422	83,963	489,355
9	Michigan	484	43	667	10,511	299	61,109	355,260
10	Massachusetts	475	43	727	9,925	289	61,842	355,473
11	Maryland	409	39	454	8,418	246	50,275	291,675
12	Indiana	369	36	483	7,372	209	42,730	249,056
13	Georgia	329	29	377	8,514	235	51,808	298,317
14	Louisiana	324	32	339	7,131	188	40,740	236,444
15	Missouri	305	28	377	5,435	157	31,476	183,033
16	North Carolina	301	29	347	6,518	189	39,589	229,591
17	Tennessee	269	26	283	5,169	150	30,870	179,656
18	Washington	248	23	308	6,201	181	37,787	218,889
19	Virginia	248	24	303	5,991	174	36,963	214,083
20	Wisconsin	226	18	320	4,789	137	27,923	162,404
21	Arizona	214	19	268	5,215	144	30,053	173,721
22	Connecticut	206	18	340	4,091	125	24,097	140,140
23	Kentucky	198	22	213	3,764	110	22,385	130,403
24	Minnesota	193	15	291	4,713	134	27,979	161,954
25	Alabama	175	16	184	3,200	92	18,646	108,961

Metro Areas: Health Impacts from Diesel Fine Particles (1999)

Metropolitan Area	Rank	Deaths	Cancer Deaths	Heart Attacks
New York, NY	1	2,729	202	4,342
Los Angeles, CA	2	918	72	1,193
Chicago, IL	3	755	65	1,021
Philadelphia, PA	4	727	69	990
Boston, MA	5	391	36	602
Houston, TX	6	356	35	444
San Francisco, CA	7	291	23	358
Miami, FL	8	288	23	358
Baltimore, MD	9	285	28	290
Detroit, MI	10	279	25	378
Pittsburgh, PA	11	237	21	340
Washington, DC	12	226	19	302
St. Louis, MO	13	217	20	263
Dallas, TX	14	205	19	258
Atlanta, GA	15	199	17	239
Tampa, FL	16	185	18	210
Phoenix, AZ	17	183	16	230
Cleveland, OH	18	180	15	232
Cincinnati, OH	19	171	18	219
Seattle, WA	20	165	15	208

Metropolitan Area	Rank	Deaths	Cancer Deaths	Heart Attacks
San Diego, CA	21	150	13	191
Portland, OR	22	140	13	157
Minneapolis, MN	23	133	11	205
New Orleans, LA	24	128	13	131
Riverside, CA	25	123	10	142
Baton Rouge, LA	26	102	10	109
Milwaukee, WI	27	95	8	130
Columbus, OH	28	84	9	113
Indianapolis, IN	29	82	8	107
Louisville, KY	30	82	9	91
Memphis, TN	31	81	7	79
Kansas City, MO	32	79	8	109
Providence, RI	33	76	7	119
Bridgeport, CT	34	69	6	121
Beaumont, TX	35	65	7	65
Orlando, FL	36	65	7	85
Allentown, PA	37	65	5	101
Hartford, CT	38	63	5	100
Las Vegas, NV	39	62	7	71
Virginia Beach, VA	40	62	6	65

Metro Areas: Per Capita Impacts from Diesel Fine Particles (1999)

Rank Based on Mortality Risk	MSA	Deaths per 100,000 Adults	Heart Attacks per 100,000 Adults	Cancer Risk per Million
1	Beaumont, TX	29	29	865
2	Baton Rouge, LA	27	29	992
3	New York, NY	25	40	959
4	Philadelphia, PA	22	29	658
5	Trenton, NJ	20	31	699
6	Baltimore, MD	19	19	584
7	Huntington, WV	18	18	477
8	New Orleans, LA	17	18	889
9	Pittsburgh, PA	15	22	415
10	Cincinnati, OH	15	19	504
11	Boston, MA	15	23	563
12	Chicago, IL	15	20	539
13	Mobile, AL	14	15	435
14	Longview, WA	14	15	441
15	Houston, TX	14	18	691
16	Allentown, PA	14	22	450
17	Cleveland, OH	14	18	416
18	Toledo, OH	14	17	423
19	Los Angeles, CA	14	18	633
20	Lancaster, PA	14	22	463
21	Scranton, PA	14	18	319
22	St. Louis, MO	14	17	405
23	Reading, PA	14	21	428
24	Lake Charles, LA	14	14	437
25	Springfield, OH	13	16	356
26	Portland, OR	13	14	488
27	Bridgeport, CT	13	22	494
28	Harrisburg, PA	12.	19	412
29	York, PA	12	21	460
30	Wheeling, WV	12	14	309
31	Lebanon, PA	12	19	373
32	Evansville, IN	12	15	368
33	Memphis, TN	12	12	397
34	Savannah, GA	12	13	376
35	Dayton, OH	12	16	389
36	Vineland, NJ	12	17	365
37	Tampa, FL	12	14	365
38	Louisville, KY	12	13	384
39	Sandusky, OH	12	15	345
40	Kankakee, IL	12	14	336
41	San Francisco, CA	12	14	480
42	Muncie, IN	11	14	327
43	Duluth, MN	11	14	308
44	Michigan City, IN	11	15	370
45	Salt Lake City, UT	11	14	533
46	New Haven, CT	11	18	365
47	Steubenville, OH	11	13	279
48	Milwaukee, WI	11	15	376
49	South Bend, IN	11	15	342
50	Detroit, MI	11	15	381

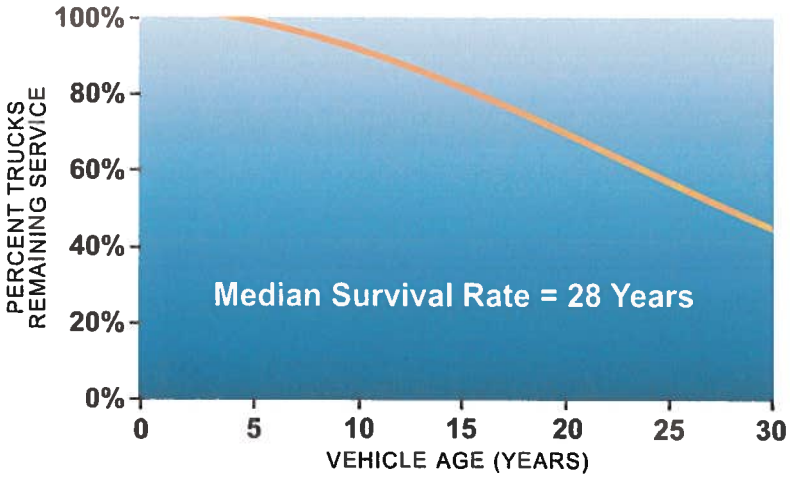
The Dirty Diesel Legacy

Since 1997, the U.S. EPA has promulgated major regulations that impose stringent emissions controls on new diesel vehicles, requiring tight emission standards and cleaner diesel fuel. These standards go into effect in 2007 and phase in over the next few decades. For example, the table below illustrates the progressively tighter standards for particulate matter and nitrogen oxides from trucks and buses over the next few years.

However, the emission rates of the diesel engines on the road and in use on construction sites and farms today are not affected by these rules. Considering that according to the U.S. Department of Energy the median lifetime for a heavy truck is nearly 30 years,[26] and a typical heavy duty diesel engine may power a truck for as long as one and a half million miles,[27] these vehicles will continue to pollute our air at unnecessarily high levels for years to come ***unless*** we act to clean them up now.

EPA Standards for New Trucks and Buses (g/bhphr)[25]

YEAR	NO_x	$PM_{2.5}$
1984	10.7	0.60
1991	5.0	0.25
1998	4.0	0.10
2004	2.0	0.10
2007	0.2	0.01



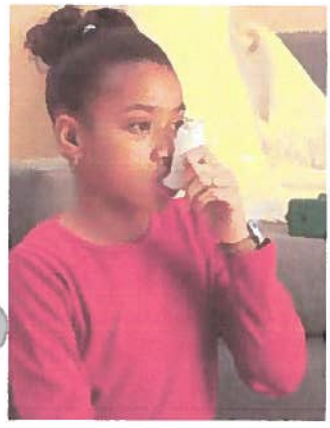
Median Heavy Truck Lifetime is Nearly 30 Years[28]

The Most Widespread Air Pollution Risk in the U.S.

There are few other sources of widespread pollution in our environment that rival diesel exhaust as an airborne toxin. America's 13 million diesel engines release a host of harmful substances including fine particles, ozone smog-forming nitrogen oxides, carbon monoxide, and a variety of toxic metals and organic gases such as formaldehyde, acrolein, and polycyclic aromatic hydrocarbons (PAH.)[29] In this report we focus on the respiratory, cardiovascular, and cancer effects of diesel fine particles only.[30]

Fine Particles are Linked to Heart Attacks, Asthma Attacks, and Stunted Lung Growth.

Fine particles have been linked to a wide variety of serious health impacts, from upper and lower respiratory ailments, such as asthma attacks and possible asthma onset, to heart attacks, stroke, and premature death, including crib death in children.[31] How risky is breathing air polluted with particles? A study published in the Journal of the American Medical Association found that living in the most polluted U.S. cities poses a risk similar to living with a smoker.[32] Based on thousands of studies compiled by EPA, federal health standards were established for fine particles in 1997.[34]



Health researchers have recently described serious health impacts of fine particles, including:

- Abnormal heart rhythms and heart attacks and atherosclerosis;[35]
- Increased incidence of stroke;[36]
- Permanent respiratory damage, characterized by fibrosis causing obstruction to airflow;[37]
- Chronic adverse effects on lung development resulting in deficits in lung function.[38]

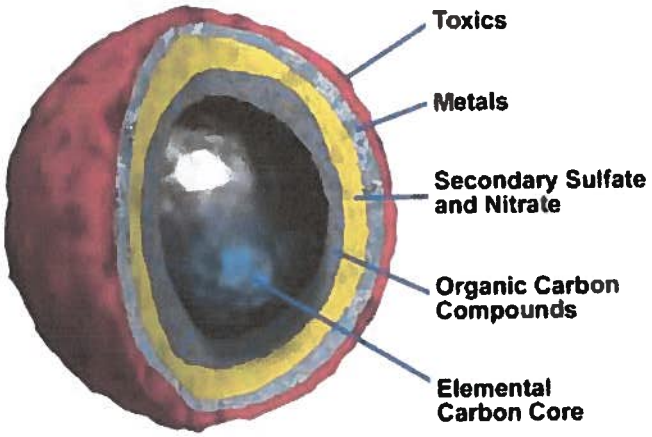
How Particulate Matter Kills

Fine particles, known as "$PM_{2.5}$", are particles less than 2.5 microns in diameter or 1/100th the width of a human hair, so small that they are often invisible. They can be deposited deep in the lung where they can affect both the respiratory and cardiovascular systems. Researchers believe that many deaths caused by particulate matter are related to cardiovascular illness. Fine particles aggravate cardiovascular disease and trigger heart attacks by invading the bloodstream and initiating an inflammatory response, disrupting heart rate and increasing blood clotting. In a recent experimental study, diesel particles caused blood clots providing "a plausible explanation for the increase in cardiovascular morbidity and mortality accompanying urban air pollution."[33]

Diesel Exhaust is a Likely Carcinogen that also Impairs Immune, Reproductive, and Nervous Systems.

In 1998, the Scientific Review Panel for the California Air Resources Board reviewed diesel exhaust as a toxic air contaminant and set a lifetime unit cancer risk from diesel particles at 3 in 10,000 persons for each microgram of annual average diesel exposure.[39] This is equivalent to 300 in a million excess lung cancers. In May 2002, EPA issued its Health Assessment for Diesel Exhaust which found diesel particulate matter to be a "likely" carcinogen. EPA did not settle on a unit risk factor but recommended a lifetime cancer risk range from 1 in 1,000 to 1 in 100,000.[40] The California unit risk falls within this range.[41]

Diesel particles are carbon at their core with toxics and carcinogenic substances attached to their surfaces.



Applying California's cancer unit risk for diesel particulate matter to the national average concentration of directly-emitted diesel fine particles in 1999, results in a conservative estimate of 1,530 excess cases of lung cancer per year for 2005.[42] An American Cancer Society study of 150 metropolitan areas across the U.S published in 2002 supports the particulate matter cancer link.[43]

Other effects include:

- **Immune System Effects** – Diesel exposure is associated with numerous immune system responses in humans and animals culminating in increased allergic inflammatory responses and suppression of infection-fighting ability. These effects include disruption of chemical signals and production of antibodies, and an alteration in mobilization of infection-fighting cells.[44]
- **Reproductive, Developmental, and Endocrine Effects** – Diesel emissions have also been associated with reproductive, developmental and endocrine effects in animals. Specifically, diesel exposure has been associated in animals with decreased sperm production,[45] masculinization of rat fetuses,[46] changes in fetal development (thymus,[47] bone[48] and nervous system[49]) and endocrine disruption, i.e., production of adrenal and reproductive hormones.[50]
- **Nervous System Effects** – In addition to animal studies that have shown neurodevelopmental effects, a human study of railroad workers suggested that diesel exposure may have caused serious permanent impairment to the central nervous system.[51]

Cancer-causing Pollutants in Diesel Exhaust

Pollutant	Diesel Emissions % of all Mobile 1996[52]	EPA Carcinogen Status	Cancer Risk (per million/microgram in 70-yr life)
Formaldehyde	52%	probable	1 in a million
Acetaldehyde	59%	probable	1 in a million
Butadiene	8%	probable	2 in a million
Acrolein	50%	possible	n/a
Benzene	5%	known	2-8 in a million
Diesel Particulate Matter	77%	probable[53]	EPA: 12 to 1210 in a million; CARB: 300 in a million[54]

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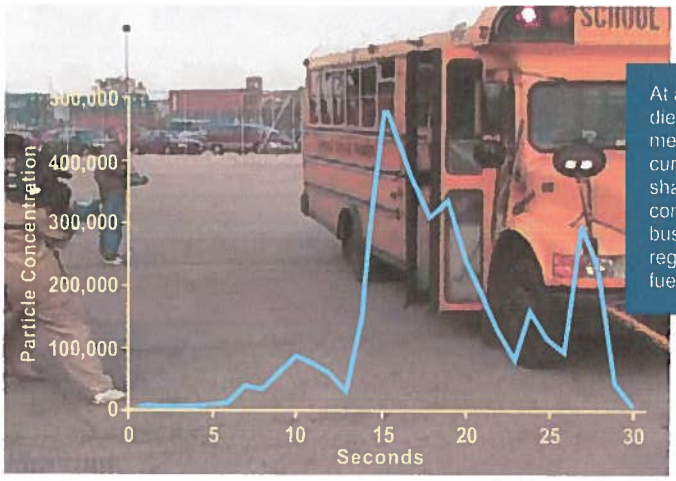
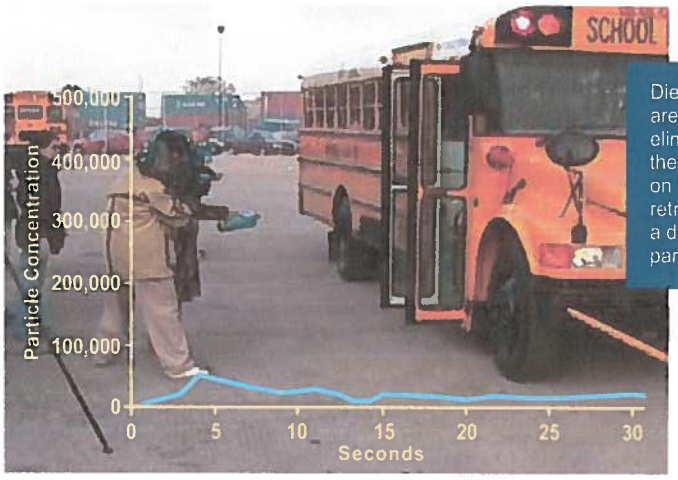
Children and Seniors are at Greatest Risk

Health researchers believe that children are more susceptible than adults to the adverse health effects of air pollution for a variety of reasons.[55] For example, children are more active than adults and therefore breathe more rapidly. Children also have more lung surface area compared to their body weight and therefore they inhale more air pound-for-pound than adults do. Compared to adults, children also have higher lung volume to body size, higher respiration rates, and spend more active time in the polluted outdoor environment. Fine particles have been linked in medical studies to serious health impacts in children such as slowed lung function growth, increased emergency room visits, increased incidences of asthma and bronchitis, and crib death. Furthermore, proximity to traffic has been linked to increased prevalence of asthma respiratory infections and allergic symptoms and asthma hospitalizations in children.[56]

Seniors are another important population at risk. Studies of the impacts of fine particles on seniors in Boston and Baltimore suggest that changes in their heart rhythms and control mechanisms occur when particle levels rise. In Phoenix, daily mortality increased in



At a bus stop, diesel particles measured at the curb spike sharply from a conventional bus running on regular diesel fuel.



Diesel particles are virtually eliminated when the bus is run on ULSD and retrofitted with a diesel particulate filter.

Children Exposed on School Buses

CATF Study: Cabin particulate matter eliminated with retrofit emissions controls.

Twenty four million students ride to school every day on yellow school buses that travel a total of four billion miles a year. While riding on a school bus is the safest way a student can travel to school,[57] children may be exposed to harmful pollutants, a concern since students spend an average of an hour and a half a day on school buses.[58] A recent study undertaken by Clean Air Task Force in cooperation with Purdue University investigated cabin air quality on school buses in three cities (Chicago, IL; Atlanta, GA; and Ann Arbor MI). The study found that particulate matter routinely entered the bus cabin from the tailpipe and the engine through the open front door. At some stops, particulate matter in the bus cabin exceeded levels in the outdoor air by as much as ten times. While idling or lined up in a schoolyard, rapid buildup of particulate matter in the buses also occurred. Most importantly, retrofit emissions controls worked: installation of a diesel particulate filter and the use of Ultra Low Sulfur Diesel (ULSD) fuel and a closed crankcase filtration device eliminated fine particles, ultrafine particles, black carbon and particle-bound PAH in the bus cabin. A closed crankcase filtration system by itself demonstrated major benefits and can provide immediate and low cost reductions in particulate matter levels on school buses. For a comprehensive report: **www.catf.us/goto/schoolbusreport**

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seniors with increased levels of elemental and organic carbon (typical of diesels and other motor vehicles) and fine particles. Collectively, these studies demonstrate that elevated fine particle levels put the elderly at risk and suggest a possible mechanistic link between fine particles and cardiovascular disease mortality.[59]

Today's Dirty Diesels

- **"On-road" or highway diesels** include many types of vehicles, such as municipal and commercial trucks and buses. Heavy duty highway diesels range from 8,500 lbs to those exceeding 60,000 lbs, such as 18-wheelers. Of the seven million diesels on the road today, 400,000 are school buses and 70,000 are transit buses. Highway diesels released 100,000 tons of directly-emitted fine particles in 2002, about one third of the total from diesels. Highway diesels also released 3.4 million tons of nitrogen oxides (NO_x) in 2002, which accounted for 16 percent of all NO_x emissions and half of all diesel NO_x emissions in the U.S. [60]

- **"Non-road" diesel engines and equipment** do not typically travel on roads or highways. There were approximately six million non-road diesel engines in service in 2003. Examples of these non-road diesels include construction equipment such as excavators, mining equipment and agricultural machinery. In 2002, 155,000 tons or half of all the fine particles directly emitted from diesels came from non-road engines. Non-road diesels also released 1.6 million tons of NO_x, 8 percent of all NO_x emissions and one quarter of all diesel NO_x emissions in the U.S. in 2002.[61]

- **Marine and river diesel** emissions are dominated by large commercial ships polluting our largest ocean and river port cities. Efforts to control pollution from shipping have focused on NO_x, although these engines also emit substantial quantities of fine particles. In 2002 marine diesel released 40,000 tons of directly-emitted fine particles, 13 percent of all diesel fine particles in the U.S. Marine diesels in the U.S. produced one million tons of diesel NO_x in 2002, 5 percent of all U.S. NO_x emissions and 14 percent of all diesel NO_x emissions.[62]

- **Locomotive diesels** account for a significant fraction of mobile source emissions in the U.S. today. In many areas, diesel trains travel through and pollute core urban and industrial areas. Diesel locomotives released 20,000 tons of directly-emitted diesel fine particles (six percent of all diesel fine particles) and 900,000 tons NO_x (13 percent of diesel NO_x). Diesel locomotives typically have a useful life of 40 years and are commonly rebuilt 5-10 times during their long service lives. For this reason, cleaning up today's locomotives is an important priority.[63]

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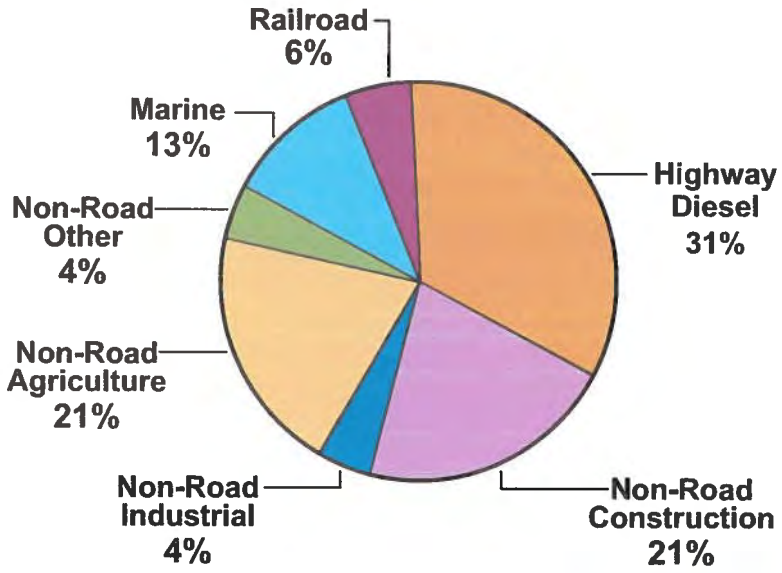


Sources of Directly-Emitted Mobile Diesel Fine Particles

Source: EPA (2004)

Diesel "Hotspots"

Diesel Exhaust is Concentrated Near Roadways and Intersections.

Unlike industrial smokestack emissions, diesel typically is emitted at ground-level in places of concentrated population in our communities along busy streets and at our places of work. We often breathe diesel exhaust where it is fresh and most toxic. While air quality modeling, such as reported in our study, estimates average exposures in a community, your individual exposure may be much greater or smaller depending on a variety of factors. For example, the distance from where you live to major roadways and the nature of your commute to work may play a role.

Exposure to diesel exhaust is highest for those who:

- **Operate or work around diesel engines** – Occupational exposures to diesel are among the highest and have been associated with increased incidence of cancer. Furthermore, a study of diesel mechanics, train crewmen, and electricians working in a closed space near diesel generators suggests that diesel exposure may have caused both airway obstruction and serious impairment to the central nervous system. The report concludes that "impaired crews may be unable to operate trains safely."[64]
- **Live or work near areas where diesel emissions are concentrated** – Ambient diesel levels are highest near highways, busy roadways, bus depots, construction sites, railroad yards, ports and inland waterways with diesel boat traffic, major bridges, tunnels, or freight warehouses. People who live or work near these

facilities face the greatest risk. Numerous recent medical studies have linked roadway proximity and traffic pollution to disease, asthma hospitalizations, and shortened life expectancy.[65] For example, a 2004 study in Ontario, Canada found increased risk of mortality from heart and lung disease in people living within 100 meters of a roadway.[66] New York City studies demonstrate that diesel trucks create air toxics hot spots at crossings, bus stops, and bus depots.[67] Rail yards can be diesel hotspots as well. For example, one study found elevated risk levels – up to 500 in a million – adjacent to a California rail yard.[68] Another study found elevated cancer risk for persons living near a ferry port.[69]

- **Regularly ride on school or transit buses, or commuter trains** – Children are exposed to elevated levels of diesel as a result of the buildup of diesel exhaust inside school buses – especially with windows closed.[70] Diesel exhaust levels on commuter trains and

People living and working near concentrated diesel emissions such as busy roadways have the greatest exposure to diesel exhaust.

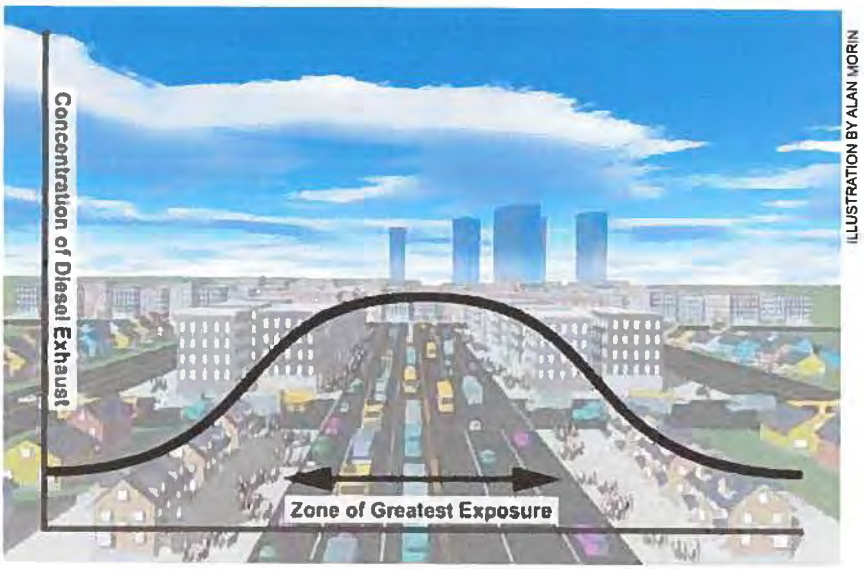


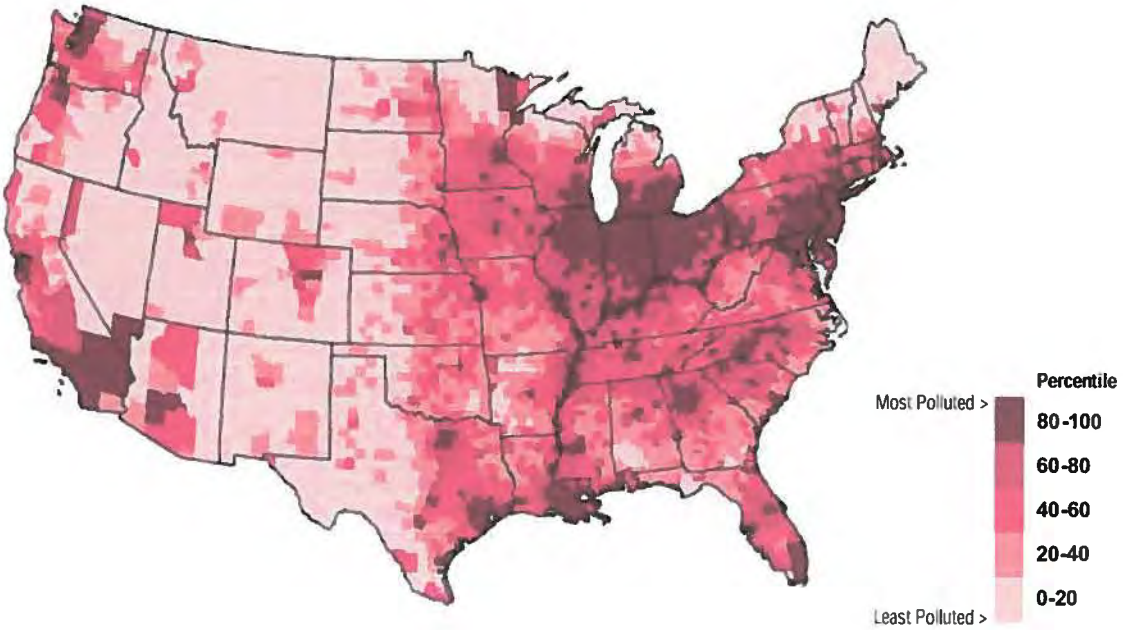
ILLUSTRATION BY ALAN MORIN

station platforms may also be high.[71]

- **Commute daily in heavy traffic** – Commuters are exposed to some of the highest diesel emissions in their cars due to pollutants released from trucks and buses on the road with them. Car occupants riding behind a diesel bus, for example, can experience extremely high levels of dangerous fine particles. Researchers in Los Angeles measured high fine particle levels (130 ug/m^3) behind an urban transit bus making numerous stops.[72] Exposures to drivers can have serious effects: a 2004 study suggests that young male state troopers experienced cardiac inflammation and heart rhythm changes from in-vehicle exposure to fine particles.[73]

Diesel exhaust from trucks and buses can be found in places we don't expect. For example it can be trapped in "urban canyons" and penetrate buildings through HVAC systems.

Exposure to diesel exhaust is also an Environmental Justice issue. Concentration of minority and low-income populations are more likely to be found in cities near diesel sources. Because these neighborhoods are exposed to some of the highest diesel exhaust levels, residents are certain to experience disproportionate health impacts.



Directly-Emitted Diesel Fine Particle Concentrations by County in the U.S. (1999)

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A Solution Within Our Reach

Diesel Fine Particles Can Be Virtually Eliminated by Emission Controls Available Today.

Virtually all of the health risk posed by diesel exhaust can be eliminated through the application of emissions control strategies available today. For example, an aggressive but feasible program to reduce diesel particle emissions nationwide 50 percent by 2010, 75 percent by 2015, and 85 percent by 2020 would save about 100,000 lives between now and 2030 – beyond those lives that will be saved under EPA's new engine regulations.[74] Adopting this as a national goal would help states and municipalities set milestones for improvement and would be consistent with EPA's recently announced goal of retrofitting the entire U.S. fleet of diesel vehicles by 2015.[75] Indeed, California has already set a Diesel Risk Reduction goal of 75 percent 2010 and 85 percent by 2020. Over the last few years the California Air Resources Board has begun to issue regulations to achieve these goals.[76]

"Retrofit, Rebuild, Replace"

A variety of practical strategies exist to reduce diesel particle levels in America: tailpipe retrofits, clean fuels, closed crankcase filtration systems, engine rebuild and replacement requirements, emission specifications for vehicles used in public works contracts, anti-idling ordinances and legislation, truck stop electrification programs, aggressive fleet turnover policies, and more.

The most cost-effective approach to reducing diesel exhaust is likely in many cases to be the direct application of retrofit technology. Although the purchase of new, much cleaner vehicles will remain an important remedial strategy, the replacement of the entire diesel fleet is an expensive proposition that will have to be phased in over time. What's more, we can meet the challenge of reducing fine particles and related air toxics without replacing all vehicles right now. Current technology can easily remove particles from diesel exhaust. Retrofits that eliminate over 90 percent of fine particles from a heavy duty diesel bus engine typically cost $3,000-$7,500. This is a small expenditure when compared to the typical $60,000-75,000 price tag for a new school bus or $300,000 for a transit bus.[77]

Retrofits are available from many engine manufacturers. They generally are easy to install especially on highway vehicles. Nonetheless, it is important to point out that retrofits are not a "one size fits all" proposition. Retrofitting a fleet calls for careful planning and, often, a mix of strategies that will depend on the make and model year of the engines being retrofitted and funds available. For example, some heavy-duty engines lack modern electronic engine controls and are therefore are too old for some retrofit devices. Other diesel equipment simply does not have space for retrofit installation. Duty cycle is an important consideration too. Some engines do not run constantly which means that catalytic retrofit devices requiring consistent high engine temperatures do not operate as efficiently. Furthermore, some engines release pollution from crankcase ventilation in addition to the tailpipe. This calls for additional strategies. For some vehicles and model years, replacement may be the best option. As a result, fleets will need to develop individualized strategies that optimize emission reduction from their vehicles and equipment. Fortunately, this is not hard to do.

Installing a diesel particulate filter (DPF) in this Atlanta school bus simply required removal and replacement of the muffler and tailpipe.

Catalyzed diesel particulate matter filters (DPF) can reduce emissions of fine particles and adsorbed air toxics by over 90 percent. DPFs have been used in thousands of on- and non-road diesel applications. Diesel oxidation catalysts (DOCs) represent a less expensive albeit less effective option. They are smaller and therefore easier to install. EPA has verified that they can reduce total particulate matter emissions by 10-30 percent. Like the DPF, the DOC is also attached to the exhaust system. Installing one on a diesel truck or bus costs about $1,000. DOCs may be appropriate for vehicles built before 1995 that lack electronic controls and for construction equipment where there is inadequate space for a DPF to be installed. DOCs have been installed in more than 1.5 million trucks in the U.S.[78]

Low Sulfur Diesel Fuels Are Requisite for Effective Retrofit Controls.

Diesel particulate filters require low sulfur fuels because sulfur in the fuel can foul the emission control device. Unfortunately, low sulfur fuels are not available everywhere in the U.S. today (see http://www.epa.gov/otaq/retrofit/fuelsmap.htm for the current fuel availability map). Where ULSD is available, decision makers should consider requiring installation of filters where possible. Federal regulations have established diesel fuel and additive formulation requirements for on-road vehicles, limiting fuel sulfur content to 15 ppm nationwide beginning in 2006 for use with 2007 highway vehicles. Starting in 2010, non-road equipment will be required to use ULSD.

Biodiesel is another potential low-sulfur fuel choice that can achieve modest reductions in emissions when used as a blend, or higher reductions when used at 100 percent. Biodiesel is an alternative diesel fuel made from either animal fats or plants such as soybeans.

Ultra low sulfur diesel fuel will be available nationwide mid-2006.

Cleaning up All School Buses Within a Decade

With today's emissions controls, students need not be exposed to diesel exhaust while riding to school. EPA in the summer of 2004 announced the goal of retrofitting all existing school buses with pollution controls within a decade.[79] Funding retrofits and cleaner fuel presents the greatest obstacle facing school districts. To achieve this goal, adequate funds must be appropriated by states and the federal government.

Recommendations

Cities and States Must Act to Reduce Diesel.

The fine particle pollution problem is so widespread in the U.S. about one quarter of the U.S. population resides in areas that violate the standard. EPA recently formally designated over 200 counties in "nonattainment" with the annual fine particle standard.[80] Countless additional commuters may also spend significant time in areas exceeding the standard where they work. But the rest of the country is not safe from the risk posed by diesel particles – science tells us that particle-related health impacts don't stop once the standard is achieved. Health research has shown that there are adverse health impacts from particles even at very low concentrations.[81]

Cities and states that have been designated as "nonattainment" must act now to achieve meaningful reductions in fine particles. For those areas, state implementation plans must be developed and presented to EPA for approval within three years. Controls must then be implemented and air quality standards achieved by 2010. For this reason, states and cites must start now to determine how to achieve substantial emissions reductions. With rules to reduce particles from power plants pending at EPA and expected to be finalized in the near future, diesel emissions will become the largest remaining share of the problem and the most cost-effective solution, one that largely is within the control of states and municipalities.

MA TURNPIKE AUTHORITY

Cities should adopt and enforce anti-idling ordinances.

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Cities and states should:

- Establish ambitious goals for reducing risk to their citizens by cleaning up existing diesels;
- Identify priority geographic areas and diesel "hotspots" for immediate attention;
- Adopt a package of options for reducing diesel exhaust including:
  - Retrofits accomplished by replacing mufflers with an optimal mix of filters or oxidation catalysts depending on vehicle age and type;
  - Requiring Ultra Low Sulfur Diesel and cleaner alternative fuels;
  - Closed crankcase ventilation systems to eliminate engine exhaust from penetrating the cabins of school and transit buses;
  - Engine rebuild and replacement requirements;
  - Truck stop electrification programs to give long-haul truckers a way to power their rigs overnight without running their engines;
  - Contract specifications requiring cleanup of trucks and construction equipment used in public works projects.
- Adopt diesel cleanup measures as federally-enforceable requirements in State Implementation Plans (SIPs) for the attainment of the fine particle and ozone air quality standards;
- Create and fund programs to provide money for diesel equipment owners to replace or rebuild high-polluting diesel engines;
- Adopt and enforce anti-idling ordinances and legislation.

To meet this challenge, several states and cities have begun to take action. California continues to lead the way in reducing diesel emissions: adopting stricter fine particle air quality standards, developing a statewide diesel risk reduction plan, and establishing a state program to clean up on- and non-road diesel engines ranging from garbage trucks to stationary generators.[82] When completed, the California program will regulate emissions from all existing diesels within its jurisdiction.

Trucks parked at New York Thruway rest area shut off their engines and plug into IdleAire facility for heat and electricity.

In New York, over 120,000 kids now ride a school bus that has had a retrofit kit installed to reduce diesel emissions. Under city and state law all New York City-sponsored construction projects are required to use ULSD and all heavy equipment engines at the sites must be retrofitted. Likewise, Seattle, King County, and the State of Washington have made a solid start on diesel cleanup from on- and non-road vehicles, and ships including a commitment to retrofit up to 8,000 school buses using local, state, federal, and SEP monies and buy up to 250 new diesel/electric hybrid buses. Other cities also have made a start.[83]

California and Texas have created funds – the "Carl Moyer" program in California and the Texas Emission Reduction Program (TERP) – to provide funding for diesel equipment owners to replace or rebuild high-polluting diesel engines.

NEW FLYER

Some cities are choosing Diesel Electric Hybrid buses as an alternative to conventional diesel buses.

Washington Must Support States

States and cities cannot meet the challenge of diesel pollution alone. U.S. EPA has recognized the dangers and societal costs of diesel exhaust and set tighter emission standards for new highway and non-road diesel engines and mandated the availability beginning in 2006 of Ultra Low Sulfur Diesel (ULSD) fuel nationwide. These requirements must be retained with no backsliding. In addition, EPA has set a national goal of cleaning up all of America's existing diesels by 2015 and has established a voluntary retrofit program to begin to meet it.[84] However, this challenge will only be met with an aggressive set of policies and adequate funding to ensure the goal can be accomplished.

Many states do not have the resources to clean up state and municipally-owned vehicles. They will need the support of the federal government to achieve EPA's goal.

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Federal action may also be needed to clean up transient diesel vehicles, including long-haul trucks, marine diesel shipping in U.S. ports, and locomotives that typically travel from city to city dispersing their emissions along travel corridors. Because the Clean Air Act contains limited authority for EPA to establish national diesel retrofit rules, federal legislation will ultimately be needed to establish federal requirements and funding for a national retrofit program for all diesel engines as well as these interstate diesels.

The Federal government should:

- Pass legislation providing funding for the cleanup of municipal and state fleet vehicles;
- Explore regulatory options for reducing emissions from existing interstate fleets such as long-haul trucks, shipping, and locomotives;
- Retain and enforce the tighter new engine and cleaner fuel standards for highway and non-road diesels.

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12 This analysis is based on methodology approved by U.S. EPA's Science Advisory Board and used by EPA in the Regulatory Impact Analysis (RIA) of the non-road rule. EPA Final Regulatory Impact Analysis, "Control of Emissions from Nonroad Diesel Engines," EPA420-R-04-007. (May 2004) http://www.epa.gov/nonroad-diesel/2004fr/420r 04007.pdf. It begins with EPA emissions inventory data, models the dispersion of those emissions using the Regional Emissions Modeling System for Acid Deposition (REMSAD) air quality model, and then applies a damage function model using concentration-response relationships to estimate adverse health endpoints from modeled changes in air quality. This analysis estimates the adverse health endpoints attributable to diesel PM2.5 in the year 2010. For a summary of CATF's methodology and FAQs please go to www.catf.us/goto/dieselhealth/ and click on "learn more." For Abt Associates' ASPEN and REMSAD reports please see: www.catf.us/goto/AbtASPEN/ and www.catf.us/goto/AbtREMSAD/.

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14 Through only those diesel regulations promulgated to date, California will reduce diesel fine particles by 30 percent from year 2000 levels. California has announced plans to promulgate additional critical regulations in the next few years to address significant sources such as construction, agriculture, and inland shipping. California Air Resources Board (CARB) 2004a. Air Quality Almanac Emission Projections. Online at http://www.arb.ca.gov/emisinv/emsmain/emsmain.htm; California Air Resources Board (CARB). 2003a. Staff Report: Initial Statement of Reasons: Proposed Diesel Particulate Matter Control Measure for On Road Heavy-Duty Residential and Commercial Solid Waste Collection Vehicles. Sacramento, CA: California Environmental Protection Agency. California Air Resources Board (CARB) 2003b Staff Report: Initial Statement of Reasons for Proposed Rulemaking: Airborne Toxic Control Measure for Stationary Compression Ignition Engines. Sacramento, CA: California Environmental Protection Agency, Stationary Source Division Emissions Assessment Branch;. California Air Resources Board (CARB) 2003c. REVISED – Staff Report: Initial Statement of Reasons for Proposed Rulemaking: Airborne Toxic Control Measure for In-use Diesel Fueled Transport Refrigeration Units (TRU) and TRU Generator Sets, and Facilities Where TRUs Operate. Sacramento, CA: California Environmental Protection Agency, Stationary Source Division Emissions Assessment Branch. The Union of Concerned Scientists recently estimated the costs and benefits of achieving the CARB Diesel Risk Reduction goal. See Union of Concerned Scientists, *Sick of Soot: Reducing the Health Impacts of Diesel Pollution in California* (June 2004) available online at: http://www.ucsusa.org/clean_vehicles/trucks_and_buses/page.cfm?pageID=1429

15 This analysis was performed by multiplying modeled ASPEN (Assessment System for Population Exposure Nationwide) 1999 county-level ambient diesel PM2.5 concentration data times. (1) the upper and lower bounds of EPA's possible diesel particulate matter cancer risk range; and (2) the California Air Resources Board diesel cancer unit risk factor. See: California Diesel Risk Reduction Plan: http://www.arb.ca.gov/diesel/documents/rrpapp.htm; EPA, Health Assessment Document for Diesel Exhaust, Office of Research and Development, EPA/600/8-90/057F (May 2002). The United States Public Interest Research Group previously used

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17 The number per million is the chance in a population of a million people who might be expected to get cancer over a 70-year lifetime. A potential cancer risk of 10 in a million means if one million people were exposed to a certain level of a pollutant or chemical there is a chance that 10 of them may develop cancer over their 70-year lifetime. This would be 10 new cases of cancer above the expected rate of cancer in the population. According to CARB the expected rate of cancer for all causes, including smoking, is about 200,000 to 250,000 chances in a million (one in four to five people).

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19 This finding is based on inhalation as the only exposure path and is limited to the thirty-three air toxics included in EPA's National Air Toxics Assessment (NATA). The relative cancer risk of diesel particulate matter is calculated as a ratio of the cancer risk of all air toxics tracked by EPA in the NATA divided by the risk of diesel particulate. We calculated the cancer risk for diesel PM in the U.S. based by applying the CARB cancer unit risk factor for diesel particulate matter to 1999 ASPEN model average national ambient concentration results for diesel PM. (Source for national toxic risk: Inside EPA, Inside Washington Publishers, December 15, 2004.)

20 According to the EPA's categorization of counties as urban or rural, the average ASPEN 1999 ambient diesel fine particle concentration is 1.3822 ug/m^3 for urban counties and 0.4730 ug/m^3 for rural counties. The overall national average is 1.2096 ug/m^3. These averages are population weighted. These averages convert (using the 0.0003 factor) to cancer risks of 415 per million urban, 142 per million rural, and 363 per million average.

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84 For more information on EPA's Voluntary Retrofit Program see: http://www.epa.gov/otaq/retrofit

CLEAN AIR TASK FORCE

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BOARD MEETING DATE: April 2, 2010
AGENDA NO. 25

PROPOSAL:

Annual Meeting of the Brain & Lung Tumor and Air Pollution Foundation

SYNOPSIS:

This item is to conduct the annual meeting of the Brain & Lung Tumor and Air Pollution Foundation. The Foundation staff will present an annual report detailing the research supported by the Foundation over the past year, the Foundation's plans for the future, and a financial report.

COMMITTEE:

Not Applicable

RECOMMENDED ACTIONS:

Receive and file the annual report and ratify the Foundation disbursements described in the annual report.

Barry R. Wallerstein, D.Env.
Executive Officer

2009 Annual Report

1. Background

In February, 2003, the Board established the Brain Tumor and Air Pollution Foundation. In March, 2004 the Foundation amended its Articles of Incorporation to change its name to Brain & Lung Tumor and Air Pollution Foundation and to specify that its purpose is related to the effects of air pollution on brain and lung cancer. The mission of the Foundation is to support research studies on the association between air pollution and brain and lung cancer, as well as research for the development of novel therapeutics for such tumors. To carry out its purpose, the Foundation has funded research projects investigating the links between air pollution and brain and lung tumors. The dollar amount of the funding received to date is $3,722,568. The current projects are described below.

2. Directors and Officers

The Directors of the Foundation are:	Michael D. Antonovich, Chairman Dennis Yates, Vice Chairman Bill Campbell Dr. Thomas Godfrey Josie Gonzalez
The Foundation's staff is:	Barry Wallerstein, Chief Executive Officer Denise Whitcher, Secretary Lisa Virgo, Treasurer

3. Report on the Foundation's Activities

Current Research Projects

In 2008, the Foundation Board approved funding for the following projects.

A. Brain Tumors and Air Pollution
Principal Investigator: Dr. Keith Black, Cedars Sinai Medical Center
Approved Funding: $1,250,000
Allocated Funding: $625,000

In previous studies funded by the Foundation, the researchers discovered that the activities of several genes were altered in laboratory animals exposed to concentrated ambient particulate pollutants. These genes may play a significant role in the development of brain tumors. In the new study, a more detailed analysis at the molecular level is being conducted. Individual areas of the brain, as well as other organs, are being included to determine if there are specific tissue types that are affected by particulate matter exposures. The research is being done in collaboration with the UC Irvine School of Medicine. This project is currently ongoing, and a report of results is expected by the end of this year.

B. Childhood Brain Tumors and Air Pollution
Principal Investigator: Roberta McKean-Cowdin, Ph.D., USC School of Medicine
Approved Funding: $220,000
Allocated Funding: $199,627

In a preliminary epidemiologic investigation on the potential role of air pollution with brain tumor risk funded by the Foundation, the researchers found a significant association of risk of brain tumors in children and exposure to PM2.5. The study population included children between the ages of 0-5 years diagnosed with brain tumors from in Los Angeles, Orange, Riverside, and San Bernardino counties from 1991 through 2002. This new study is conducting additional analyses including more detailed estimates of PM2.5 exposure based on geospatial extrapolations of monitoring data, and also includes distance of residential address from roadways as an estimate of exposure to traffic-related pollutant emissions. The study population is being expanded to include data from the West Coast Childhood Brain Tumor study. The latter database includes children aged 1-19 years diagnosed with brain tumors in Los Angeles county from 1984

through 1991. This project is currently ongoing, and a report of results is expected by the end of this year.

4. Financial Report

As of December 31, 2009, the Foundation had a cash balance of $689,263. Following is an accounting of the Foundation's operations since its inception (7/23/03):

Revenue from Operations	
Contributions	$3,722,568
Interest Income	36,256
Total Revenue from Operations	***$3,758,824***
Operating Expenses	
Grants Awarded	
-Cedars-Sinai	$2,684,250
-USC	377,967
Corporation Filing Costs	820
Bank charges	524
Professional fees-audit	6,000
Total Operating Expenses	***$3,069,561***
Cash Balance, 12/31/09	**$689,263**

5. Plans for Upcoming Year

The Foundation will continue monitoring the progress of existing research projects. The Foundation will evaluate potential new projects and provide funding to the extent that additional funds become available.

The Foundation Board asked that any funds transferred to the Health Effects Research Fund by the AQMD Governing Board be reserved for the Foundation's use to support brain and lung tumor and air pollution research, but not transferred until specific projects are identified by the Foundation Board. The Foundation Board also asked staff to prepare a plan for future research.

This page updated: March 25, 2010
URL: http://www.aqmd.gov/hb/2010/April/100425a.htm

Technical Support Document for Cancer Potency Factors:

Methodologies for derivation, listing of available values, and adjustments to allow for early life stage exposures.

April 2009

California Environmental Protection Agency

Office of Environmental Health Hazard Assessment

Air Toxicology and Epidemiology Branch

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EXECUTIVE SUMMARY

The Air Toxics "Hot Spots" Information and Assessment Act (AB 2588, Connelly) was enacted in September 1987. Under this Act, stationary sources of air pollution are required to report the types and quantities of certain substances their facilities routinely release into the air. The goals of the Air Toxics "Hot Spots" Act are to collect emission data, identify facilities having localized impacts, ascertain health risks posed by those facilities, notify nearby residents of significant risks and reduce emissions from significant sources.

The Technical Support Document for Cancer Potency Factors (TSD) contains cancer unit risks and potency factors for 107 of the 201 carcinogenic substances or groups of substances for which emissions must be quantified in the Air Toxics Hot Spots program. These unit risks are used in the cancer risk assessment of facility emissions.

The purposes of this revision to the TSD is to provide updated calculation procedures used to derive the estimated unit risk and cancer potency factors, and to describe the procedures used to consider the increased susceptibility of infants and children compared to adults to carcinogens. This updates cancer risk assessment methods originally laid out in the California Department of Health Services' Guidelines for Chemical Carcinogen Risk Assessment (CDHS, 1985), and more recently summarized in the previous Hot Spots technical support document Part II (OEHHA, 2005a). Summaries of cancer potency factors and the underlying data are provided in Appendix A and B. [these did not undergo revision and are not included in this review package.]

The procedures used to consider the increased susceptibility to carcinogens of infants and children as compared to adults include the use of age-specific weighting factors in calculating cancer risks from exposures of infants, children and adolescents, to reflect their anticipated special sensitivity to carcinogens

This document is one part of the Air Toxics Hot Spots Program Risk Assessment Guidelines. The other documents originally included in the Guidelines are Part I: Technical Support Document for the Determination of Acute Toxicity Reference Exposure Levels for Airborne Toxicants; Part III: Technical Support Document for Determination of Noncancer Chronic Reference Exposure Levels; Part IV: Technical Support Document for Exposure Assessment and Stochastic Analysis; Part V: Air Toxic Hot Spots Program Risk Assessment Guidelines. As a part of the same revision process which led to production of this revised TSD on cancer potencies, the original TSDs for Acute and Chronic Reference Exposure Levels have been replaced with a new unified TSD for Acute, 8-hour and Chronic Reference Exposure Levels.

The major changes to the TSD include the following:

- Based on the OEHHA analysis of the potency by lifestage at exposure, OEHHA proposes weighting cancer risk by a factor of 10 for exposures that occur from birth to 2 years of age, and by a factor of 3 for exposures that occur from 2 years through 15 years of age. We propose to apply this weighting factor to all carcinogens, regardless of purported mechanism of action, unless chemical-specific data exist to the contrary. In cases where

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there are adequate data for a specific carcinogen of potency by age, we would use the data to make any adjustments to risk.

- OEHHA proposes to use the Benchmark Dose method to compute potency factors rather than the more traditional linearized multistage model (LMS), although the LMS will still be used in some instances. The BMDL model essentially uses an empirical fit to the data (usually best with the multistage model), and then extrapolates with a straight line from the 95 % lower confidence limit of the BMD (BMDL) to zero. This method is simpler and does not assume any underlying theoretical mechanisms at the low dose range. The BMDL method results in very similar estimates of potency as the LMS method.

- OEHHA will use scaling based on body weight to the ¾ power, rather than to the 2/3 power.

- OEHHA's evaluations of the carcinogenicity of chemicals generally follow the guidelines laid out by IARC for identification and classification of potential human carcinogens, which are described in detail in the most recent revision of the *Preamble* to the IARC monographs series (IARC, 2006).

PREFACE

The Air Toxics "Hot Spots" Information and Assessment Act (AB 2588, Connelly) was enacted in September 1987. Under this Act, stationary sources are required to report the types and quantities of certain substances their facilities routinely release into the air. The goals of the Air Toxics "Hot Spots" Act are to collect emission data, identify facilities having localized impacts, ascertain health risks posed by those facilities, notify nearby residents of significant risks and reduce emissions from significant sources.

The Technical Support Document for Cancer Potency Factors (TSD) contains cancer unit risks and potency factors for 107 of the 201 carcinogenic substances or groups of substances for which emissions must be quantified in the Air Toxics Hot Spots program. These unit risks are used in risk assessment of facility emissions. The TSD provides updated calculation procedures used to derive the estimated unit risk and cancer potency factors, and procedures to consider early-life susceptibility to carcinogens. Summaries of cancer potency factors and the underlying data are provided in Appendix A and B. [these did not undergo revision and are not included in this review package.]

In this document, OEHHA is responding to the requirements of the 1999 Children's Environmental Health Protection Act, (SB25, Escutia) by revising the procedures for derivation and application of cancer potency factors to take account of general or chemical-specific information which suggests that children may be especially susceptible to certain carcinogens (OEHHA, 2001a). The revised cancer potency derivation procedures described will not be used to impose any overall revisions of the existing cancer potencies, although they do reflect updated methods of derivation. However, individual cancer potency values will be reviewed as part of the ongoing re-evaluation of health values mandated by SB 25, and revised values will be listed in updated versions of the appendices to this document as necessary. The revisions also include the use of weighting factors in calculating cancer risks from exposures of infants, children and adolescents, to reflect their anticipated special sensitivity to carcinogens. Similar legal mandates to update risk assessment methodology and cancer potencies apply to the OEHHA program for development of Public Health Goals (PHGs) for chemicals in drinking water, and Proposition 65 No Significant Risk Levels (NSRLs). The NSRLs may also be revised to reflect concerns for children's health. Revising these numbers will require the originating program to reconsider the value in an open public process. For example, OEHHA would need to release any revised potency factors for public comment and review by the Scientific Review Panel on Toxic Air Contaminants (SRP) prior to adoption under the TAC program. The procedures for outside parties to request reevaluation of cancer potency values by the programs which originated those values are listed in Appendix G.

Appendices A and B provide previously adopted Cal/EPA values which were included in the previous version of the TSD for Cancer Potency Factors (OEHHA, 2005a). Cal/EPA values were developed under the Toxic Air Contaminant (TAC) program, the PHG program, the Proposition 65 program, or in some cases specifically for the Air Toxics Hot Spots program. All the Cal/EPA values are submitted for public comments and external peer review prior to adoption by the program of origin. In the future, new values developed by the Toxic Air

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Contaminants or Hot Spots programs or other suitable sources will be added as these are approved.

Some U.S. EPA IRIS cancer unit risk values were adopted under the previous versions of these guidelines, and these values will continue to be used unless and until revised by Cal/EPA. U.S. EPA has recently revised its cancer risk assessment guidelines (U.S. EPA, 2005a). Some of the recommended changes in methodology could result in slightly different potency values compared to those calculated by the previous methodology, although in practice a number of the recommendations (for example, the use of ¾ power of the body weight ratio rather than ⅔ power for interspecies scaling) have been available in draft versions of the revised policy for some time and appear in many more recent assessments. U.S. EPA has stated that cancer potency values listed in IRIS will not be revisited solely for the purpose of incorporating changes in cancer potency value calculation methods contained in the revised cancer risk assessment guidelines. U.S. EPA has also issued supplementary guidelines on assessing cancer risk from early-life exposure (U.S. EPA, 2005b).

OEHHA uses a toxic equivalency factor procedure for dioxin-like compounds, including polychlorinated dibenzo-*p*-dioxins, dibenzofurans and polychlorinated biphenyls (PCBs). The Toxicity Equivalency Factor scheme (TEF_{WHO-97}) developed by the World Health Organization/European Center for Environmental Health (WHO-ECEH) is used for determining cancer unit risk and potency values for these chemicals where individual congener emissions are available (Appendix C).

This document is one part of the Air Toxics Hot Spots Program Risk Assessment Guidelines. The other documents originally included in the Guidelines are Part I: Technical Support Document for the Determination of Acute Toxicity Reference Exposure Levels for Airborne Toxicants; Part III: Technical Support Document for Determination of Noncancer Chronic Reference Exposure Levels; Part IV: Technical Support Document for Exposure Assessment and Stochastic Analysis; Part V: Air Toxic Hot Spots Program Risk Assessment Guidelines. As a part of the same revision process which led to production of this revised TSD on cancer potencies, the original TSDs for Acute and Chronic Reference Exposure Levels have been replaced with a new unified TSD for Acute, 8-hour and Chronic Reference Exposure Levels.

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APPENDICES

Appendix A. A lookup table containing unit risk and cancer potency values.

Appendix B. Chemical-specific summaries of the information used to derive unit risk and cancer potency values.

Appendix C. A description of the use of toxicity equivalency factors for determining unit risk and cancer potency factors for polychlorinated dibenzo-*p*-dioxins, dibenzofurans and dioxin-like polychlorinated biphenyls.

Appendix D. A listing of Toxic Air Contaminants identified by the California Air Resources Board.

Appendix E. Descriptions of the International Agency for Research on Cancer (IARC) and U.S. Environmental Protection Agency (U.S. EPA) carcinogen classifications.

Appendix F. An asbestos quantity conversion factor for calculating asbestos concentrations expressed as 100 fibers/m^3 from asbestos concentrations expressed as $\mu g/m^3$.

Appendix G. Procedures for revisiting or delisting cancer potency factors by the program of origin.

Appendix H. Exposure routes and studies used to derive cancer unit risks and slope factors.

Appendix I. "Assessing susceptibility from early-life exposure to carcinogens": Barton *et al.*, 2005 (from *Environmental Health Perspectives).*

Appendix J. "In Utero and Early Life Susceptibility to Carcinogens: The Derivation of Age-at-Exposure Sensitivity Measures" – conducted by OEHHA's Reproductive and Cancer Hazard Assessment Branch.

Appendix K. Additions and corrections from prior document versions.

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INTRODUCTION

The Technical Support Document (TSD) for Describing Available Cancer Potency Factors provides technical information support for the Air Toxics Hot Spots Program Risk Assessment Guidelines. The TSD consists of 12 sections:

1. The TSD introduction.
2. A description of the methodologies used to derive the unit risk and cancer potency values listed in the lookup table.
3. A lookup table containing unit risk and cancer potency values. (Appendix A)
4. Chemical-specific summaries of the information used to derive unit risk and cancer potency values. (Appendix B).
5. A description of the use of toxicity equivalency factors for determining unit risk and cancer potency factors for polychlorinated dibenzo-*p*-dioxins, dibenzofurans and dioxin-like polychlorinated biphenyls (Appendix C).
6. A listing of Toxic Air Contaminants identified by the California Air Resources Board (Appendix D).
7. Descriptions of the International Agency for Research on Cancer (IARC) and U.S. Environmental Protection Agency (U.S. EPA) carcinogen classifications (Appendix E).
8. An asbestos quantity conversion factor for calculating asbestos concentrations expressed as 100 fibers/m^3 from asbestos concentrations expressed as $\mu g/m^3$ (Appendix F).
9. Procedures for revisiting or delisting cancer potency factors by the program of origin (Appendix G).
10. Exposure routes and studies used to derive cancer unit risks and slope factors (Appendix H).
11. "Assessing susceptibility from early-life exposure to carcinogens": Barton *et al.*, 2005 (from *Environmental Health Perspectives)* (Appendix I).
12. "In Utero and Early Life Susceptibility to Carcinogens: The Derivation of Age-at-Exposure Sensitivity Measures" – conducted by OEHHA's Reproductive and Cancer Hazard Assessment Branch (Appendix J)

SELECTION OF CANCER POTENCY VALUES

The Office of Environmental Health Hazard Assessment (OEHHA) has developed a number of cancer potencies for use in the Toxic Air Contaminants and Air Toxics Hot Spots programs. This document also provides summaries of cancer potency factors which were originally developed for other California Environmental Protection Agency (Cal/EPA) programs, or by the U.S. EPA. These were reviewed for accuracy, reliance on up-to-date data and methodology, and applicability in the context of the Air Toxics Hot Spots program. Values found appropriate were adopted after public and peer review rather than devoting the resources necessary for a full *de novo* assessment. Thus, cancer potency values (CPF) included in the Technical Support Document (TSD) for Cancer Potency Factors were from the following sources:

1. Toxic Air Contaminant documents
2. Standard Proposition 65 documents
3. U.S.EPA Integrated Risk Information Systems (Office of Health and Environmental Assessment, U.S.EPA)
4. Expedited Proposition 65 documents
5. Other OEHHA assessments , for example for the drinking water program.

All the cancer potency value sources used generally follow the recommendations of the National Research Council on cancer risk assessment (NRC, 1983, 1994). All Cal/EPA program documents undergo a process of public comment and scientific peer review prior to adoption, although the procedures used vary according to the program. The publication procedure for Toxic Air Contaminant documents includes a public comment period and review by the Scientific Review Panel on Toxic Air Contaminants (SRP) before identification of a Toxic Air Contaminant by the Air Resources Board of the California Environmental Protection Agency (Cal/EPA). Furthermore, a petition procedure is available to initiate TAC document review and revision if appropriate because of new toxicity data. Documents developed for the Air Toxics Hot Spots program similarly undergo public comment and peer review by the SRP before adoption by the Director of OEHHA. The standard Proposition 65 document adoption procedure includes a public comment and external peer review by the Proposition 65 Carcinogen Identification Committee. The expedited Proposition 65 document adoption procedure included a public comment period. Risk assessments prepared for development of Public Health Goals (PHGs) for chemicals in drinking water are subject to two public comment periods before the final versions and responses to comments are published on the OEHHA Web site. PHG documents may also receive external peer review. Documents from U.S. EPA's Integrated Risk Information System (IRIS) receive external peer review and are posted on the Internet for public viewing during the external peer review period, and any public comments submitted are considered by the originating office. Additionally, public comment may be solicited during the document posting period. Future preference for use of developed cancer potency factors/unit risks will be done on a case by case basis. Preference will be given to those assessments most relevant to inhalation exposures of the California population, to the most recent derivations using the latest data sets and scientific methodology, and to those having undergone the most open and extensive peer review process.

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CANCER RISK ASSESSMENT METHODOLOGIES

This section describes in general the methodologies used to derive the cancer unit risk and potency factors listed in this document. As noted in the Preface to this document, no new cancer unit risks or potency factors were developed for this document. All of the values contained here were previously developed in documents by Cal/EPA or U.S. EPA. Following the recommendations of the National Academy of Sciences (NRC, 1983), Cal/EPA and U.S. EPA have both used formalized cancer risk assessment guidelines, the original versions of which (California Department of Health Services, 1985; U.S. EPA, 1986) were published some time ago. Both these guidelines followed similar methodologies.

In the twenty years since these original guidelines were published there have been a number of advances in the methodology of cancer risk assessment. There have additionally been considerable advances in the quantity of data available not only from animal carcinogenesis bioassays and epidemiological studies, but also from mechanistic studies of carcinogenesis and related phenomena. Some of these advances have been incorporated into newer risk assessments by both agencies on a more or less *ad hoc* basis. There has also been an ongoing effort to provide updated risk assessment guidance documents. In 1995, U.S. EPA released for public comment the "Proposed and Interim Guidelines for Carcinogen Risk Assessment", which was the first of several drafts released for public comment. Many risk assessments appearing since then have used elements of the recommendations contained in that document, in spite of its draft status. A final version of the U.S. EPA's revised cancer risk assessment guidelines has now been released (U.S. EPA, 2005a). Although these new guidelines incorporate a number of substantial changes from their predecessors (U.S. EPA, 1986; 1995), U.S. EPA has stated that cancer potency values listed in IRIS will not be revisited solely for the purpose of incorporating changes in cancer potency value calculation methods.

Cal/EPA has not produced a revised cancer risk assessment guideline document to replace the original version (DHS, 1985). Rather, Cal/EPA has relied on incorporating new data and methodologies as these became available, and described the methods used on a case by case basis in the individual risk assessment documents where these went beyond the original guidance. However, this revision of the TSD for cancer potencies provides a convenient opportunity to summarize the current status of the methodology used by OEHHA for the air toxics programs, and also to highlight points of similarity to, and difference from, the recommendations of U.S. EPA (2005a).

In this document, OEHHA intends to follow the recommendations of the NRC (1994) in describing a set of clear and consistent principles for choosing and departing from default cancer risk assessment options. NRC identified a number of objectives that should be taken into account when considering principles for choosing and departing from default options. These include, "protecting the public health, ensuring scientific validity, minimizing serious errors in estimating risks, maximizing incentives for research, creating an orderly and predictable process, and fostering openness and trustworthiness". The OEHHA cancer risk methodologies discussed in this document are intended to generally meet those objectives cited above.

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Hazard Identification

This section will describe: 1) how weight of evidence evaluations are used in hazard evaluation; 2) guidelines for inferring causality of effect; 3) the use of human and animal carcinogenicity data, as well as supporting evidence (e.g. genetic toxicity and mechanistic data); 4) examples of carcinogen identification schemes.

Evaluation of Weight of Evidence

In evaluating the range of evidence on the toxicity and carcinogenicity of a compound, mixture or other agent, a "weight-of-evidence" approach is generally used to describe the body of evidence on whether or not exposure to the agent causes a particular effect. Under this approach, the number and quality of toxicological and epidemiological studies, as well as the consistency of study results and other sources of data on biological plausibility, are considered. Diverse and sometimes conflicting data need to be evaluated with respect to possible explanations of differing results. Consideration of methodological issues in the review of the toxicological and epidemiological literature is important in evaluating associations between exposure to an agent and animal or human health effects. This aspect of the evaluation process has received particular emphasis with respect to epidemiological data, where concerns as to the statistical and biological significance and reliability of the data and the impacts of confounding and misclassification are pressing. Such concerns are also relevant to some extent in the interpretation of animal bioassay data and mechanistic studies. Although the test animals, laboratory environment and characterization of the test agent are usually much better controlled than the equivalent parameters in an epidemiological study, the small sample size can be problematic. In addition, there are uncertainties associated with extrapolation of biological responses from test animal species to humans.

Criteria for Causality

There has been extensive discussion over the last two centuries on causal inference. This has been particularly with regard to epidemiological data, but is also relevant to interpretation of animal studies. Most epidemiologists utilize causal inference guidelines based on those proposed by Bradford Hill (1971). OEHHA has relied on these and on recommendations by IARC (2006), the Institute of Medicine (2004), the Surgeon General's Reports on Smoking (U.S. DHHS, 2004) and standard epidemiologic texts (*e.g.* Lilienfeld and Lilienfeld, 1980; Rothman and Greenland, 1998). The criteria for determination of causality used by OEHHA have been laid out in various risk assessment documents. The summary below is adapted from the Health Effects section of the document prepared to support the identification of environmental tobacco smoke (ETS) as a Toxic Air Contaminant (OEHHA, 2005b).

1. *Strength of Association.* A statistically significant strong association, which is easier to detect if there is a high relative risk, between a factor and a disease is often viewed as an important criterion for inferring causality because, all other things being equal, a strong and statistically significant association makes alternative explanations for the disease less likely. However, as discussed in Rothman and Greenland (1998), the fact that a relative risk is small in magnitude does not exclude a casual association between the risk factor

and the outcome in question. Since it is more difficult to detect (i.e., reach statistical significance) a small magnitude risk, ~~they are~~it is just as likely to ~~be causal~~indicate causality as a larger magnitude risk~~s~~.

When assessing all evidence, it is important to consider the strength of the study design (particularly controlling for confounding variables, obtaining an unbiased sample, measurement error) and the level of statistical significance (i.e., the ability to exclude a Type I [false positive] error). The power of the study to detect biologically meaningful effects (i.e., the risk of a Type II [false negative] error) is important in considering studies that do not reach traditional (i.e., $P<.05$) statistical significance, particularly if the biological endpoint is serious. If the outcome is serious and the study small (i.e., low power), a larger P value (e.g., $P<.10$) may be adequate evidence for identifying an effect.

There are a number of examples of statistically significant, small magnitude associations that are widely accepted as causal, such as causal links between air pollution and cardiovascular/pulmonary mortality and between second-hand smoke exposure and various cancers and heart disease. From a public health perspective, even a small magnitude increase in risk for a common disease can mean large numbers of people affected by the health outcome when exposure is frequent and widespread, as measured by the population attributable risk or attributable fraction. Small magnitude of association must not be confused with statistical significance, which is much more important.

2. *Consistency of Association.* If several investigations find an association between a factor and a disease across a range of populations, geographic locations, times, and under different circumstances, then the factor is more likely to be causal. Consistency argues against hypotheses that the association is caused by some other factor(s) that varies across studies. Unmeasured confounding is an unlikely explanation when the effect is observed consistently across a number of studies in different populations.

   Associations that are replicated in several studies of the same design or using different epidemiological approaches or considering different sources of exposure and in a number of geographical regions are more likely to represent a causal relationship than isolated observations from single studies (IARC, 2006). If there are inconsistent results among investigations, possible reasons are sought, such as adequacy of sample size or control group, methods used to assess exposure, or range in levels of exposure. The results of studies judged to be rigorous are emphasized over those of studies judged to be methodologically less rigorous. For example, studies with the best exposure assessment are more informative for assessing the association between ETS and breast cancer than studies with limited exposure assessment, all else being equal.

3. *Temporality.* Temporality means that the factor associated with causing the disease occurs in time prior to development of the disease. The adverse health effect should occur at a time following exposure that is consistent with the nature of the effect. For example, respiratory irritation immediately following exposure to an irritant vapor is temporally consistent, whereas ~~effects~~ irritation noted only years later may not be. On the other hand, tumors, noted immediately following exposure, might be temporally

inconsistent with a causal relationship, but tumors arising after a latency period of months (in rodents) or years (in rodents or humans) would be temporally consistent.

4. *Coherence and Biological Plausibility.* A causal interpretation cannot conflict with what is known about the biology of the disease. The availability of experimental data or mechanistic theories consistent with epidemiological observations strengthens conclusions of causation. For example, the presence of known carcinogens in tobacco smoke supports the concept that exposure to tobacco smoke could cause increased cancer risk. Similarly, if the mechanism of action for a toxicant is consistent with development of a specific disease, then coherence and biological plausibility can be invoked. It should be noted that our understanding of the biology of disease, and therefore biological plausibility, changes in light of new information which is constantly emerging from molecular biology (including epigenetics), and from new clinical and epidemiological investigations revealing effects influenced by genetic polymorphisms, pre-existing disease, and so forth.

5. *Dose-Response.* A basic tenet of toxicology is that increasing exposure or dose generally increases the response to the toxicant. While dose-response curves vary in shape and are not necessarily always monotonic, an increased gradient of response with increased exposure makes it difficult to argue that the factor is not associated with the disease. To argue otherwise necessitates that an unknown factor varies consistently with the dose of the substance and the response under question. While increased risk with increasing levels of exposure is considered to be a strong indication of causality, absence of a graded response does not exclude a causal relationship (IARC, 2006).

   The dose-response curves for specific toxic effects may be non-monotonic. Under appropriate circumstances, where the dose response shows saturation, the effect of exposures could be nearly maximal, with any additional exposure having little or no effect. In some instances, a response is seen strongly in susceptible subpopulations, and the dose-response is masked by mixing susceptible and non-susceptible individuals in a sample. Further, there are examples of U-shaped or inverted U-shaped dose-response curves, (e.g., for endocrine disrupters) (Almstrup et al., 2002; Lehmann et al., 2004). Finally, timing of exposure during development may mask an overall increase in risk with increasing dose.

6. *Specificity.* Specificity is generally interpreted to mean that a single cause is associated with a single effect. It may be useful for determining which microorganism is responsible for a particular disease, or associating a single carcinogenic chemical with a rare and characteristic tumor (e.g., liver angiosarcoma and vinyl chloride, or mesothelioma and asbestos). However, the concept of specificity is not helpful when studying diseases that are multifactorial, or toxic substances that contain a number of individual constituents, each of which may have several effects and/or target sites.

7. *Experimental evidence.* While experiments are often conducted over a short period of time or under artificial conditions (compared to real-life exposures), experiments offer the opportunity to collect data under highly controlled conditions that allow strong causal conclusions to be drawn. Experimental data that are consistent with epidemiological

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results strongly support conclusions of causality. There are also "natural experiments" that can be studied with epidemiological methods, such as when exposure of a human population to a substance declines or ceases; if the effect attributed to that exposure decreases, then there is evidence of causality. One example of this is the drop in heart disease death and lung cancer risk after smoking cessation.

It should be noted that the causal criteria are guidelines for judging whether a causal association exists between a factor and a disease, rather than hard-and-fast rules. Lilienfeld and Lilienfeld (1980) note that "*In medicine and public health, it would appear reasonable to adopt a pragmatic concept of causality. A causal relationship would be recognized to exist whenever evidence indicates that the factors form part of the complex of circumstances that increases the probability of the occurrence of disease and that a diminution of one or more of these factors decreases the frequency of that disease. After all, the reason for determining the etiological factors of a disease is to apply this knowledge to prevent the disease.*" Rothman and Greenland (2005) discuss the complexities of causation and the use of rules and deductive methods in causal inference. They also concur with Bradford Hill and others that a determination of causality is a pragmatic conclusion rather than an absolute verdict, and advocate that these criteria should be seen as "*deductive tests of causal hypotheses*".

Data sources

Human studies: epidemiology, ecological studies and case reports

The aim of a risk assessment for the California Air Toxics programs is to determine potential impact on human health. Ideally therefore, the hazard identification would rely on studies in humans to demonstrate the nature and extent of the hazard. However, apart from clinical trials of drugs, experimental studies of toxic effects in human subjects are rarely undertaken or justifiable. Pharmacokinetic studies using doses below the threshold for any toxic effect have been undertaken for various environmental and occupational agents, but are not usually regarded as appropriate for suspected carcinogens.

The human data on carcinogens available to the risk assessor therefore mostly consist of epidemiological studies of existing occupational or environmental exposures. It is easier to draw reliable inferences in situations where both the exposures and the population are substantial and well-defined, and accessible to direct measurement rather than recall. Thus, many important findings of carcinogenicity to humans are based on analysis of occupational exposures. Problems in interpretation of occupational epidemiological data include simultaneous exposure to several different known or suspected carcinogens, imprecise quantification of exposures and confounding exposures such as active or passive tobacco smoking. The historical database of occupational data has a bias towards healthy white adult males. Thus, the hazard analysis of these studies may not accurately characterize effects on women, infants, children or the elderly, or on members of minority ethnic groups. Nevertheless, the analysis of occupational epidemiological studies, including meta-analyses, has proved an important source for unequivocal identification of human carcinogens.

Epidemiological evidence may also be obtained where a substantial segment of a general population is exposed to the material of interest in air, drinking water or food sources. Rigorous

cohort and case-control studies may sometimes be possible, in which exposed individuals are identified, their exposure and morbidity or mortality evaluated, and compared to less exposed but otherwise similar controls. More often at least the initial investigation is a cross-sectional study, where prevalence of exposures and outcomes is compared in relatively unexposed and exposed populations. Such studies are hypothesis-generating, but are important sources of information nevertheless, and can often also justify more costly and labor-intensive follow-up cohort and/or case-control studies.

The clinical medical literature contains many case reports where a particular health outcome is reported along with unusual exposures that might have contributed to its occurrence. These reports typically describe a single patient or a small group, and have no statistical significance. They are nevertheless useful as indications of possible associations that deserve follow-up using epidemiological methods, and as supporting evidence, addressing the plausibility of associations measured in larger studies.

Animal studies

Although the observation of human disease in an exposed population can provide definitive hazard identification, adequate data of this type are not always available. More often, risk estimates have to be based on studies in experimental animals, and extrapolation of these results to predict human toxicity. The animals used are mostly rodents, typically the common laboratory strains of rat and mouse.

Rats and mice have many similarities to humans. Physiology and biochemistry are similar for all mammals, especially at the fundamental levels of xenobiotic metabolism, DNA replication and DNA repair that are of concern in identifying carcinogens. However, there are also several important differences between rodents and humans. Rodents, with a short life span, have differences in cell growth regulation compared to longer-lived species such as the human. For instance, whereas laboratory investigations have suggested that mutations in two regulatory genes (*e.g.* H-ras and p-53) are sometimes sufficient to convert a rodent cell to a tumorigenic state, many human cancers observed clinically have seven or eight such mutations. In addition, cultured normal human cells have a very stable karyotype, whereas cultured rodent cells facilely undergo tetraploidization and then aneuploidization in cell culture. Further, cultured human cells senesce and rarely undergo spontaneous immortalization (frequency is 10^{-7} or less), whereas cultured rodent cells facilely undergo immortalization at frequencies on the order of 10^{-3}. The use of genomics to study chemical carcinogenesis is relatively new, but the differences at present appear to be a matter of degree rather than kind.

Differences in regulation of cell division are another likely reason for variation between species in the site of action of a carcinogen, or its potency at a particular site. A finding of carcinogenesis in the mouse liver, for instance, is a reasonably good indicator of potential for carcinogenesis at some site in the human, but not usually in human liver (Huff, 1999). The mouse liver (and to a lesser extent that of the rat) is a common site of spontaneous tumors. It is also relatively sensitive to chemical carcinogenesis. The human liver is apparently more resistant to carcinogenesis; human liver tumors are unusual except when associated with additional predisposing disease, such as hepatitis B or alcoholic cirrhosis, or exposure to aflatoxin B1, or simultaneous exposure to hepatitis B virus and aflatoxin B1. Conversely, other

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tumor sites are more sensitive in the human than in experimental animals. Interspecies variation in site and sensitivity to carcinogenesis may also arise from differences in pharmacokinetics and metabolism, especially for carcinogens where metabolic activation or detoxification is important. This variability may cause important differences in sensitivity between individuals in a diverse population such as humans. Variability between individuals in both susceptibility and pharmacokinetics or metabolism is probably less in experimental animal strains that are bred for genetic homogeneity.

Animal carcinogenesis studies are often designed to maximize the chances of detecting a positive effect, and do not necessarily mimic realistic human exposure scenarios. Thus extrapolation from an experimentally accessible route to that of interest for a risk assessment may be necessary. Even for studies by realistic routes such as oral or inhalation, doses may be large compared to those commonly encountered in the environment, in order to counter the limitation in statistical power caused by the relatively small size of an animal experiment. Whereas the exposed population of an epidemiological study might number in the thousands, a typical animal study might have fifty individuals per exposure group. With this group size any phenomenon with an incidence of less than about 5% is likely to be undetectable. Statistically significant results may be obtained even with groups as small as ten animals per dose group, when incidence of a tumor that is rare in the controls approached 100% in a treated group. The consensus experimental design for animal carcinogenesis studies, which has evolved over the last 50 years of investigation, is represented by the protocol used by the U.S. National Toxicology Program (NTP) for studies using oral routes (diet, gavage or drinking water) or inhalation. These carcinogenesis bioassays usually involve both sexes of an experimental species, and most often two species. NTP has standardized the use of the C57BlxC3H F_1 hybrid mouse, and the Fischer 344 rat as the standard test species, although NTP has announced plans to substitute use of the Wistar Han rat for the Fisher 344 rat. There is now an extensive database of background tumor incidences, normal physiology, biochemistry, histology and anatomy for these strains, which aids in the interpretation of pathological changes observed in experiments. Nevertheless, there is enough variation in background rates of common tumors that the use of concurrent controls is essential for hazard identification or dose-response assessment. "Historical control" data are mainly used to reveal anomalous outcomes in the concurrent controls. The fact that a significantly elevated incidence of a tumor relative to the concurrent control group is within the range of historical controls at that site for the test sex and strain is not necessarily grounds for dismissing the biological significance of the finding.

Groups of fifty animals of each sex and species are used, with control groups, and several dose groups, the highest receiving the maximum tolerated dose (MTD). Recent study designs have emphasized the desirability of at least three dose levels covering a decade with "logarithmic" spacing (*i.e.* MTD, 1/2 MTD or 1/3 MTD, and 1/10 MTD). This extended design is aimed at providing better dose-response information, and may contribute important additional information, such as mechanistic insights, for the hazard identification phase.

Supporting evidence: genetic toxicity, mechanistic studies

Investigators have developed additional data sources that can support or modify the conclusions of animal carcinogenesis bioassays, and provide information on mechanisms of action of agents suspected of being carcinogenic based on epidemiological studies or animal bioassays.

Genetic damage in exposed organisms includes both gene mutations (point or frameshift), and larger scale effects such as deletions, gene amplification, sister-chromatid exchanges, translocations and loss or duplication of segments or whole chromosomes. These genetic effects of chemical exposures are deleterious in their own right. In addition, since carcinogenesis results from somatic mutations and similar genetic alterations, agents that cause genetic damage generally have carcinogenic potential. Conversely, many known carcinogens are also known to be genotoxic, although there is also a significant class of carcinogens that are not directly genotoxic according to the usual tests. These latter agents presumably work by some other mechanism, such as methylation of tumor suppressor genes or demethylation of cellular proto-oncogenes, although recent genetic studies have shown that even tumors induced by these agents may show mutations, deletions or amplification of growth regulatory genes.

Experimental procedures to demonstrate and measure genetic toxicity may involve exposure of intact animals, and examination of genetic changes in, for example, bone marrow cells (or cells descended from these e.g. the micronucleus test, which detects remnants of chromosomal fragments in immature erythrocytes), mutations in flies (*Drosophila)*, or appearance of color spots in the coat of mice. However, many tests have employed single celled organisms or mammalian cells in culture. The best known of these tests is the *Salmonella* reverse mutation assay, popularly known as the Ames test after its inventor. This is representative of a larger class of tests for mutagenic activity in prokaryotic organisms (bacteria), which necessarily only look at gene-level mutations. Similar tests in eukaryotic microorganisms (yeasts, *Aspergillus*) and cultured mammalian cells also detect chromosomal effects. Many tests using microorganisms *in vitro* involve addition of activating enzymes (*e.g.* liver postmitochondrial supernatant – "S9") to mimic the metabolism of promutagenic chemicals *in vivo*. Another type of test examines the induction in mammalian cells of morphological transformation or anchorage-independent growth. These two chemically induced, *in vitro* changes are considered two of the many changes that fibroblastic cells must undergo on their route to neoplastic transformation (tumorigenicity). These various genetic tests contribute different information, which may be used to amplify and confirm conclusions drawn from human studies or animal bioassays, or to draw conclusions in the absence of epidemiological or bioassay data. In the latter case they have also been used in prioritizing agents for further evaluation by means of bioassays.

Carcinogen Identification schemes

Some regulatory programs, such as California's Safe Drinking Water and Toxics Enforcement Act ("Proposition 65") and various activities of the U.S. EPA, require that explicit lists of substances having the potential to act as human carcinogens be maintained. Other such lists are developed by non-regulatory research organizations, such as the U.S. National Toxicology Program and the International Agency for Research on Cancer (IARC), an international program of the World Health Organization. The California air toxics programs do not have any statutory requirement to "identify" carcinogens. The requirement instead is to identify hazardous substances as Toxic Air Contaminants, and to determine whether or not a threshold concentration, below which no adverse effects are expected, is likely to exist:

HEALTH AND SAFETY CODE, Division 26 (Air Resources), § 39660.

(2) The evaluation shall also contain an estimate of the levels of exposure that may cause or contribute to adverse health effects. If it can be established that a threshold of adverse health effects exists, the estimate shall include both of the following factors:

(A) The exposure level below which no adverse health effects are anticipated.

(B) An ample margin of safety that accounts for the variable effects that heterogeneous human populations exposed to the substance under evaluation may experience, the uncertainties associated with the applicability of the data to human beings, and the completeness and quality of the information available on potential human exposure to the substance. In cases in which there is no threshold of significant adverse health effects, the office shall determine the range of risk to humans resulting from current or anticipated exposure to the substance.

In practice however this requirement amounts to the need to establish whether or not a substance is carcinogenic. Any such effects are clearly harmful. Whereas the great majority of non-cancer health effects of chemicals are regarded as having a threshold, the default assumption for carcinogens is that there is no threshold (as described below). OEHHA follows the guidelines laid out by IARC for identification and classification of potential human carcinogens, which are described in detail in the most recent revision of the *Preamble* to the IARC monographs series (IARC, 2006). The IARC Monograph series provides evaluations of the carcinogenicity of individual substances or commonly occurring mixtures. The evaluation guidelines used are similar to those used by other scientific or regulatory authorities, including U.S.EPA.

The data inputs to hazard identification for carcinogens are human epidemiological studies, animal bioassays, along with supporting evidence such as mechanistic and genotoxicity data and structure-activity comparisons. IARC also assembles data on the structure and identity of the agent. The list of agents considered includes specific chemicals and also complex mixtures, occupational and lifestyle factors, physical and biological agents, and other potentially carcinogenic exposures.

IARC evaluations determine the quality of evidence for both animal and human evidence as falling into one of four categories: sufficient evidence of carcinogenicity, limited evidence of carcinogenicity, inadequate evidence of carcinogenicity and evidence suggesting lack of carcinogenicity. Stringent requirements for data quality are imposed. In view of their crucial importance, these definitions are quoted directly from the *Preamble* (IARC 2006):

"(a) Carcinogenicity in humans

Sufficient evidence of carcinogenicity: The Working Group considers that a causal relationship has been established between exposure to the agent and human cancer. That is, a positive relationship has been observed between the exposure and cancer in studies in which chance, bias and confounding could be ruled out with reasonable confidence. A statement that there is *sufficient evidence* is followed by a separate sentence that identifies the target organ(s) or tissue(s) where an increased risk of cancer was observed in humans. Identification of a specific target organ or tissue does not preclude the possibility that the agent may cause cancer at other sites.

Limited evidence of carcinogenicity: A positive association has been observed between exposure to the agent and cancer for which a causal interpretation is considered by the Working Group to be credible, but chance, bias or confounding could not be ruled out with reasonable confidence.

Inadequate evidence of carcinogenicity: The available studies are of insufficient quality, consistency or statistical power to permit a conclusion regarding the presence or absence of a causal association between exposure and cancer, or no data on cancer in humans are available.

Evidence suggesting lack of carcinogenicity: There are several adequate studies covering the full range of levels of exposure that humans are known to encounter, which are mutually consistent in not showing a positive association between exposure to the agent and any studied cancer at any observed level of exposure. The results from these studies alone or combined should have narrow confidence intervals with an upper limit close to the null value (e.g. a relative risk of 1.0). Bias and confounding should be ruled out with reasonable confidence, and the studies should have an adequate length of follow-up. A conclusion of *evidence suggesting lack of carcinogenicity* is inevitably limited to the cancer sites, conditions and levels of exposure, and length of observation covered by the available studies. In addition, the possibility of a very small risk at the levels of exposure studied can never be excluded.

(b) Carcinogenicity in experimental animals

Carcinogenicity in experimental animals can be evaluated using conventional bioassays, bioassays that employ genetically modified animals, and other in-vivo bioassays that focus on one or more of the critical stages of carcinogenesis. In the absence of data from conventional long-term bioassays or from assays with neoplasia as the end-point, consistently positive results in several models that address several stages in the multistage process of carcinogenesis should be considered in evaluating the degree of evidence of carcinogenicity in experimental animals.

The evidence relevant to carcinogenicity in experimental animals is classified into one of the following categories:

Sufficient evidence of carcinogenicity: The Working Group considers that a causal relationship has been established between the agent and an increased incidence of malignant neoplasms or of an appropriate combination of benign and malignant neoplasms in (a) two or more species of animals or (b) two or more independent studies in one species carried out at different times or in different laboratories or under different protocols. An increased incidence of tumours in both sexes of a single species in a well-conducted study, ideally conducted under Good Laboratory Practices, can also provide *sufficient evidence*.

A single study in one species and sex might be considered to provide *sufficient evidence of carcinogenicity* when malignant neoplasms occur to an unusual degree with regard to incidence, site, type of tumour or age at onset, or when there are strong findings of tumours at multiple sites.

Limited evidence of carcinogenicity: The data suggest a carcinogenic effect but are limited for making a definitive evaluation because, e.g. (a) the evidence of carcinogenicity is

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restricted to a single experiment; (b) there are unresolved questions regarding the adequacy of the design, conduct or interpretation of the studies; (c) the agent increases the incidence only of benign neoplasms or lesions of uncertain neoplastic potential; or (d) the evidence of carcinogenicity is restricted to studies that demonstrate only promoting activity in a narrow range of tissues or organs.

Inadequate evidence of carcinogenicity: The studies cannot be interpreted as showing either the presence or absence of a carcinogenic effect because of major qualitative or quantitative limitations, or no data on cancer in experimental animals are available.

Evidence suggesting lack of carcinogenicity: Adequate studies involving at least two species are available which show that, within the limits of the tests used, the agent is not carcinogenic. A conclusion of *evidence suggesting lack of carcinogenicity* is inevitably limited to the species, tumour sites, age at exposure, and conditions and levels of exposure studied."

IARC utilizes the evaluations of animal and human data, along with supporting evidence including genotoxicity, structure-activity relationships, and identified mechanisms, to reach an overall evaluation of the potential for carcinogenicity in humans. The revised *Preamble* (IARC, 2006) includes a description of the data evaluation criteria for this supporting evidence, and indications as to the situations where the availability of supporting evidence may be used to modify the overall conclusion from that which would be reached on the basis of bioassay and/or epidemiological evidence alone. The overall evaluation is expressed as a numerical grouping, the categories of which are described below, as before by directly quoting IARC (2006):

"Group 1: The agent is *carcinogenic to humans.*

This category is used when there is *sufficient evidence of carcinogenicity* in humans. Exceptionally, an agent may be placed in this category when evidence of carcinogenicity in humans is less than *sufficient* but there is *sufficient evidence of carcinogenicity* in experimental animals and strong evidence in exposed humans that the agent acts through a relevant mechanism of carcinogenicity.

Group 2.

This category includes agents for which, at one extreme, the degree of evidence of carcinogenicity in humans is almost *sufficient*, as well as those for which, at the other extreme, there are no human data but for which there is evidence of carcinogenicity in experimental animals. Agents are assigned to either Group 2A (*probably carcinogenic to humans*) or Group 2B (*possibly carcinogenic to humans*) on the basis of epidemiological and experimental evidence of carcinogenicity and mechanistic and other relevant data. The terms *probably carcinogenic* and *possibly carcinogenic* have no quantitative significance and are used simply as descriptors of different levels of evidence of human carcinogenicity, with *probably carcinogenic* signifying a higher level of evidence than *possibly carcinogenic*.

Group 2A: The agent is *probably carcinogenic to humans.*

This category is used when there is *limited evidence of carcinogenicity* in humans and *sufficient evidence of carcinogenicity* in experimental animals. In some cases, an agent may be classified in this category when there is *inadequate evidence of carcinogenicity* in humans and *sufficient evidence of carcinogenicity* in experimental animals and strong evidence that the carcinogenesis is mediated by a mechanism that also operates in humans. Exceptionally, an agent may be classified in this category solely on the basis of *limited evidence of carcinogenicity* in humans. An agent may be assigned to this category if it clearly belongs, based on mechanistic considerations, to a class of agents for which one or more members have been classified in Group 1 or Group 2A.

Group 2B: The agent is *possibly carcinogenic to humans.*

This category is used for agents for which there is *limited evidence of carcinogenicity* in humans and less than *sufficient evidence of carcinogenicity* in experimental animals. It may also be used when there is *inadequate evidence of carcinogenicity* in humans but there is *sufficient evidence of carcinogenicity* in experimental animals. In some instances, an agent for which there is *inadequate evidence of carcinogenicity* in humans and less than *sufficient evidence of carcinogenicity* in experimental animals together with supporting evidence from mechanistic and other relevant data may be placed in this group. An agent may be classified in this category solely on the basis of strong evidence from mechanistic and other relevant data.

Group 3: The agent is *not classifiable as to its carcinogenicity to humans.*

This category is used most commonly for agents for which the evidence of carcinogenicity is *inadequate* in humans and *inadequate* or *limited* in experimental animals.

Exceptionally, agents for which the evidence of carcinogenicity is *inadequate* in humans but *sufficient* in experimental animals may be placed in this category when there is strong evidence that the mechanism of carcinogenicity in experimental animals does not operate in humans.

Agents that do not fall into any other group are also placed in this category.

An evaluation in Group 3 is not a determination of non-carcinogenicity or overall safety. It often means that further research is needed, especially when exposures are widespread or the cancer data are consistent with differing interpretations.

Group 4: The agent is *probably not carcinogenic to humans.*

This category is used for agents for which there is *evidence suggesting lack of carcinogenicity* in humans and in experimental animals. In some instances, agents for which there is *inadequate evidence of carcinogenicity* in humans but *evidence suggesting lack of carcinogenicity* in experimental animals, consistently and strongly supported by a broad range of mechanistic and other relevant data, may be classified in this group."

The IARC hazard evaluation system provides a detailed and generally accepted scheme to classify the strength of evidence as to the possible human carcinogenicity of chemicals and other agents. This includes careful consideration of mechanistic data and other supporting evidence, the evaluation of which is also important to inform selection of models or defaults used in dose response assessment, as is described below. The extended consideration of supporting evidence is in fact the primary difference between more recent versions of the guidance from IARC, and also by other organizations including U.S. EPA, and the original versions of that guidance. In fact, the basic criteria for hazard identification based on bioassay and epidemiological data have not changed substantially in other respects from earlier guidance documents, including that originally published by California (DHS, 1985). Although as noted earlier the California Air Toxics programs do not categorize identified carcinogens, it has generally been the practice to regard any agent with an IARC overall classification in Group 1 or Group 2 as a known or potential human carcinogen. This implies the selection of various policy-based default options, including absence of a threshold in the dose-response curve, unless specific data are available to indicate otherwise. The same basic identification criteria are used by OEHHA scientific staff to determine the appropriate treatment of agents not evaluated by IARC, or for which newer data or revised interpretations suggest that an earlier IARC determination is no longer appropriate.

U.S. EPA has also proposed a scheme for carcinogen hazard identification and strength of evidence classification in their recently finalized Guidelines for Carcinogen Risk Assessment (U.S. EPA, 2005). These principally differ from the IARC guidance in recommending a more extensive narrative description rather than simply a numerical identifier for the identified level of evidence, and also to some degree in the weight accorded to various types of supporting evidence. However, for most purposes they may be regarded as broadly equivalent to the scheme used by IARC, and OEHHA has chosen to cite the IARC (2006) *Preamble* as representing the most up-to-date and generally accepted guidance on this issue.

Dose Response Assessment

The dose-response phase of a cancer risk assessment aims to characterize the relationship between an applied dose of a carcinogen and the risk of tumor appearance in a human. This is usually expressed as a cancer slope factor ["potency" – in units of reciprocal dose - usually $(mg/kg\text{-}body\ weight.day)^{-1}$ or "unit risk" – reciprocal air concentration – usually $(\mu g/m^3)^{-1}$] for the lifetime tumor risk associated with lifetime continuous exposure to the carcinogen at low doses. Cancer potency factors may also be referred to as "cancer slope factors". (As will be described later, additional algorithms may need to be applied to determine risk for specific age groups, or at higher doses where toxicokinetic factors have significant effect.) The basic methodologies recommended in this document are similar to those described by U.S. EPA (2005a) in their Carcinogen Risk Assessment Guidelines. This document therefore refers to U.S. EPA (2005a) for explanation of detailed procedures, and will provide only a brief summary except in cases where OEHHA recommendations are different from or more explicit than those of U.S. EPA.

The following descriptions of methods for dose response assessment, and considerations in their application, apply in principle to the analysis of both animal and human (epidemiological) cancer incidence data. Indeed, the original formulation of the multistage model (Armitage and Doll, 1954) described below was developed based on human cancer incidence. Nevertheless, the

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number and quality of human cancer incidence datasets is limited. The more complex analyses have usually only been possible for animal experimental data, where the interindividual variability and the exposure conditions can be both measured and controlled. Most commonly, epidemiological studies have necessarily used a form of multivariate analysis to separate the effects of several different variables relating to exposure, demographics and behaviors (e.g. smoking). In these analyses it is usually assumed that the effect measure(s) vary linearly with the exposure: any more complex variance assumptions might exceed the power of the data to determine the required model parameters. However, there are exceptions, especially for occupational studies where the critical exposure is measured as a continuous variable (rather than just categorical) and where the effect of this exposure is substantial relative to other confounding factors. For example, OEHHA (1998) used a multistage model dealing with both exposure intensity and duration in the analysis of cancer incidence in railroad workers exposure to diesel exhaust (Garshick et al., 1988)

Interspecies Extrapolation

The procedures used to extrapolate low-dose human cancer risk from epidemiological or animal carcinogenicity data are generally health-protective in that they determine an upper confidence bound on the risk experienced by an exposed population. As statistical estimates they cannot be regarded as definite predictions of the risk faced by any one specific individual, who might for a variety of reasons, including individual exposure and susceptibility, experience a risk different from the estimate. The risk assessment procedures used aim to include the majority of variability in the general human population within the confidence bound of the estimate, although the possibility that some individuals might experience either lower or even no risk, or a considerably higher risk, cannot be excluded. Additionally, differences may exist between the characteristics of the general public and those of studied populations. For example, healthy workers, the subject of most epidemiological studies, are often found to have lower rates of morbidity and mortality than the general population (Wen et al., 1983; Monson, 1986; Rothman and Greenland, 1998). Most human data are derived from studies of largely male adult workers and risk estimates cannot take into account specific physiological factors of women, children, and older populations that may affect the potency of a carcinogen, including early age-at-exposure.

Dose-response assessment based on environmental epidemiological studies may involve evaluation of health impacts at exposure levels within the range of those measured in the study population. However, more usually the source data are studies of occupationally exposed humans or of animals, in which case the exposures in the study are likely to be much higher than those of concern for risk assessments relating to community or ambient exposures. Further, even when extrapolation from animal species to humans is not required, the general population to which the URF is applied may differ in characteristics relative to the occupational population studied. It is therefore necessary to extrapolate from the available data to the population and exposure range of concern, which is done by using a dose-response model derived from the source data. The models used fall into three main classes; mechanistically based models, empirical models and (where data are lacking to support a true data-based model) default assumptions. The factors affecting the dose-response relationships for carcinogenesis may also be divided into those relating to absorption, distribution, metabolism and excretion on the one hand (*i.e.* toxicokinetics), and those relating to the underlying dose-response characteristics of carcinogenesis at the tissue or cellular level (*i.e.* toxicodynamics). In this sense the problem of

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dose response assessment for carcinogens is similar to that for non-cancer toxic effects. The toxicokinetic models used may in fact be similar for both situations, but the toxicodynamic models are generally different.

Intraspecies Extrapolation and Inter-individual Variability

In estimating the impact of a particular level of exposure to a carcinogen on a target human population, it is necessary to consider the range of susceptibility in the target population. In the present case this is typically defined as the general population of the State of California, including of course women (some of whom are pregnant), infants and children, the elderly, the sick, and those with genetic polymorphisms or acquired differences which affect their susceptibility to carcinogens. In general it has been assumed that the upper-bound risk estimates obtained from the standard toxicodynamic models described below are sufficiently health-protective to cover the intrinsic variability of the adult human target population, in spite of the fact that these models do not explicitly address this type of variability, except in the few cases where an estimate is based on epidemiological data from a large and unselected study group (U.S. EPA, 2005a). However, various analyses (Drew et al., 1983; Barton et al., 2005; Appendix J) have suggested that this assumption is inadequate to cover the expected variability within a human population that includes infants and children. Accordingly both U.S. EPA (2005b) and this document ~~(page 30 *et seq.*)~~ now offer guidance on the use of age-specific adjustment factors to allow for the potentially greater sensitivity of infants and children to chemical carcinogenesis.

The ability to accommodate human variability with regard to the toxicokinetic factors affecting susceptibility to carcinogens varies with the level of detail used in the particular assessment. If the generic interspecies extrapolation approach based on body weight is used without any explicit toxicokinetic model then the assumption is made, as in the case of toxicodynamic variability, that the overall health-protective assumptions made are sufficient to cover the toxicokinetic variability. On the other hand if explicit models such as those referenced in the following paragraph are used, this variability may be more explicitly accommodated by using parameter values which are taken as point estimates from measured distributions of population values, or by using Monte Carlo techniques to include those distributions in the model (Bois et al., 1996; OEHHA, 1992; 2001b).

Toxicokinetic Models

Considerable literature exists showing the importance of understanding the toxicokinetics of carcinogens in understanding their mechanism of action, sites of impact and dose-response relationships. U.S. EPA (2005) in Section 3.1 refers to the importance of identifying an appropriate dose metric for the dose-response analysis. Early cancer risk assessments typically used applied dose as the dose metric, which is adequate in simple cases provided appropriate correction factors are applied for interspecies extrapolation. However, it is often observed that the uptake, metabolism and elimination of the carcinogenic substance (and/or a procarcinogen and metabolites) is non-linear, especially at the higher doses employed in experimental animal studies (Hoel *et al.*, 1983, Gaylor *et al.*, 1994). Extrapolation to lower doses where such relationships tend to linearity (Hattis, 1990) is aided by the use of toxicokinetic models. These may be relatively simple compartment models, or sophisticated "physiologically based pharmacokinetic (PBPK) models" which to a greater or lesser degree model the actual

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biochemical and physiological events of toxicokinetic importance. Applications of both types of model may be found in various risk assessment documents prepared for the Toxic Air Contaminants program (and other OEHHA risk assessments). Since the details vary widely according to the nature of the chemical and the availability of appropriate kinetic data these general guidelines will defer to those examples rather than attempt a fuller exposition here. Further analysis of the use of toxicokinetic modeling in extrapolation from animals to humans, and in accounting for interindividual variability among adult humans, infants and children is presented in the Air Toxics Hot Spots *Technical Support Document for the Derivation of Noncancer Reference Exposure Levels* (OEHHA, ~~2007: Public Review Draft~~2008). Although this refers to the use of toxicokinetic modeling in non-cancer risk assessment, the primary considerations are similar for cancer risk assessment.

Toxicodynamic Models

An early use of mechanistic analysis to support risk assessment was the development of the Armitage-Doll multistage model of dose-response for carcinogenesis. The multistage model was initially developed on theoretical grounds, and by examination of epidemiological and animal data on time to tumor incidence. Subsequent discovery of the molecular biology of proto-oncogenes has provided a basis for explaining the model in terms of actual biological events and systems (Barrett and Wiseman, 1987). This model was developed by Crump and others into the "linearized multistage model", which has been extensively used for carcinogen risk assessment. It leads to a number of partially verifiable predictions, including linearity of the dose-response relationship at low doses, which is observed for many genotoxic carcinogens. It also predicts the form of the dose-response relationship at higher doses, which generally follow a polynomial form (subject to sampling and background corrections) except where other identifiable factors such as pharmacokinetics intervene.

It has been argued that the simple linearized form of the multistage model has limitations as a description of carcinogenic mechanisms, which detract from its usefulness and generality. Cell proliferation is known to be important in the progression of cancer. It may actually be the primary mechanism of action for a few carcinogens, as opposed to the direct modification of DNA by the carcinogen or a metabolite which is assumed to cause the mutational event at each stage in the original multistage description. A cell proliferation model has been developed (Moolgavkar and Knudson, 1981), which retains the concept of an initiating mutational event (in most cases caused by interaction of the chemical with DNA, although it could also be a spontaneous mutation) as in the original multistage model, but also considers proliferation, death or terminal differentiation of both normal and initiated cells. This model is thought to better describe the biological events in carcinogenesis. However, it has not been used extensively in risk assessment because it requires many parameters that are difficult to define and measure (such as proliferation and death rates for various classes of cell). If these cannot be accurately determined, the model has too many free parameters and is not helpful in defining extrapolated values for risk assessment purposes. This highlights a general problem in using mechanistic models in carcinogen risk assessment, which is that the carcinogenesis data themselves are generally insufficient to define fully the dose response curve shape at low doses or provide much mechanistic information. The analysis is therefore supplemented with policy-based assumptions (such as the expectation of linearity at low doses) and, wherever possible, additional

experimental measurements relating to the mechanism of action, in order to make meaningful prediction of risk from environmental exposures to humans.

Because of the difficulties in validating simplified mechanistic models such as the basic multistage model, and the additional difficulty of parameter estimation with more complex mechanistic models, the new U.S. EPA guidelines (U.S. EPA, 2005a) and some recent California risk assessments have chosen instead to use a less overtly mechanistic approach. This approach combines benchmark dose methodology (described below) with an explicit choice of the method for low-dose extrapolation, either assuming low-dose linearity or, for certain carcinogens where data indicate that this is appropriate, a "margin of exposure" or safety/uncertainty factor based approach. This benchmark method is now normally recommended for carcinogen dose response analysis, and the results generally differ little from those derived by the linearized multistage model. Although the linearized multistage method is no longer recommended as the default approach for cancer potency estimation it remains a plausible alternative in many cases, and still has useful applications, such as for time-to-tumor analyses for which benchmark methods are not yet widely available. Additionally, a considerable number of existing cancer potencies in Appendices A and B, and used in the Air Toxics Hot Spots program were derived by this method. Many of these would not be significantly different if calculated by the benchmark approach, and are unlikely to be replaced soon by newly calculated values. The linearized multistage method will therefore also be briefly described here.

Benchmark dose methodologies

The use of benchmark dose methodology has been explored by various investigators [including Gaylor et al. (1998); van Landingham et al. (2001) and Crump (1984, 1995, 2002)] as a tool for dose response extrapolation. This has been recommended in regulatory guidelines for both carcinogenic (U.S. EPA, 2005a) and non-carcinogenic (U.S. EPA, 1995) endpoints. The basic approach is to fit an arbitrary function to the observed incidence data, and to select a "point of departure" (POD) (benchmark dose) *within the range of the observed data.* From this a low dose risk estimate or assumed safe level may be obtained by extrapolation, using an assumed function (usually linear) or by application of uncertainty factors. The critical issue here is that no assumptions are made about the nature of the underlying process in fitting the data. The assumptions about the shape of the dose response curve (linear, threshold, etc.) are explicitly confined to the second step of the estimation process, and are chosen on the basis of policy, mechanistic evidence or other supporting considerations. The benchmark chosen is a point at the low end of the observable dose-response curve. Usually a dose at which the incidence of the tumor is 10% is chosen for animal studies, although lower effect levels may be appropriate for large epidemiological data sets. Because real experimental data include variability in the response of individual subjects, and measurement errors, likelihood methodology is applied in fitting the data. A lower confidence bound (usually 95%) of the effective dose (LED_{10}), rather than its maximum likelihood estimate (MLE), is used as the point of departure. This properly reflects the uncertainty in the estimate, taking a cautious interpretation of highly variable or error-prone data. It also reflects the instability of MLE values from complex curve-fitting routines, which has been recognized as a problem also with the linearized multistage model.

For cancer dose-response estimation using the benchmark dose method, either animal bioassay data or epidemiological data provide a suitable basis. In the absence of a pharmacokinetic model

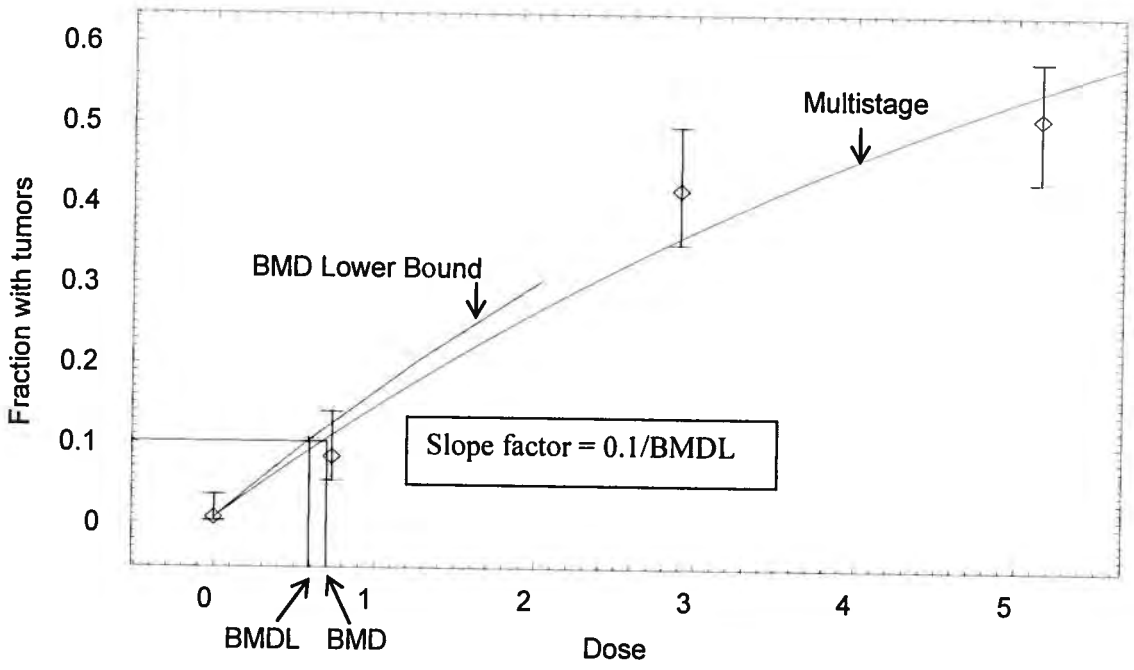
(which could provide tissue-specific dose metrics), the potency would ordinarily be based on the time-weighted average exposure during the exposure or dosing period. The model used to fit the data can be chosen from a range of available alternative quantal models, depending on which provides the best fit to the data in the observable range. In practice, the multistage polynomial fit developed for the linearized multistage model works well for most tumor data sets. Here it is being used merely as a mathematical curve-fitting tool, where the model well fits the data set, without making assumptions about its validity as a biological model of carcinogenesis.

Suitable polynomial fits and estimates of the benchmark may be obtained using U.S. EPA's BMDS software. The benchmark often used is the 95% lower confidence bound on the dose producing 10% tumor incidence. However, if data are available which include a significant dose-response at less than 10% tumor incidence, then that lower benchmark should be used (e.g. LED_{05} or LED_{01}). Other software such as Tox_Risk, which was used for the linearized multistage model, has been used successfully, although the earlier GLOBAL program and its relatives are less suitable as curve-fitting tools for benchmark dose analysis.

Since it is usually assumed in cancer risk estimation that the low-dose response relationship is linear, risk estimates and a potency value (slope factor) may be obtained by linear extrapolation from an appropriate benchmark dose. The potency is the slope of that line ($0.1/LED_{10}$). The low dose linearity assumption is a general default for any carcinogen, and it is unlikely to be altered for genotoxic carcinogens.

A calculation using the benchmark dose approach (using a polynomial model with exponents restricted to zero or positive values), and linear extrapolation from the LED_{10} to obtain a potency estimate is shown in Figure 1 (the figure was generated by the U.S. EPA's BMDS program). This is based on tumor incidence data from an actual experiment with vinyl bromide in rats (Benya *et al.*, 1982), with metabolized dose calculated by means of a pharmacokinetic model (Salmon *et al.*, 1992). The value of q_1^* obtained by this calculation would then be corrected for the duration of the experiment if it had lasted for less than the standard rat lifetime, and for bodyweight and route-specific pharmacokinetic factors as described below. This is in addition to the correction for exposure duration that would be necessary if the study had not lasted for 105 weeks, and the interspecies correction, both of which are described below.

Figure 1. Benchmark dose calculation for tumor data in rats exposed to vinyl bromide



From Salmon *et al.* (1992), based on data from Benya *et al.* (1982)

Linearized Multistage Model

Quantal analyses

A "multistage" polynomial (U.S. EPA, 1986, 2005a; Anderson *et al.*, 1983), based on the mechanistic insights of the original Armitage and Doll model of cancer induction and progression, has been used extensively by U.S. EPA, OEHHA and other risk assessors to model the dose response for lifetime risk of cancer. It usually is used for analysis of animal bioassay data, although related approaches have occasionally been used with epidemiological data. In mathematical terms, the probability of dying with a tumor (P) induced by an average daily dose (d) is:

$$P(d) = 1 - \exp[-(q_0 + q_1 d + q_2 d^2 + \ldots + q_j d^j)]$$

with constraints

$$q_i \geq 0 \text{ for all i.}$$

Equivalently, $A(d) = 1 - \exp[-(q_1 d + q_2 d^2 + \cdots + q_k d^k)]$,

where $A(d) = \dfrac{P(d) - P(0)}{1 - P(0)}$ is the extra risk over background at dose d.

The q_i model parameters are constants that can be estimated by fitting the polynomial to the data from the bioassay, *i.e.* the number of tumor bearing animals (as a fraction of the total at risk) at each dose level, including the controls. The fit is optimized using likelihood methodology, assuming that the deviations from expected values follow a χ^2 distribution, with the number of degrees of freedom (and hence the maximum number of terms allowed in the polynomial) determined by the number of points in the data set. All the coefficients of the terms are constrained to be zero or positive, so the curve is required to be straight or upward curving, with no maxima, minima or other points of inflection. In addition to the maximum likelihood estimates of the parameters, the upper 95% confidence ~~bounds~~ limits on these parameters are calculated.

The parameter q_0 represents the background lifetime incidence of the tumor. The 95% upper confidence limit of the slope factor q_1~~, or more usually its upper bound~~ (q_1^*), is termed the cancer potency. The maximum likelihood estimate (MLE) of q_1 is not usually regarded as a reliable estimate for several reasons. First, it fails to reflect the uncertainty and variability in the data which affect the value of the estimate. This is an important issue for protection of public health, which is emphasized by current regulatory guidelines. Secondly, due to the variable order of the polynomial and the effect of some terms being zero as opposed to having a small but finite value, the MLE is unstable, and may show large and unpredictable changes in response to very slight changes in the input data. It may also erratically have a zero value, even when the data imply a significant positive dose-response relationship. The MLE is not a measure of central tendency for this estimate distribution (which is always asymmetrical and often multi-peaked). For small doses, the cancer potency is the ratio of excess lifetime cancer risk to the average daily dose received. Details of the estimation procedure are given in Crump (1981) and Crump, Guess, and Deal (1977). Several software programs are available to perform the necessary calculations, including U.S. EPA's BMDS, Tox_Risk and the earlier GLOBAL programs by Crump and colleagues, and Mstage, written by Crouch (1987).

When dose is expressed in units of mg/kg-d, the potency is given in units of $(\text{mg/kg-d})^{-1}$. Likewise, when the model input is in units of concentration ($\mu g/m^3$, ppb), the potency is given in units of $(\mu g/m^3)^{-1}$ or $(\text{ppb})^{-1}$. As in the case of potencies obtained by the benchmark approach, the experiment-based potency value needs to be corrected for less-than lifetime or intermittent exposure, and extrapolated from the test species to humans. Risk calculations using potency value estimated using the linearized multistage model predict the cancer risk at low doses only, with the higher order terms of the fitted polynomial being ignored since their contribution is negligible at low doses.

Selection of Site and Tumor Type

In developing cancer potency estimates from animal data, standard practice has been to use dose-response data for the most sensitive tumor site as the basis of the estimate (CDHS, 1985). Where tumors of more than one histological type (e.g. adenomas and carcinomas) are observed at a single site, the combined incidence, i.e. proportion of animals affected with at least one tumor of

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any of the relevant types, is used for dose-response assessment. The same rules for combining tumor types are generally applied in determining statistical significance for carcinogen identification (IARC, 2006). Tumor types considered to represent different stages of progression following initiation of a common original normal cell type are combined, whereas tumor types having different cellular origins are generally not combined by this procedure. Other considerations that may influence choice of site for dose response estimation include the quality of the data (especially, the statistical impact of a high or variable rate of a particular tumor type and site in control animals), and biological relevance to humans. However, it is an important principle that, just as for the hazard identification phase, concordance of site or tumor type between animal models and human health effects may occur but is not assumed or required.

Carcinogens inducing tumors at multiple sites

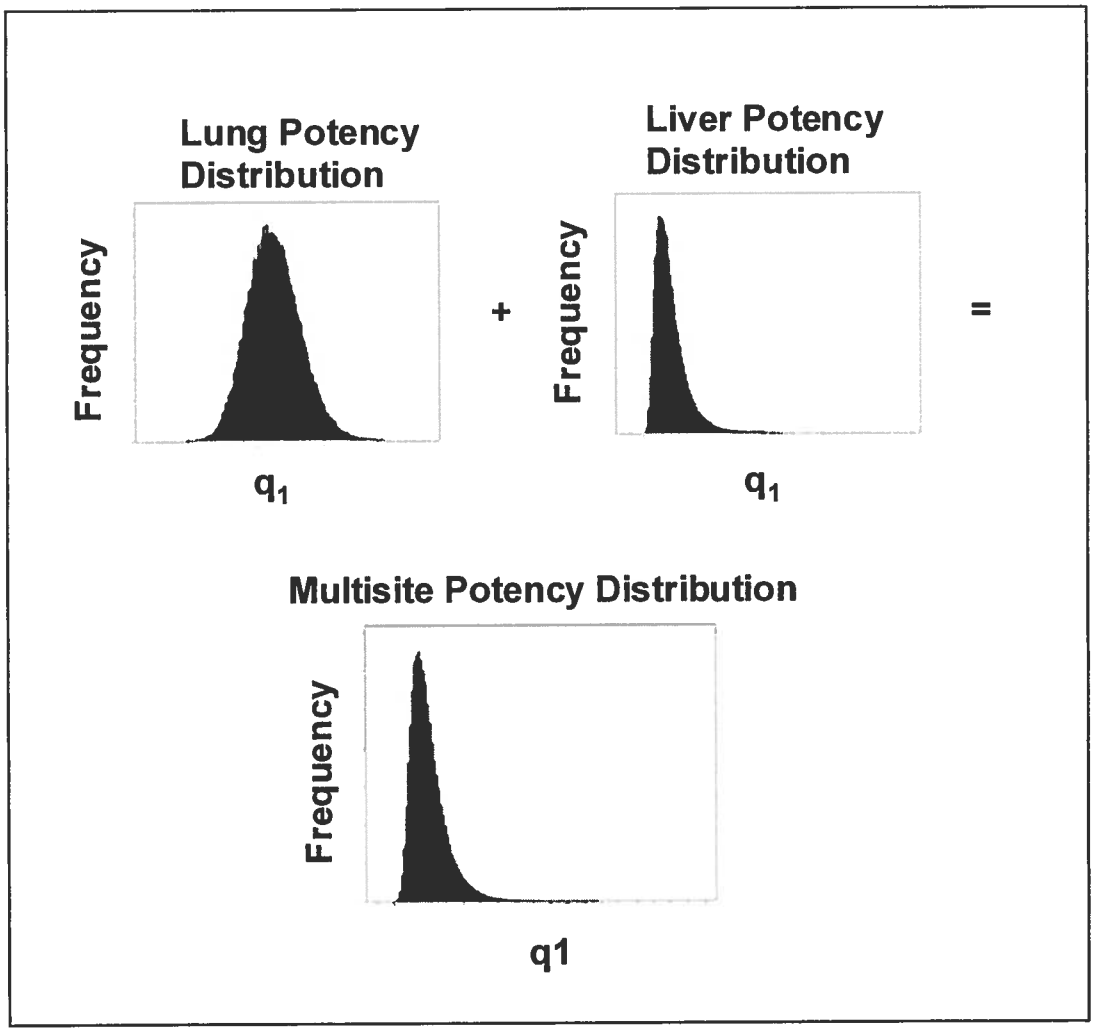
For most carcinogens, the selection of the most sensitive site in the animal studies is recognized as providing a risk estimate which is appropriate to protect human health. However, for chemicals that induce tumors at multiple sites, the single-site approach may underestimate the true carcinogenic potential. For example, the overall assessment of cancer risk from cigarette smoking (U.S. DHHS, 1982) or ionizing radiation (NRC, 1990) is not based on risk at one site, such as lung cancer. Instead, total cancer risk is estimated from all the sites at which agent-induced tumors are observed (lung, bladder, leukemia, etc), combined.

For carcinogens that induce tumors at multiple sites and/or with different cell types in a particular species and sex, OEHHA derives the animal cancer potency by probabilistically summing the potencies from the different sites and/or cell types. Using the combined potency distribution takes into account the multisite tumorigenicity and provides a basis for estimating the cumulative risk of all treatment-related tumors.

The linear term (q_1) of either the multistage model or the multistage-in-dose, Weibull-in-time model is first estimated based on the dose-response data for each of the treatment-related tumor sites. Statistical distributions, rather than point estimates, are generated at each site by tracing the profile likelihood of the linear term (q_1) (Zeise et al., 1991). The distributions of q_1 for each of the treatment-related sites are then statistically summed using a Monte Carlo approach and assuming independence (Figure 2). The sum is created by adding the linear term for each tumor site, according to its distribution, through random sampling. The upper 95 percent confidence limit on the summed distribution is taken as the multisite animal cancer potency estimate (McDonald et al., 2003, McDonald and Komulainen, 2005).

OEHHA has applied this approach in several recent dose-response analyses, including that for naphthalene presented in Appendix B of this document.

Figure 2. Addition of potency distributions for multi-site cancer potency derivations.



Early-Lifestage Cancer Potency Adjustments

In recent years, there have been growing concerns regarding the exposure of children to environmental chemicals, including the possibility that they may be more susceptible than adults to injury caused by those chemicals. The California Legislature passed the Children's Environmental Health Protection Act (Senate Bill 25, Escutia; Chapter 731, Statutes of 1999; "SB 25") to help address these concerns. Under SB25, OEHHA is mandated to consider infants and children specifically, where data permit, in evaluating the health effects of Toxic Air Contaminants (TACs).

The development of cancer is one of the adverse health effects that may occur in children as a result of exposure to environmental chemicals. The document "Prioritization of Toxic Air Contaminants under the Children's Environmental Health Protection Act" (OEHHA, 2001a) noted that risks of cancer from exposures to carcinogens occurring from conception through puberty can be different than those from exposures occurring in adulthood. Exposure to a carcinogen early in life may result in a greater lifetime risk of cancer for several reasons:

1. Cancer is a multistage process and the occurrence of the first stages in childhood increases the chance that the entire process will be completed, and a cancer produced, within an individual's lifetime.
2. Tissues undergoing rapid growth and development may be especially vulnerable to carcinogenic agents. During periods of increased cell proliferation there is rapid turnover of DNA, and more opportunity for misrepair of damage (e.g., DNA breaks, crosslinks, adducts) or alterations to result in permanent changes to the DNA (e.g., mutations, altered DNA methylation) that may ultimately lead to cancer.
3. During early development, a greater proportion of the body's cells are relatively undifferentiated stem cells, and as such represent a large target population of somatic cells capable of passing along permanent changes to the DNA during future cell divisions.
4. There may be greater sensitivity to hormonal carcinogens early in life since the development of many organ systems is under hormonal control (e.g., male and female reproductive systems, thyroid control of CNS development).
5. Other factors that may play a role in increased cancer risk from exposures during critical developmental periods include differences in immunological activity, intestinal absorption, biliary and kidney excretion, blood and fat distribution, and expression of enzyme systems that activate or detoxify carcinogens.

Data in humans and animals for a variety of carcinogens suggest that exposures to such carcinogens early in life may result in a greater lifetime risk of cancer compared to exposures later in life. Examples of this effect in humans are carcinogenicity due to ionizing radiation, diethylstilbestrol (DES), chemotherapeutic agents, and tobacco smoke.
Ionizing radiation exposure carries an increased risk of cancer when exposures occur early in life compared to adult exposures for a number of tumor types. Children exposed to ionizing radiation (diagnostic X-rays) *in utero* demonstrate a larger excess of leukemia cases than

children exposed to ionizing radiation postnatally (NRC, 1990). Exposure to radioisotopes (^{131}I, ^{137}Cs, ^{134}Cs, ^{90}Sr) as a consequence of the 1986 Chernobyl nuclear accident resulted in an elevated thyroid cancer incidence in children but not adults (Moysich, 2002). Treatment of children for Hodgkins lymphoma with both chemotherapeutic agents and irradiation has been shown to increase the risk of secondary tumors (Swerdlow et al., 2000; Franklin et al., 2006). Age at irradiation in Hodgkin's disease patients treated with radiotherapy strongly influenced the risk of developing breast cancer. The relative risk (RR) of developing breast cancer was 136 for women treated before 15 years of age, 19 for women 15-24 years of age, and 7 for those 24-29 years of age. In women above 30 years of age, the risk was not increased (Hancock *et al.*, 1993).

DES was administered to pregnant women in the 1940s-1960s for the purpose of preventing pregnancy loss. In 1970, Herbst and Scully described 7 cases of vaginal adenocarcinoma (6 cases of the clear-cell type) in women aged 15-22 years. This type of cancer is extremely rare in that age range. A follow-up epidemiological study included an additional case, and noted the fact that the mothers of 7 of the 8 patients had been treated with DES during their pregnancy (Herbst *et al.*, 1971). Reports by other investigators confirmed the association between maternal use of DES during pregnancy and the development of vaginal adenocarcinoma in their female offspring (Preston-Martin, 1989). It was observed that *in utero* DES exposure resulted in female genital tract morphological changes which correlated with both dose and duration of exposure, and those changes were not related to the maternal conditions which were the reason for the DES administration. Additionally, the risk of occurrence of those morphological changes declined with increasing gestational age at first exposure (O'Brien *et al.*, 1979; Preston-Martin, 1989). In contrast, vaginal adenocarcinoma incidence did not increase in the exposed mothers themselves, indicating an increased early-life susceptibility to the carcinogenic effects of DES.

There is evidence in the epidemiological literature indicating that exposure to tobacco smoke during puberty may increase risk of breast cancer later in life, particularly among women who are NAT2 slow deacetylators (Marcus *et al.*, 2000; Morabia *et al.*, 2000; Lash and Aschengrau, 1999). Wiencke et al. (1999) report that early age at initiation of smoking is associated with a higher level of DNA adducts in lung tissue of former-smokers with lung cancer.

It has also been observed by Smith *et al.* (2006) that human *in utero* or early childhood exposure to arsenic in drinking water results in significantly increased lung cancer incidences during adult life.

Data from animal studies provide additional examples of increased sensitivity to early life (typically postnatal and juvenile) exposures. These effects span a range of target tissues, including the liver (vinyl chloride, safrole), brain (methylnitrosourea), reproductive tract (DES, tamoxifen), and lung (urethane) (OEHHA, 2001a).

In the following sections we summarize two efforts to evaluate quantitatively the effect of lifestage at exposure on carcinogenic response in experimental animal studies. The first section provides a description of OEHHA's analysis of data on the effect of age at exposure on carcinogenic potency. (Details of this analysis are in Appendix J.) The second section describes U.S. EPA's work in this area. (We also provide the published paper in Appendix I that presents the U.S. EPA analyses.) Both analyses used extant data available in the published literature. U.S. EPA used their analysis to modify the procedures they have used to estimate cancer risk by

weighting risk by specific factors for childhood exposures. The weighting factors are a policy choice supported by U.S. EPA's data analysis. The results of OEHHA's analysis, summarized below and described in detail in Appendix J, support the decision to modify policy to weight risk when exposure occurs during childhood. Thus, OEHHA is also proposing to weight risk when exposure occurs in childhood.

OEHHA Analysis of the Effect of Age at Exposure on Cancer Potency

The analysis of animal cancer studies which include early life exposure by the Reproductive and Cancer Hazard Assessment Branch (RCHAB) of OEHHA also supports the application of lifestage-specific cancer potency factor adjustments. This analysis is provided in detail as Appendix J of this document.

Early-in-life susceptibility to carcinogens has long been recognized by the scientific community and clinicians as a public health concern. Numerous scientific publications and symposia have addressed this issue over the years and the scientific literature contains a number of human clinical findings and epidemiological studies of early life cancer susceptibility. While there are many indications of increased human cancer susceptibility in early life, the magnitude of the impact has been difficult to gauge. Until recently risk assessment procedures have not in general addressed the issue. As described in the next section, in 2005 the U.S. EPA adopted an approach to weight carcinogens by age at exposure if they act via a mutagenic mode of action. The California legislature in 2000 directed OEHHA to assess methodologies used in addressing early-in-life risk, compile animal data to evaluate those methods, and develop methods to adequately address carcinogenic exposures to the fetus, infants, and children (Children's Environmental Health Initiative [AB 2872, Shelly]; California Health and Safety Code [HSC] section 901 [a] through [e]).

OEHHA assessed cancer risk assessment methodologies, and found that the existing risk assessment approaches did not adequately address the possibility that risk from early-in-life and adult exposures may differ. OEHHA further concluded that there was a need to address early-in-life cancer risk, and undertook studies to develop methods for doing so. Age-related cancer susceptibility data were identified from published animal cancer bioassays in which these issues were addressed. Two types of studies with early-in-life exposures were compiled. The first type are "multi-lifestage exposure studies." These studies have at least two groups exposed during different lifestages: One dose group is exposed to a chemical only during one of the following lifestages (Figure 3):

- prenatal (from conception to birth),
- postnatal (from birth to weaning),
- juvenile (from weaning to sexual maturity).

The second dose group is exposed for some period of time at an older age, preferably during the adult lifestage, that is, after sexual maturity. This group served as the reference group. In some cases where there was no adult exposure group, animals exposed as juveniles served as the reference group. Multi-lifestage exposure studies are available for many chemicals, enabling the exploration of patterns in early-life susceptibility across chemicals.

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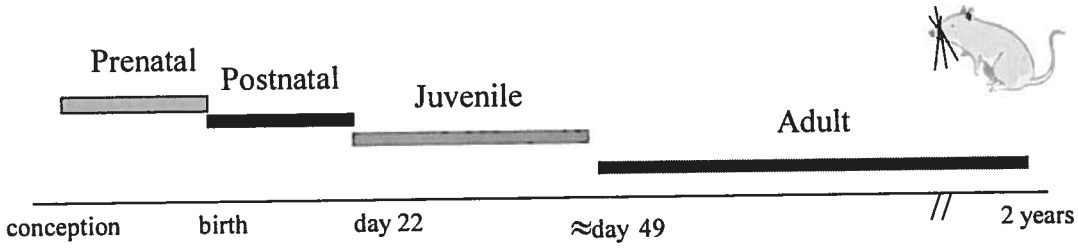
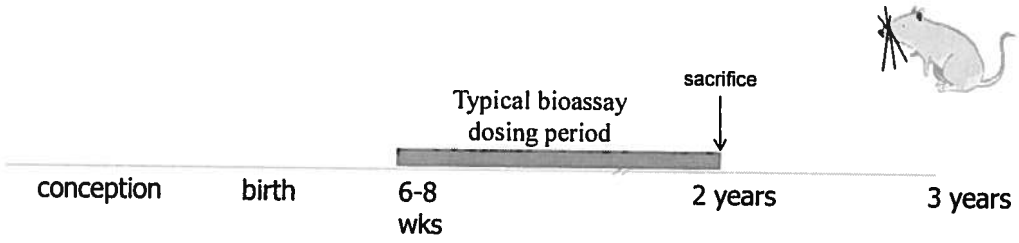
Figure 3. Definition of Rodent Lifestage Adopted in the OEHHA Analyses



OEHHA also conducted "chemical-specific case studies" of early-life sensitivity for two carcinogens, ethyl-N-nitrosoamine (DEN) and N-ethyl-N-nitrosourea (ENU) that combine data from a number of studies. These "chemical-specific case studies" were conducted to explore the feasibility of analyzing chemical-specific data on age susceptibility from single-lifestage exposure experiments. For these chemicals, OEHHA compiled from the literature a second type of study, "single-lifestage exposure experiments." In these experiments dose groups were exposed only during a particular lifestage and, unlike the "multi-lifestage exposure studies," there was no requirement that the same study also include groups exposed during a different lifestage. Thus, single-lifestage exposure experiments were identified as being either prenatal, postnatal, juvenile, or adult exposure studies. For each of the two chemicals, there were many prenatal studies conducted that were compiled, analyzed, and grouped together. Postnatal studies from different publications were similarly compiled, analyzed and grouped together, as were juvenile studies. Adult studies were not available for either DEN or ENU, thus for both chemicals juvenile exposure studies served as the referent for prenatal studies, and for postnatal studies.

Typical cancer bioassays such as those conducted in rats and mice by NTP involve exposing animals starting at six to eight weeks of age, which is the time at which these animals reach sexual maturity (late teenagers relative to humans). The experiments are run for two years, ending when the animal is in late middle age. Thus, early and very late life exposures are not included in the typical rodent bioassay (see Figure 4). If the NTP bioassay is used as a basis for estimating cancer potency, the potency and resulting risk estimates may be too low. Thus OEHHA focused on finding studies that evaluated early in life exposures.

Figure 4. Dosing Period for Typical Rodent Bioassays.



Since bioassays examining the effect of age at exposure on carcinogenesis were conducted by various investigators for different purposes, there is a great deal of variation across studies in terms of dose selection, duration of exposure, number of animals, and length of study duration. To be included in the compilation of studies with early life exposure, a study or an experimental group in a study had to meet minimum requirements.

The criteria for study inclusion are as follows:

- Treated groups were exposed to a single chemical carcinogen or a single carcinogenic chemical mixture.
- Study groups were not compromised by severe treatment-related non-cancer toxicity.
- Overall the duration of exposure period plus observation period exceeded 40 weeks, unless animals died of tumor.
- For included dose groups, the study must report age at dosing, age at sacrifice, and site-specific tumor incidence.
- Each lifestage exposure treatment group has an appropriate concurrent control group, or, for rare tumors only, an appropriate historical control.
- The studies were on mammals.
- Each treatment and control group consists of at least ten animals, unless the conduct and design of the study was well done in all other aspects (e.g., the length of the study was sufficiently long to observe treatment-related tumors) and tumor incidence was high in treated groups and very low in controls.
- Site specific tumor data were reported, not only total number of tumor bearing animals.
- The test compound was administered in the diet, water, via gavage, or by intraperitoneal (i.p.), intravenous (i.v.), or subcutaneous (s.c.) injection. For dermal and subcutaneous injection studies, distal tumor findings are utilized (for dermal, other than skin tumors; for injection, non-injection site tumors).

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- While studies designed to histopathologically examine tumors at multiple sites were preferred, studies that examined only a select set of organ/tissue sites were not excluded if the sites examined were known with confidence to be the only target tissues for the chemical and lifestage in question in that particular strain of animal.

Different approaches were taken to identify animal cancer studies that included groups of animals exposed during early life stages. First, MEDLINE and TOXLINE (National Library of Medicine) databases were searched using combinations of various key words for cancer (e.g., tumor(s), neoplasm(s), cancer, neoplasia, cancerous, neoplasms-chemically induced) and for early-life exposure (e.g., age, age-at-exposure, development (al), prenatal, *in utero*, gestation (al), postnatal, neonatal, juvenile, weaning, weanling, adolescent, adolescence, young). Second, the extensive compilation of bioassays in the *Survey of Compounds which have been Tested for Carcinogenic Activity*, was reviewed. This survey, formerly maintained by the National Cancer Institute as Public Health Service Publication Number 149, or PHS 149, is now available from a private source electronically as CancerChem, 2000. Third, from bibliographies from relevant published papers additional studies were identified. Finally the Single Dose Database developed by Calabrese and Blain (1999) was obtained and utilized to identify additional publications that appeared to contain potentially useful data. All of these publications were evaluated to determine if the study dosed separate groups of animals early in life and at or near adulthood. A total of 145 publications, providing data on 84 chemicals, were identified as meeting the criteria for study inclusion. A subset of these met the criteria for inclusion in the multi-lifestage exposure analysis.

Finally, for the OEHHA multi-lifestage analyses, we define "experiment" as a study component consisting of a control group as well as a treated group(s) exposed during the same lifestage (i.e., prenatal, postnatal, juvenile or adult), and using the same experimental protocol (e.g., route of exposure, strain, species, laboratory). Thus, by our definition one publication may report multiple experiments.

In the OEHHA analysis, data from studies on 23 unique carcinogens, 20 of which are considered to act via primarily genotoxic modes of action, were analyzed. Of these 20 carcinogens, 15 are thought to require metabolic activation to the ultimate carcinogenic species (Table 1~~Table 1Table 1~~). Fourteen carcinogens, including one thought to act via primarily nongenotoxic modes of action, were included in the prenatal multi-lifestage exposure studies. Eighteen carcinogens, including two thought to act via primarily nongenotoxic modes of action, were included in the postnatal multi-lifestage exposure studies. Five carcinogens were included in the juvenile multi-lifestage exposure studies. The case study chemicals, DEN and ENU, are both genotoxic. ENU is a direct acting alkylating agent, while DEN requires metabolic activation.

Table 1. Carcinogens for which studies with multi-lifestage exposures in animal studies are available

Genotoxic carcinogens requiring metabolic activation
Benzidine
Benzo[a]pyrene
Dibutylnitrosamine
Diethylnitrosamine (DEN)
7,12-Dimethylbenz[a]anthracene (DMBA)
Dimethylnitrosamine (DMN)
Di-n-propylnitrosamine (DPN)
1 -Ethyl-nitrosobiuret
2-Hydroxypropylnitrosamine
3-Hydroxyxanthine
3-Methylcholanthrene (3-MC)
4-(Methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK)
Safrole
Urethane
Vinyl chloride
Genotoxic carcinogens not requiring metabolic activation
Butylnitrosourea
1,2-Dimethylhydrazine
Ethylnitrosourea (ENU)
Methylnitrosourea (MNU)
ß-Propiolactone
Nongenotoxic carcinogens
1,1-Bis(p-chlorophenol)-2,2,2-trichloroethane (DDT)
Diethylstilbestrol (DES)
2,3,7,8-Tetrachlorodibenzodioxin (TCDD)

Cancer Potency Estimation

Statistical methods were developed and used to analyze the data and derive measures of early-life susceptibility. These are described in detail in Appendix J. In brief, a cancer potency (the slope of the dose response curve) was developed for each of the experiments selected using the linearized multistage model. This model was chosen because of widespread use in risk assessment, and its flexibility in being able to fit many different data sets needed to evaluate the effect of lifestage-at-exposure on cancer potency. The dose metric used for the potency analyses is cumulative dose normalized to body weight. The cancer potency is thus expressed as the increase in tumor probability with increasing cumulative dose in units of mg/kg body weight.

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To take into account uncertainty in potency estimation, cancer potencies are depicted by a statistical distribution, rather than by a single, fixed value, using methods described in Appendix J. While these methods have typically been used to obtain and report the 95th percentile of the cancer slope parameter for cancer risk assessment purposes, here OEHHA utilized the full distribution of the cancer slope parameter to derive measures of early-life susceptibility to carcinogens. This was done to systematically take into account uncertainty in the analysis.

For experiments where treatment related tumors were observed at multiple sites or at the same site but arising from different cell types, slopes from these sites were statistically combined by summing across the potency distributions (assuming independence across the sites that were observed) to create an overall multisite cancer potency. It is not uncommon that a carcinogen causes more than one type of cancer or causes tumors at different sites depending on lifestage at exposure. For example, in humans tobacco smoke causes cancers of the lung, bladder, and certain other organs. This multi-site carcinogenicity is frequently observed in animal experiments as well. In order to account for this, all treatment-related tumors that were observed in a given lifestage were taken into account in estimating cancer potency from that particular experiment.

Addressing Early-Age Sensitivity in Estimating Cancer Risk: Age Sensitivity Factors

Inherent Sensitivity of Lifestages – Lifestage Potency Ratios

For this analysis, OEHHA calculates the ratio of cancer potency derived from an early lifestage exposure experiment(s) to that derived from an experiment(s) conducted in adult animals. OEHHA used the potency distributions for the individual lifestage exposures, rather than a point estimate, to derive the ratios. The lifestage cancer potency ratio is then described as a distribution and one can select specific percentiles from the distribution to better understand and bound the uncertainty (Figure 5). Of particular importance is the location of the ratio distribution in relation to the reference value of 1.0, which would mean no difference in risk from exposures at early versus adult lifestages. A lifestage cancer potency ratio distribution that primarily lies above the value of 1.0 indicates early life exposures to a carcinogen result in a stronger tumor response relative to adult exposure. Conversely, a lifestage cancer potency ratio distribution that mainly lies below the value of 1.0 indicates early life exposure to a carcinogen results in a weaker tumor response relative to adult exposure.

A lifestage potency (LP) ratio distribution was derived for each multi-lifestage study, resulting in 22 prenatal ratio distributions representing 14 unique carcinogens, 55 postnatal LP ratio distributions representing 18 unique carcinogens, and seven juvenile LP ratio distributions representing five unique carcinogens. The LP ratio distributions for a given early lifestage were combined into a single "LP ratio mixture distribution," in order to show the range of susceptibilities of that lifestage to the carcinogens studied.

LP ratio mixture distributions for a given early lifestage were developed by (1) obtaining a single LP ratio distribution for each chemical (when a chemical is represented by more than one study) and then (2) equally sampling across all chemicals. When a chemical is represented by more than one study, then the LP ratio distributions from all studies of that chemical were combined by equally sampling from each LP ratio distribution via Monte Carlo methods to obtain a single

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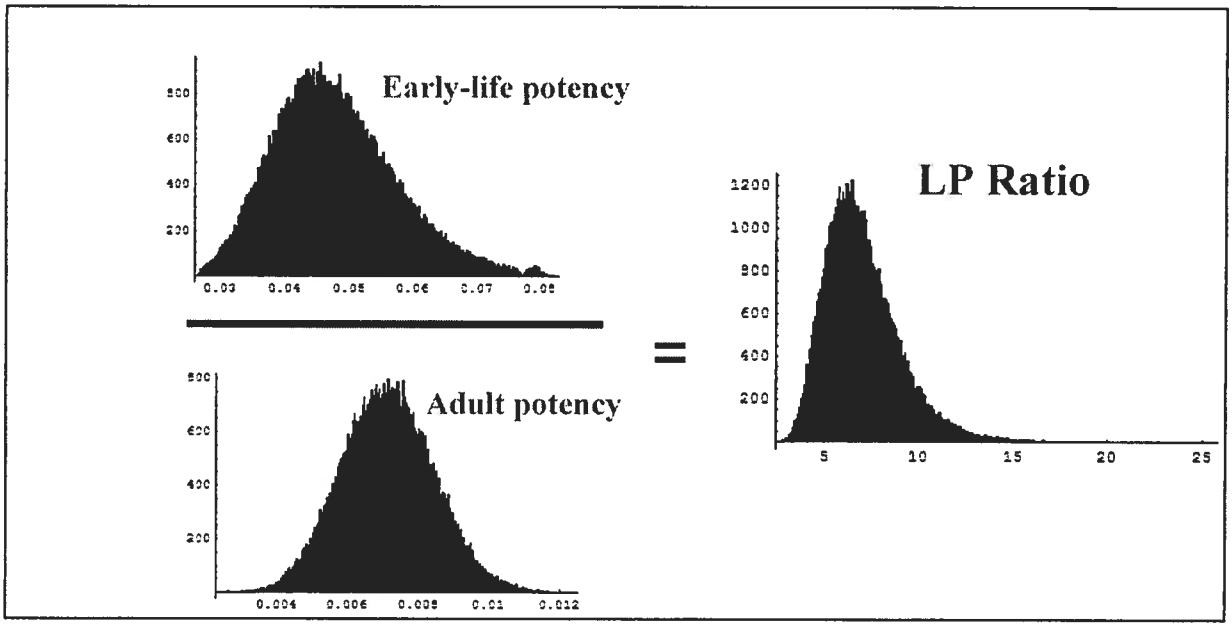
LP ratio distribution for that chemical. (Appendix J describes this in more detail, as well as a sensitivity analysis that included two alternative sampling methods.) Once each chemical is represented by a single LP ratio distribution, then the LP ratio mixture distribution for each early lifestage (prenatal, postnatal, and juvenile) is obtained by equally sampling across all of the chemicals via Monte Carlo methods.

Figure 5. Lifestage Potency Ratio (LPR) distribution.

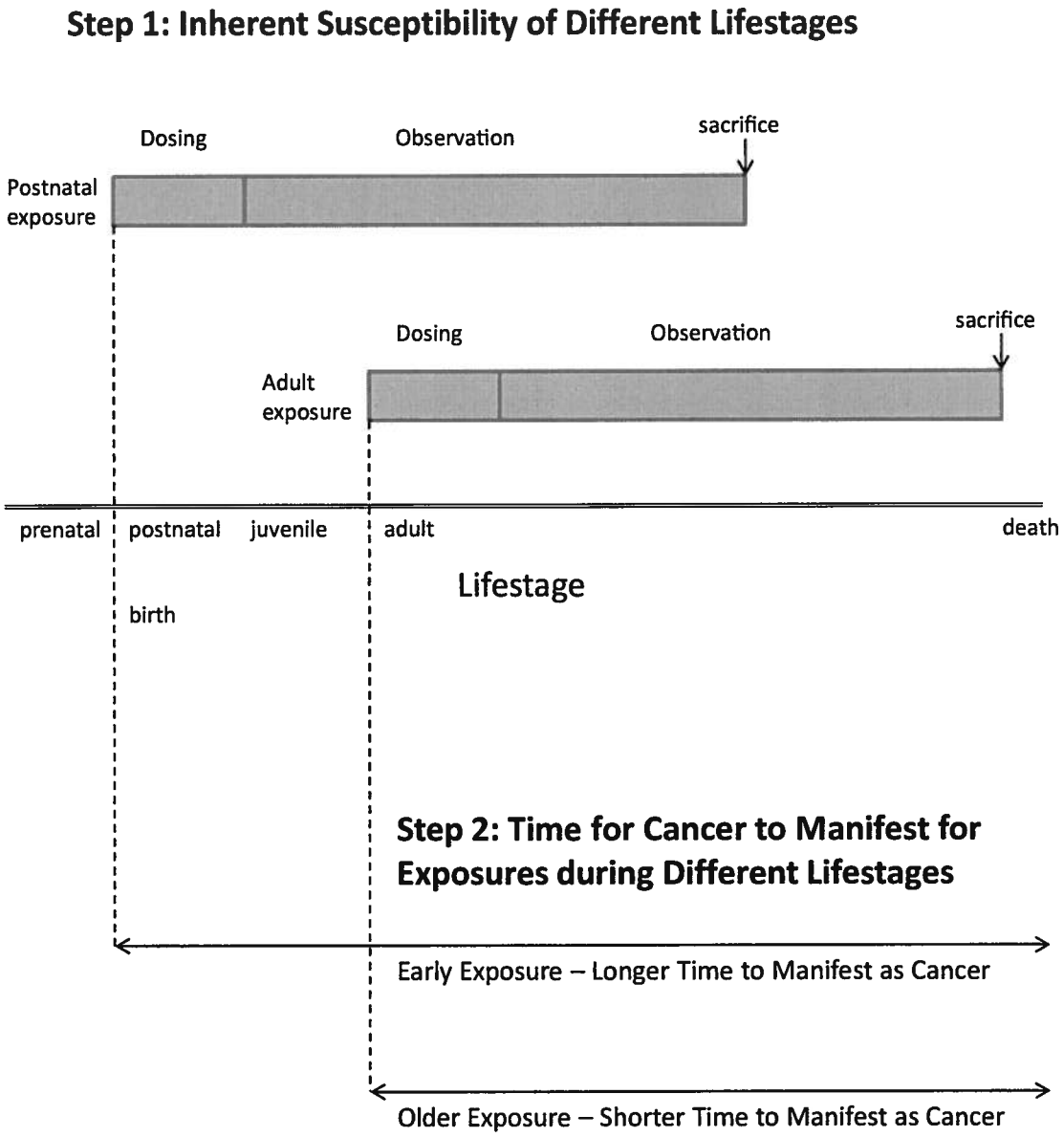


Effect of longer time period for cancer to manifest

The LP ratios described above characterize the inherent susceptibility of early lifestages to carcinogen exposure, by comparing potencies for individuals followed for similar periods of time and similarly exposed, but exposed during different lifestages. Age-specific adjustments to the cancer potency must also take into account the longer period of time that carcinogen exposure to the young has to manifest as cancer. Empirical data from studies of both humans and animals demonstrate that, for many cancers, cancer risk increases with age, or time since first exposure. While some cancers have been seen to increase by as much as the sixth power of age, a general approach taken for example by the National Toxicology Program in analyzing tumor incidences in its chronic bioassays is to assume that cancer risk increases by the third power of age. Thus, consistent with the approach used by the NTP in analyzing rodent cancer bioassay data, the longer period of time that exposed young have to develop tumors is addressed by taking into account time-of-dosing. This was done by multiplying the LP ratio by a time-of-dosing factor, to yield an age sensitivity factor (ASF). Specifically, the prenatal LP ratio is multiplied by a factor of 3.0, the postnatal LP ratio is multiplied by a factor of 2.9, and the juvenile LP ratio is multiplied by 2.7. Thus, ASFs were developed for each experiment, by first calculating the LP ratio to address inherent susceptibility of early lifestages relative to adults, and then accounting for the effect of years available to manifest a tumor following carcinogen exposure. (see Figure

6). Note that we are not using the term "sensitivity" in the immunologic sense (e.g., sensitization), but rather are using the term more generically.

Figure 6. Issues addressed by the Age-Sensitivity Factor (ASF)



Application of this approach for risk associated with lifetime exposures would include an ASF of less than 1 for exposures during the latter part of adult life for carcinogens that act on early stages. Therefore, the addition of this adjustment to the younger lifestages but not to the later part of the adult period could overestimate the risk of whole-life exposures. On the other hand, the 70 year "lifetime" used in estimating lifetime cancer risk does not reflect the longer lifespan of the U.S. population. Further, as noted above, the animal bioassays on which potency was based typically exclude pre-weaning dosing and sacrifice animals during their late middle-age. Use of cancer potencies calculated from standard assays can therefore understate lifetime cancer risk. The ASF calculated for carcinogens includes both inherent sensitivity of developing animals and the available time since exposure to develop cancer.

Results of OEHHA Analysis

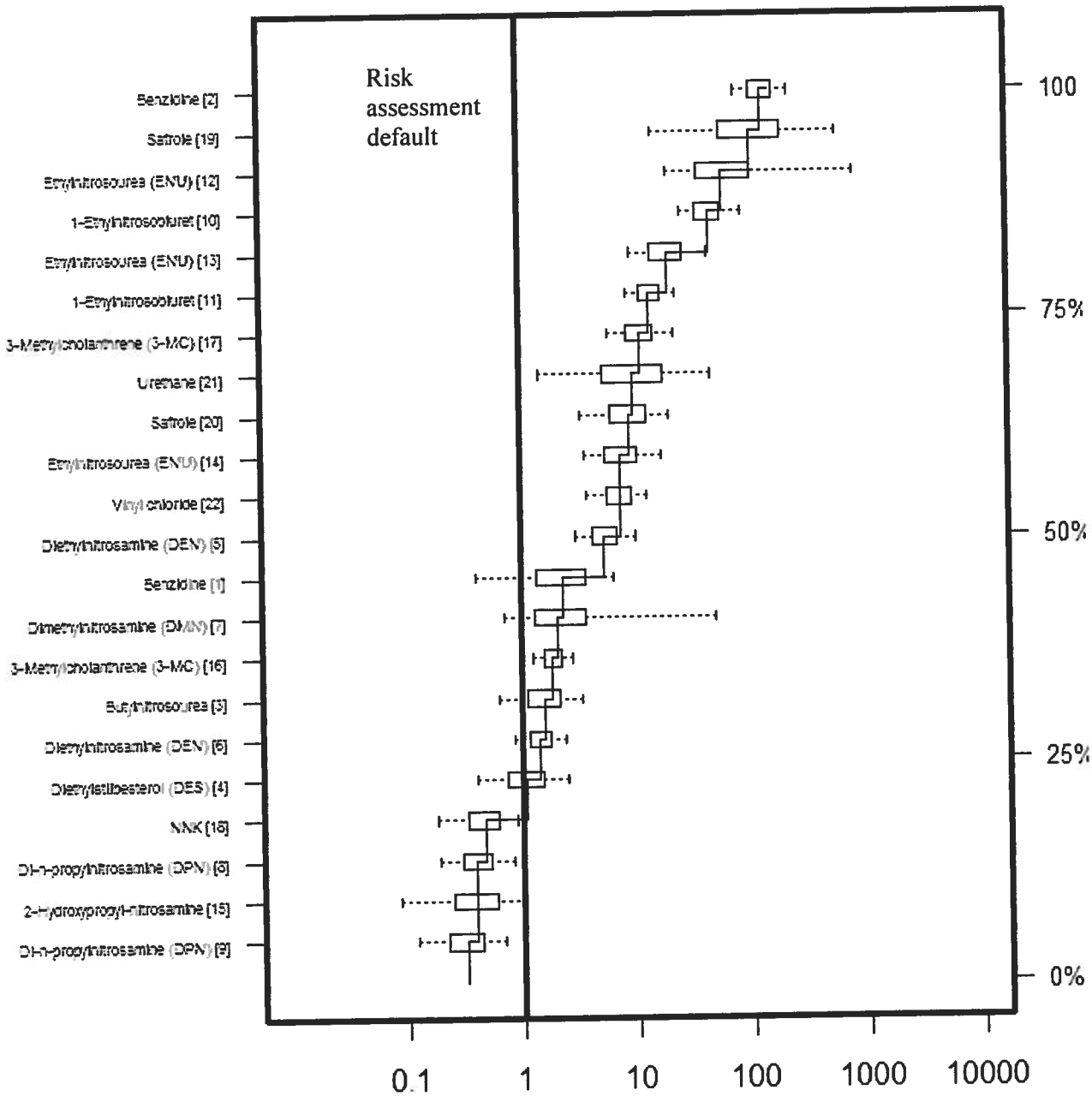
The analyses indicate that both the prenatal and postnatal lifestages can be, but are not always, much more susceptible to developing cancer than the adult lifestage. The analyses also indicated that the ASFs for these age windows vary by chemical, gender and species.

Regarding prenatal lifestage exposure, few cases were indicative of equal inherent adult and prenatal susceptibility, with an LP ratio of unity. The LP ratio distribution was roughly bimodal, with LP ratios for several studies significantly greater than unity and several others significantly less than unity. Figure 7 below shows the ASFs from each of the prenatal multi-lifestage exposure studies, displayed as a cumulative frequency profile. The median of the prenatal ASF mixture distribution was 2.9 (see also Table 6 in Appendix J),

The modality in the prenatal LP ratio distribution was reflected in the DEN and ENU case studies, with results for DEN suggesting inherently less sensitivity than older animals from exposure *in utero*, and for ENU just the opposite. For the DEN and ENU case studies, the referent groups were juvenile rather than adult animals, and the results may have underestimated the LP ratio and ASF, to the extent that some of the apparent sensitivity for DEN and ENU in the prenatal period carries through to the juvenile period. ENU is a direct acting carcinogen that does not require metabolic activation, whereas DEN can not be metabolized to any significant extent by fetal tissues until relatively late in gestation. This may explain the lower fetal susceptibility of DEN. However, prenatal metabolic status is not the sole determinant of prenatal susceptibility; e.g., benzidine and safrole require metabolic activation and exhibit greater susceptibility from prenatal exposure.

The median of the postnatal ASF mixture distribution was 13.5 (see Table 7 in Appendix J). Figure 8 below shows the ASFs from each of the postnatal multi-lifestage exposure studies, displayed as a cumulative frequency profile. Thus, for the chemicals studied, there was generally greater susceptibility to carcinogens during the early postnatal compared to the adult period, particularly when the ASF accounts for the longer period cancer has to manifest when exposure occurs early in life. The DEN and ENU case studies also exhibited substantial extra susceptibility during the postnatal period. To summarize, for most of the carcinogens studied here, animals are inherently more sensitive in the postnatal period, as indicated by Figure 8.

Figure 7. Prenatal ASF Cumulative Frequency Profile

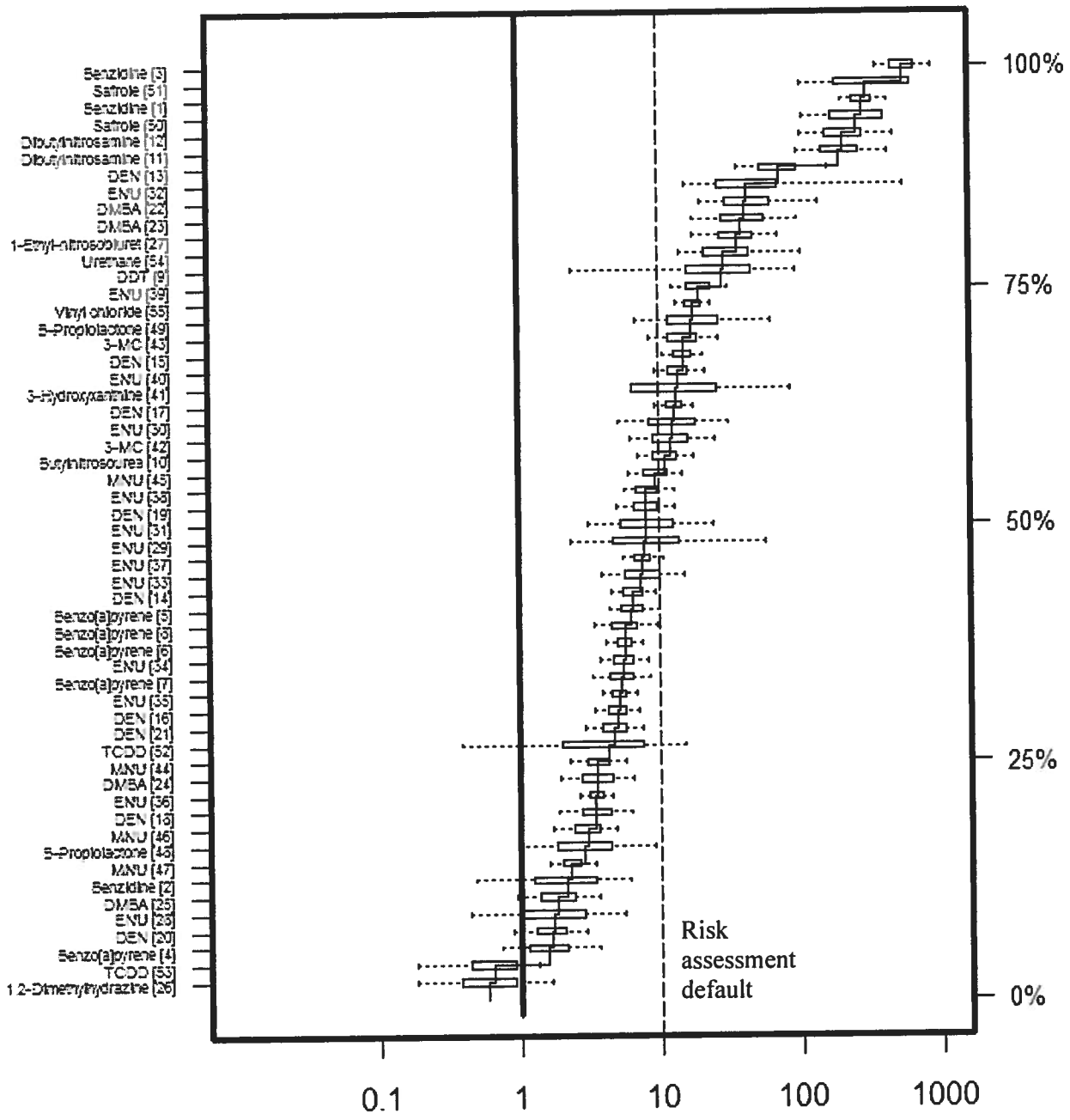


The median of the prenatal ASF mixture distribution was 2.9 (see also Table 6 in Appendix J).
References are given in the legend on the next page

Figure 7 Legend (References as in Appendix J)

1. Vesselinovitch *et al.* (1979a), mouse, B6C3F$_1$, F, day -9 to 21
2. Ibid, M, day -9 to 21
3. Zeller *et al.* (1978), rat, Sprague Dawley, M/F day -2
4. Turusov *et al.* (1992), mouse, CBA, F, day -2
5. Mohr et al. (1975), hamster, Syrian Golden, day -15 to -1
6. Mohr *et al.* (1995), hamster, Syrian Golden, F, day -3
7. Althoff *et al.* (1977), hamster, Syrian Golden, M/F, day -9 to -3
8. Ibid, day -9 to -3
9. Althoff and Grandjean (1979), hamster, Syrian Golden, F, day -9 to -3
10. Druckrey and Landschutz (1971), rat, BD IX, M/F, day -10
11. Ibid, day -3
12. Naito *et al.* (1981), rat, Wistar, day -9
13. Ibid, day -9
14. Tomatis *et al.* (1977), rat, BDVi, F, day -5
15. Althoff and Grandjean (1979), hamster, Syrian Golden, M/F, day -9 to -3
16. Tomatis *et al.* (1971), mouse, CF-1, F day -4 to -1
17. Turusov *et al.* (1973), mouse, CF-1, F, day -2
18. Anderson *et al.* (1989), mouse, C3H & B6C3 F$_1$,M/F day -8 to -4
19. Vesselnovitch *et al.* (1979a), mouse, B6C3 F$_1$, M, day -9 to -3
20. Vesselnovitch *et al.* (1979b), mouse, B6C3 F$_1$, F day -9 to -3
21. Choudari Kommineni *et al.* (1970), rat, MRC, M/F, day -4
22. Maltoni *et al.* (1981), rat, Sprague Dawley, M/F day -13 to -7

Figure 8. Postnatal ASF Cumulative Frequency Profile



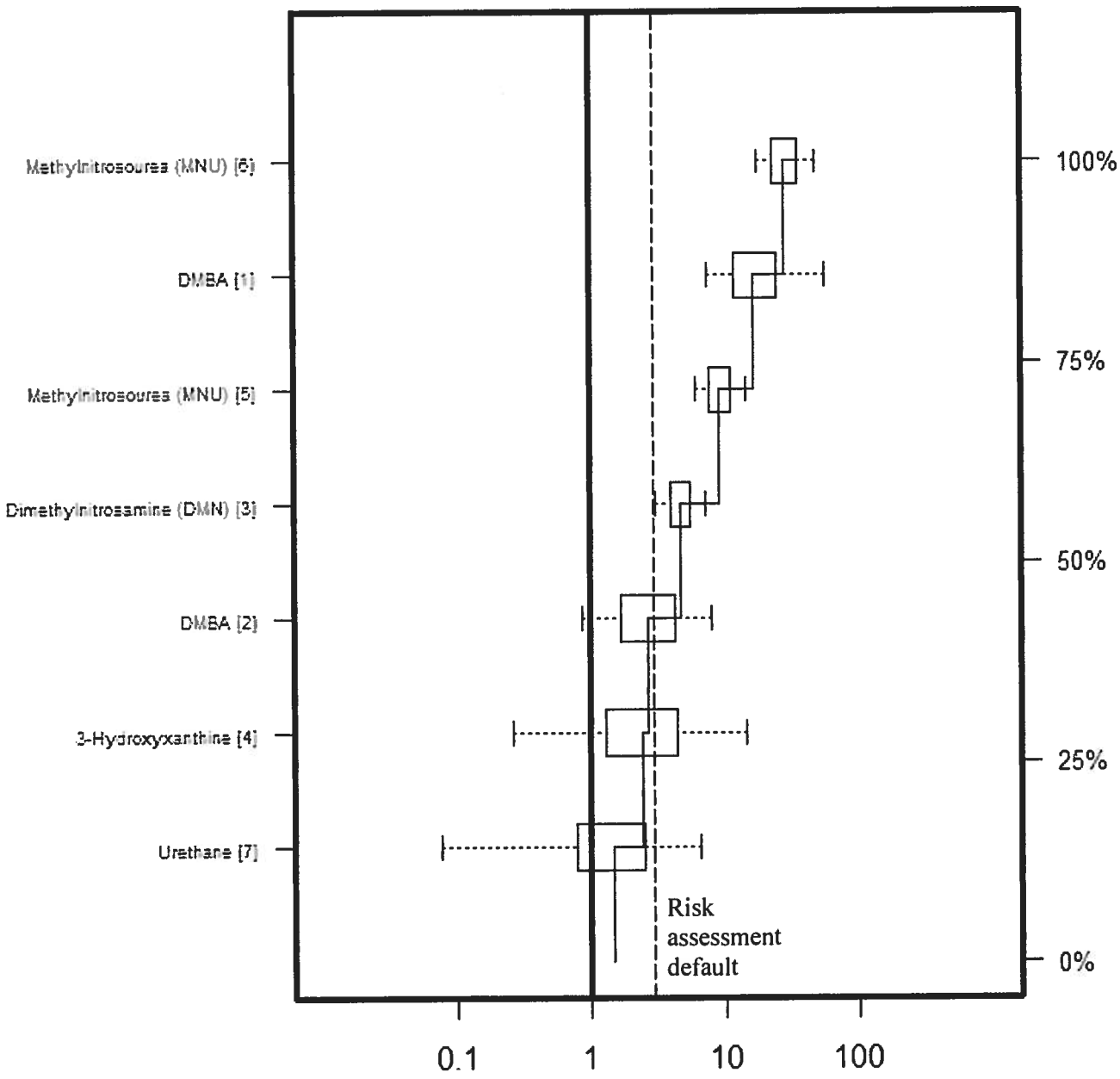
The median of the postnatal ASF mixture distribution is 13.5. The dotted line represents the default ASF for weighting risk for carcinogen exposures between birth and 2 years of age (see next section). References are given in the legend on the next page.

Figure 8~~Figure 8~~~~Figure 8~~ Legend (References as in Appendix J)

1 Vesselinovitch *et al.* (1975b), mouse, B6C3F$_1$, M, day 7-27
2 Vesselinovitch *et al.* (1979), mouse, B6C3F$_1$, F, day 1-21
3 Ibid, M, day 1-21
4 Truhaut *et al.* (1966), mouse, swiss, M/F, day 1
5 Vesselinovitch *et al.* (1975a), mouse, B6C3F$_1$, F, day 1
6 Ibid, M, day 1
7 Ibid, C3A F$_1$, F, day 1
8 Ibid, M, day 1
9 Vesselinovitch *et al.* (1979a), mouse, B6C3F$_1$, M, day 1-28
10 Zeller *et al.* (1978), rat, Sprague Dawley, M/F, day 2
11 Wood *et al.* (1970), mouse, IF x C57, F, day 1-15
12 Ibid, M, day 1-15
13 Rao and Vesselinovitch (1973), mouse, B6C3F$_1$, M, day 15
14 Vesselinovitch *et al.* (1984), mouse, B6C3F$_1$, F, day 1
15 Ibid, M, day 1
16 Ibid, F, day 15
17 Ibid, F, day 15
18 Ibid, C3A F$_1$, F, day 1
19 Ibid, M, day 1
20 Ibid, F, day 15
21 Ibid, M, day 15
22 Meranze *et al.* (1969), rat, Fels-Wistar, F, day 10
23 Ibid, M, day 10
24 Walters (1966), mouse, BALB/c, F, day 17
25 Ibid, M, day 17
26 Martin *et al.* (1974), rat, BDIX, M/F, day 10
27 Druckrey and Landschutz (1971), rat, BDIX, M/F, day 10
28 Naito *et al.* (1985), gerbil, mongolian, F, day 1
29 Ibid, M, day 1
30 Bosch (1977), rat, WAG, F, day 8
31 Ibid, M, day 8
32 Naito *et al.* (1981), rat, Wistar, F, day 7
33 Ibid, M, day 7
34 Vesselinovitch *et al.* (1974), mouse, B6C3F$_1$, F, day 1
35 Ibid, M, day 1
36 Ibid, F, day 15
37 Ibid, M, day 15
38 Ibid, C3A F$_1$, F, day 1
39 Ibid, M, day 1
40 Ibid, M, day 15
41 Anderson *et al.* (1978), rat, Wistar, F, day 9
42 Klein (1959), mouse, A/He, F, day 8-31
43 Ibid, M, day 8-31
44 Terracini and Testa (1970), mouse, B6C3F$_1$, F, day 1
45 Ibid, M, day 1
46 Terracini *et al.* (1976), mouse, C3Hf/Dp, F, day 1
47 Ibid, M, day 1
48 Chernozemski and Warwick (1970), mouse, B6A F$_1$, F, day 9
49 Ibid, M, day 9
50 Vesselinovitch *et al.* (1979a), mouse, B6C3F$_1$, M, day 1-21
51 Vesselinovitch *et al.* (1979b), mouse, B6C3F$_1$, M, day 1-21
52 Della Porta *et al.* (1987), mouse, B6C3F$_1$, F, day 10-45
53 Ibid, M, day 10-45
54 Choudari Kommineni *et al.* (1970), rat, MRC, M/F, day 1-17
55 Maltoni *et al.* (1981), rat, Sprague Dawley, M/F, day 1-35

There were only five chemicals and seven studies, two of which were not independent, available to examine susceptibility in the juvenile period. The juvenile LP ratios indicated significantly greater susceptibility in this period for three independent studies, with the remaining studies consistent with equal inherent susceptibility to adult animals (see Figure 16 in Appendix J). Figure 9~~Figure 9~~~~Figure 9~~ below shows the ASFs from each of the juvenile multi-lifestage exposure studies, displayed as a cumulative frequency profile. The median of the juvenile ASF mixture distribution was 4.5 (see Table 8 in Appendix J) .

Figure 9. Juvenile ASF Cumulative Frequency Profile



The median of the juvenile ASF mixture distribution is 4.5. The dotted line represents the default value for weighting risk from carcinogen when exposures occur between 2 and 15 years of age (see next section).

Figure 9 Legend (References as in Appendix J)

1.Meranze *et al.* (1969), rat, Fels-Wistar, F, day 45
2. Ibid, M, day 451
3.Noronha and Goodall (1984), rat, CRL/CDF, M, day 46
4. Anderson *et al.* (1978), rat, Wistar, F, day 28
5. Grubbs *et al.* (1983), rat, Sprague Dawley, F, day 50-57
6. Ibid, M, day 50-57
7. Choudari Kommineni *et al.* (1970), rat, MRC, M/F, day 28-43

The studies that comprise the set of multi-lifestage exposure studies available for these analyses were not homogeneous. That is, they do not represent observations from the same distribution. Sensitivity analyses were conducted to test the robustness of the findings to different procedures for analyzing data and combining results. Of the methods used to combine the LC ratio distributions for underlying studies within each lifestage, the method of equally weighting studies within a chemical appeared to best represent the available data.

In calculating the ASF, to take into account the longer period of time for early carcinogen exposures to result in tumors, the hazard function was assumed to increase with the third power of age. This assumption is standard and has been borne out by a number of observations (Bailer and Portier, 1988) If the true rate of increase with age is greater than that, then the use of these ASFs may result in underestimates of the true sensitivity of these early life stages.

As the multi-lifestage exposure and case studies show, there appears to be considerable variability in age-at-exposure related susceptibility across carcinogens. There is also variability in age-at-exposure related susceptibility among studies of the same carcinogen. The sources of variability evident in the analyzed studies include timing of exposure within a given age window, and gender, strain, and species differences in tumor response. The set of studies identified and analyzed was not sufficiently robust to fully describe the variability quantitatively. This variability raises concerns that selection of the median (the 50th percentile) estimates may considerably underestimate effects for certain agents or population groups. Relatively large variability in humans in response to carcinogens is expected to be common (Finkel, 1995). On the other hand, the numbers of carcinogens represented in the available data are limited and may not be representative of the population of carcinogens to which we are exposed (e.g., greater than 500 on the Proposition 65 list alone). Thus, the size of the weighting factors used to weight risk by age at exposure is a policy decision.

Several of the carcinogens studied induced tumors at multiple sites in the same experiment, and at different sites, depending upon the lifestage during which exposure occurred. For these cases the combined multisite potency distribution referred to above was the basis for the lifestage comparison. This approach differs from other researchers investigating early vs. late in life differences who focused on tumor site-specific measures of carcinogenic activity (e.g., Barton *et al.*, 2005; Hattis *et al.*, 2004, 2005). OEHHA believes that use of combined multisite potency distributions provides a more complete approach for considering age specific differences in carcinogenic activity. However, the observation that early life is generally a period of increased susceptibility was similarly found using the tumor site-specific approach by these other researchers.

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One limitation of the approach was the focus on lifestages, without attempting to describe changes in susceptibility that occur within a lifestage. Timing of carcinogen exposure within a given age window can affect the cancer outcome. For example, experiments with 1-ethyl-1-nitroso-biuret in prenatal and adult rats showed a three-fold difference in activity between groups exposed on prenatal day -10 versus prenatal day -3. In a second example, female rats exposed early in the adult period were more than three times as sensitive to the breast cancer effects of MNU as females exposed six weeks later. In general, the adult comparison groups in the multi-lifestage exposure studies were fairly young. The extent to which this may result in an overall bias of the results presented here is unclear. Also for several cases, juvenile animals were used as the later life exposure group. In these cases the ASFs are likely underestimates of the relative sensitivity of the prenatal and postnatal lifestages, compared to that of the adult lifestage.

Excluded from the analysis were early in life studies in which the period of exposure for a specific exposure group crossed multiple lifestages. An example of results from studies of this type is provided by mouse studies for two non-genotoxic carcinogens, diphenylhydantoin (Chhabra *et al.*, 1993a) and polybrominated biphenyls (PBBs) (Chhabra *et al.*, 1993b), in which exposures began prior to conception, and continued throughout the prenatal, postnatal, and post-weaning period, up to the age of eight weeks. The data demonstrate an increased sensitivity of the early life period. Some studies that crossed multiple lifestages were included in the analyses of Barton *et al.* (2005) (Appendix I), which are consistent with the general conclusions discussed above.

Selection of Default Age-Sensitivity Factors (ASF)

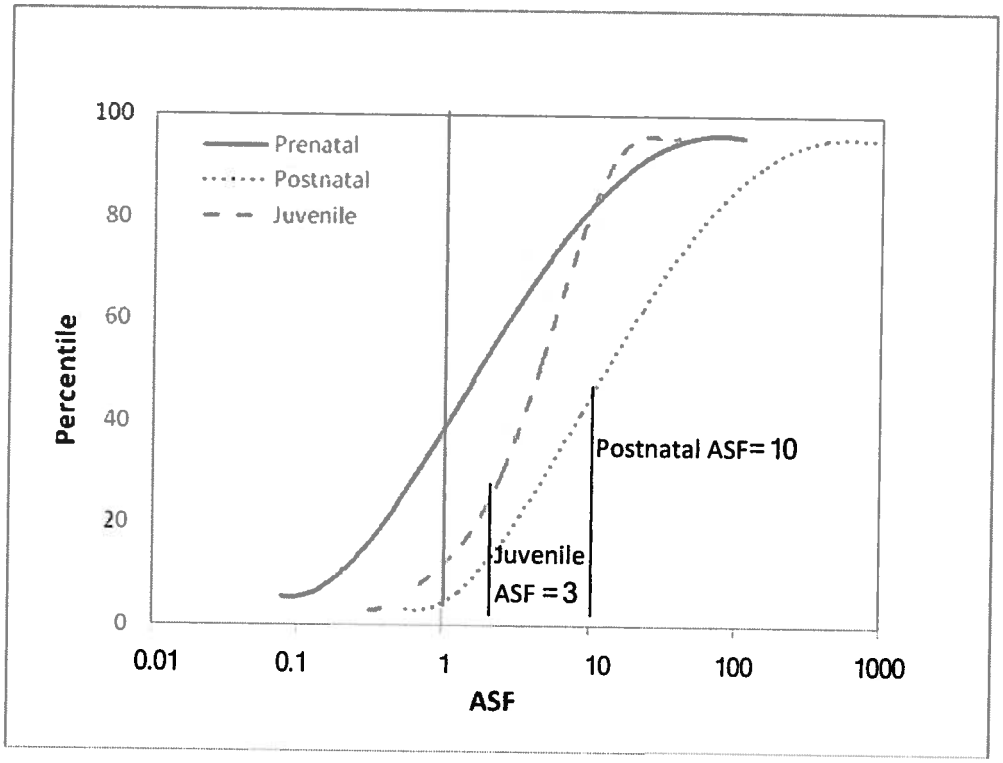
Selection of appropriate values to use to weight exposures that occur early in life using default ASFs for prenatal, postnatal and juvenile exposures is complicated by the limited database of chemicals and studies available for analysis, and the broad distribution of results for different chemicals as is shown in Figure 7, Figure 8, and Figure 9~~Figure 9~~~~Figure 9~~ (see also Appendix J). In view of the variability thus shown, and the considerable uncertainty in applying conclusions from this relatively small set of chemicals to the much larger number of chemicals of concern, it is probably unreasonable to specify a default ASF with greater than half-log precision (*i.e.* values of 1, 3, 10, 30 etc.). Therefore, in the absence of chemical-specific data, OEHHA ~~will~~ proposes to apply a default ASF of 10 for ages birth to 2 years, and a factor of 3 for ages 2 through 15 years to account for potential increased sensitivity to carcinogens during childhood. A factor of 10 for postnatal exposures falls just below the median estimate of the ASF for postnatal studies. This is also the value selected by U.S. EPA; while it is consistent with the OEHHA analysis, it may underestimate risk for some chemicals. The broad distribution of observed chemical-specific sensitivity ratios clearly indicates ~~certain number of~~that there are some chemicals for which the sensitivity ratio is much larger than 10. Further research is needed to develop criteria for identifying these cases. Similarly, a factor of 3 for juvenile exposures is consistent with the range of estimates derived from the multi-lifestage exposure studies, and falls close to the median juvenile ASF estimate. It is acknowledged that there are few data available on which to base an estimate for the juvenile period. A factor of 3 adjusts for the longer time available for cancer to manifest, but may not fully account for some inherent differences in susceptibility to cancer, for example ~~those observed~~the observed susceptibility of ~~in~~ breast tissue of pubescent girls exposed to radiation. For specific carcinogens where data indicate enhanced sensitivity during lifestages other than the immediate postnatal and juvenile periods, or demonstrate ASFs

different from the default ASFs, the chemical-specific data should be used in order to adequately protect public health.

The ASFs will be applied to all carcinogens, regardless of the theorized mode of action. While U.S. EPA currently intends to apply weighting factors only to those carcinogens with "a mutagenic mode of action"(U.S.EPA, 2005), OEHHA notes that there is evidence that early life is a susceptible time for carcinogens that are thought to act via non-mutagenic mode of action (DES is a prime example). Defining a mutagenic mode of action may be problematic if approached narrowly (ERG, 2008). Further, carcinogens may have multiple modes of action and one mode may predominant over other modes at different lifestages. The complexity of carcinogenesis argues against restricting the ASF to chemicals acting via a mutagenic mode of action.

Figure 10~~Figure 10~~Figure 10 provides a visual comparison of the ASF mixture distributions for the three early-life stages, prenatal, postnatal, and juvenile. In this figure, which is in log space, the policy choice for weighting factors of 10 for birth to age 2 years and 3 for the period of life from 2 to 15 years of age are indicated on the figure. ~~The x-axis represents the exponent (the figure is in log space).~~ It is apparent from this figure that weighting risk from exposures to carcinogens early in life is well-supported.

Figure 10. Prenatal, Postnatal, and Juvenile ASF Mixture Distributions and relation to default ASFs



OEHHA recognizes the limitations in the data and analyses presented, as discussed above. However, the analyses do provide some guidance on the extent risk may be over or underestimated by current approaches. While there is a great deal of variability across chemicals in the prenatal ASFs, the data indicate that the potency associated with prenatal carcinogen exposure is not zero. A factor of 3 is close to the median ASF, while a factor of 10 falls roughly at the 70th percentile of the prenatal ASF estimate. ~~This value~~An ASF could be applied as a default ~~ASF to the potency estimate~~ when calculating lifetime cancer risk in humans arising from carcinogen exposures that occur *in utero*. In view of the considerable variability in the data for different carcinogens and the limited database available for analysis, OEHHA is not ~~including~~ proposing the application of ~~this~~ a specific factor to cancer potency estimates for prenatal exposures as a default position in these Guidelines. However, given that the rodent is born at a stage of maturation similar to a third trimester fetus, it may be reasonable to include the third trimester in the potency weighting proposed for birth to age 2 years. T~~t~~he applicability of a cancer potency adjustment factor for prenatal exposure will be evaluated on a case-by-case basis, and may be used as evidence develops that supports such use. The consideration of prenatal exposures, including application of an appropriate susceptibility factor, would not make a large difference for risk estimates based on continuous lifetime exposures, due to the relatively short duration of gestation. However, risk estimates for short-term or intermittent exposures ~~might~~ would be ~~significantly~~ slightly increased by inclusion of the risks to the fetus during the prenatal period. Thus, risk may be underestimated when this lifestage is excluded from the analysis.

Age Bins for Application of ASFs

The choice of human ages to which the ASFs apply is based on toxicodynamic ~~information on functional maturation of major organ systems~~ and toxicokinetic considerations. Important toxicodynamic factors related to susceptibility to carcinogens include ~~and the concept that~~ the rate of cellular proliferation and differentiation, which is quite high during organ maturation ~~processes renders the tissue more susceptible to carcinogenesis~~. In addition, toxicokinetic differences by age are important, ~~as noted earlier,~~ due to impacts on detoxification and clearance of ~~xenobiotics~~carcinogens (see following section). OEHHA's analysis of the influence of age-at-exposure on carcinogenesis broke the experimental rodent ~~age bins~~data into age bins that we termed "lifestages" ~~into~~ including prenatal, "postnatal" (birth to weaning, about day 21) and "juvenile" (weaning to sexual maturation, or about day 22 to about day 49). Experiments were placed into the lifestage bins if exposure occurred at some time during the experimental rodent age bin. ~~The investigations of age at exposure and cancer potency used in OEHHA's analysis were all done with dissimilar protocols, and the windows of susceptibility are quite varied by chemical and organ system.~~

There is no simple way to compare the rodent age groups used in the OEHHA analysis of available data to equivalent age groups in humans. Complicating factors include variations in organ system structural and functional maturation both within and between species. Further, the rodent age bins were chosen by gross indicators of development namely birth, weaning and sexual maturation, not on the basis of known susceptibility to carcinogenesis. Thus, critical factors relating to carcinogen susceptibility by age are the focus of the choice of human age bins to which the ASFs of 10 and 3 apply, rather than an attempt at exact correlation of rodent lifestage bin with human age.

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Public Comments

The investigations of age at exposure and cancer potency used in OEHHA's analysis were not conducted by standardized protocol. Further, the windows of susceptibility are quite varied by chemical and organ system, even within the lifestages defined in the OEHHA analysis. ~~Additional complications in~~ This complicates choosing a default ASF and the human age bin to which it applies ~~are associated with changes in the potency by age at exposure that can be large for specific chemicals~~. Examples from animal studies provided in the appendix include the chemical diethylnitrosamine (DEN). The cancer potency varied over several orders of magnitude depending on when during gestation and postnatal life the exposure occurred. While the inability to metabolize DEN in early gestation influences the carcinogenicity of the compound, it is unlikely the only explanation. Benzidine and safrole also require metabolic activation but are more potent with prenatal exposure. A three-fold difference in potency between exposure on postnatal day 3 and postnatal day 10 is noted for 1-ethyl-1-nitrosobiuret in rats. There are also human examples of extensive variation of potency by age at exposure, including radiation, DES, and chemotherapeutic agents. The diversity of responses to different agents obviously underscores uncertainty in the choice of age bins to apply the default ASFs. However, the ASFs are a ***default*** to use when you have no chemical-specific data on influence of age-at-exposure on potency in order to protect public health. There will always be specific chemical examples where the ASF for either the birth-<2 yrs or 2-<16 yrs age bin is quite a bit larger or quite a bit smaller than the default.

In the following sections, we discuss our logic in ~~choosing~~proposing age bins of birth to age <2 years, and 2 to age <16 years to which the ASFs of 10 and 3 apply, respectively, and offer risk estimate results from other possible age bins.

Toxicokinetic Factors Relevant to Age Bins

Choice of the age-bins to which the default ASFs are applied is based on our understanding of the two primary drivers of age-related sensitivity to carcinogens, namely age-related toxicokinetic factors and toxicodynamic factors. In the case of toxicokinetics, the largest postnatal differences in xenobiotic metabolic capability occur between infants and adults. As noted in OEHHA (2001) and reviewed in detail elsewhere (e.g., Cresteil et al., 1998; Ginsberg et al., 2004), hepatic drug metabolism by the cytochrome p450 family of enzymes and the Phase II conjugating enzymes undergoes a maturation process during the first few years of life. The hepatic cytochrome p450 enzymes exist in fetal isoforms at birth, and progressively change to adult isoforms at a relatively early stage of postnatal development. Thus, in humans the metabolic capability towards prototypical substrates develops over the first year of life towards adult levels. Similarly, the largest differences in metabolic capability of Phase II enzymes (conjugation of xenobiotic metabolites prior to excretion) tend to be between infants and adults. Other factors such as renal capability also are most different between neonates and adults. Thus, the first 2 years of life would encompass the increased sensitivity of early life stages due to toxicokinetic differences between early life and adulthood.

Ontogeny of cytochrome P-450 Enzymes in Humans.

Cresteil (1998) describes three groups of neonatal cytochrome P450: Cyp3A7 and Cyp4A1 present in fetal liver and active on endogenous substrates; an early neonatal group including Cyp2D6 and 2E1 which surge within hours of birth; and a later developing group, Cyp3A4,

Cyp2Cs, and Cyp1A2. Total Cyp 3A protein, a major cytochrome p450 enzyme responsible for biotransformation of many xenobiotics, is relatively constant in neonates and adults. However, Cyp3A7 is the primary fetal form (Hakkola et al., 1998), while Cyp3A4 is the primary adult hepatic form of the 3A series. At one month there is about one-third of the Cyp3A4 activity as an adult liver (Lacroix et al., 1997; Hakkola et al., 1998). Allegaert *et al.* (2007) stated that Cyp3A4 (testosterone-6ß-hydroxylase) activity equaled or exceeded adult activity after 1 year of age. Cyp2E1, which metabolizes benzene, trichloroethylene and toluene, among others, increases gradually postnatally, reaching about one-third of adult levels by one year of age and attains adult levels by 10 years of age (Vieira et al., 1996; Cresteil, 1998). Cyp1A2, and Cyp2C9 and 2C19, the most abundant Cyp2 enzymes in adult human liver, appear in the weeks after birth, and reach 30%to 50% of adult levels at about 1 year of age (Treluyer et al., 1997; Hines and McCarver, 2002). Cyp1A1 is expressed in fetal liver where it can activate such xenobiotics as benzo[a]pyrene and aflatoxin B1 (Shimada et al., 1996), but is less important in adult liver (Hakkola et al., 1998).

Ontogeny of cytochrome P-450 Enzymes in Rodents.

Hart et al. (2009) report developmental profiles of a number of cytochrome P-450 enzymes (measured as levels of mRNA transcripts of the specific genes) in mice. They identified three groups of isoforms. Group 1 (Cyp3A16 in both sexes; Cyp3A41b in males) appeared rapidly after birth but declined to essentially zero at 15-20 days, which is the period of weaning in mice. A second group (Cyp2E1, Cyp3A11 and Cyp4A10 in both sexes; Cyp3A41b in females) also increased rapidly after birth, but reached a stable maximal level by postnatal day 5. The third group (Cyp1A2, Cyp2A4, Cyp2B10, Cyp2C29, Cyp2D22, Cyp2F2, Cyp3A13 and Cyp3A25) were expressed only at low levels until days 10 to 15, but reached high stable levels by day 20.

ElBarbry et al. (2007) examined the developmental profiles of two toxicologically significant cytochrome P-450 enzymes, Cyp1A2 and Cyp2E1 in rats. mRNA transcripts of these genes were very low postnatally, but thereafter increased to reach a peak at weaning (postnatal day 21 - 28 for rats). Immunoreactive Cyp1A2 and Cyp2E1 proteins were first detectable at postnatal day 3 and reached 50% of adult levels at weaning and adult levels at puberty. Differences in profiles between gene expression as ~~M~~mRNA and appearance of specific proteins as determined by immunoassay may reflect changes in the relative importance of transcription and translation control process at various phases in development. Enzyme activities characteristic of Cyp1A2 and Cyp2E1 were found to parallel gene expression levels (ElBarbry et al., 2007) rather than immunodetectable protein levels, so there may also be issues of cross-reactivity between these two isoenzymes and others for which gene expression was not measured in these experiments.

In summary, the gene expression data in rats and mice show differences in details, but broadly resemble one another in that the main changes occur in the early postnatal period, with the major adjustments completed at or around the time of weaning, although the adult pattern may not be completely established until puberty. There do not appear to be substantive data for experimental species other than rats and mice, although the situation in humans appears similar in general outline and one may conclude that this pattern or some variant of it is a characteristic of mammalian species in general.

Ontogeny of Phase II enzymes

Phase II conjugating enzymes are generally less active in the neonate than the adult (Milsap and Jusko, 1994). Hence, there is concern that detoxification and elimination of chemicals is slower in infants. Expression of some of the UGT enzymes matures to adult levels in two months after birth, although glucuronidation of some drugs by the UGT1A subfamily does not reach adult levels until puberty (Levy et al., 1975; Snodgrass, 1992; McCarver and Hines, 2002). Reduced glucuronidation in neonates slows the clearance of *N*-hydroxyarylamines, phenol, and benzene metabolites. Acetylation by the N-acetyltransferases and sulfation by sulfotransferases are generally somewhat comparable to adult levels, although it varies by tissue and by specific sulfotransferase (McCarver and Hines, 2002). Glutathione (GSH) sulfotransferase (GST) is present as a fetal isoform which decreases postnatally, while GST-alpha and GST-mu increase over the first few years of life to adult levels (McCarver and Hines, 2002). Epoxide hydrolase, important in detoxifying reactive epoxide metabolites, is present in neonatal liver although at much reduced activity relative to adults (McCarver and Hines, 2002).

Clearances of drugs in infants and children *vs.* adults

Several investigators have evaluated age-related drug disposition (Renwick, 1998; Renwick et al., 2000; Ginsberg et al., 2002; Hattis et al., 2003). Renwick et al. (2000) noted higher internal doses in neonates and young infants versus adults for seven drugs that are substrates for glucuronidation, one with substrate specificity for CYP1A2, and four with substrate specificity for CYP3A4 metabolism. Ginsberg et al (2002) evaluated toxicokinetic information on 45 drugs in children and adults metabolized by different cytochrome P450 pathways, Phase II conjugations, or eliminated unchanged by the kidney. These authors noted half-lives in infants 3-9-fold longer than those of adults. It was also shown that the bulk of the elevated child/adult half-life ratios occurred primarily in the 0 to 6 month age range, and that for some compounds the clearance is actually higher in the 6 month to 2 year age grouping. In evaluating the interindividual variability by age, Hattis et al (2003) note that the largest interindividual variability occurs in the youngest children, apparently due to variability in development of critical metabolism and elimination pathways. Anderson and Holford (2008) noted that a comparison of three early-life drug clearance models (surface area, allometric ¾ power and per kilogram scaling) all demonstrated an increase in clearance over the first year of life due to the maturation of metabolic capacity.

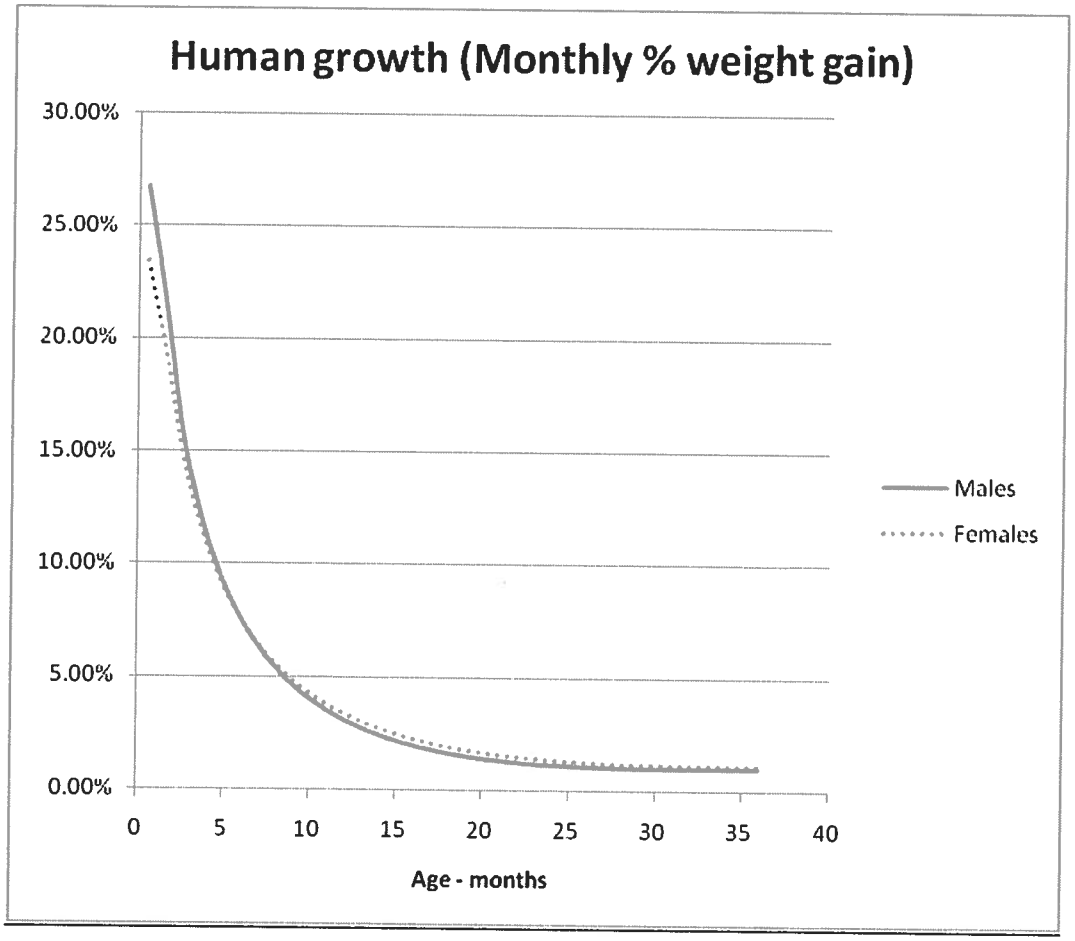
Renal elimination depends on maturity of processes related to tubular reabsorption and secretion, and glomerular filtration rates. At birth, the glomerular filtration rate (GFR) is low (2-4 ml/min), increases in the first few days (8-20 ml/min) and slowly increases to adult values in 8-12 month old infants (Plunkett et al., 1992; Kearns et al, 2003).

Newborn and young animals have less capacity to excrete chemicals into the bile than do adult animals. A number of chemicals are excreted more slowly via bile in neonates than adult rats, including ouabain, the glucuronide conjugate of sulfobromophthalein (Klaassen, 1973), and methyl mercury (Ballatori and Clarkson, 1982), resulting in a longer half-life in neonates.

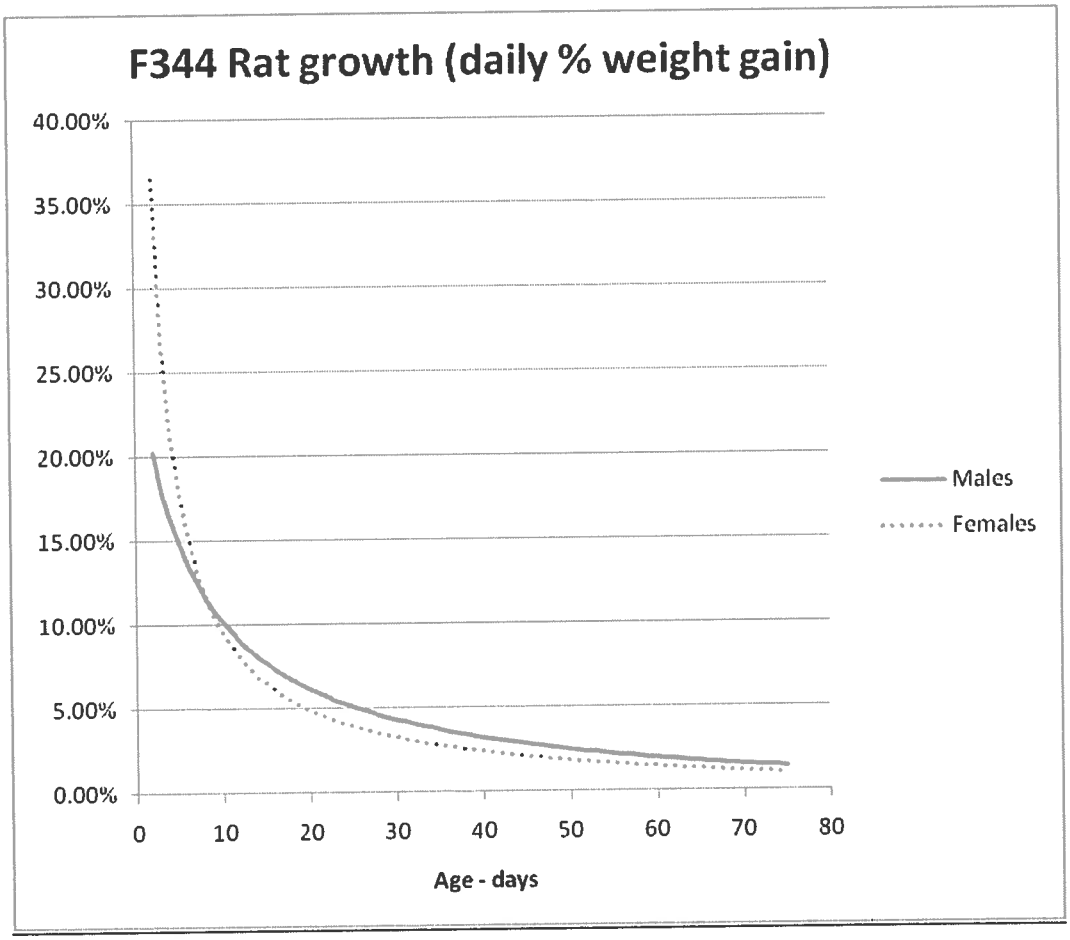
Toxicodynamic Factors Relevant to Age Bins

Important as the developmental changes in toxicokinetics are in determining sensitivity to carcinogens and other toxicants, it is likely that the toxicodynamic differences, i.e. intrinsic differences in susceptibility to carcinogenesis at the tissue or cellular level are even more influential. Changes in cell division rates and differentiation, which are thought to be important toxicodynamic determinants of susceptibility to carcinogenesis, peak in the first 2 years of life for most major organ systems. Cell division continues to accommodate growth throughout childhood and adolescence, extending in some cases even into the young adult period in both humans and experimental animals. Adolescence is an important period for organ cell division and differentiation for the mammary gland and reproductive organs.

As noted above, one of the key factors influencing susceptibility to carcinogenesis is believed to be cell division rate, which acts both by forcing error-prone repair which fixes DNA damage as mutated gene sequences (McLean et al, 1982) and by promoting expansion of mutated clones (Moolgavkar and Knudson, 1981). Actual cell division rates as a function of age are hard to determine for practical and (in the human case) ethical reasons. However, growth curves expressed as the proportional increment in body weight with time may be regarded as a reasonable although not perfect surrogate since for most tissues of the body cell size does not change markedly during growth. Both humans and rodents show remarkably high growth rates in infancy, which then drop steeply to a lower but still significant period during childhood. A growth spurt at the beginning of adolescence is noticeable in its absolute magnitude, especially in males, but does not approach the proportional growth rate seen in infancy. The time intervals proposed to reflect the period of highest sensitivity to carcinogenesis (birth to weaning, about 21 days in rodents, up to 24 months in humans) encompass the period of highest growth rate and thus is is assumed the highest cell division rates, as show in the following charts:



Data from CDC NHANES 2000:
http://www.cdc.gov/nchs/about/major/nhanes/growthcharts/datafiles.htm



Data from Tables A3 and A4 of Appendix J

Cell division rates in adult rodents and humans are harder to relate to growth curves since at least some tissues retain active cell division as part of their ongoing functionality and repair. In humans growth in body weight slows to essentially zero at the end of adolescence (and any later increments represent tissue specific changes such as increase in muscle or adipose tissue mass rather than overall growth). On the other hand, rodents continue to increase in body size (at a modest rate compared to that seen in earlier lifestages) throughout the adult period. However, it appears reasonable to conclude from the body weight data that an essentially adult pattern of overall cell division is established by the late adolescent period (age six weeks in rodents; 16 years in humans). This clearly does not include the marked growth and increases in cell division and physiological activities seen in the reproductive system and its accessories during puberty.

Organ development

The age intervals chosen for the ASFs are generally supported by human organ system development data. Examples of supporting data are available for the lung, brain, immune system and liver. Zeltner and Burri (1987) stated that postnatal lung development consists of an alveolar stage, which lasts to about 1-1.5 years of age, and a stage of microvascular maturation, which

exists from the first months after birth to the age of 2-3 years. Pinkerton and Joad (2006) describe alveolar proliferation as occurring most prominently in the 0-2 year age range, with alveolar expansion continuing in the 2-8 year age range. Ballinoti et al. (2008) demonstrated that addition of alveoli rather than expansion is a major mode of lung growth in infants and toddlers by measuring a constant carbon monoxide diffusion capacity to lung volume from 3 through 23 months of age. Kajekar (2007) also considered the 0-2 age range to be the primary period of alveolar development, although there is continued cellular proliferation resulting in lung growth and expansion up to approximately 18 years of age.

Rice and Barone (2000) note that most of the cell proliferation phase of human radial glia and neuronal growth is finished by 2 years of age, based on evidence in Bayer et al. (1993). They note further that numerous studies have shown actively proliferating brain regions are more susceptible to anti-mitotic agents than the same structures after active proliferation ceases. Peak brain growth as a percentage of body weight occurs at birth and around post-natal day (PND) 7-8 in humans and rats, respectively (Watson *et al.*, 2006). De Graaf-Peters and Hadders-Algra (2006) reviewed the ontogeny of the human central nervous system and found that a large amount of axon and dendrite sprouting and synapse formation and the major part of telencephalic myelination take place during the first year after birth. While the brain continues to remodel itself throughout life, cellular proliferation in the whole brain peaks by about one year of age and is relatively complete by age 2. Development of the blood-brain barrier (BBB) appears to continue in humans until approximately 6 months of age. Rat BBB functionality is essentially complete by approximately two weeks after birth (Watson *et al.*, 2006).

The immune system development occurs in stages primarily prenatally in primates and both pre- and post-natally in rodents (Dietert et al., 2000). Formation and expansion of hematopoetic stem cells is followed by expansion of lineage-specific stem cells, colonization of bone marrow and thymus, and maturation of cells to immunocompetence. In the primate, this is largely complete by 1 to 2 years of age (Holsapple et al., 2003), although establishment of immune memory develops throughout childhood and beyond. In the rodent, maturation to immunocompetence occurs postnatally from birth to about 30 days of age. In terms of carcinogenesis, perhaps one of the more important immune cells is the NK cell, thought to be responsible for immune surveillance and killing of circulating transformed cells. Based on immunohistochemistry, the principal cell lines including NK cells are present at gestation day 100 in the monkey and are at about 60% of adult values at birth (Holladay and Smialowicz, 2000).

As noted above, renal and hepatic clearance are both lower in humans at birth than in adults. Nephrogenesis is complete by 35 ~~month~~weeks gestation in humans and before birth in the mouse (but after birth in the rat). The ability to concentrate urine and the development of acid-base equilibrium ~~occur~~appear in the first few months after birth (Zoetis and Hurtt, 2003). Renal clearance of drugs, a function of a number of processes in the kidney, appears to be comparable to adults within the first few months of life (Hattis et al., 2003; Ginsberg et al., 2002) , while glomerular filtration, which rises rapidly over the first few postnatal months, is at adult values by two years of age (Zoetis and Hurtt, 2003). While complete anatomic maturity of the human liver is noted by 5 years of age (Walthall et al, 2005), liver function also appears to mature within the first year of life as seen by drug clearance studies cited above.

Critical Windows of Susceptibility to Carcinogens

It has been shown that there are critical windows during development both pre-and postnatally where enhanced susceptibility to carcinogenesis occurs (Anderson et al, 2000). Some of these observations relate to factors affecting the incidence of cancers in childhood, resulting from prenatal or preconception mutational events. For example, prenatal exposure to ionizing radiation and DES can result in leukemia and vaginal carcinoma, respectively, in childhood. Although obviously a source of great concern, these cancers appearing during childhood are relatively rare compared to cancers appearing later in life. Thus the concern in risk assessment for early in life exposures is to address the lifetime cancer incidence as a result of these exposures, including both cancers appearing during childhood and those appearing later.

OEHHA (see Appendix J) and other investigators (U.S. EPA, 2005; Barton et al, 2005; Hattis et al., 2004) have examined the available rodent data on sensitivity to carcinogenic exposures early in life. All these investigators found substantial increases in sensitivity to carcinogens in animal studies where exposures to young animals were compared to similar exposures to adults. Hattis et al. (2004) reported maximum likelihood estimates for the ratio of carcinogenic potency during the period from birth to weaning to the adult potency of between 8.7 and 10.5, whereas Barton et al (2005) reported a weighted geometric mean of 10.4 for the ratio of juvenile (less than 6-8 weeks) to adult potency in rodents. However, the number of experiments which provide information of this type, and the carcinogenic agents which have been studied, are relatively limited. Hattis examined several different datasets and study designs, but these covered only 13 different chemicals, while Barton et al. reported analyses for six of the 18 chemicals which they examined. OEHHA's analysis included data in rodents on 23 chemicals, and found median potency ratios of 13.5 for the postnatal period (birth to day 22) and 4.5 for the juvenile period (postnatal days 22 to 49) relative to adults (day 49 to 2 years). These potency ratios include the adjustment for time to manifest tumor (e.g., age to the power of three), unlike the earlier investigations. All these investigations identified variations in the observed lifetime potency ratio depending on the type of experimental design, the sex of the animals, the time of exposure and especially between chemicals. Nevertheless these analyses, although falling far short of a comprehensive evaluation of the age dependence of carcinogenic potency for all the chemicals of interest, do show a consistent overall trend of increasing potency for exposures early in life, especially soon after birth.

An evaluation of cancer induction by ionizing radiation also provides support for the concept of enhanced sensitivity to carcinogenesis at younger ages. Various studies of this phenomenon have been undertaken in animal models, but the important point for the present discussion is that epidemiological data exist which indicate age-dependent sensitivity in humans (U.S. EPA, 1994; 1999). The most extensive data set showing age-dependent effects is that for Japanese survivors of the atomic bomb explosions at Hiroshima and Nagasaki. Analysis of these data shows linear increases in tumor incidence at a number of sites with increasing radiation dose and younger age at exposure. There are other data suggesting humans are more susceptible to chemical carcinogens when exposure occurs in childhood. These data exist for tobacco smoke (Marcus et al., 2000; Wiencke et al., 1999) and chemotherapy and radiation (Mauch et al., 1996; Swerdlow et al., 2000; Franklin et al., 2006).

Proposed ~~A~~age bins for application of default age sensitivity factors

In developing a default science-based risk assessment policy to address this general conclusion, one key variable to define is the age interval or intervals over which age-dependent sensitivity factors should be applied. Different investigators have considered different age ranges, but in general the more sensitive period has at least been defined as including the time from birth up to mid-adolescence when the major phases of growth and hormonal change are complete. ~~This can be somewhat consistently defined in the case of laboratory rodents whose genetic and environmental factors are relatively constant; a transition point in the range of 6 to 8 weeks is generally identified as the start of adulthood. For humans there is inevitably a lot more variation in the timing of developmental landmarks. The comparison of human development with that of rodents is complicated by the fact that the various organ systems have markedly different pre and postnatal timetables, both between species and between organ systems. Thus there is no single timeline of developmental equivalence for humans and rodents. Nevertheless there is a general similarity for all mammals.~~

It is also recognized that, apart from the dramatic prenatal developmental events, the earliest postnatal stages represent the greatest differences in physiology and biochemistry from the adult~~,~~. This reflects~~ing~~ the immaturity of many organ systems, extremely rapid growth and the incomplete maturation of various metabolic capabilities. ~~In animal studies, as reflected in the analysis of carcinogenesis by OEHHA, an important developmental milestone is generally identified at the time of weaning, which in rodents occurs at or about postnatal day 21.~~As noted earlier, the rodent age bins in OEHHA's analysis were based on gross developmental milestones (birth, weaning, sexual maturity). OEHHA's analysis of studies that included exposure sometime between birth and weaning indicated this period as having the highest sensitivity to carcinogenesis. The data for the later juvenile period (postnatal days 22 to 49) are somewhat sparse, covering only three carcinogens and only one where there are corresponding data for both infant and juvenile lifestages. However, it appears based on the overall range of potency ratios observed for the juvenile period that sensitivity to many carcinogens is elevated in this period also, but to a lesser extent than during the first 22 days. [Hattis et al. (2005) and Barton et al. (2005) report analyses for exposures at any time during the juvenile period, i.e. up to 6-8 weeks, and do not separate by additional age bins].

Weaning is not such an obvious or consistently timed transition for humans, being subject to a wide range of cultural and economic variables. However, it is generally considered that the human infant period encompasses the first two years of life. This period includes the most rapid periods of cellular division and differentiation for the major organ systems (excluding the breast and reproductive organs). Although there is linear growth between 2 and 8 years of age, the organ development is largely although not entirely complete.

Thus, considering both the development of major organ systems and the associated differences in toxicodynamic and toxicokinetic factors, OEHHA ~~chose~~proposes to apply the postnatal ASF derived from rodent studies (birth to ~21 days) to the human age intervals of ~~1~~birth - <2years. Similarly, OEHHA chose to apply the "juvenile" ASF derived from rodent studies (~22- ~49 days) to the human ages 2 - <16 years. This timetable was also selected by U.S. EPA (2005) in their supplemental guidance for assessing early-life susceptibility to carcinogens. They describe their choice of critical periods as follows:

> "The adjustments described below reflect the potential for early-life exposure to make a greater contribution to cancers appearing later in life. The 10-fold adjustment represents an approximation of the weighted geometric mean tumor incidence ratio from juvenile or adult exposures in the repeated dosing studies (see Table 8). This adjustment is applied for the first 2 years of life, when toxicokinetic and toxicodynamic differences between children and adults are greatest (Ginsberg et al., 2002; Renwick, 1998). Toxicokinetic differences from adults, which are greatest at birth, resolve by approximately 6 months to 1 year, while higher growth rates extend for longer periods. The 3-fold adjustment represents an intermediate level of adjustment that is applied after 2 years of age through <16 years of age. This upper age limit represents middle adolescence following the period of rapid developmental changes in puberty and the conclusion of growth in body height in NHANES data (Hattis et al., 2005). Efforts to map the approximate start of mouse and rat bioassays (i.e., 60 days) to equivalent ages in humans ranged from 10.6 to 15.1 years (Hattis et al., 2005)."

There is general agreement that rodents are born at a maturational stage approximately equivalent to a third trimester human fetus. Thus, there is good rationale to include the third trimester of pregnancy in the age bin for application of the ASF of 10.

While there is strong evidence that growth and therefore cell proliferation rates and cell differentiation are extremely high prior to age 2, there is still residual uncertainty with respect to the cutpoint for application of the ASFs of 10 and 3. Thus, another possible approach is to move the cut point for the application of the ASF of 10 to a later age to account for this uncertainty. We present the effect on risk estimates of varying cutpoints in Tables 2 and 3.

Special consideration of puberty

In addition to the general concerns over increased sensitivity to carcinogenesis during infancy and childhood, there are specific concerns for exposure during the period when hormonal and developmental changes associated with puberty are in process, especially for carcinogens with hormonal modes of action or with impacts on the reproductive system and its accessory organs. At puberty, there is increased development of breast and reproductive organs that clearly involves rapid cellular division and differentiation. Thus, for carcinogens that induce mammary and reproductive organ cancers, puberty represents a time of increased sensitivity. As noted in the section on Selection of Default Age-Sensitivity Factors (page 48), if the risk assessor is evaluating a chemical with the potential for more than usually enhanced potency during this period, such as those which induce mammary or reproductive organ tumors (e.g., a polycyclic aromatic hydrocarbon), then the risk assessment may use a larger ASF to calculate risk from exposure during puberty. OEHHA may recommend chemical-specific ASFs for puberty to the local air quality management districts for use in the Air Toxics Hot Spots program.

Application of ASFs in Risk Assessment

The effect of using the proposed default ASFs in calculating cancer risk over a 70 year lifetime, and for a 9 year exposure common in the Hot Spots program risk assessments is demonstrated in Table 2 and Table 3 below. Ignoring for the moment the increased exposures to carcinogens that children experience, the effect of the weighting factors is to increase the lifetime cancer risk by about 2. For risks from shorter exposures, such as the commonly used 9 year exposure scenario, OEHHA proposes to evaluate risk starting at age 0 in the surrounding general population. The weighting factors in this case increase the risk to a larger extent. Depending on the exposure scenario, the use of age-specific distributions for uptake rates for air, food and water would also increase the risk estimates significantly independent of any application of ASFs. This is because the uptake rates for all these media per unit of body weight are higher in children and, especially, infants.

Assessing risks to short-term exposures to carcinogens involves additional uncertainties. The cancer potency factors are generally based on long-term exposures. However, in reality, the local air districts in California are frequently assessing risk from short term activities related to construction, mitigation of contaminated soils, and so forth. OEHHA recommends that when assessing such shorter term projects, the districts assume a minimum of 2 years of exposure and apply the slope factors and the 10 fold ASF to such assessments. Exposure durations longer than 2 years would use the method for the remaining years as noted above.

Table 2. Example of default ASF use for a lifetime exposure (not adjusted for age-specific exposure)

Carcinogen Potency = 1 $(mg/kg\text{-}d)^{-1}$
Exposure = 0.0001 mg/kg-d
No consideration of differences of exposure

No adjustment: Lifetime Risk = potency × dose			Risk
70 year Lifetime risk = 1 × 0.0001			1.0×10^{-4}
With proposed default ASF of 10 for birth to age 2 and 3 for age 2 to 16 years: LR = Σ (potency x dose x ASF x fraction of lifetime)	ASF	Duration	Risk
R (birth to age 2 yrs)	10	2/70	0.286×10^{-4}
R (age 2 to 16 yrs)	3	13/70	0.557×10^{-4}
R (age 16 to 70 yrs)	1	55/70	0.786×10^{-4}
70 year Lifetime Risk			1.6×10^{-4}
With proposed default ASF of 10 for third trimester to age 2 and 3 for ages 2 to 16 years: LR = Σ (potency x dose x ASF x fraction of lifetime)	ASF	Duration	Risk
R (third trimester to age 2yrs)	10	2.25/70.25	0.320×10^{-4}
R (age 2 to age 16 yrs)	3	13/70.25	0.555×10^{-4}
R (age 16 to 70 yrs)	1	55/70.25	0.783×10^{-4}
70 year Lifetime Risk			1.66×10^{-4}
With proposed default ASF of 10 for birth to age 5 and 3 for the ages 5 to 16 years: LR = Σ (potency x dose x ASF x fraction of lifetime)	ASF	Duration	Risk
R (birth to age 5)	10	4/70	0.571×10^{-4}
R (age 5 to 16 yrs)	3	11/70	0.471×10^{-4}
R (age 16 to 70 yrs)	1	55/70	0.786×10^{-4}
70 year Lifetime Risk			1.8×10^{-4}

Table 3. Example of default ASF use for a 9-year exposure

Carcinogen Potency = 1 $(mg/kg\text{-}d)^{-1}$
Exposure = 0.0001 mg/kg-d
No consideration of differences of exposure

No adjustment: Total Risk = potency × dose x fraction of lifetime		Duration	Risk
9-year Total Risk		9/70	**0.13×10^{-4}**
With default ASF of 10 for birth to age 2, and 3 thereafter: LR = Σ (potency x dose x ASF x fraction of lifetime)	ASF	Duration	Risk
R (birth to age 2 yrs)	10	2/70	0.286×10^{-4}
R (age 3 to 9 yrs)	3	7/70	0.300×10^{-4}
9 year Total Risk			**0.59×10^{-4}**
With default ASF of 10 for third trimester to age 2 and 3 thereafter: LR = Σ (potency x dose x ASF x fraction of lifetime)	ASF	Duration	Risk
R (third trimester to age 2yrs)	10	2.25/70.25	0.325×10^{-4}
R (age 2 to 9 yrs)	3	7/70.25	0.300×10^{-4}
9 year Total Risk			**0.625×10^{-4}**
With default ASF of 10 to age 5 and 3 thereafter: LR = Σ (potency x dose x ASF x fraction of lifetime)	ASF	Duration	Risk
R (birth to age 5 yrs)	10	4/70	0.571×10^{-4}
R (age 5 to 9 yrs)	3	5/70	0.214×10^{-4}
9 year Total Risk			**0.785×10^{-4}**

U.S.EPA Analysis of the Effect of Age at Exposure on Cancer Potency

U.S. EPA addressed the potential for increased susceptibility to cancer caused by environmental chemicals when the exposure occurs during an early lifestage in "Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens" (U.S. EPA, 2005b) (referred to henceforth as the Supplemental Guidance). This document is intended to be a companion to the revised "Guidelines for Carcinogen Risk Assessment" (U.S. EPA, 2005a). We present a summary of their analysis, which support the policy decision to weight cancer potency and therefore risk by age-at-exposure. As previously noted, there are several methodological differences between the U.S. EPA analysis and the OEHHA analysis. Of note, in the OEHHA analysis all treatment-related tumors that were observed in a given lifestage exposure experiment were taken into account in estimating cancer potency. Thus in comparing cancer potencies

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associated with early life vs. adult exposure, OEHHA compared the total cancer risk associated with exposure during a given lifestage, rather than comparing the risk for cancers at one single site in each lifestage, as the U.S. EPA did. In addition, the age groupings are a bit different in the U.S. EPA analysis than those used by OEHHA in their analysis (described above). For example, prenatal (*in utero*) exposures were not part of the analysis performed by U.S. EPA, and that Agency's analyses did not distinguish between postnatal and juvenile exposures.

U.S. EPA oral exposure cancer risk methodology relies on estimation of the lifetime average daily dose, which can account for exposure factor differences between adults and children (e.g. eating habits and body weight). However, early lifestage susceptibility differences have not been taken into consideration when cancer potency factors were calculated. The Supplemental Guidance document focused on studies that define the potential duration and degree of increased susceptibility that may arise from early-life exposures. An analysis of those studies including a detailed description of the procedures used was published in Barton *et al.* (2005) (included as Appendix I). The criteria used to decide if a study could be included in the quantitative analysis are as follows (excerpted from U.S. EPA, 2005b):

1. Exposure groups at different post-natal ages in the same study or same laboratory, if not concurrent (to control for a large number of potential cross-laboratory experimental variables including pathological examinations),
2. Same strain/species (to eliminate strain-specific responses confounding age-dependent responses),
3. Approximately the same dose within the limits of diets and drinking water intakes that obviously can vary with age (to eliminate dose-dependent responses confounding age-dependent responses),
4. Similar latency period following exposures of different ages (to control for confounding latency period for tumor expression with age-dependent responses), arising from sacrifice at >1 year for all groups exposed at different ages, where early-life exposure can occur up to about 7 weeks. Variations of around 10 to 20% in latency period are acceptable,
5. Postnatal exposure for juvenile rats and mice at ages younger than the standard 6 to 8 week start for bioassays; prenatal (*in utero*) exposures are not part of the current analysis. Studies that have postnatal exposure were included (without adjustment) even if they also involved prenatal exposure,
6. "Adult" rats and mice exposure beginning at approximately 6 to 8 weeks old or older, i.e. comparable to the age at initiation of a standard cancer bioassay (McConnell, 1992). Studies with animals only at young ages do not provide appropriate comparisons to evaluate age-dependency of response (e.g., the many neonatal mouse cancer studies). Studies in other species were used as supporting evidence, because they are relatively rare and the determination of the appropriate comparison ages across species is not simple, and
7. Number of affected animals and total number of animals examined are available or reasonably reconstructed for control, young, and adult groups (i.e., studies reporting only percent response or not including a control group would be excluded unless a reasonable estimate of historical background for the strain was obtainable).

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Cancer potencies were estimated from a one-hit model (a restricted form of the Weibull time-to-tumor model), which estimates cumulative incidence for tumor onset. U.S. EPA (2005b) compared the estimated ratio of the cancer potency from early-life exposure to the estimated cancer potency from adult exposure. The general form of the equation for the tumor incidence at a particular dose, [P(dose)] is:

$$P(dose) = 1-[1-P(0)]\exp(-\text{cancer potency}*\text{dose})$$

where P(0) is the incidence of the tumor in controls. The ratio of juvenile to adult cancer potencies at a single site were calculated by fitting this model to the data for each age group. The model fit depended upon the design of the experiment that generated the data. Studies evaluated by U.S. EPA had two basic design types: experiments in which animals were exposed either as juveniles or as adults (with either a single or multiple dose in each period), and experiments in which exposure began either in the juvenile or in the adult period, but once started, continued through life.

The model equations for the first study type are:

$$P_A = P_0 + (1-P_0)\,(1-e^{-m_A \delta_A})$$

$$P_J = P_0 + (1-P_0)\,(1-e^{-m_A e^{\lambda} \delta_J})$$

where A and J refer to the adult and juvenile period, respectively, λ is the natural logarithm of the juvenile:adult cancer potency ratio, P_0 is the fraction of control animals with the particular tumor type being modeled, P_x is the fraction of animals exposed in age period x with the tumor, m_A is the cancer potency, and δ_x is the duration or number of exposures during age period x.

The goal of the model is to determine λ, which is the logarithm of the estimated ratio of juvenile to adult cancer potencies. This serves as a measure of potential susceptibility for early-life exposure.

For the second study type, the model equations take into account that exposures that were initiated in the juvenile period continue through the adult period. The model equations for the fraction of animals exposed only as adults with tumors in this design are the same as in the first study type, but the fraction of animals whose first exposure occurred in the juvenile period is:

$$P_J = P_0 + (1-P_0)\,(1-e^{-m_A e^{\lambda}(\delta_J - \delta_A) - m_A \delta_A})$$

δ_J includes the duration of exposure during the juvenile period and the subsequent adult period.

Parameters in these models were estimated using Bayesian methods and all inferences about the ratios were based on the marginal posterior distribution of λ. A complete description of these procedures (including the potential effect of alternative Bayesian priors that were examined) was published in Barton *et al.* (2005) (Appendix I). This method produced a posterior mean ratio of the early-life to adult cancer potency, which is an estimate of the potential susceptibility of early-life exposure to carcinogens. Ratios of greater or less than one indicate greater or less susceptibility from early-life exposure, respectively.

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U.S. EPA reviewed several hundred studies reporting information on 67 chemicals or complex mixtures that are carcinogenic via perinatal exposure. Eighteen chemicals were identified which had animal study designs involving early-life and adult exposures in the same experiment. Of those 18 chemicals, there were overlapping subsets of 11 chemicals involving repeated exposures during early postnatal and adult lifestages and 8 chemicals using acute exposures (usually single doses) at different ages. Those chemicals are listed in Table 4~~Table 4~~~~Table 4~~.

Table 4 Chemicals having animal cancer study data available with early-life and adult exposures in the same experiment.

Chemical	Study Type
Amitrole	repeat dosing
Benzidine	repeat dosing
Benzo[a]pyrene (BaP)	acute exposure
Dibenzanthracene (DBA)	acute exposure
Dichlorodiphenyltrichloroethane (DDT)	lifetime exposure, repeat dosing
Dieldrin	lifetime exposure, repeat dosing
Diethylnitrosamine (DEN)	acute exposure, lifetime exposure
Dimethylbenz[a]anthracene (DMBA)	acute exposure
Dimethylnitrosamine (DMN)	acute exposure
Diphenylhydantoin, 5,5-(DPH)	lifetime exposure, repeat dosing
Ethylnitrosourea (ENU)	acute exposure
Ethylene thiourea (ETU)	lifetime exposure, repeat dosing
3-Methylcholanthrene (3-MC)	repeat dosing
Methylnitrosourea (NMU)	acute exposure
Polybrominated biphenyls (PBBs)	lifetime exposure, repeat dosing
Safrole	lifetime exposure, repeat dosing
Urethane	acute exposure, lifetime exposure
Vinyl chloride (VC)	repeat dosing

U.S. EPA calculated the difference in susceptibility between early-life and adult exposure as the estimated ratio of cancer potency at specific sites from early-life exposure over the cancer potency from adult exposure for each of the studies that were determined qualitatively to have appropriate study designs and adequate data. The results were grouped into four categories: 1) mutagenic chemicals administered by a chronic dosing regimen to adults and repeated dosing in the early postnatal period (benzidine, diethylnitrosamine, 3-methylcholanthrene, safrole, urethane and vinyl chloride); 2) chemicals without positive mutagenicity data administered by a chronic dosing regimen to adults and repeated dosing in the early postnatal period (amitrole, dichlorodiphenyltrichloroethane (DDT), dieldrin, ethylene thiourea, diphenylhydantoin, polybrominated biphenyls); 3) mutagenic chemicals administered by an acute dosing regimen

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(benzo[*a*]pyrene, dibenzanthracene, diethylnitrosamine, dimethylbenzanthracene, dimethylnitrosamine, ethylnitrosourea, methylnitrosourea and urethane); 4) chemicals with or without positive mutagenicity data with chronic adult dosing and repeated early postnatal dosing.

The acute dosing animal cancer studies were considered qualitatively useful by U.S. EPA because they involve identical exposures with defined doses and time periods demonstrating that differential tumor incidences arise exclusively from age-dependent susceptibility. However, they were not used to derive a quantitative cancer potency factor age adjustment, primarily because most of the studies used subcutaneous or intraperitoneal injection as a route of exposure. These methods have not been considered quantitatively relevant routes of environmental exposure for human cancer risk assessment by U.S. EPA, for reasons including the fact that these routes of exposure are expected to have a partial or complete absence of first pass metabolism which could affect potency estimates. Additionally, U.S. EPA decided that cancer potency estimates are usually derived from chronic exposures, and therefore, any adjustment to those potencies should be from similar exposures.

The repeated dosing studies with mutagenic chemicals using exposures during early postnatal and adult lifestages were used to develop a quantitative cancer potency factor age adjustment. Studies with repeated early postnatal exposure were included in the analysis even if they also involved earlier maternal and/or prenatal exposure, while studies addressing only prenatal exposure were not used in the analysis. The weighted geometric mean susceptibility ratio (juvenile to adult) for repeated and lifetime exposures in this case was 10.4 (range 0.12 – 111, 42% of ratios greater than 1).

USEPA suggests the use of age-dependent-adjustment factors (ADAF) for chemicals acting through a mutagenic mode of action., based on the results of the preceding analysis, which concluded that cancer risks generally are higher from early-life exposure than from similar exposure doses and durations later in life:

1. For exposures before 2 years of age (i.e., spanning a 2-year time interval from the first day of birth until a child's second birthday), a 10-fold ADAF.

2. For exposures between 2 and <16 years of age (i.e., spanning a 14-year time interval from a child's second birthday until their sixteenth birthday), a 3-fold ADAF.

3. For exposures after turning 16 years of age, no adjustment (ADAF=1).

The ADAF of 10 used for the 0 – 2 years of age range is approximately the weighted geometric mean cancer potency ratio from juvenile versus adult exposures in the repeated dosing studies. U.S. EPA considered this period to display the greatest toxicokinetic and toxicodynamic differences between children and adults. Data were not available to calculate a specific dose-response adjustment factor for the 2 to <16-year age range, so EPA selected an ADAF of 3 because it was half the logarithmic scale difference between the 10-fold adjustment for the first two years of life and no adjustment (*i.e.*, 1-fold) for adult exposure. The ADAF of 3 represents an intermediate level of adjustment applied after 2 years of age through <16 years of age. The upper age limit (16 years of age) reflects the end of puberty and the attainment of a final body height. U.S. EPA recognizes that the use of a weighted geometric mean of the available study

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data to develop an ADAF for cancer potencies may either overestimate or underestimate the actual early-life cancer potency for specific chemicals, and therefore emphasizes in the Supplemental Guidance that chemical-specific data should be used in preference to these default adjustment factors whenever such data are available.

U.S. EPA is recommending the ADAFs described above only for mutagenic carcinogens, because the data for non-mutagenic carcinogens were considered to be too limited and the modes of action too diverse to use this as a category for which a general default adjustment factor approach can be applied. OEHHA considers this approach to be insufficiently health protective. There is no obvious reason to suppose that the toxicokinetics of non-mutagens would be systematically different from those of mutagens. It would also be inappropriate to assume by default that non-mutagenic carcinogens are assumed to need a toxicodynamic correction factor of 1. Most if not all of the factors that make individuals exposed to carcinogens during an early-lifestage potentially more susceptible than those individuals exposed during adulthood also apply to non-mutagenic carcinogen exposures (*e.g.*, rapid growth and development of target tissues, potentially greater sensitivity to hormonal carcinogens, differences in metabolism). It should also be noted that carcinogens that do not cause gene mutations may still be genotoxic by virtue of causing chromosomal damage. Additionally, many carcinogens do not have adequate data available for deciding on a specific mode of action, or do not necessarily have a single mode of action. For these reasons, OEHHA will apply the default cancer potency factor age adjustments described above to all carcinogens unless data are available which allow for the development of chemical-specific cancer potency factor age adjustments. In those cases, an agent-specific model of age dependence (based on observational or experimental data) might be used, or alternative (larger or smaller) adjustment factors and age ranges may be applied where understanding of the mechanism of action and target tissues makes this appropriate.

Other Source Documents for Cancer Risk Assessment Guidance

As noted previously, the cancer potencies and unit risks tabulated in this technical support document have been developed by various programs over a number of years. The methods used therefore necessarily varied according to the date of the assessment and the program responsible. The following section summarizes the sources and procedures most commonly applied, and their historical context where this is apposite.

United States Environmental Protection Agency (U.S. EPA)

The U.S. EPA was one of the first regulatory agencies to develop and apply cancer risk assessment methodology. Their guidance documents and technical publications have been influential for many programs, including the California Air Toxics (Toxic Air Contaminants and Hot Spots) programs.

Guidelines for Carcinogen Risk Assessment (U.S. EPA, 1986)

Prior to the more recent guidelines updating project which, after nearly ten years of internal and public review drafts culminated in the 2005 final revision (see below), U.S. EPA carcinogen risk assessment procedures were generally as described in Anderson *et al.* (1983) and "Guidelines for Carcinogen Risk Assessment" (U.S. EPA, 1986). These methods, which are outlined below, were used to calculate the Integrated Risk Information System (IRIS) cancer potency values, some of which are cited in this document. U.S. EPA has always indicated that cancer risk estimates based on adequate human epidemiologic data are preferred if available over estimates based on animal data. Although the newer guidelines offer alternative methods for dose-response analysis of animal bioassays, and updated consideration of specific topics such as lifestage-related differences in sensitivity, and mechanism of action for some types of carcinogen, the underlying principles, and many of the specific procedures developed in these original guidelines are still applicable and in use.

U.S. EPA Calculation of Carcinogenic Potency Based on Animal Data

In extrapolating low-dose human cancer risk from animal carcinogenicity data, it is generally assumed that most agents that cause cancer also damage DNA, and that the quantal type of biological response characteristic of mutagenesis is associated with a linear non-threshold dose-response relationship. U.S. EPA stated that the risk assessments made with this model should be regarded as conservative, representing the most plausible upper limit for the risk. The mathematical expression used by U.S. EPA in the 1986 guidelines to describe the linear non-threshold dose-response relationship at low doses is the linearized multistage procedure developed by Crump (1980). This model is capable of fitting almost any monotonically increasing dose-response data, and incorporates a procedure for estimating the largest possible linear slope at low extrapolated doses that is consistent with the data at all experimental dose levels. A description of the linearized multistage procedure has been provided above (page 292928). U.S. EPA used an updated version (GLOBAL86, Howe *et al.*, 1986) of the computer program GLOBAL79 developed by Crump and Watson (1979) to calculate the point estimate and the 95% upper confidence limit of the extra risk $A(d)$.

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U.S. EPA separated tumor incidence data according to organ sites or tumor types. The incidence of benign and malignant tumors was combined whenever scientifically defensible. U.S. EPA considered this incidence combination scientifically defensible unless the benign tumors are not considered to have the potential to progress to the associated malignancies of the same histogenic origin. The primary comparison in carcinogenicity evaluation is tumor response in dosed animals as compared to contemporary matched control animals. However, U.S. EPA stated that historical control data could be used along with concurrent control data in the evaluation of carcinogenic responses, and notes that for the evaluation of rare tumors, even small tumor responses may be significant compared to historical data. If several data sets (dose and tumor incidence) are available (different animal species, strains, sexes, exposure levels, exposure routes) for a particular chemical, the data set used in the model was the set where the incidence is statistically significantly higher than the control for at least one test dose level and/or where the tumor incidence rate shows a statistically significant trend with respect to dose level. The data set generating the highest lifetime cancer risk estimate (q_1^*) was chosen where appropriate. An example of an inappropriate data set would be a set which generates an artifactually high risk estimate because of a very small number of animals used. If there are 2 or more data sets of comparable size for a particular chemical that are identical with respect to species, strain, sex and tumor sites, the geometric mean of q_1^* estimated from each of those data sets was used for risk estimation. U.S. EPA assumed that mg/surface area/day is an equivalent dose between species. Surface area was further assumed to be proportional to the 2/3 power of the weight of the animal in question. Equivalent dose was therefore computed using the following relationship:

$$d = \frac{l_e * m}{L_e * W^{2/3}}$$

where L_e = experimental duration, l_e = exposure duration, m = average dose (mg/day) and W = average animal weight. Default average body weights for humans, rats and mice are 70, 0.35 and 0.03 kg, respectively.

Exposure data expressed as ppm in the diet were generally converted to mg/day using the relationship m = ppm * F * r, where ppm is parts per million of the chemical in the diet, F is the weight of the food consumed per day in kg, and r is the absorption fraction (assumed to be 1 in the absence of data indicating otherwise). The weight of food consumed, calories required, and animal surface area were generally all considered to be proportional to the 2/3 power of the animal weight, so:

$$m \propto \text{ppm} * W^{2/3} * r, \text{ or } \frac{m}{rW^{2/3}} \propto \text{ppm}$$

The relationship could lead to the assumption that dietary ppm is an equivalent exposure between species. However, U.S. EPA did not believe that this assumption is justified, since the calories/kg food consumed by humans is significantly different from that consumed by laboratory animals (primarily due to differences in moisture content). An empirically derived food factor, $f = F/W$ was used, which is the fraction of a species' body weight consumed per day as food. U.S. EPA (1986) gave the f values for humans, rats and mice as 0.028, 0.05 and 0.13, respectively.

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Dietary exposures expressed as concentrations in ppm were converted to mg/surface area using the following relationship:

$$\frac{m}{r * W^{2/3}} = \frac{\text{ppm} * F}{W^{2/3}} = \frac{\text{ppm} * f * W}{W^{2/3}} = \text{ppm} * f * W^{2/3}$$

Exposures expressed as mg/kg/day ($m/Wr = s$) were converted to mg/surface area using the relationship:

$$\frac{m}{rW^{2/3}} = s * W^{2/3}$$

The calculation of dose when exposure is via inhalation was performed for cases where 1) the chemical is either a completely water-soluble gas or aerosol and is absorbed proportionally to the amount of inspired air, or 2) where the chemical is a partly water-soluble gas which reaches an equilibrium between the inspired air and body compartments. After equilibrium is attained, the rate of absorption is proportional to metabolic rate, which is proportional to the rate of oxygen consumption, which is related to surface area.

Exposure expressed as mg/day to completely water-soluble gas or aerosols can be calculated using the expression $m = I * v * r$, where I is the inspiration rate/day in m^3, v is the concentration of the chemical in air (mg/m^3), and r is the absorption fraction (assumed to be the same for all species in the absence of data to the contrary; usually 1). For humans, the default inspiration rate of 20 m^3 has been adopted. Inspiration rates for 113 g rats and 25 g mice have been reported to be 105 and 34.5 liters/day, respectively. Surface area proportionality can be used to determine inspiration rate for rats and mice of other weights; for mice, $I = 0.0345\ (W / 0.025)^{2/3}$ m^3/day; for rats, $I = 0.105\ (W / 0.113)^{2/3}$ m^3/day. The empirical factors for air intake/kg/day (i) for humans, rats and mice are 0.29, 0.64 and 1.3, respectively. Equivalent exposures in mg/surface area can be calculated using the relationship:

$$\frac{m}{W^{2/3}} = \frac{Ivr}{W^{2/3}} = \frac{iWvr}{W^{2/3}} = iW^{1/3}vr$$

Exposure expressed as mg/day to partly water-soluble gases is proportional to surface area and to the solubility of the gas in body fluids (expressed as an absorption coefficient r for that gas). Equivalent exposures in mg/surface area can be calculated using the relationships $m = kW^{2/3} * v * r$, and $d = m/W^{2/3} = kvr$. The further assumption is made that in the case of route-to-route extrapolations (e.g., where animal exposure is via the oral route, and human exposure is via inhalation, or vice versa), unless pharmacokinetic data to the contrary exist, absorption is equal by either exposure route.

Adjustments were made for experimental exposure durations shorter than the lifetime of the test animal; the slope q_1^* was increased by the factor $(L/L_e)^3$, where L is the normal lifespan of the experimental animal and L_e is the duration of the experiment. This assumed that if the average dose d is continued, the age-specific rate of cancer will continue to increase as a constant function of the background rate. Since age-specific rates for humans increase by at least the 2nd power of the age, and often by a considerably higher power (Doll, 1971), there is an expectation

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that the cumulative tumor rate, and therefore q_1^*, will increase by at least the 3rd power of age. If the slope q_1^* is calculated at age L_e, it would be expected that if the experiment was continued for the full lifespan L at the same average dose, the slope q_1^* would have been increased by at least $(L/L_e)^3$.

U.S. EPA Calculation of Carcinogenic Potency Based on Human Data

U.S. EPA stated that existing human epidemiologic studies with sufficiently valid exposure characterization are always used in evaluating the cancer potency of a chemical. If they showed a carcinogenic effect, the data were analyzed to provide an estimate of the linear dependence of cancer rates on lifetime cancer dose (equivalent to the factor q_1^*). If no carcinogenic effect was demonstrated and carcinogenicity had been demonstrated in animals, then it was assumed that a risk does exist, but it is smaller than could have been observed in the epidemiologic study. An upper limit of cancer incidence was calculated assuming that the true incidence is just below the level of detection in the cohort studied, which is largely determined by the cohort size. Whenever possible, human data are used in preference to animal data. In human epidemiologic studies, the response is measured as the relative risk of the exposed cohort of individuals compared to the control group. The excess risk ($R(X)$ - 1, where $R(X)$ is relative risk) was assumed to be proportional to the lifetime average exposure X, and to be the same for all ages. The carcinogenic potency is then equal to $[R(X) - 1]/X$ multiplied by the lifetime risk at that site in the general population. According to this original procedure, the confidence limit for the excess risk was not usually calculated: this decision was ascribed to the difficulty in accounting for inherent uncertainty in the exposure and cancer response data. More recent assessments have taken the opposite view and attempted to calculate and characterize this uncertainty by determining confidence limits, *inter alia*.

Guidelines for Carcinogen Risk Assessment (U.S. EPA, 2005a)

U.S. EPA revised its "Guidelines for Carcinogen Risk Assessment" (referred to henceforth as the "U.S. EPA Guidelines") in 2005. Compared to the 1986 version of this document, more emphasis is placed on establishing a "mode of action" (MOA). The following excerpt provides a definition of this term:

> "The term "mode of action" is defined as a sequence of key events and processes, starting with interaction of an agent with a cell, proceeding through operational and anatomical changes, and resulting in cancer formation. A "key event" is an empirically observable precursor step that is itself a necessary element of the mode of action or is a biologically based marker for such an element. Mode of action is contrasted with "mechanism of action," which implies a more detailed understanding and description of events, often at the molecular level, than is meant by mode of action".

Cancer risk assessments performed under the prior U.S. EPA Guidelines sometimes included a MOA description. However, the 1986 U.S. EPA Guidelines did not explicitly mandate the development of a MOA description in cancer risk assessments.

The MOA information is then used to govern how a cancer risk assessment shall proceed. Tumor incidence data sets arising from a MOA judged to be not relevant to humans are not used

to extrapolate a cancer potency factor. If an MOA cannot be determined or is determined to have a low-dose linear dose-response and a nonmutagenic MOA, then a linear extrapolation method is used to develop a cancer potency factor. The same linear extrapolation is used for all lifestages, unless chemical specific information on lifestage or population sensitivity is available. Carcinogens that act via an MOA judged to have a nonlinear low-dose dose response are modeled using MOA data, or the RfD/RfC risk assessment method is used as a default. Adjustments for susceptible lifestages or populations are to be performed as part of the risk assessment process.

If a carcinogen is deemed to act via a mutagenic MOA, then the data from the MOA analysis is evaluated to determine if chemical-specific differences between adults and juveniles exist and can be used to develop a chemical-specific risk estimate incorporating lifestage susceptibility. If this cannot be done, then early-life susceptibility is assumed, and age-dependent adjustment factors (ADAFs) are applied as appropriate to develop risk estimates. In cases where it is not possible to develop a toxicokinetic model to perform cross-species scaling of animal tumor data sets which arise from oral exposures, the U.S. EPA Guidelines state that administered doses should be scaled from animals to humans on the basis of equivalence of $mg/kg^{3/4}$-d (milligrams of the agent normalized by the 3/4 power of body weight per day). This is a departure from the 1986 U.S. EPA guidelines, which used a 2/3 power of body weight normalization factor. Other adjustments for dose timing, duration and route are generally assumed to be handled in similar fashion to that described for the 1986 guidelines, although of course updated parameter values would be used where available.

The 2005 U.S. EPA Guidelines also use benchmark dose methodology (described above, page 27) to develop a "point-of departure" (POD) from tumor incidence data. For linear extrapolation, the POD is used to calculate a cancer potency factor, and for nonlinear extrapolation the POD is used in the calculation of a reference dose (RfD) or reference concentration (RfC).

It should be noted that none of the cancer potency factors listed in this document were obtained from U.S. EPA risk assessments performed under the 2005 U.S. EPA Guidelines. All U.S. EPA IRIS cancer potency values contained in this document were obtained from risk assessments using the 1986 U.S. EPA Guidelines.

Office of Environmental Health Hazard Assessment (OEHHA), California Environmental Protection Agency

The cancer risk assessment procedures originally used by the Office of Environmental Health Hazard Assessment (OEHHA) are outlined in "Guidelines for Chemical Carcinogen Risk Assessments and their Scientific Rationale" (referred to below as the Guidelines) (CDHS, 1985). These procedures were generally used in generating Toxic Air Contaminant (TAC) cancer potency values, standard Proposition 65 cancer potency values and Public Health Goal (PHG) cancer potency values. Expedited Proposition 65 cancer potency values depart somewhat from those procedures and are discussed separately below.

OEHHA cancer risk assessment methodology as described by CDHS (1985) generally resembled that used at that time by U.S. EPA (Anderson *et al.*, 1983; U.S. EPA, 1986). OEHHA risk

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assessment practice similarly reflects the evolution of the technical methodology (e.g. as described in U.S. EPA, 2005a) since the original guidelines were published. The basic principles and procedures described below are still considered applicable. More recent additions to OEHHA cancer risk assessment methods such as the use of benchmark dose methodologies and early-lifestage cancer potency adjustments are discussed above. The Guidelines state that both animal and human data, when available, should be part of the dose-response assessment.

OEHHA Calculation of Carcinogenic Potency Based on Animal Data

The procedures used to extrapolate low-dose human cancer risk from animal carcinogenicity data assumed that a carcinogenic change induced in a cell is transmitted to successive generations of cell descendents, and that the initial change in the cell is an alteration (e.g. mutation, rearrangement, etc.) in the cellular DNA. Non-threshold models are used to extrapolate to low-dose human cancer risk from animal carcinogenicity data.

Several models were proposed for extrapolating low-dose human cancer risk from animal carcinogenicity data in the original Guidelines. These models include the Mantel-Bryan method (log-probit model), the one-hit model, the linearized multistage procedure, the gamma multihit model, and a number of time-to-tumor models. The Guidelines stated that time-to-tumor models (i.e., a Weibull-in-time model) should be used for low-dose extrapolation in all cases where supporting data are available, particularly when survival is poor due to competing toxicity. However, the Guidelines also noted the difficulty of determining the actual response times in an experiment. Internal tumors are generally difficult to detect in live animals and their presence is usually detected only at necropsy. Additionally, use of these models often requires making the determination of whether a tumor was the cause of death, or was found only coincidentally at necropsy when death was due to other causes. Further, competing causes of death, such as chemical toxicity, may decrease the observed time-to-tumor for nonlethal cancers by allowing earlier necropsy of animals in higher dose groups. The linearized multistage (LMS) procedure was noted as being an appropriate method for dose extrapolation in most cases, with the primary exception being a situation in which sufficient empirical data are available to indicate a dose-response curve of a "quasi-threshold" type (e.g., flat for two or three dose levels, then curving sharply upwards). In this case, the LMS procedure may underestimate the number of stages and overestimate the low-dose risks. In this case, the gamma multihit model was suggested as being a potential alternative. The Mantel-Bryan model was described as having little biological basis as applied to carcinogenesis, and being likely to underestimate risks at low doses. The Guidelines stated that this model should not be used for low dose extrapolation. More recent practice has departed from these original guidelines in some respects, for instance by experimenting with cell-proliferation based models in a few cases: however the LMS model remained the preferred extrapolation model for most purposes. Some of the difficulties in achieving a satisfactory fit to tumor incidence data were found to be alleviated by application of toxicokinetic models and use of an internal rather than applied dose metric with the LMS model. This has resulted in the alternative models originally advocated (Gamma multihit, Mantel-Bryan) being mostly abandoned. As noted above (Dose-Response Assessment, page 23), the use of allegedly biologically based statistical models such as LMS has fallen from favor in recent years, and benchmark dose methodology has become the preferred method for extrapolating cancer potency values from animal cancer incidence data. However, it should also be noted that results

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generated by the LMS model and benchmark dose methodology from the same data set are often quite similar.

The 1985 Guidelines stated that both animal and human data, when available, should be part of the dose-response assessment. Although preference was given to human data when these were of adequate quality, animal studies may provide important supporting evidence. Low-dose extrapolation of human cancer risk from animal carcinogenicity data was generally based on the most sensitive site, species and study demonstrating carcinogenicity of a particular chemical, unless other evidence indicates that the data set in question is not appropriate for use. Where both benign and malignant tumors are induced at the same site and the benign tumors are considered to have the potential to progress to malignant tumors, the incidence data for both types of tumors could be combined to form the basis for risk assessment. Pharmacokinetic data on chemical metabolism, effective dose at target site, or species differences between laboratory test animals and humans were considered in dose-response assessments when available. In performing exposure scaling from animals to humans, the "surface area" correction (correcting by the 2/3 power of body weight) was used unless specific data indicates that this should not be done. The Guidelines assumed that in the absence of evidence to the contrary, chemicals that cause cancer after exposure by ingestion will also cause cancer after exposure by inhalation, and vice versa. These original proposals have continued in use with little change except that currently, TAC and PHG cancer potency factor calculations use a 3/4 power of body weight correction for interspecies scaling, in line with current U.S. EPA practice. The standard Proposition 65 cancer potency factor calculations still use a 2/3 power correction because the cancer potency calculation method is specified in regulation (California Health and Safety Code 25249.5 *et seq.*).

Cancer unit risk factors [in units of $(\mu g/m^3)^{-1}$]have been calculated from cancer potency factors [in units of $(mg/kg\text{-}day)^{-1}$] using the following relationship:

$$UR = \frac{CPF * 20\ m^3}{70\ kg\ *\ CV}$$

where UR is the cancer unit risk, CPF is the cancer potency factor, 70 kg is the reference human body weight, 20 m^3 is the reference human inspiration rate/day, and CV is the conversion factor from mg to µg (= 1000). The cancer unit risk describes the excess cancer risk associated with an inhalation exposure to a concentration of 1 $\mu g/m^3$ of a given chemical; the cancer potency factor describes the excess cancer risk associated with exposure to 1 mg of a given chemical per kilogram of body weight.

It should be noted that although this default method is still used in deriving published cancer unit risk values, for site-specific risk assessments age-appropriate distributions and percentile values are used in the current version of the Hot Spots exposure assessment document. Where exposure to children occurs (as it does in most exposures to the general population surrounding a source site) it is also necessary to apply the age-specific adjustment factors for the appropriate durations in accordance with the guidance offered above (Page 30 *et seq.*).

OEHHA Calculation of Carcinogenic Potency Based on Human Data

Human epidemiologic studies with adequate exposure characterization are used to evaluate the cancer potency of a chemical. If they show a carcinogenic effect, the data are analyzed to provide an estimate of the linear dependence of cancer rates on lifetime cancer dose. The 1985 Guidelines stated that with continuous exposure, age-specific incidence continues to increase as a power function (e.g., t^3 or t^4) of the elapsed time since initial exposure. Lifetime risks can be estimated by applying such a power function to the observed data and extrapolating beyond the actual followup period. OEHHA has generally undertaken the calculation of study power and confidence bounds on the potency estimate as important tools to establish the credibility of the estimate obtained and in comparing this with other estimates (from other human studies or from animal data). Due to the diversity in quality and type of epidemiological data, the specific approaches used in OEHHA risk assessments based on human epidemiologic studies vary on a case by case basis rather than following explicit general guidelines. Examples of the methods used can be observed in the Toxic Air Contaminant documents (these documents are listed in Appendix D: the methods used are described in the compound summaries provided in Appendix B).

Expedited Proposition 65 Cancer Risk Assessment Methodology

Expedited cancer potency values developed for several agents listed as carcinogens under Proposition 65 (California Health and Safety Code 25249.5 *et seq.*) were derived from selected animal carcinogenicity data sets of the Carcinogenic Potency Database (CPDB) of Gold *et al.* (1984, 1986, 1987, 1989, 1990, 1997) using default procedures specified in the administrative regulations for Proposition 65 (Title 22 California Code of Regulations [CCR] 12703). OEHHA hazard assessments usually describe all relevant data on the carcinogenicity (including dose-response characteristics) of the chemical under examination, followed by an evaluation of any pharmacokinetic and mechanistic (e.g. genotoxicity) data. An evaluation of the data set for the chemical may indicate that adjustments in target dose estimates or use of a dose response model different from the default are appropriate. The procedure used to derive expedited Proposition 65 cancer potency values differs from the usual methodology in two ways. First, it relies on cancer dose response data evaluated and extracted from the original literature by Gold *et al.* Second, the choice of a linearized multistage procedure for generating cancer potency values is automatic, and pharmacokinetic adjustments are not performed. The methods used to develop expedited cancer potency values incorporate the following assumptions:

1. The dose response relationship for carcinogenic effects in the most sensitive species tested is representative of that in humans.
2. Observed experimental results can be extrapolated across species by use of the interspecies factor based on "surface area scaling."
3. The dose to the tissue giving rise to a tumor is assumed to be proportional to the administered dose.
4. The linearized multistage polynomial procedure can be used to extrapolate potency outside the range of experimental observations to yield estimates of "low" dose potency.
5. Cancer risk increases with the third power of age.

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The Carcinogenic Potency Database of Gold *et al.* (1984, 1986, 1987, 1989, 1990) contains the results of more than 4000 chronic laboratory animal experiments on 1050 chemicals by combining published literature with the results of Federal chemical testing programs (Technical Reports from the Carcinogenesis Bioassay Program of the National Cancer Institute (NCI)/National Toxicology Program (NTP) published prior to June 1987). The published literature was searched (Gold *et al.*, 1984) through the period December 1986 for carcinogenicity bioassays; the search included the Public Health Service publication "Survey of Compounds Which Have Been Tested for Carcinogenic Activity" (1948-1973 and 1978), monographs on chemical carcinogens prepared by the International Agency for Research on Cancer (IARC) and Current Contents. Also searched were Carcinogenesis Abstracts and the following journals: British Journal of Cancer, Cancer Letters, Cancer Research, Carcinogenesis, Chemosphere, Environmental Health Perspectives, European Journal of Cancer, Food and Cosmetics Toxicology, Gann, International Journal of Cancer, Journal of Cancer Research and Clinical Oncology (formerly Zeitschrift fur Krebsforschung und Klinische Onkologie), Journal of Environmental Pathology and Toxicology, Journal of Toxicology and Environmental Health, Journal of the National Cancer Institute, and Toxicology and Applied Pharmacology. Studies were included in the database if they met the following conditions:

1. The test animals were mammals.
2. Chemical exposure was started early in life (100 days of age or less for hamsters, mice and rats).
3. Route of administration was via the diet, drinking water, gavage, inhalation, intravenous injection or intraperitoneal injection.
4. The test chemical was administered alone (not in combination with other chemicals).
5. Chemical exposure was chronic (*i.e.*, duration of exposure was at least one-fourth the standard lifespan for that species), with not more than 7 days between exposures.
6. The experiment duration was at least half the standard lifespan for the species used.
7. The study design included a control group and at least 5 animals/exposure group.
8. No surgical interventions were performed.
9. Pathology data were reported for the number of animals with tumors (not total number of tumors).
10. All results reported were original data (not analysis of data reported by other authors).

Included in their data set tabulations are estimates of average doses used in the bioassay, resulting tumor incidences for each of the dose levels employed for sites where significant responses were observed, dosing period, length of study and histopathology. Average daily dose levels were calculated assuming 100% absorption. Dose calculations follow procedures similar to those of Cal/EPA and U.S. EPA; details on methods used and standard values for animal lifespans, body weights, and diet, water and air intake are listed in Gold *et al.* (1984). OEHHA (1992) reviewed the quality assurance, literature review, and control procedures used in compiling the data and found them to be sufficient for use in an expedited procedure. Cancer potency estimates were derived by applying the mathematical approach described in the section below to dose response data in the Gold *et al.* database.

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The following criteria were used for data selection:

1. Data sets with statistically significant increases in cancer incidence with dose ($p \leq 0.05$) were used. (If the authors of the bioassay report considered a statistically significant result to be unrelated to the exposure to the carcinogen, the associated data set was not used.)
2. Data sets were not selected if the endpoint was specified as "all tumor-bearing animals" or results were from a combination of unrelated tissues and tumors.
3. When several studies were available, and one study stood out as being of higher quality due to numbers of dose groups, magnitude of the dose applied, duration of study, or other factors, the higher quality study was chosen as the basis for potency calculation if study results were consistent with those of the other bioassays listed.
4. When there were multiple studies of similar quality in the sensitive species, the geometric mean of potencies derived from these studies was taken. If the same experimentalists tested two sexes of the same species/strain under the same laboratory conditions, and no other adequate studies were available for that species, the data set for the more sensitive sex was selected.
5. Potency was derived from data sets that tabulate malignant tumors, combined malignant and benign tumors, or tumors that would have likely progressed to malignancy.

Cancer potency was defined as the slope of the dose response curve at low doses. Following the default approach, this slope was estimated from the dose response data collected at high doses and assumed to hold at very low doses. The Crump linearized multistage polynomial (Crump *et al.*, 1977) was fit to animal bioassay data:

$$\text{Probability of cancer} = 1 - \exp[-(q_0 + q_1 d + q_2 d^2 + \ldots)]$$

Cancer potency was estimated from the upper 95 % confidence bound on the linear coefficient q_1, which is termed q_1^*.

For a given chemical, the model was fit to a number of data sets. As discussed in the section above, the default was to select the data for the most sensitive target organ in the most sensitive species and sex, unless data indicated that this was inappropriate. Deviations from this default occur, for example, when there are several bioassays or large differences exist between potency values calculated from available data sets.

Carcinogenicity bioassays using mice and/or rats will often use an exposure duration of approximately two years. For standard risk assessments, this is the assumed lifespan for these species. Animals in experiments of shorter duration are at a lower risk of developing tumors than those in the standard bioassay; thus potency is underestimated unless an adjustment for experimental duration is made. In estimating potency, short duration of an experiment was taken into account by multiplying q_1^* by a correction factor equal to the cube of the ratio of the assumed standard lifespan of the animal to the duration of the experiment (T_e). This assumes that the cancer hazard would have increased with the third power of the age of the animals had they lived longer:

$$q_{animal} = q_1^* * (104 \text{ weeks}/T_e)^3$$

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In some cases excess mortality may occur during a bioassay, and the number of initial animals subject to late occurring tumors may be significantly reduced. In such situations, the above described procedure can, at times, significantly underestimate potency. A time-dependent model fit to individual animal data (i.e., the data set with the tumor status and time of death for each animal under study) may provide better potency estimates. When Gold *et al.* indicated that survival was poor for a selected data set, a time-dependent analysis was attempted if the required data were available in the Tox Risk (Crump *et al.*, 1991) data base. The Weibull multistage model (Weibull-in-time; multistage-in-dose) was fit to the individual animal data.

To estimate human cancer potency, q_{animal} values derived from bioassay data were multiplied by an interspecies scaling factor (K; the ratio of human body weight (bw_h) to test animal body weight (bw_a), taken to the 1/3 power (Anderson *et al.*, 1983)):

$$K = (bw_h/bw_a)^{1/3}$$

Thus, cancer potency = $q_{human} = K * q_{animal}$

Chemical-specific Descriptions of Cancer Potency Value Derivations

Unit Risk and potency values for chemicals whose cancer potency values were obtained from Toxic Air Contaminant documents, standard or expedited Proposition 65 documents, U.S. EPA's Integrated Risk Information System (IRIS) documents and Health Effects Assessment Summary Table (HEAST) entries, or from other documents prepared by OEHHA's Air Toxicology and Epidemiology Branch or Pesticide and Environmental Toxicology Branch are presented in Appendix A. Information summaries for these chemicals are presented in Appendix B.

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CAPCOA

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CEQA & Climate Change

Evaluating and Addressing Greenhouse Gas Emissions from Projects Subject to the California Environmental Quality Act

January 2008

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Disclaimer

The California Air Pollution Control Officers Association (CAPCOA) has prepared this white paper consideration of evaluating and addressing greenhouse gas emissions under the California Environmental Quality Act (CEQA) to provide a common platform of information and tools to support local governments.

This paper is intended as a resource, not a guidance document. It is not intended, and should not be interpreted, to dictate the manner in which an air district or lead agency chooses to address greenhouse gas emissions in the context of its review of projects under CEQA.

This paper has been prepared at a time when California law has been recently amended by the Global Warming Solutions Act of 2006 (AB 32), and the full programmatic implications of this new law are not yet fully understood. There is also pending litigation in various state and federal courts pertaining to the issue of greenhouse gas emissions. Further, there is active federal legislation on the subject of climate change, and international agreements are being negotiated. Many legal and policy questions remain unsettled, including the requirements of CEQA in the context of greenhouse gas emissions. This paper is provided as a resource for local policy and decision makers to enable them to make the best decisions they can in the face of incomplete information during a period of change.

Finally, this white paper reviews requirements and discusses policy options, but it is not intended to provide legal advice and should not be construed as such. Questions of legal interpretation, particularly in the context of CEQA and other laws, or requests for advice should be directed to the agency's legal counsel.

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List of Acronyms and Abbreviations

Acronym/ Abbreviation	Meaning
AB 32	Assembly Bill 32 Global Warming Solutions Act of 2006
AG	Attorney General
ARB	Air Resources Board
ASTM	American Society of Testing and Material
BAAQMD	Bay Area Air Quality Management District
BAU	Business as Usual
BEES	Building for Environmental and Economic Sustainability
Calfire	California Fire
Caltrans	California Department of Transportation
CAP	Criteria Air Pollutants
CAPCOA	California Air Pollution Control Officers Association
CARB	California Air Resource Board
CAT	Climate Action Team
CCAP	Center for Clean Air Policy
CCAR	California Climate Action Registry
CDFA	California Department of Food and Agriculture
CEC	California Energy Commission
CEQA	California Environmental Quality Act
CF	Connectivity Factor
CH_4	Methane
CIWMB	California Integrated Waste Management Board
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CNG	Compressed Natural Gas
CPUC	California Public Utilities Commission
CUFR	California Urban Forestry
DGS	Department of General Services
DOE	U.S. Department of Energy
DOF	Department of Finance
DPF	Diesel Particulate Filter
DWR	Department of Water Resources
E85	85% Ethanol
EEA	Massachusetts Executive Office of Energy and Environmental Affairs
EERE	Energy Efficiency and Renewable Energy
EIR	Environmental Impact Report
EOE	Encyclopedia of Earth
EPA	U.S. Environmental Protection Agency
ETC	Edmonton Trolley Coalition
EV	Electric Vehicles
FAR	Floor Area Ratio

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GHG	Greenhouse Gas
GGEP	Greenhouse Gas Emissions Policy
GGRP	Greenhouse Gas Reduction Plan
GP	General Plan
GWP	Global Warming Potential
IGCC	Integrated Gasification Combined Cycle
IOU	Investor Owned Utility
IPCC	International Panel on Climate Change
IT	Information Technology
ITE	Institute of Transportation Engineers
J&S	Jones & Stokes
km	Kilometer
LandGem	Landfill Gas Emissions Model
LEED	Leadership in Energy and Environmental Design
LNG	Liquefied Natural Gas
MBUAPCD	Monterey Bay Unified Air Pollution Control District
MEPA	Massachusetts Environmental Policy Act
MND	Mitigated Negative Declaration
MMT CO_2e	Million Metric Tons Carbon Dioxide Equivalent
MW	Megawatts
N_2O	Nitrous Oxide
NACAA	National Association Clean Air Agencies
ND	Negative Declaration
NEV	Neighborhood Electric Vehicle
NIST	National Institute of Standards and Technology
NO_X	Oxides of Nitrogen
NREL	National Renewable Energy Laboratory
NSCAPCD	Northern Sonoma County Air Pollution Control District
NSR	New Source Review
OPR	State Office of Planning and Research
PFC	Perfluorocarbon
PG&E	Pacific Gas & Electric
POU	Publicly Owned Utility
PM	Particulate Mater
RoadMod	Road Construction Emissions Model
ROG	Reactive Organic Gas
RPS	Renewable Portfolio Standards
RTP	Regional Transportation Plan
S-3-05	Executive Order S-3-05
SB	Senate Bill
SBCAPCD	Santa Barbara County Air Pollution Control District
SCAQMD	South Coast Air Quality Management District
SCM	Sustainable Communities Model
SIP	State Implementation Plan
SJVAPCD	San Joaquin Valley Unified Air Pollution Control District
SLOCAPCD	San Luis Obispo County Air Pollution Control District

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SMAQMD	Sacramento Metropolitan Air Quality Management District
SMUD	Sacramento Municipal Utilities District
SO_X	Sulfur Oxides
SP	Service Population
SRI	Solar Reflectance Index
SWP	State Water Project
TAC	Toxic Air Contaminants
TBD	To Be Determined
TDM	Transportation Demand Management
TMA	Transportation Management Association
THC	Total Hydrocarbon
UC	University of California
ULEV	Ultra Low Emission Vehicle
UNFCCC	United Nations Framework Convention on Climate Change
URBEMIS	Urban Emissions Model
USGBC	U.S. Green Building Council
VMT	Vehicle Miles Traveled
VTPI	Victoria Transit Policy
YSAQMD	Yolo-Solano Air Quality Management District

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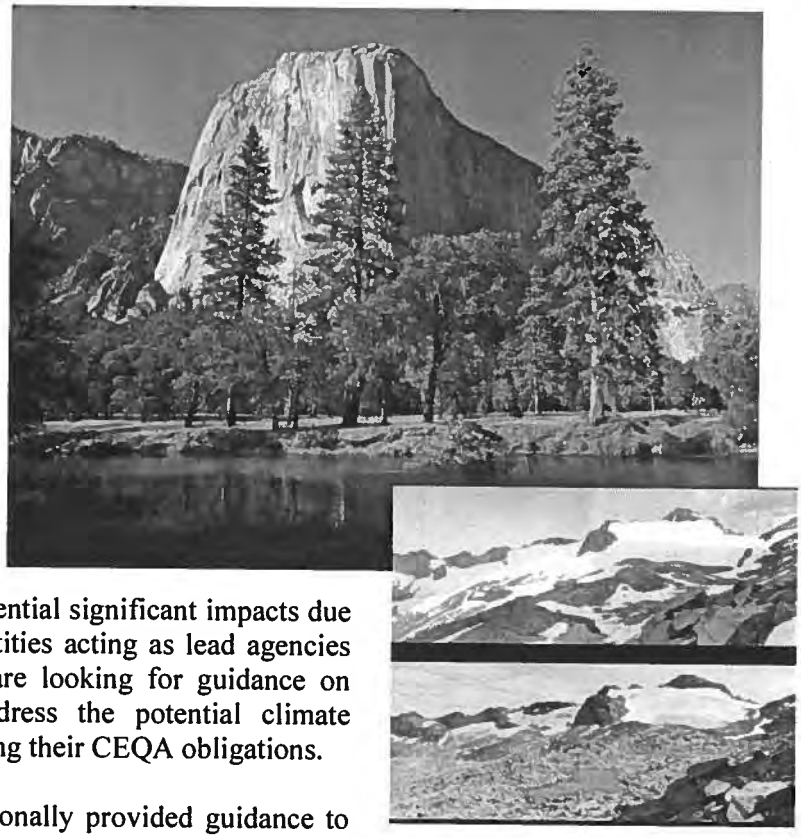
Introduction

The California Environmental Quality Act (CEQA) requires that public agencies refrain from approving projects with significant adverse environmental impacts if there are feasible alternatives or mitigation measures that can substantially reduce or avoid those impacts. There is growing concern about greenhouse gas emissions[1] (GHG) and recognition of their significant adverse impacts on the world's climate and on our environment. In its most recent reports, the International Panel on Climate Change (IPCC) has called the evidence for this "unequivocal." In California, the passage of the Global Warming Solutions Act of 2006 (AB 32) recognizes the serious threat to the "economic well-being, public health, natural resources, and the environment of California" resulting from global warming. In light of our current understanding of these impacts, public agencies approving projects subject to the CEQA are facing increasing pressure to identify and address potential significant impacts due to GHG emissions. Entities acting as lead agencies in the CEQA process are looking for guidance on how to adequately address the potential climate change impacts in meeting their CEQA obligations.



Air districts have traditionally provided guidance to local lead agencies on evaluating and addressing air pollution impacts from projects subject to CEQA. Recognizing the need for a common platform of information and tools to support decision makers as they establish policies and programs for GHG and CEQA, the California Air Pollution Control Officers Association has prepared a white paper reviewing policy choices, analytical tools, and mitigation strategies.

This paper is intended to serve as a resource for public agencies as they establish agency procedures for reviewing GHG emissions from projects under CEQA. It considers the application of thresholds and offers three alternative programmatic approaches toward

[1] Throughout this paper GHG, CO_2, CO_2e, are used interchangeably and refer generally to greenhouse gases but do not necessarily include all greenhouse gases unless otherwise specified.

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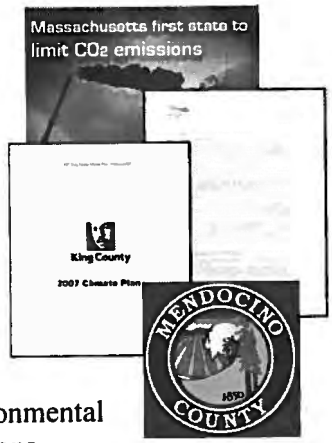
determining whether GHG emissions are significant. The paper also evaluates tools and methodologies for estimating impacts, and summarizes mitigation measures. It has been prepared with the understanding that the programs, regulations, policies, and procedures established by the California Air Resources Board (CARB) and other agencies to reduce GHG emissions may ultimately result in a different approach under CEQA than the strategies considered here. The paper is intended to provide a common platform for public agencies to ensure that GHG emissions are appropriately considered and addressed under CEQA while those programs are being developed.

Examples of Other Approaches

Many states, counties, and cities have developed policies and regulations concerning greenhouse gas emissions that seek to require or promote reductions in GHG emissions through standards for vehicle emissions, fuels, electricity production/renewables, building efficiency, and other means. A few have developed guidance and are currently considering formally requiring or recommending the analysis of greenhouse gas emissions for development projects during their associated environmental processes. Key work in this area includes:



- Massachusetts Office of Energy and Environmental Affairs Greenhouse Gas Emissions Policy;
- King County, Washington, Executive Order on the Evaluation of Climate Change Impacts through the State Environmental Policy Act;
- Sacramento AQMD interim policy on addressing climate change in CEQA documents; and
- Mendocino AQMD updated guidelines for use during preparation of air quality impacts in Environmental Impact Reports (EIRs) or mitigated negative declarations.

The following paper evaluates options for lead agencies to ensure that GHG emissions are appropriately addressed as part of analyses under CEQA. It considers the use of significance thresholds, tools and methodologies for analyzing GHG emissions, and measures and strategies to avoid, reduce, or mitigate impacts.

Greenhouse Gas Significance Criteria

This white paper discusses three basic options air districts and lead agencies can pursue when contemplating the issues of CEQA thresholds for greenhouse gas emissions. This paper explores each path and discusses the benefits and disbenefits of each. The three basic paths are:

- No significance threshold for GHG emissions;

- GHG emissions threshold set at zero; or
- GHG threshold set at a non-zero level.

Each has inherent advantages and disadvantages. Air districts and lead agencies may believe the state or national government should take the lead in identifying significance thresholds to address this global impact. Alternatively, the agency may believe it is premature or speculative to determine a clear level at which a threshold should be set. On the other hand, air districts or lead agencies may believe that every GHG emission should be scrutinized and mitigated or offset due to the cumulative nature of this impact. Setting the threshold at zero will place all discretionary projects under the CEQA microscope. Finally, an air district or lead agency may believe that some projects will not benefit from a full environmental impact report (EIR), and may believe a threshold at some level above zero is needed.

This paper explores the basis and implications of setting no threshold, setting a threshold at zero and two primary approaches for those who may choose to consider a non-zero threshold. The first approach is grounded in statute (AB 32) and executive order (EO S-3-05) and explores four possible options under this scenario. The options under this approach are variations of ways to achieve the 2020 goals of AB 32 from new development, which is estimated to be about a 30 percent reduction from business as usual.

The second approach explores a tiered threshold option. Within this option, seven variations are discussed. The concepts explored here offer both quantitative and qualitative approaches to setting a threshold as well as different metrics by which tier cut-points can be set. Variations range from setting the first tier cut-point at zero to second-tier cut-points set at defined emission levels or based on the size of a project. It should be noted that some applications of the tiered threshold approach may require inclusion in a General Plan or adoption of enabling regulations or ordinances to render them fully effective and enforceable.

Greenhouse Gas Analytical Methodologies

The white paper evaluates various analytical methods and modeling tools that can be applied to estimate the greenhouse gas emissions from different project types subject to CEQA. In addition, the suitability of the methods and tools to characterize accurately a project's emissions is discussed and the paper provides recommendations for the most appropriate methodologies and tools currently available.

The suggested methodologies are applied to residential, commercial, specific plan and general plan scenarios where GHG emissions are estimated for each example. This chapter also discusses estimating emissions from solid waste facilities, a wastewater treatment plant, construction, and air district rules and plans.

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Another methodology, a service population metric, that would measure a project's overall GHG efficiency to determine if a project is more efficient than the existing statewide average for per capita GHG emissions is explored. This methodology may be more directly correlated to a project's ability to help achieve objectives outlined in AB 32, although it relies on establishment of an efficiency-based significance threshold. The subcommittee believes this methodology may eventually be appropriate to evaluate the long-term GHG emissions from a project in the context of meeting AB 32 goals. However, this methodology will need further work and is not considered viable for the interim guidance presented in this white paper.

Greenhouse Gas Mitigation Measures

Common practice in environmental protection is first to avoid, then to minimize, and finally to compensate for impacts. When an impact cannot be mitigated on-site, off-site mitigation can be effectively implemented in several resource areas, either in the form of offsetting the same impact or preserving the resource elsewhere in the region.

This white paper describes and evaluates currently available mitigation measures based on their economic, technological and logistical feasibility, and emission reduction effectiveness. The potential for secondary impacts to air quality are also identified for each measure. A summary of current rules and regulations affecting greenhouse gas emissions and climate change is also provided.

Reductions from transportation related measures (e.g., bicycle, pedestrian, transit, and parking) are explored as a single comprehensive approach to land use. Design measures that focus on enhancing alternative transportation are discussed. Mitigation measures are identified for transportation, land use/building design, mixed-use development, energy efficiency, education/social awareness and construction.

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Purpose

CEQA requires the avoidance or mitigation of significant adverse environmental impacts where there are feasible alternatives available. The contribution of GHG to climate change has been documented in the scientific community. The California Global Warming Solutions Act of 2006 (AB 32) mandates significant reductions in greenhouse gases (GHG); passage of that law has highlighted the need to consider the impacts of GHG emissions from projects that fall under the jurisdiction of the California Environmental Quality Act (CEQA). Because we have only recently come to fully recognize the potential for significant environmental impacts from GHG, most public agencies have not yet established policies and procedures to consider them under CEQA. As a result, there is great need for information and other resources to assist public agencies as they develop their programs.

Air districts have historically provided guidance to local governments on the evaluation of air pollutants under CEQA. As local concern about climate change and GHG has increased, local governments have requested guidance on incorporating analysis of these impacts into local CEQA review. The California Air Pollution Control Officers Association (CAPCOA), in coordination with the CARB, the Governor's Office of Planning and Research (OPR) and two environmental consulting firms, has harnessed the collective expertise to evaluate approaches to analyzing GHG in CEQA. The purpose of this white paper is to provide a common platform of information and tools to address climate change in CEQA analyses, including the evaluation and mitigation of GHG emissions from proposed projects and identifying significance threshold options.

CEQA requires public agencies to ensure that potentially significant adverse environmental effects of discretionary projects are fully characterized, and avoided or mitigated where there are feasible alternatives to do so. Lead agencies have struggled with how best to identify and characterize the magnitude of the adverse effects that individual projects have on the global-scale phenomenon of climate change, even more so since Governor Schwarzenegger signed Executive Order S-3-05 and the state Legislature enacted The Global Warming Solutions Act of 2006 (AB 32). There is now a resounding call to establish procedures to analyze and mitigate greenhouse gas (GHG) emissions. The lack of established thresholds does not relieve lead agencies of their responsibility to analyze and mitigate significant impacts, so many of these agencies are seeking guidance from state and local air quality agencies. This white paper addresses issues inherent in establishing CEQA thresholds, evaluates tools, catalogues mitigation measures and provides air districts and lead agencies with options for incorporating climate change into their programs.

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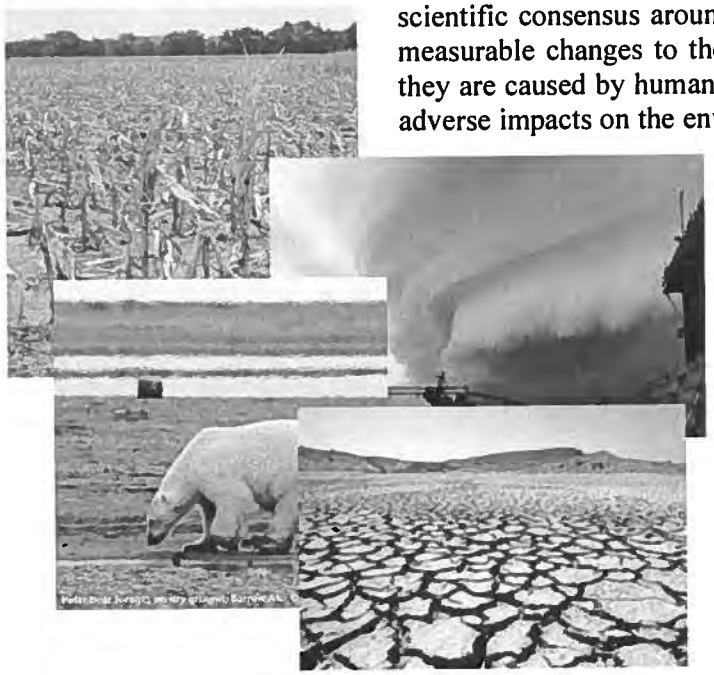
Background

National and International Efforts

International and Federal legislation have been enacted to deal with climate change issues. The Montreal Protocol was originally signed in 1987 and substantially amended in 1990 and 1992. In 1988, the United Nations and the World Meteorological Organization established the IPCC to assess the scientific, technical and socioeconomic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts, and options for adaptation and mitigation. The most recent reports of the IPCC have emphasized the scientific consensus around the evidence that real and measurable changes to the climate are occurring, that they are caused by human activity, and that significant adverse impacts on the environment, the economy, and human health and welfare are unavoidable.



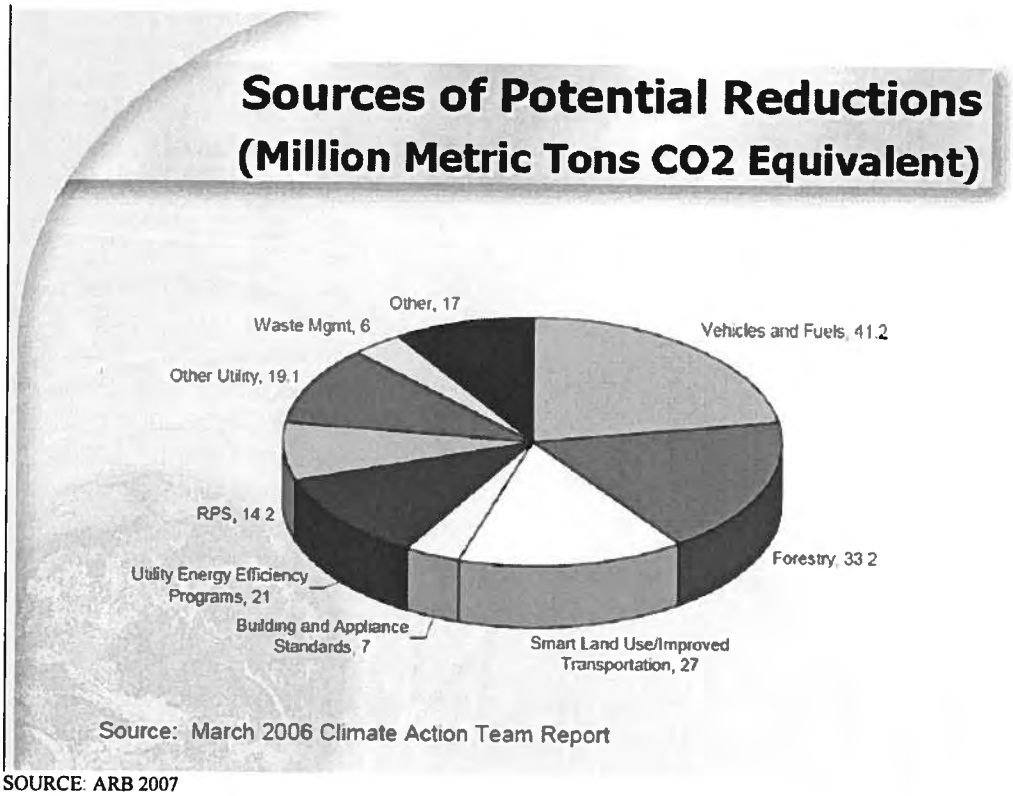
In October 1993, President Clinton announced his Climate Change Action Plan, which had a goal to return greenhouse gas emissions to 1990 levels by the year 2000. This was to be accomplished through 50 initiatives that relied on innovative voluntary partnerships between the private sector and government aimed at producing cost-effective reductions in greenhouse gas emissions. On March 21, 1994, the United States joined a number of countries around the world in signing the United Nations Framework Convention on Climate Change (UNFCCC). Under the Convention, governments agreed to gather and share information on greenhouse gas emissions, national policies, and best practices; launch national strategies for addressing greenhouse gas emissions and adapting to expected impacts, including the provision of financial and technological support to developing countries; and cooperate in preparing for adaptation to the impacts of climate change.

These efforts have been largely policy oriented. In addition to the national and international efforts described above, many local jurisdictions have adopted climate change policies and programs. However, thus far little has been done to assess the significance of the affects new development projects may have on climate change.

Executive Order S-3-05

On June 1, 2005, Governor Schwarzenegger issued Executive Order S-3-05 (S-3-05). It included the following GHG emission reduction targets: by 2010, reduce GHG emissions to 2000 levels; by 2020, reduce GHG emissions to 1990 levels; by 2050, reduce GHG emissions to 80 percent below 1990 levels. To meet the targets, the Governor directed the Secretary of the California Environmental Protection Agency to coordinate with the Secretary of the Business, Transportation and Housing Agency, Secretary of the Department of Food and Agriculture, Secretary of the Resources Agency, Chairperson of the CARB, Chairperson of the Energy Commission and President of the Public Utilities Commission on development of a Climate Action Plan.

The Secretary of CalEPA leads a Climate Action Team (CAT) made up of representatives from the agencies listed above to implement global warming emission reduction programs identified in the Climate Action Plan and report on the progress made toward meeting the statewide greenhouse gas targets that were established in the Executive Order.



SOURCE: ARB 2007

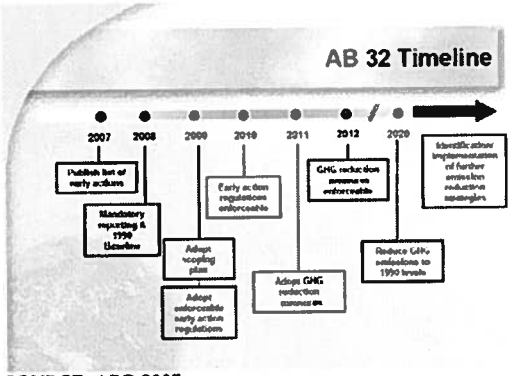
In accord with the requirements of the Executive Order, the first report to the Governor and the Legislature was released in March 2006 and will be issued bi-annually thereafter. The CAT Report to the Governor contains recommendations and strategies to help ensure the targets in Executive Order S-3-05 are met.

California Global Warming Solutions Act of 2006 (AB 32)

In 2006, the California State Legislature adopted the California Global Warming Solutions Act of 2006. AB 32 establishes a cap on statewide greenhouse gas emissions and sets forth the regulatory framework to achieve the corresponding reduction in statewide emissions levels. AB 32 charges the California Air Resources Board (CARB), the state agency charged with regulating statewide air quality, with implementation of the act. Under AB 32, greenhouse gases are defined as: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

The regulatory steps laid out in AB 32 require CARB to: adopt early action measures to reduce GHGs; to establish a statewide greenhouse gas emissions cap for 2020 based on 1990 emissions; to adopt mandatory reporting rules for significant source of greenhouse gases; and to adopt a scoping plan indicating how emission reductions will be achieved via regulations, market mechanisms and other actions; and to adopt the regulations needed to achieve the maximum technologically feasible and cost-effective reductions in greenhouse gases.

AB 32 requires that by January 1, 2008, the State Board shall determine what the statewide greenhouse gas emissions inventory was in 1990, and approve a statewide greenhouse gas emissions limit that is equivalent to that level, to be achieved by 2020. While the level of 1990 GHG emissions has not yet been approved, CARB's most recent emission inventory indicates that California had annual emissions of 436 million metric tons of carbon dioxide equivalent (MMT CO_2e) in 1990 and 497 MMT CO_2e in 2004.



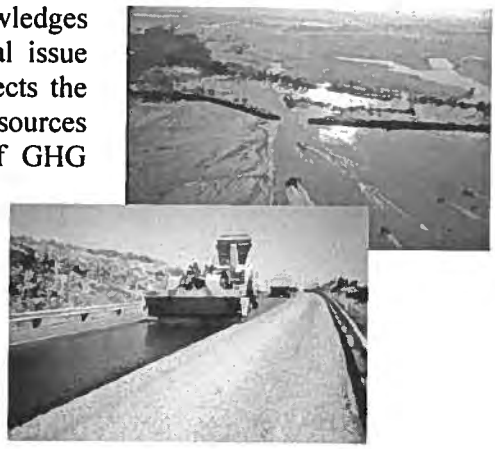
SOURCE: ARB 2007

The regulatory timeline laid out in AB 32 requires that by July 1, 2007, CARB adopt a list of discrete early action measures, or regulations, to be adopted and implemented by January 1, 2010. These actions will form part of the State's comprehensive plan for achieving greenhouse gas emission reductions. In June 2007, CARB adopted three discrete early action measures. These three new proposed regulations meet the definition of "discrete early action greenhouse gas reduction measures," which include the following: a low carbon fuel standard; reduction of HFC-134a emissions from non-professional servicing of motor vehicle air conditioning systems; and improved landfill methane capture. CARB estimates that by 2020, the reductions from those three discrete early action measures would be approximately 13-26 MMT CO_2e.

CARB evaluated over 100 possible measures identified by the CAT for inclusion in the list of discrete early action measures. On October 25, 2007 CARB gave final approval to the list of Early Action Measures, which includes nine discrete measures and 35

additional measures, all of which are to be enforceable by January 1, 2010. AB 32 requires that by January 1, 2009, CARB adopt a scoping plan indicating how emission reductions will be achieved via regulations, market mechanisms and other actions.

Senate Bill 97



Senate Bill (SB) 97, signed in August 2007, acknowledges that climate change is an important environmental issue that requires analysis under CEQA. This bill directs the OPR to prepare, develop, and transmit to the Resources Agency guidelines for the feasible mitigation of GHG emissions or the effects of GHG emissions, by July 1, 2009. The Resources Agency is required to certify or adopt those guidelines by January 1, 2010. This bill also protects projects funded by the Highway Safety, Traffic Reduction, Air Quality and Port Security Bond Act of 2006, or the Disaster Preparedness and Flood Protection Bond Act of 2006 (Proposition 1B or 1E) from claims of inadequate analysis of GHG as a legitimate cause of action. This latter provision will be repealed on January 1, 2010. Thus, this "protection" is highly limited to a handful of projects and for a short time period.

The Role of Air Districts in the CEQA Process

Air districts assume one of three roles in the CEQA process. They may be lead agencies when they are adopting regulations and air quality plans. In some instances, they can also be a lead agency when approving permits to construct or operate for applicants subject to district rules. However, in many cases where an air district permit is involved, another agency has broader permitting authority over the project and assumes the role of lead agency. In these situations, the air district becomes what is referred to as a responsible agency under CEQA. When CEQA documents are prepared for projects that do not involve discretionary approval of a district regulation, plan or permit, the air district may assume the role of a concerned or commenting agency. In this role, it is typical for air districts to comment on CEQA documents where there may be air quality-related adverse impacts, such as projects that may create significant contributions to existing violations of ambient standards, cause a violation of an ambient standard or create an exposure to toxic air contaminants or odors. In some cases, the air district may also act in an "advisory" capacity to a lead agency early on in its review of an application for a proposed development project.

A few air districts in California began developing significance thresholds for use in CEQA analyses in the late 1980's and early 1990's. By the mid-1990's most air districts had developed CEQA thresholds for air quality analyses. Many of the districts have included in their guidance the analysis of rule development and permits that may be subject to CEQA.

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What is Not Addressed in this Paper

Impacts of Climate Change to a Project

The focus of this paper is addressing adverse impacts to climate change and the ability to meet statewide GHG reduction goals caused by proposed new land development projects.

CEQA also requires an assessment of significant adverse impacts a project might cause by bringing development and people into an area affected by climate change (CEQA Guidelines §15126.2). For example, an area that experiences higher average temperatures due to climate change may expose new development to more frequent exceedances and higher levels of ozone concentrations. Alternatively, a rise in sea level brought on by climate change may inundate new development locating in a low-lying area. The methodologies, mitigation and threshold approaches discussed in this paper do not specifically address the potential adverse impacts resulting from climate change that may affect a project.

Impacts from Construction Activity

Although construction activity has been addressed in the analytical methodologies and mitigation chapters, this paper does not discuss whether any of the threshold approaches adequately addresses impacts from construction activity. More study is needed to make this assessment or to develop separate thresholds for construction activity. The focus of this paper is the long-term adverse operational impacts of land use development.

Introduction

Any analysis of environmental impacts under CEQA includes an assessment of the nature and extent of each impact expected to result from the project to determine whether the impact will be treated as significant or less than significant. CEQA gives lead agencies discretion whether to classify a particular environmental impact as significant. "The determination of whether a project may have a significant effect on the environment calls for careful judgment on the part of the public agency involved," ref: CEQA Guidelines §15064(b) ("Guidelines"). Ultimately, formulation of a standard of significance requires the lead agency to make a policy judgment about where the line should be drawn distinguishing adverse impacts it considers significant from those that are not deemed significant. This judgment must, however, be based on scientific information and other factual data to the extent possible (Guidelines §15064(b)).

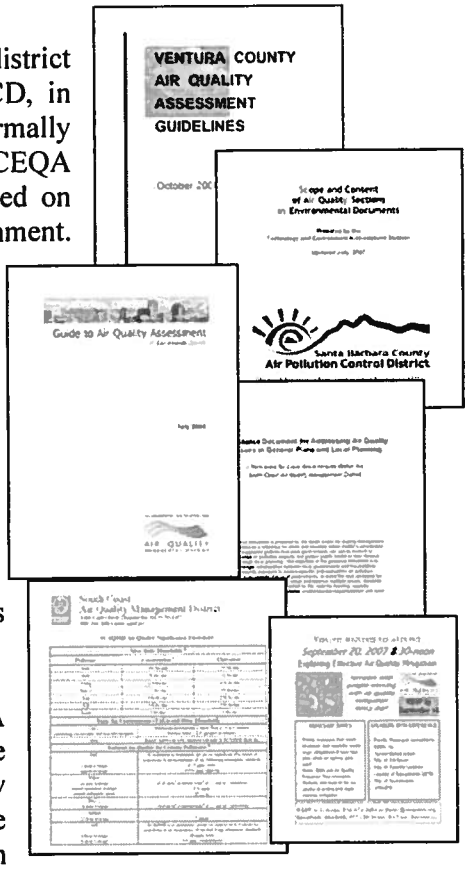
CEQA does not require that agencies establish thresholds of significance. Guidelines §15064.7(a) encourages each public agency "...to develop and publish thresholds of significance that the agency uses in the determination of the significance of environmental effects. A threshold of significance is an identifiable quantitative, qualitative or performance level of a particular environmental effect, non-compliance with which means the effect will normally be determined to be significant by the agency and compliance with which normally means the effect will be determined to be less than significant."

Once such thresholds are established, an impact that complies with the applicable threshold will "normally" be found insignificant and an impact that does not comply with the applicable threshold will "normally" be found significant.

Additionally, Guidelines §15064.7(b) requires that if thresholds of significance are adopted for general use as part of the lead agency's environmental review process they must be adopted by ordinance, resolution, rule or regulation, and developed through a public review process and be supported by substantial evidence.

While many public agencies adopt regulatory standards as thresholds, the standards do not substitute for a public agency's use of careful judgment in determining significance. They also do not replace the legal standard for significance (i.e., if there is a fair argument, based on substantial evidence in light of the whole record that the project may have a significant effect, the effect should be considered significant) (Guidelines §15064(f)(1). Also see *Communities for a Better Environment v. California Resource Agency* 103 Cal. App. 4th 98 (2002)). In other words, the adoption of a regulatory standard does not create an irrebuttable presumption that impacts below the regulatory standard are less than significant.

Summary of CEQA Thresholds at Air Districts



This section briefly summarizes the evolution of air district CEQA significance thresholds. Ventura County APCD, in 1980, was the first air district in California that formally adopted CEQA significance thresholds. Their first CEQA assessment document contained impact thresholds based on project type: residential, nonresidential, and government. Then, as now, the District's primary CEQA thresholds applied only to ROG and NO_x. The 1980 Guidelines did not address other air pollutants.

Santa Barbara County APCD and the Bay Area AQMD adopted thresholds in 1985. The South Coast AQMD recommended regional air quality thresholds in 1987 for CO, SO_2, NO_2, particulates, ROG, and lead. Most of the other California air districts adopted CEQA guidance and thresholds during the 1990's. Air districts have updated their thresholds and guidelines several times since they were first published.

Originally, most districts that established CEQA thresholds focused on criteria pollutants for which the district was nonattainment and the thresholds only addressed project level impacts. Updates during the 1990's began to add additional air quality impacts such as odors, toxic air contaminants and construction. Several air districts also developed thresholds for General Plans that relied on an assessment of the plan consistency with the district's air quality plans. A consistency analysis involves comparing the project's land use to that of the general plan and the population and employment increase to the forecasts underlying the assumptions used to develop the air quality plan.

Most air district thresholds for CEQA are based on the threshold for review under the New Source Review (NSR). The NSR threshold level is set by district rule and is different depending on the nonattainment classification of the air district. Areas with a less severe classification have a higher NSR trigger level while the most polluted areas have the lowest NSR trigger level. Some districts, such as Ventura County APCD, have significantly lower CEQA thresholds that are not tied to the NSR requirements. In Ventura, one set of CEQA thresholds is 25 pounds per day for all regions of Ventura County, except the Ojai Valley. The second set of CEQA thresholds was set at 5 pounds per day for the Ojai Valley.

The Sacramento Metropolitan AQMD bases its thresholds for ozone precursors on the projected land use share of emission reductions needed for attainment. The emission reductions needed to reach attainment are based on commitments made in the state implementation plan (SIP) prepared for the federal clean air act.

CEQA Considerations in Setting Thresholds

Public agencies use significance thresholds to disclose to their constituents how they plan on evaluating and characterizing the severity of various environmental impacts that could be associated with discretionary projects that they review. Significance thresholds are also used to help identify the level of mitigation needed to reduce a potentially significant impact to a less than significant level and to determine what type of an environmental document should be prepared for a project; primarily a negative declaration, mitigated negative declaration or an environmental impact report.

While public agencies are not required to develop significance thresholds, if they decide to develop them, they are required to adopt them by ordinance, resolution, rule or regulation through a public process. A lead agency is not restrained from adopting any significance threshold it sees as appropriate, as long as it is based on substantial evidence. CEQA Guidelines §15064.7 encourages public agencies to develop and publish significance thresholds that are identifiable, quantitative, qualitative or performance level that the agency uses in the determination of the significance of environmental effects. The courts have ruled that a "threshold of significance" for a given environmental effect is simply that level at which the lead agency finds the effects of the project to be significant.

Before an agency determines its course with regard to climate change and CEQA, it must be made clear that a threshold, or the absence of one, will not relieve a lead agency from having to prepare an EIR or legal challenges to the adequacy of an analysis leading to a conclusion, or lack of a conclusion, of significance under CEQA. CEQA has generally favored the preparation of an EIR where there is any substantial evidence to support a fair argument that a significant adverse environmental impact may occur due to a proposed project. This paper explores three alternative approaches to thresholds, including a no threshold option, a zero threshold option and a non-zero threshold option.

Fair Argument Considerations

Under the CEQA fair argument standard, an EIR must be prepared whenever it can be fairly argued, based on substantial evidence in the administrative record, that a project may have a significant adverse effect on the environment. "Substantial evidence" comprises "enough relevant information and reasonable inferences from this information that a fair argument can be made to support a conclusion, even though other conclusions might also be reached." (Guidelines §15384) This means that if factual information is presented to the public agency that there is a reasonable possibility the project could have

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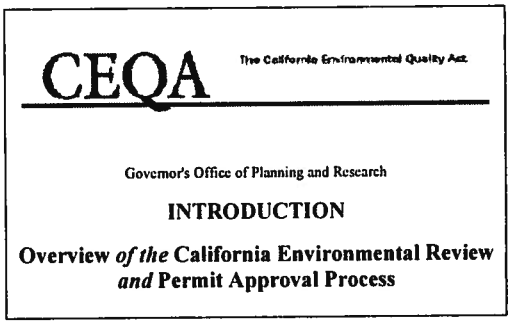
a significant effect on the environment, an EIR is required even if the public agency has information to the contrary (Guidelines §15064 (f)).

The courts have held that the fair argument standard "establishes a low threshold for initial preparation of an EIR, which reflects a preference for resolving doubts in favor of environmental review." (*Santa Teresa Citizen Action Group v. City of San Jose* [2003] 114 Cal.App.4th 689) Although the determination of whether a fair argument exists is made by the public agency, that determination is subject to judicial scrutiny when challenged in litigation. When the question is whether an EIR should have been prepared, the court will review the administrative record for factual evidence supporting a fair argument.

The fair argument standard essentially empowers project opponents to force preparation of an EIR by introducing factual evidence into the record that asserts that the project may have a significant effect on the environment. This evidence does not need to be conclusive regarding the potential significant effect.

In 1998, the Resources Agency amended the State CEQA Guidelines to encourage the use of thresholds of significance. Guidelines §15064 (h) provided that when a project's impacts did not exceed adopted standards, the impacts were to be considered less than significant. The section went on to describe the types of adopted standards that were to be considered thresholds. Guidelines § 15064.7 provided that agencies may adopt thresholds of significance to guide their determinations of significance. Both of these sections were challenged when environmental groups sued the Resources Agency in 2000 over the amendments. The trial court concluded that §15064.7 was proper, if it was applied in the context of the fair argument standard.


CEQA The California Environmental Quality Act

Governor's Office of Planning and Research

INTRODUCTION

Overview *of the* California Environmental Review *and* Permit Approval Process

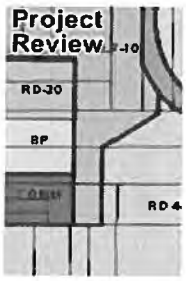
At the appellate court level, §15064(h) was invalidated. [2] Establishing a presumption that meeting an adopted standard would avoid significant impacts was "inconsistent with controlling CEQA law governing the fair argument approach." The Court of Appeal explained that requiring agencies to comply with a regulatory standard "relieves the agency of a duty it would have under the fair argument approach to look at evidence beyond the regulatory standard, or in contravention of the standard, in deciding whether an EIR must be prepared. Under the fair argument approach, any substantial evidence supporting a fair argument that a project may have a significant environmental effect would trigger the preparation of an EIR." (*Communities for a Better Environment v. California Resources Agency* [2002] 103 Cal.App.4th 98)

[2] Prior §15064(h) has been removed from the State CEQA Guidelines. Current §15064(h) discusses cumulative impacts.

In summary, CEQA law does not require a lead agency to establish significance thresholds for GHG. CEQA guidelines encourage the development of thresholds, but the absence of an adopted threshold does not relieve the agency from the obligation to determine significance.

Defensibility of CEQA Analyses

The basic purposes of CEQA, as set out in the State CEQA Guidelines, include: (1) informing decision makers and the public about the significant environmental effects of proposed projects; (2) identifying ways to reduce or avoid those impacts; (3) requiring the implementation of feasible mitigation measures or alternatives that would reduce or avoid those impacts; and (4) requiring public agencies to disclose their reasons for approving any project that would have significant and unavoidable impacts (Guidelines §15002). CEQA is enforced through civil litigation over procedure (i.e., did the public agency follow the correct CEQA procedures?) and adequacy (i.e., has the potential for impacts been disclosed, analyzed, and mitigated to the extent feasible?).



The California Supreme Court has held that CEQA is "to be interpreted in such manner as to afford the fullest possible protection to the environment within the reasonable scope of the statutory language." (*Friends of Mammoth v. Board of Supervisors* [1972] 8 Cal.3d 247, 259) Within that context, the role of the courts is to weigh the facts in each case and apply their judgment. Although the court may rule on the adequacy of the CEQA work, the court is not empowered to act in the place of the public agency to approve or deny the project for which the CEQA document was prepared. Further, the court's review is limited to the evidence contained in the administrative record that was before the public agency when it acted on the project.

Putting aside the issue of CEQA procedure, the defensibility of a CEQA analysis rests on the following concerns:

- whether the public agency has sufficiently analyzed the environmental consequences to enable decision makers to make an intelligent decision;
- whether the conclusions of the public agency are supported by substantial evidence in the administrative record; and
- whether the agency has made a good faith effort at the full disclosure of significant effects.

CEQA analyses need not be perfect or exhaustive -- the depth and breadth of the analysis is limited to what is "reasonably feasible." (Guidelines §15151) At the same time, the analysis "must include detail sufficient to enable those who did not participate in its preparation to understand and to consider meaningfully the issues raised by the proposed

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project." (Laurel Heights Improvement Assn. v. Regents of University of California (1988) 47 Cal.3d 376)

By itself, establishment of a GHG threshold will not insulate individual CEQA analyses from challenge. Defensibility depends upon the adequacy of the analysis prepared by the lead agency and the process followed. However, the threshold can help to define the boundaries of what is a reasonable analysis by establishing when an analysis will be required and the basic scope of that analysis. The threshold would attempt to define the point at which an analysis will be required and when a level of impact becomes significant, requiring preparation of an EIR. If the threshold includes recommendations for the method or methods of analysis, it can establish the minimum level of analysis to address this issue.

Considerations in Setting Thresholds for Stationary Source Projects

In many respects, the analysis of GHG emissions from stationary sources is much more straightforward than the analysis of land use patterns, forecasted energy consumption, and emissions from mobile sources. The reason is that, for the most part, the latter analyses depend largely on predictive models with myriad inputs and have a wider range of error. Emissions from stationary sources involve a greater reliance on mass and energy balance calculations and direct measurements of emissions from the same or similar sources. Energy demand is more directly tied to production, and even associated mobile source emissions will likely fall within narrower predictive windows.

Implementing CEQA Without a Threshold

A lead agency is not required to establish significance thresholds for GHG emissions from stationary sources. The lead agency may find that it needs more information or experience evaluating GHG from these types of projects to determine an appropriate significance threshold. As with other project types, the lead agency could conduct a project specific analysis to determine whether an environmental impact report is needed and to determine the level of mitigation that is appropriate. The agency might also rely on thresholds established for criteria pollutants as a screening method, and analyze GHG emissions (and require mitigation) from projects with emissions above the criteria pollutant thresholds. Over time, the agency could amass information and experience with specific project categories that would support establishing explicit thresholds. The lead agency may also choose to base local CEQA thresholds on state guidelines or on the category-specific reduction targets established by ARB in its scoping plan for implementing AB32. Resource constraints and other considerations associated with implementing CEQA without GHG thresholds for stationary sources would be similar to those outlined for other types of projects (see Chapter 5 – No Threshold Option).

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Implementing CEQA with Threshold of Zero

A lead agency may find that any increase in GHG emissions is potentially significant under CEQA. The resources and other considerations for implementing a threshold of zero for stationary sources are the same as those outlined for other types of projects (see Chapter 6 – Zero Threshold Option).

Implementing CEQA with a Non-Zero Threshold

A lead agency may identify one or more non-zero thresholds for significance of emissions of GHG from stationary sources. The agency could elect to rely on existing thresholds for reviewing new or modified stationary sources of GHG, if the state or local air district has established any. The agency could also apply the threshold(s) established for non-stationary sources to GHG emissions from stationary sources. Significance thresholds could also be established by ordinance, rule, or policy for a given category of stationary sources; this approach is especially conducive to a tiered threshold approach. For example, the agency could establish significance and mitigation tiers for stationary compression-ignition diesel-fueled generators. Under such an approach, the project proponent could be first required to use a lower GHG-emitting power source if feasible, and if not, to apply mitigation based on the size of the generator and other defined considerations, such as hours of operation. Certain classes of generators could be found to be insignificant under CEQA (e.g., those used for emergency stand-by power only, with a limit on the annual hours of use). As with non-stationary projects, the goal of establishing non-zero thresholds is to maximize environmental protection, while minimizing resources used. Resource and other considerations outlined for non-stationary projects are applicable here (see Chapter 7 – Non-Zero Threshold Options).

Implementing CEQA with Different Thresholds for Stationary and Non-stationary Projects

Although a lead agency may apply the same thresholds to stationary and non-stationary projects, it is not required to do so. There are, in fact, some important distinctions between the two types of projects that could support applying different thresholds. The lead agency should consider the methods used to estimate emissions. Are the estimates a "best/worst reasonable scenario" or are they based on theoretical maximum operation? How accurate are the estimates (are they based on models, simulations, emission factors, source test data, manufacturer specifications, etc.)? To what extent could emissions be reduced through regulations after the project is constructed if they were found to be greater than originally expected (i.e., is it possible to retrofit emissions control technology onto the source(s) of GHG at a later date, how long is the expected project life, etc.)? Are there emission limits or emissions control regulations (such as New Source Review) that provide certainty that emissions will be mitigated? Generally, stationary source emissions are based on maximum emissions (theoretical or allowed under law or regulation), are more accurate, and are more amenable to retrofit at a later time than non-stationary source emissions. It is also more likely that category specific

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rules or some form of NSR will apply to stationary sources than non-stationary projects. Notwithstanding, it is almost always more effective and cost-efficient to apply emission reduction technology at the design phase of a project. There are, therefore, a number of considerations that need to be evaluated and weighed before establishing thresholds – and which may support different thresholds for stationary and non-stationary projects. Furthermore, the considerations may change over time as new regulations are established and as emissions estimation techniques and control technology evolves.

Direct GHG Emissions from Stationary Sources

The main focus of this paper has been the consideration of projects that do not, in the main, involve stationary sources of air pollution, because stationary source projects are generally a smaller percentage of the projects seen by most local land use agencies. That said, some discussion of stationary sources is warranted. As the broader program for regulating GHG from these sources is developed, the strategies for addressing them under CEQA will likely become more refined.

The primary focus of analysis of stationary source emissions has traditionally been those pollutants that are directly emitted by the source, whether through a stack or as fugitive releases (such as leaks). CAPCOA conducted a simplified analysis of permitting activity to estimate the number of stationary source projects with potentially significant emissions of greenhouse gases that might be seen over the course of a year. This analysis looked only at stationary combustion sources (such as boilers and generators), and only considered direct emissions. A lead agency under CEQA may see a different profile of projects than the data provided here suggest, depending on what other resources are affected by projects. In addition, air districts review like-kind replacements of equipment to ensure the new equipment meets current standards, but such actions might not constitute a project for many land use agencies or other media regulators. The data does provide a useful benchmark, however, for lead agencies to assess the order of magnitude of potential stationary source projects. A similar analysis is included for non-stationary projects in Chapter 7.

Table 1: Analysis of GHG Emissions from Stationary Combustion Equipment Permits[3]

	BAAQMD	SMAQMD	SJVUAPCD	SCAQMD
Total Applications for Year	1499	778	1535	1179
Affected at threshold of:				
900 metric tons/year	26	43	63	108
10,000 metric tons/year	7	5	26	8
25,000 metric tons/year	3	1	11	4

[3] District data varies based on specific local regulations and methodologies.

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Emissions from Energy Use

In addition to the direct emissions of GHG from stationary projects, CEQA will likely need to consider the project's projected energy use. This could include an analysis of opportunities for energy efficiency, onsite clean power generation (e.g., heat/energy recovery, co-generation, geothermal, solar, or wind), and the use of dedicated power contracts as compared to the portfolio of generally available power. In some industries, water use and conservation may provide substantial GHG emissions reductions, so the CEQA analysis should consider alternatives that reduce water consumption and wastewater discharge. The stationary project may also have the opportunity to use raw or feedstock materials that have a smaller GHG footprint; material substitution should be evaluated where information is available to do so.

Emissions from Associated Mobile Sources

The stationary project will also include emissions from associated mobile sources. These will include three basic components: emissions from employee trips, emissions from delivery of raw or feedstock materials, and emissions from product transport. Employee trips can be evaluated using trip estimation as is done for non-stationary projects, and mitigations would include such measures as providing access to and incentives for use of public transportation, accessibility for bicycle and pedestrian modes of transport, employer supported car or vanpools (including policies such as guaranteed rides home, etc). Upstream and downstream emissions related to goods movement can also be estimated with available models. The evaluation will need to determine the extent of the transport chain that should be included (to ensure that all emissions in the chain have been evaluated and mitigated, but to avoid double counting). Mitigations could include direct actions by operators who own their own fleet, or could be implemented through contractual arrangements with independent carriers; again, the evaluation will need to consider how far up and down the chain mitigation is feasible and can be reasonably required.

Comparing Emissions Changes Across Pollutant Categories

The potential exists for certain GHG reduction measures to increase emissions of criteria and toxic pollutants known to cause or aggravate respiratory, cardiovascular, and other health problems. For instance, GHG reduction efforts such as alternative fuels and methane digesters may create significant levels of increased pollutants that are detrimental to the health of the nearby population (e.g.; particulate matter, ozone precursors, toxic air contaminants). Such considerations should be included in any CEQA analysis of a project's environmental impacts. While there are many win-win

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strategies that can reduce both GHG and criteria/toxic pollutant emissions, when faced with situations that involve tradeoffs between the two, the more immediate public health concerns that may arise from an increase in criteria or toxic pollutant emissions should take precedence. GHG emission reductions could be achieved offsite through other mitigation programs.

Introduction

Under state law, it is the purview of each lead agency to determine what, if any, significance thresholds will be established to guide its review of projects under CEQA. While the state does provide guidelines for implementing CEQA, the guidelines have left the decision of whether to establish thresholds (and if so, at what level) to individual lead agencies. Frequently, lead agencies consult with resource-specific agencies (such as air districts) for assistance in determining what constitutes a significant impact on that specific resource.

With the passage of AB 32, the ARB has broad authority to regulate GHG emissions as necessary to meet the emission reduction goals of the statute. This may include authority to establish emission reduction requirements for new land use projects, and may also enable them to recommend statewide thresholds for GHG under CEQA.

In developing this white paper, CAPCOA recognizes that, as the GHG reduction program evolves over time, GHG thresholds and other policies and procedures for CEQA may undergo significant revision, and that uniform statewide thresholds and procedures may be established. This paper is intended to serve as a resource for public agencies until such time that statewide guidance is established, recognizing that decisions will need to be made about GHG emissions from projects before such guidance is available. This paper is not, however, uniform statewide guidance. As stated before, it outlines several possible approaches without endorsing any one over the others.

Some air districts may choose to use this paper to support their establishment of guidance for GHG under CEQA, including thresholds. This paper does not, nor should it be construed to require a district to implement any of the approaches evaluated here. Decisions about whether to provide formal local guidance on CEQA for projects with GHG emissions, including the question of thresholds, will be made by individual district boards.

Each of the 35 air districts operates independently and has its own set of regulations and programs to address the emissions from stationary, area and mobile sources, consistent with state and federal laws, regulations, and guidelines. The independence of the districts allows specific air quality problems to be addressed on a local level. In addition, districts have also established local CEQA thresholds of significance for criteria pollutants – also to address the specific air quality problems relative to that particular district.

The overall goal of air district thresholds is to achieve and maintain health based air quality standards within their respective air basins and to reduce transport of emissions to other air basins. In establishing recommended thresholds, air districts consider the existing emission inventory of criteria pollutants and the amount of emission reductions needed to attain and maintain ambient air quality standards.

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However, unlike criteria pollutants where individual districts are characterized by varying levels of pollutant concentrations and source types, greenhouse gases (GHG) and their attendant climate change ramifications are a global problem and, therefore, may suggest a uniform approach to solutions that ensure both progress and equity.

Under SB97, the Office of Planning and Research is directed to prepare, develop, and transmit to the Resources Agency guidelines for the feasible mitigation of GHG emissions or the effects of GHG emissions through CEQA by July 1, 2009. Those guidelines may recommend thresholds. As stated, this paper is intended to provide a common platform of information and tools to support local decision makers until such time that statewide guidance or requirements are promulgated.

Local Ability to Promulgate District-Specific GHG Thresholds

One of the primary reasons behind the creation of air districts in California is the recognition that some regions within the state face more critical air pollution problems than others and, as has often been pointed out – one size does not fit all. For example, a "Serious" federal nonattainment district would need greater emission reductions than a district already in attainment – and, therefore, the more "serious" district would set its criteria pollutant CEQA thresholds of significance much lower than the air district already in attainment.

The action of GHGs is global in nature, rather than local or regional (or even statewide or national). Ultimately there may be a program that is global, or at least national in scope. That said, actions taken by a state, region, or local government can contribute to the solution of the global problem. Local governments are not barred from developing and implementing programs to address GHGs. In the context of California and CEQA, lead agencies have the primary responsibility and authority to determine the significance of a project's impacts.

Further, air districts have primary authority under state law for "control of air pollution from all sources, other than emissions from motor vehicles." (H&SC §40000) The term air contaminant or "air pollutant" is defined extremely broadly, to mean "any discharge, release, or other propagation into the atmosphere" and includes, but is not limited to, soot, carbon, fumes, gases, particulate matter, etc. Greenhouse gases and other global warming pollutants such as black carbon would certainly be included in this definition, just as the U.S. Supreme Court held in Massachusetts v. EPA that greenhouse gases were air pollutants under the federal Clean Air Act. Therefore, air districts have the primary authority to regulate global warming pollutants from nonvehicular sources. AB 32 does not change this result. Although it gives wide responsibility to CARB to regulate greenhouse gases from all sources, including nonvehicular sources, it does not preempt the districts. AB 32 specifically states That "nothing in this division shall limit or expand the existing authority of any district..."(H&SC § 38594). Thus, districts and CARB retain concurrent authority over nonvehicular source greenhouse gas emissions.

Introduction

The CEQA statutes do not require an air district or any lead agency to establish significance thresholds under CEQA for any pollutant. While there are considerations that support the establishment of thresholds (which are discussed in other sections of this document), there is no obligation to do so.

An air district or other lead agency may elect not to establish significance thresholds for a number of reasons. The agency may believe that the global nature of the climate change problem necessitates a statewide or national framework for consideration of environmental impacts. SB 97 directs OPR to develop "guidelines for the mitigation of greenhouse gas emissions or the effects of greenhouse gas emissions by July 1, 2009," and directs the California Resources Agency to certify and adopt the guidelines by June 30, 2010.

An agency may also believe there is insufficient information to support selecting one specific threshold over another. As described earlier, air districts have historically set CEQA thresholds for air pollutants in the context of the local clean air plan, or (in the case of toxic air pollutants) within the framework of a rule or policy that manages risks and exposures due to toxic pollutants. There is no current framework that would similarly manage impacts of greenhouse gas pollutants, although the CARB is directed to establish one by June 30, 2009, pursuant to AB 32. A local agency may decide to defer any consideration of thresholds until this framework is in place.

Finally, an agency may believe that the significance of a given project should be assessed on a case-by-case basis in the context of the project at the time it comes forward.

Implementing CEQA Without Significance Thresholds for GHG

The absence of a threshold does not in any way relieve agencies of their obligations to address GHG emissions from projects under CEQA. The implications of not having a threshold are different depending on the role the agency has under CEQA – whether it is acting in an advisory capacity, as a responsible agency, or as a lead agency.

Implications of No Thresholds for an Agency Acting in an Advisory Capacity

Air districts typically act in an advisory capacity to local governments in establishing the framework for environmental review of air pollution impacts under CEQA. This may include recommendations regarding significance thresholds, analytical tools to assess emissions and impacts, and mitigations for potentially significant impacts. Although districts will also address some of these issues on a project-specific basis as responsible agencies, they may provide general guidance to local governments on these issues that

are program wide, and these are advisory (unless they have been established by regulation).

An air district that has not established significance thresholds for GHG will not provide guidance to local governments on this issue. This does not prevent the local government from establishing thresholds under its own authority. One possible result of this would be the establishment of different thresholds by cities and counties within the air district. Alternatively, the air district could advise local governments not to set thresholds and those jurisdictions may follow the air district's guidance.

It is important to note here (as has been clearly stated by the Attorney General in comments and filings) that lack of a threshold does *not* mean lack of significance. An agency may argue lack of significance for any project, but that argument would have to be carried forth on a case-by-case, project specific basis. By extension then, a decision not to establish thresholds for GHG is likely to result in a greater workload for responsible and lead agencies as they consider individual projects under CEQA.

Implications of No Thresholds for a Responsible Agency

If there are no established thresholds of significance, the significance of each project will have to be determined during the course of review. The responsible agency (e.g., the air district) will review each project referred by the lead agency. The review may be qualitative or quantitative in nature. A qualitative review would discuss the nature of GHG emissions expected and their potential effect on climate change as the district understands it. It could also include a discussion of the relative merits of alternative scenarios. A quantitative analysis would evaluate, to the extent possible, the expected GHG emissions; it would also need to evaluate their potential effect on climate change and might include corresponding analysis of alternatives. The air district, as a responsible agency, may also identify mitigation measures for the project.

The lack of established thresholds will make the determination of significance more resource intensive for each project. The district may defer to the lead agency to make this determination, however the district may be obligated, as a responsible agency, to evaluate the analysis and determination.

Implications of No Thresholds for a Lead Agency

The main impact of not having significance thresholds will be on the primary evaluation of projects by the lead agency. Without significance thresholds, the agency will have to conduct some level of analysis of every project to determine whether an environmental impact report is needed. There are three fundamental approaches to the case-by-case analysis of significance, including presumptions of significance or insignificance, or no presumption:

1. The agency can begin with a presumption of significance and the analysis would be used to support a case-specific finding of no significance. This is similar to establishing a threshold of zero, except that here, the "threshold" is rebuttable. This approach may result in a large number of projects proceeding to preparation of an environmental impact report. Because of the attendant costs, project proponents may challenge the determination of significance, although formal challenge is less likely than attempts to influence the determination.

2. The agency can begin with a presumption of insignificance, and the analysis would be used to support a case-specific finding of significance. A presumption of insignificance could be based on the perspective that it would be speculative to attempt to identify the significance of GHG emissions from a project relative to climate change on a global scale. This approach might reduce the number of projects proceeding to preparation of environmental impact reports. It is likely to have greater success with smaller projects than larger ones, and a presumption of *insignificance* may be more likely to be challenged by project opponents.

3. It is not necessary for the lead agency to have any presumption either way. The agency could approach each project from a *tabula rasa* perspective, and have the determination of significance more broadly tied to the specific context of the project; this approach is likely to be resource intensive, and creates the greatest uncertainty for project proponents. To the extent that it results in a lead agency approving similar projects based on different determinations of significance for GHG emissions, it may be more vulnerable to challenge from either proponents or opponents of the project. Alternatively, in the absence of either thresholds or presumptions, the lead agency could use each determination of significance to build its approach in the same way that subsequent judgments define the law.

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Relevant Citations

The full text of relevant citations is in Appendix A.

Public Resources Code – §21082.2, Significant Effect on Environment; Determination; Environmental Impact Report Preparation.

State CEQA Guidelines – §15064, Determining the Significance of the Environmental Effects Caused by a Project.

Introduction

If an air district or lead agency determines that any degree of project-related increase in GHG emissions would contribute considerably to climate change and therefore would be a significant impact, it could adopt a zero-emission threshold to identify projects that would need to reduce their emissions. A lead agency may determine that a zero-emission threshold is justified even if other experts may disagree. A lead agency is not prevented from adopting any significance threshold it sees as appropriate, as long as it is based on substantial evidence.

If the zero threshold option is chosen, all projects subject to CEQA would be required to quantify and mitigate their GHG emissions, regardless of the size of the project or the availability of GHG reduction measures available to reduce the project's emissions. Projects that could not meet the zero-emission threshold would be required to prepare environmental impact reports to disclose the unmitigable significant impact, and develop the justification for a statement of overriding consideration to be adopted by the lead agency.

Implementing CEQA With a Zero Threshold for GHG

The scientific community overwhelmingly agrees that the earth's climate is becoming warmer, and that human activity is playing a role in climate change. Unlike other environmental impacts, climate change is a global phenomenon in that all GHG emissions generated throughout the earth contribute to it. Consequently, both large and small GHG generators cause the impact. While it may be true that many GHG sources are individually too small to make any noticeable difference to climate change, it is also true that the countless small sources around the globe combine to produce a very substantial portion of total GHG emissions.

A zero threshold approach is based on a belief that, 1) all GHG emissions contribute to global climate change and could be considered significant, and 2) not controlling emissions from smaller sources would be neglecting a major portion of the GHG inventory.

CEQA explicitly gives lead agencies the authority to choose thresholds of significance. CEQA defers to lead agency discretion when choosing thresholds. Consequently, a zero-emission threshold has merits.

The CEQA review process for evaluating a project's impact on global climate change under the zero threshold option would involve several components. Air quality sections would be written by lead agencies to include discussions on climate change in CEQA documents, GHG emissions would be calculated, and a determination of significance would be made. The local air districts would review and comment on the climate change discussions in environmental documents. Lead agencies may then revise final EIRs to accommodate air district comments. More than likely, mitigation measures will be specified for the project, and a mitigation monitoring program will need to be put in place to ensure that these measures are being implemented.

Since CEQA requires mitigation to a less than significant level, it is conceivable that many projects subjected to a zero threshold could only be deemed less than significant with offsite reductions or the opportunity to purchase greenhouse gas emission reduction credits. GHG emission reduction credits are becoming more readily available however the quality of the credits varies considerably. High quality credits are generated by actions or projects that have clearly demonstrated emission reductions that are real, permanent, verifiable, enforceable, and not otherwise required by law or regulation. When the pre- or post-project emissions are not well quantified or cannot be independently confirmed, they are considered to be of lesser quality. Similarly, if the reductions are temporary in nature, they are also considered to be poor quality. Adoption of a zero threshold should consider the near-term availability and the quality of potential offsets.

There are also environmental justice concerns about the effects of using offsite mitigations or emission reduction credits to offset, or mitigate, the impacts of a new project. Although GHGs are global pollutants, some of them are emitted with co-pollutants that have significant near-source or regional impacts. Any time that increases in emissions at a specific site will be mitigated at a remote location or using emission reduction credits, the agency evaluating the project should ensure that it does not create disproportionate impacts.

Administrative Considerations

If electing to pursue a zero threshold, an air district or lead agency should consider the administrative costs and the environmental review system capacity. Some projects that previously would have qualified for an exemption could require further substantial analysis, including preparation of a Negative Declaration (ND), a Mitigated Negative Declaration (MND) or an EIR. Moreover, the trade-offs between the volume of projects requiring review and the quality of consideration given to reviews should be considered. It may also be useful to consider whether meaningful mitigation can be achieved from smaller projects.

Consideration of Exemptions from CEQA

A practical concern about identifying GHG emissions as a broad cumulative impact is whether the zero threshold option will preclude a lead agency from approving a large set of otherwise qualified projects utilizing a Categorical Exemption, ND, or MND. The results could be a substantial increase in the number of EIR's. This is a valid and challenging concern, particularly for any threshold approach that is based on a zero threshold for net GHG emission increases.

CEQA has specified exceptions to the use of a categorical exception. Specifically, CEQA Guidelines §15300.2 includes the following exceptions:

"(b) Cumulative Impact. All exemptions for these classes are inapplicable when the cumulative impact of successive projects of the same type in the same place, over time is significant."

(c) Significant Effect. A categorical exemption shall not be used for an activity where there is a reasonable possibility that the activity will have a significant effect on the environment due to unusual circumstances."

These CEQA Guidelines sections could be argued to mean that any net increase in GHG emissions would preclude the use of a categorical exemption. However, as described below, if the following can be shown, then the exceptions above could be argued not to apply:

(1) Cumulative local, regional and/or state GHG emissions are being reduced or will be reduced by adopted, funded, and feasible measures in order to meet broader state targets.

(2) Mandatory state or local GHG reduction measures would apply to the project's emissions such that broader GHG reduction goals would still be met and the project contributions would not be cumulatively considerable.

(3) Project GHG emissions are below an adopted significance threshold designed to take into account the cumulative nature of GHG emissions.

A similar argument could be made relative to the use of a ND (provided no additional mitigation (beyond existing mandates) is required to control GHG emissions) and to the use of a MND instead of an EIR. However, due to the "fair argument" standard, which is discussed in Chapter 3, caution is recommended in use of a ND or MND unless all three elements above can be fully supported through substantial evidence and there is no substantial evidence to the contrary. Establishing a significance threshold of zero is likely to preclude the use of a categorical exemption.

Relevant Citations

The full text of relevant citations is in Appendix A.

Public Resources Code – §21004, Mitigating or Avoiding a Significant Effect; Powers of Public Agency.

State CEQA Guidelines – §15064, Determining the Significance of the Environmental Effects Caused by a Project.

State CEQA Guidelines – §15130, Discussion of Cumulative Impacts.

State CEQA Guidelines – §15064.7, Thresholds of Significance.

Introduction

A non-zero threshold could minimize the resources spent reviewing environmental analyses that do not result in real GHG reductions or to prevent the environmental review system from being overwhelmed. The practical advantages of considering non-zero thresholds for GHG significance determinations can fit into the concept regarding whether the project's GHG emissions represent a "considerable contribution to the cumulative impact" and therefore warrant analysis.

Specifying a non-zero threshold could be construed as setting a *de minimis* value for a cumulative impact. In effect, this would be indicating that there are certain GHG emission sources that are so small that they would not contribute substantially to the global GHG budget. This could be interpreted as allowing public agencies to approve certain projects without requiring any mitigation of their GHG. Any threshold framework should include a proper context to address the *de minimis* issue. However, the CEQA Guidelines recognize that there may be a point where a project's contribution, although above zero, would not be a *considerable contribution* to the cumulative impact and, therefore, not trigger the need for a significance determination.

GHG emissions from all sources are under the purview of CARB and as such may eventually be "regulated" no matter how small. Virtually all projects will result in some direct or indirect release of GHG. However, a decision by CARB to regulate a class of sources does not necessarily mean that an individual source in that class would constitute a project with significant GHG impacts under CEQA. For example, CARB has established criteria pollutant emission standards for automobiles, but the purchase and use of a single new car is not considered a project with significant impacts under CEQA. At the same time, it is important to note that it is likely that all meaningful sources of emissions, no matter how small are likely to be considered for regulation under AB 32. It is expected that projects will have to achieve some level of GHG reduction to comply with CARB's regulations meant to implement AB 32. As such all projects will have to play a part in reducing our GHG emissions budget and no project, however small, is truly being considered *de minimis* under CARB's regulations.

This chapter evaluates a range of conceptual approaches toward developing GHG significance criteria. The air districts retained the services of J&S an environmental consulting, firm to assist with the development of a Statute and Executive Order-based threshold (Approach 1) and a tiered threshold (Approach 2) based on a prescribed list of tasks and deliverables. Time and financial constraints limited the scope and depth of this analysis, however, the work presented here may be useful in developing interim guidance while AB 32 is being implemented. J&S recognized that approaches other than those described here could be used.

As directed, J&S explored some overarching issues, such as:

- what constitutes "new" emissions?

- how should "baseline emissions" be established?
- what is cumulatively "considerable" under CEQA?
- what is "business as usual" ? and
- should an analysis include "life-cycle" emissions?

The answers to these issues were key to evaluating each of the threshold concepts.

Approach 1 – Statute and Executive Order Approach

Thresholds could be grounded in existing mandates and their associated GHG emission reduction targets. A project would be required to meet the targets, or reduce GHG emissions to the targets, to be considered less than significant.

AB 32 and S-3-05 target the reduction of statewide emissions. It should be made clear that AB 32 and S-3-05 do not specify that the emissions reductions should be achieved through uniform reduction by geographic location or by emission source characteristics. For example, it is conceivable, although unlikely, that AB 32 goals could be achieved by new regulations that only apply to urban areas or that only apply to the transportation and/or energy sector. However, this approach to evaluating GHG under CEQA is based on the presumption that a new project must at least be consistent with AB 32 GHG emission reduction mandates.

The goal of AB 32 and S-3-05 is the significant reduction of future GHG emissions in a state that is expected to rapidly grow in both population and economic output. As such, there will have to be a significant reduction in the per capita GHG output for these goals to be met. CEQA is generally used to slow or zero the impact of new emissions, leaving the reduction of existing emission sources to be addressed by other regulatory means. With these concepts in mind, four options were identified for statute/executive order-based GHG significance thresholds and are described below.

Threshold 1.1: AB 32/S-3-05 Derived Uniform Percentage-Based Reduction. AB 32 requires the state to reduce California-wide GHG emissions to 1990 levels by 2020. Reducing greenhouse gas emission levels from 2020 to 1990 levels could require a 28 to 33 percent reduction of business-as-usual GHG emissions depending on the methodology used to determine the future emission inventories. The exact percent reduction may change slightly once CARB finalizes its 1990 and 2020 inventory estimates. In this context, business-as-usual means the emissions that would have occurred in the absence of the mandated reductions. The details of the business-as-usual scenario are established by CARB in the assumptions it uses to project what the state's GHG emissions would have been in 2020, and the difference between that level and the level that existed in 1990 constitutes the reductions that must be achieved if the mandated goals are to be met.

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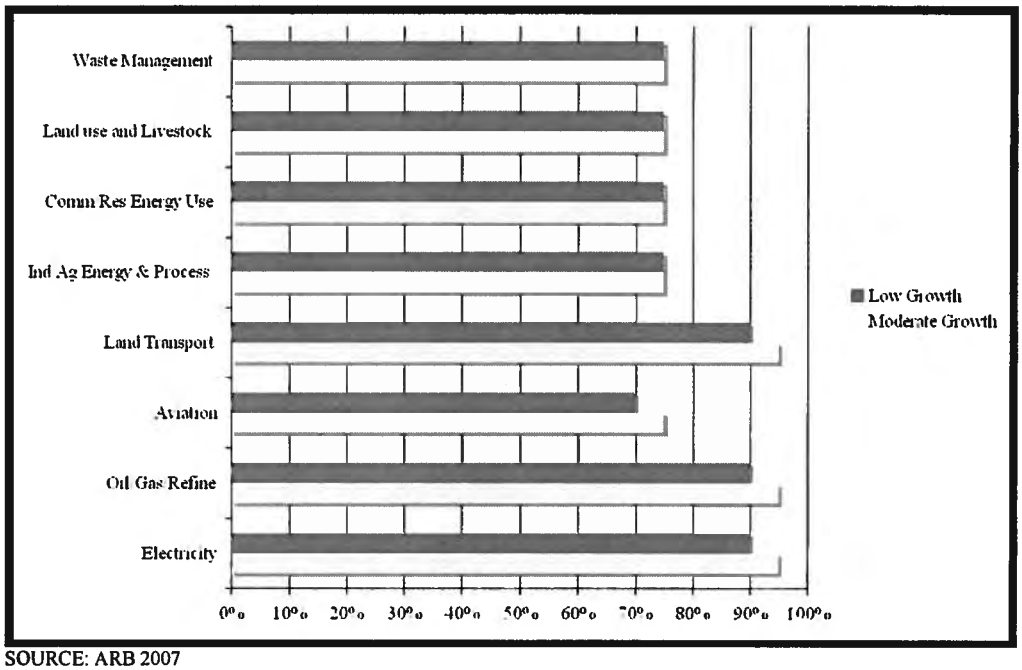
This threshold approach would require a project to meet a percent reduction target based on the average reductions needed from the business-as-usual emission from all GHG sources. Using the 2020 target, this approach would require all discretionary projects to achieve a 33 percent reduction from projected business-as-usual emissions in order to be considered less than significant. A more restrictive approach would use the 2050 targets. S-3-05 seeks to reduce GHG emissions to 80 percent below 1990 levels by 2050. To reach the 2050 milestone would require an estimated 90 percent reduction (effective immediately) of business-as-usual emissions. Using this goal as the basis for a significance threshold may be more appropriate to address the long-term adverse impacts associated with global climate change. Note that AB 32 and S-3-05 set emission inventory goals at milestone years; it is unclear how California will progress to these goals in non-milestone years.



SOURCE: ARB 2007

Threshold 1.2: Uniform Percentage-Based (e.g.50%) Reduction for New Development. This threshold is based on a presumption that new development should contribute a greater percent reduction from business-as-usual because greater reductions can be achieved at lower cost from new projects than can be achieved from existing sources. This approach would establish that new development emit 50 percent less GHG emissions than business-as-usual development. This reduction rate is greater than the recommended reduction rate for meeting the Threshold 1.1 2020 target (33 percent) but is significantly less restrictive than the Threshold 1.1 2050 target reduction rate (90 percent). If a 50 percent GHG reduction were achieved from new development, existing emissions would have to be reduced by 25 to 30 percent in order to meet the 2020 emissions goal depending on the year used to determine the baseline inventory. Although this reduction goal is reasonable for achieving the 2020 goal, it would not be possible to

reach the 2050 emissions target with this approach even if existing emissions were 100 percent controlled.

Threshold 1.3: Uniform Percentage-Based Reduction by Economic Sector. This threshold would use a discrete GHG reduction goal specific to the economic sector associated with the project. There would be specific reduction goals for each economic sector, such as residential, commercial, and industrial development. Specifying different reduction thresholds for each market sector allows selection of the best regulatory goal for each sector taking into account available control technology and costs. This approach would avoid over-regulating projects (i.e. requiring emissions to be controlled in excess of existing technology) or under-regulating projects (i.e. discouraging the use of available technology to control emissions in excess of regulations). This approach requires extensive information on the emission inventories and best available control technology for each economic sector. This data will be compiled as CARB develops its scoping plan under AB 32 and its implementing regulations; as a result, this approach will be more viable in the long term.

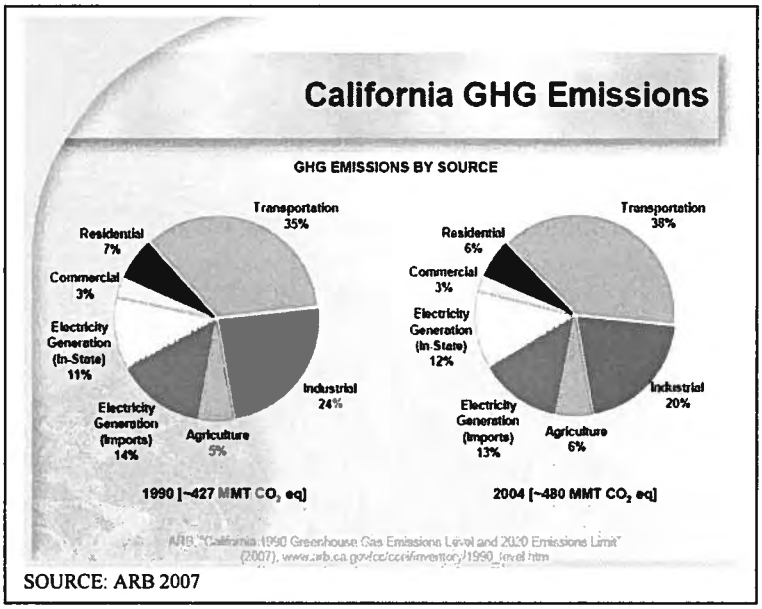
Threshold 1.4: Uniform Percentage-Based Reduction by Region. AB 32 and S-3-05 are written such that they apply to a geographic region (i.e. the entire state of California) rather than on a project or sector level. One could specify regions of the state such as the South Coast Air Basin, Sacramento Valley, or Bay Area which are required to plan (plans could be developed by regional governments, such as councils of governments) and demonstrate compliance with AB 32 and S-3-05 reduction goals at a regional level. To demonstrate that a project has less than significant emissions, one would have to show compliance with the appropriate regional GHG plan. Effectively this approach allows for analysis of GHG emissions at a landscape scale smaller than the state as a whole. Specifying regions in rough correlation to existing air basins or jurisdictional control allows for regional control of emissions and integration with regional emission reduction strategies for criteria and toxic air pollutants. Although differing GHG reduction controls for each region are possible, it is likely that all regions would be

required to achieve 1990 emission inventories by the year 2020 and 80 percent less emissions by 2050. Threshold 1.4 is considered viable long-term significance criteria that is unlikely to be used in the short term.

Implementing CEQA Thresholds Based on Emission Reduction Targets

Characterizing Baseline and Project Emissions

While the population and economy of California is expanding, all new projects can be considered to contribute new emissions. Furthermore, GHG impacts are exclusively cumulative impacts; there are no non-cumulative GHG emission impacts from a climate change perspective. "Business-as-usual" is the projection of GHG emissions at a future date based on current technologies and regulatory requirements in absence of other reductions. For example to determine the future emissions from a power plant for "business-as-usual" one would multiply the projected energy throughput by the current emission factor for that throughput. If adopted regulations (such as those that may be promulgated by CARB for AB 32) dictate that power plant emissions must be reduced at some time in the future, it is appropriate to consider these regulation standards as the new business-as-usual for a future date. In effect, business-as-usual will continue to evolve as regulations manifest. Note that "business-as-usual" defines the CEQA No Project conditions, but does not necessarily form the baseline under CEQA. For instance, it is common to subtract the future traffic with and without a project to determine the future cumulative contribution of a project on traffic conditions. However, existing conditions at the time of issuance of the notice of preparation is normally the baseline.



SOURCE: ARB 2007

Establishing Emission Reduction Targets

One of the obvious drawbacks to using a uniform percent reduction approach to GHG control is that it is difficult to allow for changes in the 1990 and future emission inventories estimates. To determine what emission reductions are required for new projects one would have to know accurately the 1990 budget and efficacy of other GHG promulgated regulations as a function of time. Since CARB will not outline its

regulation strategy for several more years, it is difficult to determine accurately what the new project reductions should be in the short term. Future updates to the 1990 inventory could necessitate changes in thresholds that are based on that inventory. It is important to note that it is difficult to create near term guidance for a uniform reduction threshold strategy since it would require considerable speculation regarding the implementation and effectiveness of forthcoming CARB regulations.

Of greater importance are the assumptions used to make the projected 2020 emission inventories. Projecting future inventories over the next 15-50 years involves substantial uncertainty. Furthermore, there are likely to be federal climate change regulations and possibly additional international GHG emission treaties in the near future. To avoid such speculation, this paper defines all future emission inventories as hypothetical business-as-usual projections.

This white paper is intended to support local decisions about CEQA and GHG in the near term. During this period, it is unlikely that a threshold based on emission reduction targets would need to be changed. However, it is possible that future inventory updates will show that targets developed on the current inventory were not stringent enough, or were more stringent than was actually needed.

Approach 2 – Tiered Approach

The goal of a tiered threshold is to maximize reduction predictability while minimizing administrative burden and costs. This would be accomplished by prescribing feasible mitigation measures based on project size and type, and reserving the detailed review of an EIR for those projects of greater size and complexity. This approach may require inclusion in a General Plan, or adoption of specific rules or ordinances in order to fully and effectively implement it.

A tiered CEQA significance threshold could establish different levels at which to determine if a project would have a significant impact. The tiers could be established based on the gross GHG emission estimates for a project or could be based on the physical size and characteristics of the project. This approach would then prescribe a set of GHG mitigation strategies that would have to be incorporated into the project in order for the project to be considered less than significant.

The framework for a tiered threshold would include the following:

- disclosure of GHG emissions for all projects;
- support for city/county/regional GHG emissions reduction planning;
- creation and use of a "green list" to promote the construction of projects that have desirable GHG emission characteristics;
- a list of mitigation measures;

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- a decision tree approach to tiering; and
- quantitative or qualitative thresholds.

Decision-Tree Approach to Tiering

CEQA guidance that allows multiple methodologies to demonstrate GHG significance will facilitate the determination of significance for a broad range of projects/plans that would otherwise be difficult to address with a single non-compound methodology. Even though there could be multiple ways that a project can determine GHG significance using a decision-tree approach, only one methodology need be included in any single CEQA document prepared by the applicant. The presence of multiple methodologies to determine significance is designed to promote flexibility rather than create additional analysis overhead. Figure 1 shows a conceptual approach to significance determination using a tiered approach that shows the multiple routes to significance determination.

Figure 1 Detail Description

Figure 1 pictorially represents how an agency can determine a project's or plan's significance for CEQA analysis using the non-zero threshold methodology. The emissions associated with a project/plan are assumed to have a significant impact unless one can arrive at a less-than-significant finding by at least one of the methodologies below.

1. Demonstrate that a General Plan (GP) or Regional Plan is in Compliance with AB32

   - For most GPs or RPs this will require demonstration that projected 2020 emissions will be equal to or less than 1990 emissions.
   - GPs or RPs are expected to fully document 1990 and 2020 GHG emission inventories.
   - Projection of 2020 emissions is complicated by the fact that CARB is expected to promulgate emission reductions in the short term. Until explicit CARB regulations are in place, unmitigated GP 2020 emission inventories represent business-as-usual scenarios.
   - EIRs for GPs or RPs which demonstrate 2020 mitigated emissions are less than or equal to 1990 emissions are considered less than significant.

2. Demonstrate the Project is Exempt Based on SB 97

   - As specified in SB 97, projects that are funded under November 2006 Proposition 1B (Highway Safety, Traffic Reduction, Air Quality and Port Security Bond Act) and 1C (Disaster Preparedness and Flood Prevention Bond Act) may be exempt from analysis until January 1, 2010.

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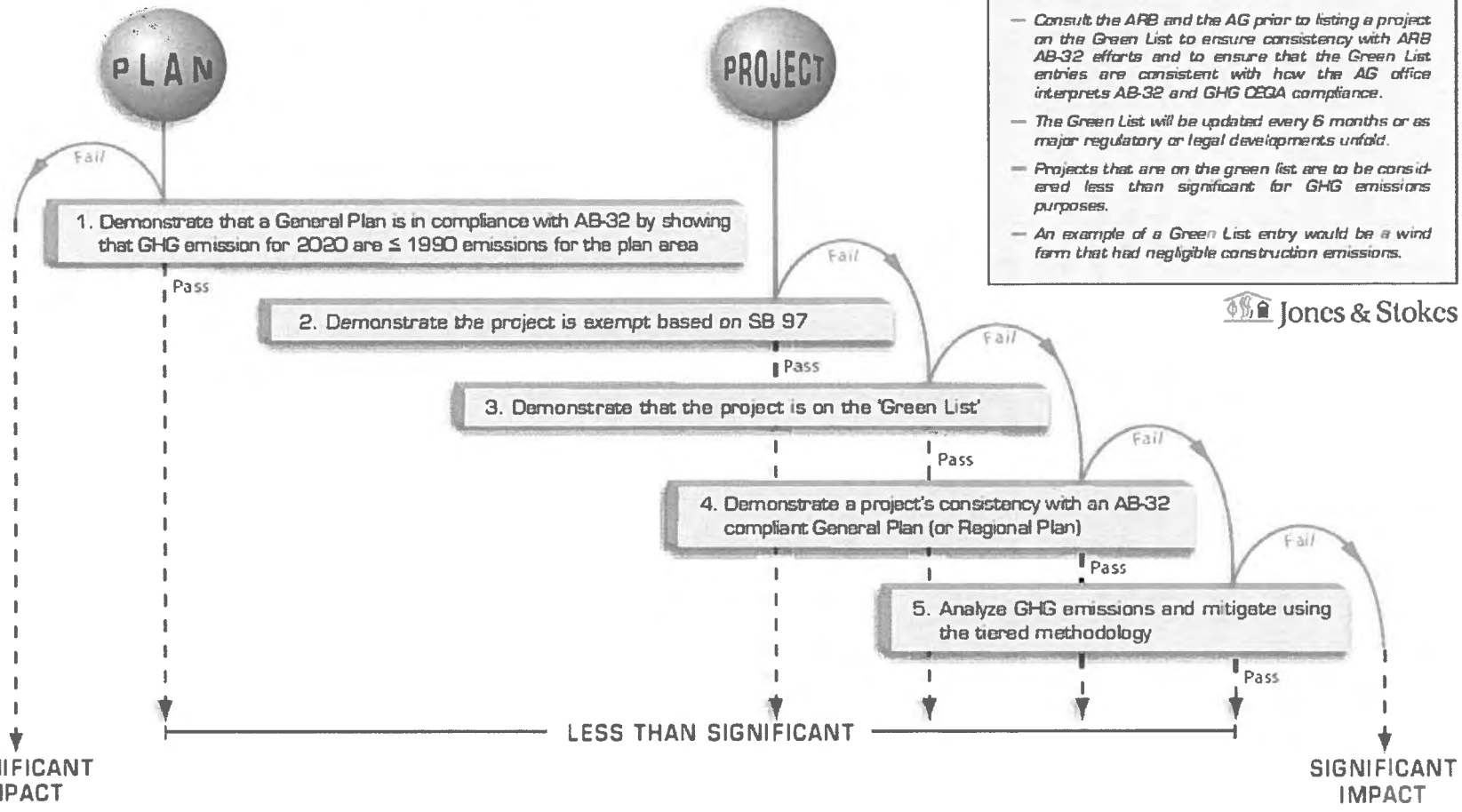
Climate Change Significance Criteria Flow Chart

- This chart pictorially represents how an agency can determine a project's or plan's significance for CEQA analysis.
- The emissions associated with a project/plan are assumed to have a significant impact unless one can arrive at a less-than-significant finding by at least one of the methodologies below.



***The Green List** (Conceptual Approach)*

- *Publish and update a list of projects and project types that are deemed a positive contribution to CA efforts to reduce GHG emissions.*
- *Consult the ARB and the AG prior to listing a project on the Green List to ensure consistency with ARB AB-32 efforts and to ensure that the Green List entries are consistent with how the AG office interprets AB-32 and GHG CEQA compliance.*
- *The Green List will be updated every 6 months or as major regulatory or legal developments unfold.*
- *Projects that are on the green list are to be considered less than significant for GHG emissions purposes.*
- *An example of a Green List entry would be a wind farm that had negligible construction emissions.*

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Figure 1
Climate Change Significance Criteria Flow Chart

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080010 GHG Emissions (rev. 10/07)

- An exemption can be used in an ND, MND, or EIR to support a less than significant finding for GHG impacts.

3. Demonstrate that the Project is on the 'Green List'

   - This list would include projects that are deemed a positive contribution to California efforts to reduce GHG emissions. If the project is of the type described on the Green List it is considered less than significant.
   - If the Green List entry description requires mitigation for impacts other than GHG, this methodology can be used in MNDs or EIRs; if the Green List entry does not require mitigation this methodology can be used in NDs, MNDs, or EIRs.

4. Demonstrate a Project's Compliance with a General Plan

   - If a project is consistent with an appropriate General Plan's Greenhouse Gas Reduction Plan (GGRP), a project can be declared less than significant.
   - Note that at this time there are no known jurisdictions that have a GGRP that has been fully subject to CEQA review. While Marin County has adopted a forward-thinking GGRP and it is described in the most recent GP update, the associated EIR does not analyze the secondary environmental impacts of some of the GGRP measures such as tidal energy. While one can reference GGRPs that have not been reviewed fully in CEQA, to attempt to show a project's compliance with such a plan as evidence that the project's GHG emission contributions are less than significant may not be supported by substantial evidence that cumulative emissions are being fully addressed in the particular jurisdiction.
   - Compliance with a CEQA-vetted GGRP can be cited as evidence for all CEQA documents (Categorical Exemption, ND, MND, and EIR).

5. Analyze GHG Emissions and Mitigate using the Tiered Methodology

   - Guidance and mitigation methodology for various development projects (residential, commercial, industrial) are listed in the form of tiered thresholds. If a project incorporates the mitigation measures specified in the tiered threshold tables the project is considered less than significant.
   - All project emissions are considered less than significant if they are less than the threshold(s).
   - If the tiered approach requires mitigation, this methodology can be used in MNDs or EIRs; if the tiered approach does not require mitigation this methodology can be used in NDs, MNDs, or EIRs.

The Green List

- The Green List would be a list of projects and project types that are deemed a positive contribution to California's efforts to reduce GHG emissions.
- If this approach is followed, it is suggested that CARB and the Attorney General (AG) are consulted prior to listing a project on the Green List to ensure consistency with CARB AB 32 efforts and to ensure that the Green List entries are consistent with how the AG office interprets AB 32 and GHG CEQA compliance.
- The Green List should be updated every 6 months or as major regulatory or legal developments unfold.
- Projects that are on the Green List are to be considered less than significant for GHG emissions purposes.
- A tentative list of potential Green List entries is presented below. Actual Green List entries should be far more specific and cover a broad range of project types and mitigation approaches. The list below is merely a proof-of-concept for the actual Green List.

1. Wind farm for the generation of wind-powered electricity
2. Extension of transit lines to currently developed but underserved communities
3. Development of high-density infill projects with easily accessible mass transit
4. Small hydroelectric power plants at existing facilities that generate 5 mw or less (as defined in Class 28 Categorical Exemption)
5. Cogeneration plants with a capacity of 50 mw or less at existing facilities (as defined in Class 29 Cat Exemption)
6. Increase in bus service or conversion to bus rapid transit service along an existing bus line
7. Projects with LEED "Platinum" rating
8. Expansion of recycling facilities within existing urban areas
9. Recycled water projects that reduce energy consumption related to water supplies that services existing development
10. Development of bicycle, pedestrian, or zero emission transportation infrastructure to serve existing regions

There are also several options for tiering and thresholds, as shown in Table 2 below. One could establish strictly numeric emissions thresholds and require mitigation to below the specific threshold to make a finding of less than significant. One could establish narrative emissions threshold that are based on a broader context of multiple approaches to GHG reductions and a presumption that projects of sufficiently low GHG intensity are less than significant.

In Concept 2A, a zero threshold would be applied to projects and thus only projects that result in a reduction of GHG emissions compared to baseline emissions would be less than significant absent mitigation. All projects would require quantified inventories. All projects that result in a net increase of GHG emissions would be required to mitigate their emissions to zero through direct mitigation or through fees or offsets or the impacts

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Table 2: Approach 2 Tiering Options

	Concept 2A Zero	Concept 2B Quantitative	Concept 2C Qualitative
Tier 1	Project results in a net reduction of GHG emissions *Less than Significant*	Project in compliance with an AB 32-compliant General/Regional Plan, on the Green List, or below Tier 2 threshold. Level 1 Reductions (Could include such measures as: bike parking, transit stops for planned route, Energy Star roofs, Energy Star appliances, Title 24, water use efficiency, etc.) *Less than Significant*	Project in compliance with an AB 32-compliant General/Regional Plan, on the Green List, or below Tier 2 threshold. Level 1 Reductions (See measures under 2B) *Less than Significant*
Tier 2	Project results in net increase of GHG emissions Mitigation to zero (including offsets) *Mitigated to Less than Significant*	Above Tier 2 threshold Level 2 Mitigation (Could include such measures as: Parking reduction beyond code, solar roofs, LEED Silver or Gold Certification, exceed Title 24 by 20%, TDM measures, etc.) *Mitigated to Less than Significant*	Above Tier 2 threshold Level 2 Mitigation (See measures under 2B) *Mitigated to Less than Significant*
Tier 3	Mitigation infeasible to reduce emissions to zero (e.g., cost of offsets infeasible for project or offsets not available) *Significant and Unavoidable*	Above Tier 2 threshold With Level 1, 2 Mitigation Level 3 Mitigation: (Could include such measures as: On-site renewable energy systems, LEED Platinum certification, Exceed Title 24 by 40%, required recycled water use for irrigation, zero waste/high recycling requirements, mandatory transit passes, offsets/carbon impact fees) *Mitigated to Less than Significant*	Above Tier 3 thresholds Quantify Emissions, Level 3 Mitigation (see measures under 2B), and Offsets for 90% of remainder *Significance and Unavoidable*

would be identified as significant and unavoidable. This could be highly problematic and could eliminate the ability to use categorical exemptions and negative declarations for a wide range of projects.

In Concepts 2B and 2C, the first tier of a tiered threshold includes projects that are within a jurisdiction with an adopted greenhouse gas reduction plan (GGRP) and General Plan/Regional Plan that is consistent with AB 32 (and in line with S-3-05), or are on the Green List, or are below the Tier 2 threshold. All Tier 1 projects would be required to implement mandatory reductions required due to other legal authority (Level 1 reductions) such as AB 32, Title 24, or local policies and ordinances. With Level 1

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reduction measures, qualifying Tier 1 projects would be considered less than significant without being required to demonstrate mitigation to zero.

In Concept 2B, the Tier 2 threshold would be quantitative, and quantified inventories would be required. Several quantitative threshold options are discussed below. A more comprehensive set of Level 2 mitigation would be required. If the project's emissions still exceed the Tier 2 threshold, an even more aggressive set of Level 3 mitigation measures would be required including offsets (when feasible) to reduce emissions below the Tier 2 threshold.

In Concept 2C, there would be two thresholds, a lower Tier 2 threshold (the "low bar") and a higher Tier 3 threshold (the "high bar"). The Tier 2 threshold would be the significance threshold for the purposes of CEQA and would be qualitative in terms of units (number of dwelling units, square feet of commercial space, etc.) or a per capita ratio. Projects above the Tier 2 threshold would be required to implement the comprehensive set of Level 2 mitigation. Projects below the Tier 2 threshold would not be required to quantify emissions or reductions. The Tier 3 threshold would be a threshold to distinguish the larger set of projects for which quantification of emissions would be required. Level 3 mitigation would be required and the project would be required to purchase offsets (when feasible) in the amount of 90 percent of the net emissions after application of Level 1 reductions and Level 2 and 3 mitigation. A variant on Concept 2C would be to require mandatory Level 3 mitigation without quantification and offsets.

Approach 2 Threshold Options

Seven threshold options were developed for this approach. The set of options are framed to capture different levels of new development in the CEQA process and thus allow different levels of mitigation. Options range from a zero first-tier threshold (Threshold 2.1) up to a threshold for GHG that would be equivalent to the capture level (i.e., number of units) of the current criteria pollutant thresholds used by some air districts (Threshold 2.4). The decision-based implementation approach discussed above could be used for any of these options. Table 3 below compares the results of each of the approaches discussed here.

Threshold 2.1: Zero First Tier Tiered Threshold.

This option would employ the decision tree concept and set the first tier cut-point at zero. The second tier cut-point could be one of the qualitative or quantitative thresholds discussed below. First-tier projects would be required to implement a list of very feasible and readily available mitigation measures.

Threshold 2.2: Quantitative Threshold Based on Market Capture

A single quantitative threshold was developed in order to ensure capture of 90 percent or more of likely future discretionary developments. The objective was to set the emission

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threshold low enough to capture a substantial fraction of future residential and non-residential development that will be constructed to accommodate future statewide population and job growth, while setting the emission threshold high enough to exclude small development projects that will contribute a relatively small fraction of the cumulative statewide GHG emissions.

The quantitative threshold was created by using the following steps:

- Reviewing data from four diverse cities (Los Angeles in southern California and Pleasanton, Dublin, and Livermore in northern California) on pending applications for development.

- Determining the unit (dwelling unit or square feet) threshold that would capture approximately 90 percent of the residential units or office space in the pending application lists.

- Based on the data from the four cities, the thresholds selected were 50 residential units and 30,000 square feet of commercial space.

- The GHG emissions associated with 50 single-family residential units and 30,000 square feet of office were estimated and were found to be 900 metric tons and 800 metric tons, respectively. Given the variance on individual projects, a single threshold of 900 metric tons was selected for residential and office projects.

- A 900 metric ton threshold was also selected for non-office commercial projects and industrial projects to provide equivalency for different projects in other economic sectors.

- If this threshold is preferred, it is suggested that a more robust data set be examined to increase the representativeness of the selected thresholds. At a minimum, a diverse set of at least 20 cities and/or counties from throughout the state should be examined in order to support the market capture goals of this threshold. Further, an investigation of market capture may need to be conducted for different commercial project types and for industrial projects in order to examine whether multiple quantitative emissions thresholds or different thresholds should be developed.

The 900-ton threshold corresponds to 50 residential units, which corresponds to the 84th percentile of projects in the City of Los Angeles, the 79th percentile in the City of Pleasanton, the 50th percentile in the City of Livermore and the 4th percentile in the City of Dublin. This is suggestive that the GHG reduction burden will fall on larger projects that will be a relatively small portion of overall projects within more developed central cities (Los Angeles) and suburban areas of slow growth (Pleasanton) but would be the higher portion of projects within moderately (Livermore) or more rapidly developing areas (Dublin). These conclusions are suggestive but not conclusive due to the small sample size. The proposed threshold would exclude the smallest proposed developments

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from potentially burdensome requirements to quantify and mitigate GHG emissions under CEQA. While this would exclude perhaps 10 percent of new residential development, the capture of 90 percent of new residential development would establish a strong basis for demonstrating that cumulative reductions are being achieved across the state. It can certainly serve as an interim measure and could be revised if subsequent regulatory action by CARB shows that a different level or different approach altogether is called for.

The 900-ton threshold would correspond to office projects of approximately 35,000 square feet, retail projects of approximately 11,000 square feet, or supermarket space of approximately 6,300 square feet. 35,000 square feet would correspond to the 46th percentile of commercial projects in the City of Los Angeles, the 54th percentile in the City of Livermore, and the 35th percentile in the City of Dublin. However, the commercial data was not separated into office, retail, supermarket or other types, and thus the amount of capture for different commercial project types is not known. The proposed threshold would exclude smaller offices, small retail (like auto-parts stores), and small supermarkets (like convenience stores) from potentially burdensome requirements to quantify and mitigate GHG emissions under CEQA but would include many medium-scale retail and supermarket projects.

The industrial sector is less amenable to a unit-based approach given the diversity of projects within this sector. One option would be to adopt a quantitative GHG emissions threshold (900 tons) for industrial projects equivalent to that for the residential/commercial thresholds described above. Industrial emissions can result from both stationary and mobile sources. CARB estimates that their suggested reporting threshold for stationary sources of 25,000 metric tons accounts for more than 90 percent of the industrial sector GHG emissions (see Threshold 2.3 for 25,000 metric ton discussion). If the CARB rationale holds, then a 900 metric ton threshold would likely capture at least 90 percent (and likely more) of new industrial and manufacturing sources. If this approach is advanced, we suggest further examination of industrial project data to determine market capture.

This threshold would require the vast majority of new development emission sources to quantify their GHG emissions, apportion the forecast emissions to relevant source categories, and develop GHG mitigation measures to reduce their emissions.

Threshold 2.3: CARB Reporting Threshold

CARB has recently proposed to require mandatory reporting from cement plants, oil refineries, hydrogen plants, electric generating facilities and electric retail providers, cogeneration facilities, and stationary combustion sources emitting $\geq$ 25,000 MT CO_2e/yr. AB 32 requires CARB to adopt a regulation to require the mandatory reporting and verification of emissions. CARB issued a preliminary draft version of its proposed reporting requirements in August 2007 and estimates that it would capture 94 percent of the GHG emissions associated with stationary sources.

This threshold would use 25,000 metric tons per year of GHG as the CEQA significance level. CARB proposed to use the 25,000 metric tons/year value as a reporting threshold, not as a CEQA significance threshold that would be used to define mitigation requirements. CARB is proposing the reporting threshold to begin to compile a statewide emission inventory, applicable only for a limited category of sources (large industrial facilities using fossil fuel combustion).

A 25,000 metric ton significance threshold would correspond to the GHG emissions of approximately 1,400 residential units, 1 million square feet of office space, 300,000 square feet of retail, and 175,000 square feet of supermarket space. This threshold would capture far less than half of new residential or commercial development.

As noted above, CARB estimates the industrial-based criteria would account for greater than 90 percent of GHG emissions emanating from stationary sources. However, industrial and manufacturing projects can also include substantial GHG emissions from mobile sources that are associated with the transportation of materials and delivery of products. When all transportation-related emissions are included, it is unknown what portion of new industrial or manufacturing projects a 25,000-ton threshold would actually capture.

An alternative would be to use a potential threshold of 10,000 metric tons considered by the Market Advisory Committee for inclusion in a Greenhouse Gas Cap and Trade System in California. A 10,000 metric ton significance threshold would correspond to the GHG emissions of approximately 550 residential units, 400,000 square feet of office space, 120,000 square feet of retail, and 70,000 square feet of supermarket space. This threshold would capture roughly half of new residential or commercial development.

Threshold 2.4: Regulated Emissions Inventory Capture

Most California air districts have developed CEQA significance thresholds for NOx and ROG emissions to try to reduce emissions of ozone precursors from proposed sources that are not subject to NSR pre-construction air quality permitting. The historical management of ozone nonattainment issues in urbanized air districts is somewhat analogous to today's concerns with greenhouse gas emissions in that regional ozone concentrations are a cumulative air quality problem caused by relatively small amounts of NOx and ROG emissions from thousands of individual sources, none of which emits enough by themselves to cause elevated ozone concentrations. Those same conditions apply to global climate change where the environmental problem is caused by emissions from a countless number of individual sources, none of which is large enough by itself to cause the problem. Because establishment of NOx/ROG emissions CEQA significance thresholds has been a well-tested mechanism to ensure that individual projects address cumulative impacts and to force individual projects to reduce emissions under CEQA, this threshold presumes the analogy of NOx/ROG emission thresholds could be used to develop similar GHG thresholds.

The steps to develop a GHG emission threshold based on the NOx/ROG analogy were as follows:

- For each agency, define its NOx/ROG CEQA thresholds.
- For each agency, define the regional NOx/ROG emission inventory the agency is trying to regulate with its NOx/ROG thresholds.
- For each agency, calculate the percentage of the total emission inventory for NOx represented by that agency's CEQA emission threshold. That value represents the "minimum percentage of regulated inventory" for NOx.
- The current (2004) California-wide GHG emission inventory is 499 million metric tons per year of CO_2 equivalent (MMT CO_2e). Apply the typical "minimum percentage of regulated inventory" value to the statewide GHG inventory, to develop a range of analogous GHG CEQA thresholds.

The preceding methodology was applied to two different air quality districts: the Bay Area Air Quality Management District (BAAQMD), a mostly-urbanized agency within which most emissions are generated from urban areas; and the San Joaquin Valley Air Pollution Control District (SJVAPCD), which oversees emissions emanating in part from rural areas that are generated at dispersed agricultural sources and area sources. For example, in the Bay Area the NOx threshold is 15 tons/year. The total NOx inventory for 2006 was 192,000 tons/year (525 tons/day). The threshold represents 0.008 percent of the total NOx inventory. Applying that ratio to the total statewide GHG emissions inventory of 499 MMT CO_2e (2004) yields an equivalent GHG threshold of 39,000 MMT CO_2e.

The range of analogous CEQA GHG thresholds derived from those two agencies is tightly clustered, ranging from 39,000 to 46,000 tons/year. A 39,000 to 46,000 metric ton threshold would correspond to the GHG emissions of approximately 2,200 to 2,600 residential units, 1.5 to 1.8 million square feet of office space, 470,000 to 560,000 square feet of retail, and 275,000 to 320,000 square feet of supermarket space. This threshold would capture far less than half of new residential or commercial development. Similarly, this threshold would capture less of new industrial/manufacturing GHG emissions inventory than Thresholds 2.2 or 2.3.

Threshold 2.5: Unit-Based Thresholds Based on Market Capture

Unit thresholds were developed for residential and commercial developments in order to capture approximately 90 percent of future development. The objective was to set the unit thresholds low enough to capture a substantial fraction of future housing and commercial developments that will be constructed to accommodate future statewide population and job growth, while setting the unit thresholds high enough to exclude small development projects that will contribute a relatively small fraction of the cumulative statewide GHG emissions. Sector-based thresholds were created by using the same steps

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and data used to create Threshold 2.2- Quantitative Threshold Based on Market Capture above.

The distribution of pending application data suggests that the GHG reduction burden will fall on larger projects that will be a relatively small portion of overall projects within more developed central cities and suburban areas of slow growth but would be the higher portion of projects within moderately or rapidly developing areas. The proposed threshold would exclude the smallest proposed developments from potentially burdensome requirements to quantify and mitigate GHG emissions under CEQA. While this would exclude perhaps 10 percent of new residential development, the capture of 90 percent of new residential development would establish a strong basis for demonstrating that cumulative reductions are being achieved across the state. It can certainly serve as an interim measure and could be revised if subsequent regulatory action by CARB shows that a different level or different approach altogether is called for.

A similar rationale can be applied to the development of a commercial threshold. Threshold 2.5 would exclude many smaller businesses from potentially burdensome requirements to quantify and mitigate GHG emissions under CEQA. It should be noted that the GHG emissions of commercial projects vary substantially. For example, the carbon dioxide emissions associated with different commercial types were estimated as follows:

- 30,000 square-foot (SF) office = 800 metric tons/year CO_2
- 30,000 SF retail = 2,500 metric tons/year CO_2
- 30,000 SF supermarket = 4,300 metric tons/year CO_2

Thus, in order to assure appropriate market capture on an emissions inventory basis, it will be important to examine commercial project size by type, instead of in the aggregate (which has been done in this paper).

The industrial sector is less amenable to a unit-based approach given the diversity of projects within this sector. One option would be to use a quantitative threshold of 900 tons for industrial projects in order to provide for rough equivalency between different sectors. Industrial emissions can result from both stationary and mobile sources. However, if the CARB rationale for > 90 percent stationary source capture with a threshold of 25,000 metric tons holds, then a 900 metric ton threshold would likely capture at least 90 percent (and likely more) of new industrial sources. Further examination of unit-based industrial thresholds, such as the number of employees or manufacturing floor space or facility size, may provide support for a unit-based threshold based on market capture.

This threshold would require the vast majority of new development emission sources to quantify their GHG emissions, apportion the forecast emissions to relevant source categories, and develop GHG mitigation measures to reduce their emissions.

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Threshold 2.6. Projects of Statewide, Regional, or Areawide Significance

For this threshold, a set of qualitative, tiered CEQA thresholds would be adopted based on the definitions of "projects with statewide, regional or areawide significance" under the Guidelines for California Environmental Quality Act, CCR Title 14, Division 6, Section 15206(b).

Project sizes defined under this guideline include the following:

- Proposed residential development of more than 500 dwelling units.
- Proposed shopping center or business establishment employing more than 1,000 persons or encompassing more than 500,000 square feet of floor space.
- Proposed commercial office building employing more than 1,000 persons or encompassing more than 250,000 square feet of floor space.
- Proposed hotel/motel development of more than 500 rooms.
- Proposed industrial, manufacturing or processing plant or industrial park planned to house more than 1,000 persons, or encompassing more than 600,000 square feet of floor space.

These thresholds would correspond to the GHG emissions of approximately 9,000 metric tons for residential projects, 13,000 metric tons for office projects, and 41,000 metric tons for retail projects. These thresholds would capture approximately half of new residential development and substantially less than half of new commercial development. It is unknown what portion of the new industrial or manufacturing GHG inventory would be captured by this approach.

Threshold 2.7 Efficiency-Based Thresholds

For this approach, thresholds would be based on measurements of efficiency. For planning efforts, the metric could be GHG emissions per capita or per job or some combination thereof. For projects, the metric could be GHG emission per housing unit or per square foot of commercial space. In theory, one could also develop metrics for GHG emissions per dollar of gross product to measure the efficiency of the economy.

This approach is attractive because it seeks to benchmark project GHG intensity against target levels of efficiency. The thresholds would need to be set such that there is reasonably foreseeable and sufficient reductions compared to business as usual to support meeting AB 32 and S-3-05 goals in time (in combination with command and control regulations). Because this approach would require substantial data and modeling to fully develop, this is a concept considered as a potential future threshold and not appropriate

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for interim guidance in the short term. Thus, it is not evaluated in the screening evaluation in the next section.

Table 3 compares the results for each of the approaches.

Table 3: Comparison of Approach 2 Tiered Threshold Options

Threshold	GHG Emission Threshold (metric tons/year)	Future Development Captured by GHG Threshold
2.1: Zero Threshold	0 tons/year	All
2.2: Quantitative Threshold Based on Market Capture	~900 tons/year	Residential development > 50 dwelling units Office space > 36,000 ft^2 Retail space >11,000 ft^2 Supermarkets >6.300 ft^2 small, medium, large industrial
2.3: CARB GHG Mandatory Reporting Threshold OR Potential Cap and Trade Entry Level	25,000 metric tons/year OR 10,000 metric tons/year	Residential development >1,400 dwelling units OR 550 dwelling units Office space >1 million ft^2 OR 400,000 ft^2 Retail space >300,000 ft^2 OR 120,000 ft^2 Supermarkets >175,000 ft^2 OR 70,000 ft^2 medium/larger industrial
2.4: Regulated Inventory Capture	40,000 – 50,000 metric tons/year	Residential development >2,200 to 2,600 dwelling units Office space >1.5 to 1.8 million ft^2 Retail space >470,000 to 560,000 ft^2 Supermarkets >270,000 to 320,000 ft^2 medium/larger industrial
2.5: Unit-Based Threshold Based on Market Capture	Not applicable.	Residential development >50 dwelling units Commercial space >50,000 ft^2 > small, medium, large industrial (with GHG emissions > 900 tonsCO2e)
2.6: Projects of Statewide, Regional, or Areawide Significance	Not applicable.	Residential development >500 dwelling units Office space >250,000 ft^2 Retail space >500,000 ft^2 Hotels >500 units Industrial project >1,000 employees Industrial project >40 acre or 650,000 ft^2
2.7: Efficiency-Based Thresholds	TBD tons/year/person TBD tons/year/unit	Depends on the efficiency measure selected.

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Implementing CEQA With Tiered Thresholds

Several issues related to Approach 2 are addressed below:

1. *Some applications of this approach may need to be embodied in a duly approved General Plan, or in some other formal regulation or ordinance to be fully enforceable.* Because CEQA does not expressly provide that projects may be deemed insignificant based on implementation of a set of mitigations, this approach may need to be supported with specific and enforceable mechanisms adopted with due public process.

2. *How would this concept affect adoption of air district rules and regulations?* Proposed air district rules and regulations may be subject to CEQA like other projects and plans. Thus, if significance thresholds were adopted by an APCD or AQMD, then they could also apply to air district discretionary actions. If GHG emissions would be increased by a rule or regulation for another regulated pollutant, that would be a potential issue for review under CEQA.

3. *Mitigation measures may not be all-inclusive; better measures now or new future technology would make these measures obsolete.* The mandatory mitigation measures could be periodically updated to reflect current technology, feasibility, and efficiency.

4. *Total reduction may not be quantified or difficult to quantify.* CEQA only requires the adoption of feasible mitigation and thus the reduction effectiveness of required mitigation should not be in question. However, the precise reduction effectiveness may indeed be difficult to identify. As described above, if a quantitative threshold is selected as the measure of how much mitigation is mandated, then best available evidence will need to be used to estimate resultant GHG emissions with mitigation adoption. If a qualitative threshold is selected, then it may not be necessary to quantify reductions.

5. *Difficult to measure progress toward legislative program goals.* One could require reporting of project inventories to the Climate Action Registry, air district, or regional council of governments, or other suitable body. Collection of such data would allow estimates of the GHG intensity of new development over time, which could be used by CARB to monitor progress toward AB 32 goals.

6. *Measures may have adverse impacts on other programs.* The identification of mandatory mitigation will need to consider secondary environmental impacts, including those to air quality.

7. *Consideration of life-cycle emissions.* In many cases, only direct and indirect emissions may be addressed, rather than life-cycle emissions. A project applicant has traditionally been expected to only address emissions that are closely related and within the capacity of the project to control and/or influence. The long chain

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8. of economic production resulting in materials manufacture, for example, involves numerous parties, each of which in turn is responsible for the GHG emissions associated with their particular activity. However, there are situations where a lead agency could reasonably determine that a larger set of upstream and downstream emissions should be considered because they are being caused by the project and feasible alternatives and mitigation measures may exist to lessen this impact.

Approach 2 Tiered Threshold with Mandatory Mitigation

As shown in Table 2, due to the cumulative nature of GHG emissions and climate change impacts, there could be a level of mandatory reductions and/or mitigation for all projects integrated into a tiered threshold approach. In order to meet AB 32 mandates by 2020 and S-3-05 goals, there will need to be adoption of GHG reduction measures across a large portion of the existing economy and new development. As such, in an effort to support a determination under CEQA that a project has a less than considerable contribution to significant cumulative GHG emissions, mitigation could be required on a progressively more comprehensive basis depending on the level of emissions.

- Level 1 Reductions – These reduction measures would apply to all projects and would only consist of AB 32 and other local/state mandates. They would be applied to a project from other legal authority (not CEQA). Level 1 reductions could include such measures as bike parking, transit stops for planned routes, Energy Star roofs, Energy Star appliances, Title 24 compliance, water use efficiency, and other measures. All measures would have to be mandated by CARB or local regulations and ordinances.

- Level 2 Mitigation – Projects that exceed the determined threshold would be required to first implement readily available technologies and methodologies with widespread availability. Level 2 Mitigation could include such measures as: parking reduction below code minimum levels, solar roofs, LEED Silver or Gold Certification, exceed Title 24 building standards by 20 percent, Traffic Demand Management (TDM) measures, and other requirements.

- Level 3 Mitigation - If necessary to reduce emissions to the thresholds, more extensive mitigation measures that represent the top tier of feasible efficiency design would also be required. Level 3 Mitigation could include such measures as: on-site renewable energy systems, LEED Platinum certification, exceed Title 24 building requirements by 40 percent, required recycled water use for irrigation, zero waste/high recycling requirements, mandatory transit pass provision, and other measures.

- Offset Mitigation – If, after adoption of all feasible on-site mitigation, the project is still found to exceed a Tier 2 quantitative threshold, or exceed a Tier 3 qualitative threshold, or if a project cannot feasibly implement the mandatory on-site mitigation, then purchases of offsets could be used for mitigation. In the case

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of a quantitative threshold, the amount of purchase would be to offset below the Tier 2 significance threshold. In the case of a qualitative threshold, the amount of purchase could be to offset GHG emissions overall to below the lowest equivalent GHG emissions among the Tier 2 qualitative thresholds. With Threshold 2.5, this would be approximately 900 tons of GHG emissions (corresponding to 50 residential units). With Threshold 2.6, this would be approximately 9,000 tons (corresponding to 500 residential units). Alternatively, one could require purchase of offsets in the amount of a set percentage (such as 90% or 50% for example) of the residual GHG emissions (after other mitigation). As discussed earlier, any decision to include or require the use of emission reduction credits (or offsets) must consider issues of availability, quality, and environmental justice.

Substantial Evidence Supporting Different Thresholds

If a project can be shown by substantial evidence not to increase GHG emissions relative to baseline emissions, then no fair argument will be available that the project contributes considerably to a significant cumulative climate change impact.

It is more challenging to show that a project that increases GHG emissions above baseline emissions does not contribute considerably to a significant cumulative climate change impact. It is critical therefore, to establish an appropriate cumulative context, in which, although an individual project may increase GHG emissions, broader efforts will result in net GHG reductions.

Approach 1-based thresholds that by default will require an equal level of GHG reductions from the existing economy (Thresholds 1.1, 1.3, and 1.4) may be less supportable in the short run (especially before 2012) than Approach 1.2 (which requires new development to be relatively more efficient than a retrofitted existing economy). This is because, prior to 2012, there will only be limited mandatory regulations implementing AB 32 that could address the existing economy in a truly systematic way that can be relied upon to demonstrate that overall GHG reduction goals can be achieved by 2020. Approach 1.2 will still rely on substantial reductions in the existing economy but to a lesser degree.

Approach 1-based thresholds that would spread the mitigation burden across a sector (Threshold 1.3) or across a region (Threshold 1.4) will allow for tradeoffs between projects or even between municipalities. In order to demonstrate that a sector or a region is achieving net reductions overall, there would need to be feasible, funded, and mandatory requirements in place promoting an overall reduction scheme, in order for a project to result in nominal net increased GHG emissions.

Approach 2-based thresholds that capture larger portions of the new development GHG inventory (Thresholds 2.2 and 2.5) would promote growth that results in a smaller increase in GHG emissions; they may therefore be more supportable than thresholds that do not and that have a greater reliance on reductions in the existing economy (Thresholds

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2.3, 2.4, and 2.6), especially in the next three to five years. With an established cumulative context that demonstrates overall net reductions, all threshold approaches could be effective in ensuring growth and development that significantly mitigates GHG emissions growth in a manner that will allow the CARB to achieve the emission reductions necessary to meet AB 32 targets. In that respect, all of these thresholds are supported by substantial evidence.

Evaluation of Non-Zero Threshold Options

Overarching issues concerning threshold development are reviewed below. Where appropriate, different features or application of the two conceptual approaches and the various options for thresholds under each conceptual approach described above are analyzed. The screening evaluation is summarized in Tables 4 (Approach 1) and 5 (Approach 2). The summary tables rate each threshold for the issues discussed below based on the level of confidence (low, medium or high) ascribed by J&S. The confidence levels relate to whether a threshold could achieve a particular attribute, such as emission reduction effectiveness. For example, a low emission reduction effectiveness rating means the threshold is not expected to capture a relatively large portion of the new development inventory.

As described above, Threshold 2.7 is not included in this evaluation because the data to develop an efficiency-based threshold has not been reviewed at this time and because this threshold is not considered feasible as an interim approach until more detailed inventory information is available across the California economy.

What is the GHG Emissions Effectiveness of Different Thresholds?

Effectiveness was evaluated in terms of whether a threshold would capture a large portion of the GHG emissions inventory and thus require mitigation under CEQA to control such emissions within the larger framework of AB 32. In addition, effectiveness was also evaluated in terms of whether a threshold would require relatively more or less GHG emissions reductions from the existing economy verses new development. This is presumptive that gains from the existing economy (through retrofits, etc.) will be more difficult and inefficient relative to requirements for new development.

Approach 1-based thresholds that require equivalent reductions relative to business-as-usual (Thresholds 1.1, 1.3, and 1.4) for both the existing and new economy will be less effective than thresholds that support lower-GHG intensity new development (Approach 1.2). However, since Approach 1-based thresholds do not establish a quantitative threshold below which projects do not have to mitigate, the market capture for new development is complete.

Approach 2-based thresholds can be more or less effective at capturing substantial portions of the GHG inventory associated with new development depending on where the quantitative or qualitative thresholds are set. Lower thresholds will capture a broader range of projects and result in greater mitigation. Based on the review of project data for

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the select municipalities described in the Approach 2 section above, thresholds based on the CARB Reporting Threshold/Cap and Trade Entry Level (Threshold 2.4) or CEQA definitions of "Statewide, Regional or Areawide" projects (Threshold 2.6) will result in a limited capture of the GHG inventory. Lower quantitative or qualitative thresholds (Thresholds 2.1, 2.2 and 2.5) could result in capture of greater than 90 percent of new development.

Are the Different Thresholds Consistent with AB 32 and S-3-05?

Thresholds that require reductions compared to business-as-usual for all projects or for a large portion of new development would be consistent with regulatory mandates. In time, the required reductions will need to be adjusted from 2020 (AB 32) to 2050 (S-3-05) horizons, but conceptually broad identification of significance for projects would be consistent with both of these mandates. Thresholds that exclude a substantial portion of new development would likely not be consistent, unless it could be shown that other more effective means of GHG reductions have already been, or will be adopted, within a defined timeframe.

All Approach 1-based thresholds would be consistent with AB 32 and S-3-05 if it can be demonstrated that other regulations and programs are effective in achieving the necessary GHG reduction from the existing economy to meet the overall state goals.

Approach 2-based thresholds that include substantive parts of the new development GHG inventory (Thresholds 2.1, 2.2 and 2.5) will be more consistent with AB 32 and S-3-05 than those that do not (Thresholds 2.3, 2.4, and 2.6) unless it can be demonstrated that other regulations and programs are effective in achieving the necessary GHG reduction from the existing economy to meet the overall state goals.

What are the Uncertainties Associated with Different Thresholds?

All thresholds have medium to high uncertainties associated with them due to the uncertainty associated with the effectiveness of AB 32 implementation overall, the new character of GHG reduction strategies on a project basis, the immaturity of GHG reduction technologies or infrastructure (such as widespread biodiesel availability), and the uncertainty of GHG reduction effectiveness of certain technologies (such as scientific debate concerning the relative lifecycle GHG emissions of certain biofuels, for example).

In general, Approach 1-based thresholds have higher uncertainties than Approach 2 thresholds because they rely on a constantly changing definition of business-as-usual. Threshold 1.2, with its relatively smaller reliance on the existing economy for GHG reductions has relatively less uncertainty than other Approach 1 thresholds. Thresholds that spread mitigation more broadly (Thresholds 1.3 and 1.4) have less uncertainty by avoiding the need for every project to mitigate equally.

Approach 2 thresholds with lower quantitative (2.1 and 2.2) or qualitative (2.5) thresholds will have uncertainties associated with the ability to achieve GHG reductions

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from small to medium projects. Approach 2 thresholds with higher quantitative (2.3, 2.4) or qualitative (2.6) thresholds will have uncertainties associated with the ability to achieve relatively larger GHG reductions from the existing economy.

What are Other Advantages/Disadvantages of the Different Thresholds?

Thresholds with a single project metric (Thresholds 1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, and 2.6) will be easier to apply to individual projects and more easily understood by project applicants and lead agencies broadly. Thresholds that spread mitigation across sectors (1.3) or regions (1.4), while simple in concept, will require adoption of more complicated cross-jurisdictional reduction plans or evaluation of broad sector-based trends in GHG intensity reduction over time. Approach 1 options would require all projects to quantify emissions in order to determine needed reductions relative to business-as-usual (which will change over time as described above). Concepts that are unit-based (Threshold 2.5 and 2.6) will not result in thresholds that have equal amount of GHG emissions, and thus equity issues may arise.

Table 4: Non-Zero Threshold Evaluation Matrix – Approach 1

Approach 1	1.1	1.2	1.3	1.4
	28% - 33% Reduction from BAU by 2020 by Project	**50% Reduction from BAU by 2020 by Project**	**28% - 33% Reduction by 2020 by Sector**	**28% - 33% Reduction by 2020 by Region**
GHG Emissions Reduction Effectiveness	**Low** - Captures all new projects but relies on a high level of reductions from the existing economy.	**Medium** - Captures all new projects and has a more realistic level of reductions from the existing economy.	**Low** - Captures all new projects but relies on a high level of reductions from the existing economy.	**Low** - Captures all new projects but relies on a high level of reductions from the existing economy.
Economic Feasibility	**Low** - Some projects will not be able to afford this level of reduction without effective market-based mechanisms like offsets.	**Low** - Some projects will not be able to afford this level of reduction without effective market-based mechanisms like offsets.	**Medium** - Sectors as a whole will be better able to achieve reductions than individual projects.	**Low** - Some regions and newly developed areas may not be able to afford this level of reduction without effective market-based mechanisms like offsets.
Technical Feasibility	**Medium** - Some projects will not be able to achieve this level of reduction without effective market-based mechanisms like offsets	**Low** - Relatively larger set of projects will not be able to achieve this level of reduction without effective market-based mechanisms like offsets	**High** - Some projects will not be able to achieve this level of reduction without effective market-based mechanisms like offsets	**Medium** - Some regions and newly developed areas may not be able to afford this level of reduction without effective market-based mechanisms like offsets.
Logistical Feasibility	**Low** - Absent broader reductions strategies, each project may reinvent the wheel each time to achieve mandated reductions.	**Low** - Absent broader reductions strategies, each project may reinvent the wheel each time to achieve mandated reductions.	**Low** - Absent broader reductions strategies, each project may reinvent the wheel each time to achieve mandated reductions.	**Low** - Absent broader reductions strategies, each project may reinvent the wheel each time to achieve mandated reductions.
Consistency with AB-32 and S-03-05	**Medium** - Would require heavy reliance on command and control gains.	**High**	**Medium-High** - Would rely on command and control gains, but would allow sectoral flexibility.	**Medium-High** - Would rely on command and control gains, but would allow regional flexibility.
Cost Effectiveness	**Low** - Will require all types of projects to reduce the same regardless of the cost/ton of GHG reductions.	**Low** - Will require all types of projects to reduce the same regardless of the cost/ton of GHG reductions.	**Low/Medium** - Allows tradeoffs within sector between high and low cost reduction possibilities but not between sectors.	**Low/Medium** - Allows tradeoffs within region between high and low cost reduction possibilities, but not between regions.
Uncertainties	**High** - BAU changes over time. Ability to reduce GHG emissions from existing economy will take years to demonstrate. Ability to limit GHG emissions from other new development will take years to demonstrate.	**Medium/High** - BAU changes over time. Ability to limit GHG emissions from other new development will take years to demonstrate.	**High** - BAU changes over time. Ability to reduce GHG emissions from existing economy will take years to demonstrate. Ability to limit GHG emissions from other new development will take years to demonstrate.	**High** - BAU changes over time. Ability to reduce GHG emissions from existing economy will take years to demonstrate. Ability to limit GHG emissions from other new development will take years to demonstrate.
Other Advantages	Simple/easy to explain.	Simple/easy to explain.	Spreads mitigation broadly	Spreads mitigation broadly
Other Disadvantages	Requires all projects to quantify emissions.	Requires all projects to quantify emissions.	Requires all projects to quantify emissions.	Requires all projects to quantify emissions.

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Table 5: Non-Zero Threshold Evaluation Matrix – Approach 2

Approach 2	2.1 **Zero Threshold**	2.2 **Quantitative (900 tons)**	2.3 **Quantitative CARB Reporting Threshold/Cap and Trade (25,000 tons/ 10,000 tons)**	2.4 **Quantitative Regulated Inventory Capture (~40,000 - 50,000 tons)**	2.5 **Qualitative Unit-Based Thresholds**	2.6 **Statewide, Regional or Areawide (CEQA Guidelines 15206(b)).**
GHG Emissions Reduction Effectiveness	**High** - Captures all sources.	**High** - Market capture at >90%. Captures diverse sources.	**Medium** - Moderate market capture.	**Low** - Low market capture.	**High** - Market capture at ~90%. Captures diverse sources; excl. smallest proj.	**Medium** - Moderate market capture. Excludes small and med. projects.
Economic Feasibility	**Low** - Early phases will be substantial change in BAU, esp. for smaller projects; may be infeasible to mitigate.	**Medium** - Early phases will be substantial change in BAU, esp. for smaller projects; may be infeasible to mitigate.	**High** - Large projects have greater ability to absorb cost.	**High** - Large projects have greater ability to absorb cost.	**Medium** - Early phases will be substantial change in BAU, esp. for smaller projects; may be infeasible to mitigate.	**High** - Large projects have greater ability to absorb cost.
Technical Feasibility	**Low** - Early phases will be substantial change in BAU, esp. for smaller projects; may be infeasible to mitigate.	**Medium** - Early phases will be substantial change in BAU, esp. for smaller projects; may be inefficient to mitigate.	**High** - Greater opportunities for multiple reduction approaches.	**High** - Greater opportunities for multiple reduction approaches.	**Medium** - Early phases will be substantial change in BAU, particularly for smaller projects may be inefficient to mitigate.	**High** - Greater opportunities for multiple reduction approaches.
Logistical Feasibility	**Low** - Unless fee or offset basis,very difficult to mitigate all projects.	**Medium** - BMPs broadly written to allow diversity; new req. will take time to integrate into new dev.	**High** - Less mitigation.	**High** - Less mitigation.	**Medium** - BMPs broadly written to allow diversity; new req. will take time to integrate into new dev.	**High** - Less mitigation.
Consistency with AB-32 and S-03-05	**High** - Market capture.	**High** - Market capture at >90%.	**Low** - Would rely on command and control success heavily.	**Low** - Would rely on command and control success heavily.	**Medium** - Need to demonstrate adequate market capture over time.	**Low** - Would rely on command and control success heavily.
Cost Effectiveness	**Low** - Will result in inefficient mitigation approaches. Efficiency will improve in time.	**Medium** - Emphasis is on new dev., req. for mitigation will result in inefficient mitigation approaches in early phases. Efficiency will improve in time.	**Medium** - Relies on command and control reductions for existing economy more heavily. With focus on larger projects, eff. of mitigation for new dev. high.	**Medium** - Relies on command and control reductions for existing economy more heavily. With focus on larger projects, eff. of mitigation for new dev. high.	**Medium** - Emphasis is on new dev.; req. for mitigation will result in inefficient mitigation approaches in early phases. Efficiency will improve in time.	**Medium** - Relies on command and control reductions for existing economy more heavily. With focus on larger projects, eff. of mitigation for new dev. high.
Uncertainties	**High** - Time to adapt for res. and comm.. sectors. Ability to mitigate without market-based mechanism for smaller projects unlikely.	**Medium/High** - Time to adapt for res. and comm.. sectors. Ability to mitigate without market-based mechanism for smaller projects uncertain.	**High** - Gains from command and control likely longer to be realized.	**High** - Gains from command and control likely longer to be realized.	**Medium/High** - Time to adapt for res. and comm.. sectors. Ability to mitigate without market-based mechanism for smaller projects uncertain.	**High** - Gains from command and control likely longer to be realized.
Other Advantages	Single threshold.	Single threshold. BMPs can be updated. Greenlist can be updated.	Single threshold. Does not change CEQA processing for most projects. CARB inventory = project inv.. All projects treated same.	Single threshold. Does not change CEQA processing for most projects. Follows established SIP practice.	BMPs can be updated. Greenlist can be updated. Unit-Based thresholds can be updated.	Existing guideline. Does not change CEQA processing for most projects. Endorsed by Cal. Chapter of the APA.
Other Disadvantages	Requires all projects to quantify emissions.	Requires nearly all projects to quantify emissions.			Sectoral projects have different GHG emis. Only largest projects to quantify emis.	Sectoral projects have different GHG emissions.

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Introduction

This chapter evaluates the availability of various analytical methods and modeling tools that can be applied to estimate the greenhouse gas emissions from different project types subject to CEQA. This chapter will also provide comments on the suitability of the methods and tools to accurately characterize a projects emissions and offer recommendations for the most favorable methodologies and tools available. Some sample projects will be run through the methodologies and modeling tools to demonstrate what a typical GHG analysis might look like for a lead agency to meet its CEQA obligations. The air districts retained the services of EDAW environmental consultants to assist with this effort.

Methodologies/Modeling Tools

There are wide varieties of discretionary projects that fall under the purview of CEQA. Projects can range from simple residential developments to complex expansions of petroleum refineries to land use or transportation planning documents. It is more probably than not, that a number of different methodologies would be required by any one project to estimate its direct and indirect GHG emissions. Table 10 contains a summary of numerous modeling tools that can be used to estimate GHG emissions associated with various emission sources for numerous types of project's subject to CEQA. The table also contains information about the models availability for public use, applicability, scope, data requirements and its advantages and disadvantages for estimating GHG emissions.

In general, there is currently not one model that is capable of estimating all of a project's direct and indirect GHG emissions. However, one of the models identified in Table 9 would probably be the most consistently used model to estimate a projects direct GHG emissions based on the majority of projects reviewed in the CEQA process. The Urban Emissions Model (URBEMIS) is designed to model emissions associated with development of urban land uses. URBEMIS attempts to summarize criteria air pollutants and CO_2 emissions that would occur during construction and operation of new development. URBEMIS is publicly available and already widely used by CEQA practitioners and air districts to evaluate criteria air pollutants emissions against air district-adopted significance thresholds. URBEMIS is developed and approved for statewide use by CARB. The administrative reasons for using URBEMIS are less important than the fact that this model would ensure consistency statewide in how CO_2 emissions are modeled and reported from various project types.

One of the shortfalls of URBEMIS is that the model does not contain emission factors for GHGs other than CO_2, except for methane (CH_4) from mobile-sources, which is converted to CO_2e. This may not be a major problem since CO_2 is the most important GHG from land development projects. Although the other GHGs have a higher global warming potential, a metric used to normalize other GHGs to CO_2e, they are emitted in far fewer quantities. URBEMIS does not calculate other GHG emissions associated with

off-site waste disposal, wastewater treatment, emissions associated with goods and services consumed by the residents and workers supported by a project. Nor does URBEMIS calculate GHGs associated with consumption of energy produced off-site. (For that matter, URBEMIS does not report criteria air pollutant emissions from these sources either).

Importantly, URBEMIS does not fully account for interaction between land uses in its estimation of mobile source operational emissions. Vehicle trip rates are defaults derived from the Institute of Transportation Engineers trip generation manuals. The trip rates are widely used and are generally considered worst-case or conservative. URBEMIS does not reflect "internalization" of trips between land uses, or in other words, the concept that a residential trip and a commercial trip are quite possibly the same trip, and, thus, URBEMIS counts the trips separately. There are some internal correction settings that the modeler can select in URBEMIS to correct for "double counting"; however, a project-specific "double-counting correction" is often not available. URBEMIS does allow the user to overwrite the default trip rates and characteristics with more project-specific data from a traffic study prepared for a project.

Residential, Commercial, Mixed-Use Type Projects/ Specific Plans

Direct Emissions

URBEMIS can be used to conduct a project-specific model run and obtain CO_2e emissions for area and mobile sources from the project, and convert to metric tons CO_2e. When a project-specific traffic study is not available, the user should consult with their local air district for guidance. Many air district staff are experienced practitioners of URBEMIS and can advise the lead agency or the modeler on how to best tailor URBEMIS default input parameters to conduct a project-specific model run. When a traffic study has been prepared for the project, the user must overwrite default trip length and trip rates in URBEMIS to match the total number of trips and vehicle miles traveled (VMT) contained in the traffic study to successfully conduct a project-specific model run. URBEMIS is recommended as a calculation tool to combine the transportation study (if available) and EMFAC emission factors for mobile-sources. Use of a project-specific traffic study gets around the main shortfall of URBEMIS: the lack of trip internalization. URBEMIS also provides the added feature of quantifying direct area-source GHG emissions.

Important steps for running URBEMIS

1. Without a traffic study prepared for the project, the user should consult with the local air district for direction on which default options should be used in the modeling exercise. Some air districts have recommendations in the CEQA guidelines.

2. If a traffic study was prepared specifically for the project, the following information must be provided:

a. Total number of average daily vehicle trips *or* trip-generation rates by land use type per number of units; and,

b. Average VMT per residential *and* nonresidential trip.

c. The user overwrites the "Trip Rate (per day)" fields for each land use in URBEMIS such that the resultant "Total Trips" and the "Total VMT" match the number of total trips and total VMT contained in the traffic study.

d. Overwrite "Trip Length" fields for residential and nonresidential trips in UBEMIS with the project-specific lengths obtained form the traffic study.

3. Calculate results and obtain the CO_2 emissions from the URBEMIS output file (units of tons per year [TPY]).

Indirect Emissions

URBEMIS does estimate indirect emissions from landscape maintenance equipment, hot water heaters, etc. URBEMIS does not however, provide modeled emissions from indirect sources of emissions, such as those emissions that would occur off-site at utility providers associated with the project's energy demands. The California Climate Action Registry (CCAR) Protocol v.2.2 includes methodology, which could be used to quantify and disclose a project's increase in indirect GHG emissions from energy use. Some assumptions must be made for electrical demand per household or per square foot of commercial space, and would vary based on size, orientation, and various attributes of a given structure. An average rate of electrical consumption for residential uses is 7,000 kilowatt hours per year per household and 16,750 kilowatt hours per thousand square feet of commercial floor space. Commercial floor space includes offices, retail uses, warehouses, and schools. These values have been increasing steadily over the last 20 years. Energy consumption from residential uses has increased due to factors such as construction and occupation of larger homes, prices of electricity and natural gas, and increased personal income allowing residents to purchase more electronic appliances. Commercial energy consumption is linked to factors such as vacancy rates, population, and sales.

The modeler will look up the estimated energy consumption for the project's proposed land uses under year of project buildout, or use the values given in the previous paragraph for a general estimate. The CCAR Protocol contains emission factors for CO_2, CH_4, and nitrous oxide. The "CALI" region grid serves most of the State of California. If a user has information about a specific utility provider's contribution from renewable sources, the protocol contains methodology to reflect that, rather than relying on the statewide average grid. The incremental increase in energy production associated with project operation should be accounted for in the project's total GHG emissions for inclusion in the environmental document.

The incremental increase in energy production associated with project operation should be accounted for in the project's total GHG emissions, but it should be noted that these emissions would be closely controlled by stationary-source control-based regulations and additional regulations are expected under AB 32. However, in the interest of disclosing project-generated GHG emissions and mitigating to the extent feasible, the indirect emissions from off-site electricity generation can be easily calculated for inclusion in the environmental document.

Example Project Estimates for GHG Emissions

Residential Project

Project Attributes:

- 68 detached dwelling units
- 15.9 acres
- 179 residents
- 0 jobs
- Located in unincorporated Placer County (PCAPCD jurisdiction)
- Analysis year 2009

As shown in Table 6, the project's direct GHG emissions per service population (SP) would be approximately 8 metric tons CO_2e/SP/year.

Table 6: Residential Project Example GHG Emissions Estimates

URBEMIS Output (Project Specific)	Metric Tons/Year CO_2e	Demographic Data	
Area-source emissions	251	Residents	179
Mobile-source emissions	1,044	Jobs	0
Indirect emissions (from CCAR Protocol)	174		
Total operational emissions	**1,469**	Service population	179
Operational emissions/SP	**8.2**		

Notes:
CO_2e = carbon dioxide equivalent; CCAR = California Climate Action Registry; SP = service population(see definition of service population below in discussion of Normalization/Service Population Metric).

Sources: EDAW 2007, ARB 2007b, CCAR 2007, CEC 2000

Commercial Project

Project Attributes:

- Free Standing Discount Superstore: 241 thousand square feet (ksf)
- 0 residents

- 400 jobs
- Located in the San Joaquin Valley Air Pollution Control District's (SJVAPCD) jurisdiction
- Analysis year 2009

Table 7: Commercial Project Example GHG Emissions Estimates

URBEMIS Output (Project Specific)	Metric Tons/Year CO_2e	Demographic Data	
Area-source emissions	464	Residents	0
Mobile-source emissions	13,889	Jobs	400
Indirect emissions (from CCAR Protocol)	1,477		
Total operational emissions	**15,830**	Service population	400
Operational emissions/SP	**39.6**		

Notes:
CO_2e = carbon dioxide equivalent; CCAR = California Climate Action Registry; SP = service population (see definition of service population below in discussion of Normalization/Service Population Metric).

Sources: EDAW 2007, ARB 2007b, CCAR 2007, CEC 2000

Specific Plan

If used traditionally with default trip rates and lengths, rather than project-specific (Traffic Analysis Zone-specific) trip rates and lengths, URBEMIS does not work well for specific plan or general plan-sized projects with multiple land use types proposed. However, in all instances, projects of these sizes (several hundred or thousand acres) would be accompanied by a traffic study. Thus, for large planning-level projects, URBEMIS can be used as a calculation tool to easily obtain project-specific mobile-source emissions. The user should follow the steps discussed above; wherein he/she overwrites the default ITE trip rates for each land use type with that needed to make total VMT match that contained in the traffic study. The URBEMIS interface is a simple calculator to combine the traffic study and EMFAC emissions factors for mobile-source CO_2.

Project Attributes:

- 985 acres
- Total dwelling units: 5,634
- Commercial/Mixed Use: 429 ksf
- Educational: 2,565 ksf
- 14,648 residents
- 3,743 jobs
- Located in Sacramento County (SMAQMD jurisdiction)
- Analysis year 2009

Table 8: Specific Plan Example GHG Emissions Estimates

URBEMIS Output (Project Specific)	Metric Tons/Year CO_2e	Demographic Data	
Area-source emissions	23,273	Residents	14,648
Mobile-source emissions	73,691	Jobs	3,743
Indirect emissions (from CCAR Protocol)	32,744		
Total operational emissions	**129,708**	Service population	18,391
Operational emissions/SP	**7.1**		

Notes:
CO_2e = carbon dioxide equivalent; CCAR = California Climate Action Registry; SP = service population (see definition of service population below in discussion of Normalization/Service Population Metric).

Sources: EDAW 2007, ARB 2007b, CCAR 2007, CEC 2000

The specific plan example, when compared to the residential or commercial examples, illustrates the benefit of a mixed-use development when you look at CO_2e emissions per resident or job (service population) metric (see definition of service population below in discussion of Normalization/Service Population Metric). Though this particular specific plan is not an example of a true jobs/housing balance, the trend is clear: accommodating residents and jobs in a project is more efficient than residents or jobs alone.

Stationary- and Area-Source Project Types

GHG emissions from stationary or area sources that require a permit to operate from the air district also contain both direct and indirect sources of emissions. Examples of these types of sources would be fossil fuel power plants, cement plants, landfills, wastewater treatment plants, gas stations, dry cleaners and industrial boilers. All air districts have established procedures and methodologies for projects subject to air district permits to calculate their regulated pollutants. It is anticipated that these same procedures and methodologies could be extended to estimate a permitted facility's GHG calculations. For stationary and area sources that do not require air district permits, the same methodologies used for permitted sources could be used in addition to URBEMIS and CCAR GRP to calculate GHG emissions from these facilities.

Wastewater Treatment Facilities

Direct GHG emissions associated with a proposed waste water treatment plant can be calculated using AP-42 emission factors from Chapter 4.3.5 Evaporative Loss Sources: Waste Water-Greenhouse Gases and the CCAR methodology. In general, most wastewater operations recover CH_4 for energy, or use a flare to convert the CH_4 to CO_2. There are many types of wastewater treatment processes and the potential for GHG emissions from different types of plants varies substantially. There is not one standard set of emission factors that could be used to quantify GHG emissions for a state

"average" treatment plant. Thus, research will need to be conducted on a case-by-case basis to determine the "Fraction Anaerobically Digested" which is a function of the type of treatment process. Indirect emissions from these facilities can be calculated using the CCAR energy use protocols and URBEMIS model for transportation emissions.

Solid Waste Disposal Facilities

Air districts will have emission estimate methodologies established for methane emissions at permitted landfills. In addition, EPA's Landfill Gas Emissions Model (LandGem) and the CCAR methodology could also be used to quantify GHG emissions from landfill off gassing; however, this model requires substantial detail be input. The model uses a decomposition rate equation, where the rate of decay is dependent on the quantity of waste in place and the rate of change over time. This modeling tool is free to the public, but substantial project detail about the operation of the landfill is needed to run the model. Indirect emissions from these facilities can be calculated using the CCAR energy use protocols and URBEMIS model for transportation emissions.

Construction Emissions

GHG emissions would occur during project construction, over a finite time. In addition, a project could result in the loss of GHG sequestration opportunity due primarily to the vegetation removed for construction. URBEMIS should be used to quantify the mass of CO_2 that would occur during the construction of a project for land development projects. Some construction projects would occur over an extended period (up to 20–30 years on a planning horizon for general plan buildout, or 5–10 years to construct a dam, for example). OFFROAD emission factors are contained in URBEMIS for CO_2 emissions from construction equipment. For other types of construction projects, such as roadway construction projects or levee improvement projects, SMAQMD's spreadsheet modeling tool, the Road Construction Emissions Model (RoadMod), should be used. This tool is currently being updated to include CO_2 emissions factors from OFFROAD.

The full life-cycle of GHG emissions from construction activities is not accounted for in the modeling tools available, and the information needed to characterize GHG emissions from manufacture, transport, and end-of-life of construction materials would be speculative at the CEQA analysis level. The emissions disclosed will be from construction equipment and worker commutes during the duration of construction activities. Thus, the mass emissions in units of metric tons CO_2e/year should be reported in the environmental document as new emissions.

General Plans

In the short-term, URBEMIS can be used as a calculation tool to model GHG emissions from proposed general plans, but only if data from the traffic study is incorporated into model input. The same methodology applied above in the specific plan example applies to general plans. The CCAR GRP can be used to approximate indirect emissions from

increased energy consumption associated with the proposed plan area. The same models and methodologies discussed previously for wastewater, water supply and solid waste would be used to estimate indirect emissions resulting from buildout of the general plan.

In the longer-term, more complex modeling tools are needed, which would integrate GHG emission sources from land use interaction, such as I-PLACE^{3}S or CTG Energetics' Sustainable Communities Custom Model attempt to do. These models are not currently available to the public and only have applicability in certain areas of the state. It is important that a tool with statewide applicability be used to allow for consistency in project treatment, consideration, and approval under CEQA.

Scenarios

At the general plan level, the baseline used for analyzing most environmental impacts of a general plan update is typically no different from the baseline for other projects. The baseline for most impacts represents the existing conditions, normally on the date the Notice of Preparation is released. Several comparative scenarios could be relevant, depending on the exact methodological approach and significance criteria used for GHG assessment:

- Existing Conditions. The GHG emissions associated with the existing, on-the-ground conditions within the planning area.

- 1990 conditions. The GHG emissions associated with the general plan area in 1990. This is relevant due to the state's AB 32 GHG emission reduction goals' benchmark year of 1990. The GHG-efficiency of 1990 development patterns could be compared to that of the general plan buildout.

- Buildout of the Existing General Plan. The GHG emissions associated with buildout of the existing general plan (without the subject update). This is the no project alternative for the purposes of general plan CEQA analysis.

- Buildout of the Updated General Plan. The GHG emissions associated with buildout of the general plan, as proposed as a part of the subject update. This would include analysis of any changes included as a part of the general plan update for the existing developed portions of the planning area. Many communities include redevelopment and revitalization strategies as a part of the general plan update. The general plan EIR can include assumptions regarding what level and type of land use change could be facilitated by infill and redevelopment. Many jurisdictions wish to provide future projects consistent with these land use change assumptions with some environmental review streamlining. In addition, many communities include transit expansions, pedestrian/bicycle pathway improvements, multi-modal facility construction, travel demand policies, energy efficiency policies, or other measures that could apply to the existing developed area, just as they may apply to any new growth

areas. Such policies could affect the overall GHG emissions of the built out general plan area.

- Increment between Buildout of Updated General Plan and Existing General Plan Area. There are many important considerations associated with the characterization of the impact of the General Plan update. The actual GHG emissions impact could be described as the difference between buildout under the existing and proposed land use plan (No-Build Alternative). However, the courts have held that an EIR should also analyze the difference between the proposed General Plan and the existing environment (*Environmental Planning & Information Council v. County of El Dorado* (EPIC) (1982) 131 Cal.App.3d 350). At the General Plan level, over the course of buildout, some new land uses are introduced, which could potentially add operational GHG emissions and potentially remove existing sequestration potential. Some properties become vacant and are not redeveloped. Other properties become vacant and then are redeveloped. Communities cannot pretend to understand fully in advance each component of land use change. The programmatic document is the preferred method of environmental analysis. Through this programmatic framework, communities develop buildout assumptions as a part of the General Plan that are normally used as a basis of environmental analysis. For certain aspects of the impact analysis, it becomes important not just to understand how much "new stuff" could be accommodated under the updated General Plan, but also the altered interactions between both "new" and "existing" land uses within the planning area. As addressed elsewhere, there are tools available for use in understanding land use/transportation interactions at the General Plan level. Without the GHG targets established by AB 32, a simple mass comparison of existing conditions to General Plan buildout might be appropriate.

However, within the current legal context, the GHG efficiency of the updated General Plan becomes the focus of analysis. Some options in this regard include:

- Estimate the GHG emissions associated with all the land uses included within the planning area upon buildout of the General Plan using no project specific information (regional, countywide, or statewide defaults). Estimate GHG emissions using project specific information from the transportation engineer, transportation demand policies, community design elements, energy efficiency requirements, wastewater treatment and other public infrastructure design changes, and other components. Compare these two calculations. Is the second calculation reduced by the percent needed to meet AB 32 goals compared to the first calculation?

- Estimate the GHG emissions associated with the 1990 planning area and the per-capita or per-service population GHG associated with the 1990 planning area. (Many communities are establishing GHG inventories using different tools). Estimate the GHG emissions associated with buildout of the proposed General Plan update and the resulting per-capita or per-service population GHG

emissions. Compare the two calculations. Is the General Plan buildout per-capita or per-service population level greater than the 1990 estimate?

Example General Plan Update: Proposed new growth area

Project Attributes:

- 10,050 single family dwelling units
- 652 multi-family dwelling units
- 136 acres parks
- 2,047 ksf commercial (regional shopping center)
- 2,113 ksf office
- 383 acres industrial park
- 31,293 new residents
- 4,945 new jobs
- Located in Stanislaus County (SJVAPCD jurisdiction)
- Analysis year 2025

Table 9: General Plan Example GHG Emissions Estimates

URBEMIS Output (Project Specific)	Metric CO_2e	Tons/Year	Demographic Data	
Construction emissions	12,083*		Residents	31,293
Area-source emissions	45,708			
Mobile-source emissions	263,954		Jobs	4,945
Indirect emissions (from CCAR Protocol)	78,385			
Total operational emissions	**388,046**		Service population	36,238
Operational emissions/SP	**10.7**			

* Approximately 241,656 metric tons CO_2e total at general plan buildout (assumes 20-year buildout period). Construction emissions were not included in total operational emissions.
Notes:
CO_2e = carbon dioxide equivalent; CCAR = California Climate Action Registry; SP = service population (see definition of service population below in discussion of Normalization/Service Population Metric).
Sources: EDAW 2007, ARB 2007b, CCAR 2007, CEC 2000

Due to the programmatic level of analysis that often occurs at the general plan level, and potential for many relevant GHG emission quantities, it could be preferable to use a qualitative approach. Such an analysis could address the presence of GHG-reducing policy language in the general plan.

Three possible tiers of approaches to addressing GHG mitigation strategies, either as general plan policy, general plan EIR mitigation measures, or both, include:

- Forward planning
- Project toolbox
- Defer to GHG reductions plan

The three basic approaches are described below.

1. Bring reduction strategies into the plan itself. The most effective way for local jurisdictions to achieve GHG emissions reductions in the medium- and long-term is through land use and transportation policies that are built directly into the community planning document. This involves creating land use diagrams and circulation diagrams, along with corresponding descriptive standards, that enable and encourage alternatives to travel and goods movement via cars and trucks. The land use and circulation diagrams provide a general framework for a community where people can conduct their everyday business without necessarily using their cars. The overall community layout expressed as a part of the land use and circulation diagrams is accompanied by a policy and regulatory scheme designed to achieve this community layout. Impact fees, public agency spending, regulations, administrative procedures, incentives, and other techniques are designed to facilitate land use change consistent with the communities' overall vision, as expressed in policy and in the land use diagram. There are many widely used design principles that can be depicted in land use and circulation diagrams and implemented according to narrative objectives, standards, and policies:

- Connectivity. A finely-connected transportation network shortens trip lengths and creates the framework for a community where homes and destinations can be placed close in proximity and along direct routes. A hierarchical or circuitous transportation network can increase trip lengths and create obstacles for walking, bicycling, and transit access. This policy language would likely be found in the Circulation Element.

- Compactness. Compact development, by its nature, can increase the efficiency of infrastructure provision and enable travel modes other than the car. If communities can place the same level of activity in a smaller space, GHG emissions would be reduced concurrently with VMT and avoid unnecessary conversion of open space. This policy language would likely be found in the Land Use Element.

- Diversity. Multiple land use types mixed in proximity around central "nodes" of higher-activity land uses can accommodate travel through means other than a car. The character and overall design of this land use mix is, of course, different from community to community. This policy language would likely be found in the Land Use Element.

- Facilities. Pedestrian, bicycle, and public transportation improvements, planning, and programming are sometimes an afterthought. To get a more GHG-efficient mode share, safe and convenient bike lanes, pedestrian pathways, transit shelters, and other facilities are required to be planned along with the vehicular travel network. This policy language would likely be found in the Circulation Element.

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- Redevelopment. One way to avoid GHG emissions is to facilitate more efficient and economic use of the lands in already-developed portions of a community. Reinvestment in existing neighborhoods and retrofit of existing buildings is appreciably more GHG efficient than greenfield development, and can even result in a net reduction in GHG emissions. This policy language would likely be found in the Conservation or Land Use Element.

- Housing and Employment. Most communities assess current and future economic prospects along with long-range land use planning. Part of the objective for many communities is to encourage the coalescence of a labor force with locally available and appropriate job opportunities. This concept is best known as "jobs-housing balance." This policy language would likely be found in the Housing Element.

- Planning Level Versus Project Level. For transportation-related GHG emissions that local governments can mitigate through land use entitlement authority, the overall community land use strategy and the overall transportation network are the most fruitful areas of focus. The reduction capacity of project-specific mitigation measures is greatly limited if supportive land use and transportation policies are lacking at the community planning level. The regional economic context, of course, provides an important backdrop for land use and transportation policy to address GHG emissions. Within this context, the general plan is the readily available tool for local governments to establish such land use and transportation strategies. This policy language would likely be found in the Land Use and Circulation Elements.

- Shipping Mode Shift. Locate shipping-intensive land uses in areas with rail access. Some modes of shipping are more GHG-intensive than others. Rail, for example, requires only about 15 to 25 percent of the energy used by trucks to ship freight equivalent distances and involves reduced transportation-related GHG emissions. Cities and counties have little direct control over the method of shipment that any business may choose. Nevertheless, as a part of the general planning process, cities and counties can address constraints on the use of rail for transporting goods. This policy language would likely be found in the Land Use and Circulation Elements.

2. Provide a "toolbox" of strategies after the project site has been selected. In addition to the examples of design principles that are built into the community planning process, communities can offer project applicants a range of tools to reduce GHG emissions. Mitigation strategies are elaborated in detail in Chapter 9.

3. Defer to General Plan implementation measure. Develop and implement a GHG Emissions Reduction Plan. Another option for local governments would be development of an implementation measure as a part of the general plan that outlines an enforceable GHG reduction program. Perhaps the most well known example of this approach is the result of California's Attorney General settlement of the lawsuit brought against San

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Bernardino County. The County has agreed to create a 1990 GHG inventory and develop measures to reduce such emissions according to the state's overall goals. Other communities have pursued similar programs (i.e., the City of San Diego, Marin County). Along with the inventories, targets, and example reduction measures, these programs would include quantitative standards for new development; targets for reductions from retrofitting existing development; targets for government operations; fee and spending program for GHG reduction programs; monitoring and reporting; and other elements. The local government itself should serve as a model for GHG reduction plan implementation, by inventorying emissions from government operations and achieving emission reductions in accordance with the plan's standards. An optional climate change element could be added to contain goals, policies, and this implementation strategy, or this could belong in an optional air quality element.

Other Project Types

Air District Rules, Regulations and Air Quality Plans

Air district air quality plans, rules and regulations could have the potential to increase or decrease GHG emissions within their respective jurisdiction. In general, air district air quality plans, rules and regulations act to reduce ozone precursors, criteria air pollutant and toxic air contaminant emissions, which would almost always act to reduce GHG emissions simultaneously. However, this may not always be the case.

Air Quality Plans

Air districts will have to include GHG emissions analysis as part of their criteria air pollutant and toxic air contaminant air pollutant analysis when considering the adoption of air quality plans and their subsequent rules and regulations needed to implement the plans. Multiple models and methodologies will be needed to accomplish this analysis.

Regional Transportation Plans

Regional transportation plans would also need to be evaluated on a case-by-case basis to determine if a net increase or decrease in GHG emissions would occur. Complex interactions between the roadway network, operating conditions, alternative transportation availability (such as public transit, bicycle pathways, and pedestrian infrastructure), and many other independent parameters specific to a region should be considered. Regional transportation models exist to estimate vehicular emissions associated with regional transportation plans, which includes the ability to estimate GHG emissions.

Normalization/Service Population Metric

The above methodology would provide an estimate of the mass GHG emissions generated by a proposed project, which could be compared to a mass emission threshold. EDAW developed a methodology that would measure a project's overall GHG efficiency

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in order to determine if a project is more efficient than the existing statewide average for per capita GHG emissions. The following steps could be employed to estimate the GHG-"efficiency," which may be more directly correlated to the project's ability to help obtain objectives outlined in AB 32, although it relies on establishment of an efficiency-based significance threshold. The subcommittee believes this methodology may eventually be appropriate to evaluate the long-term GHG emissions from a project in the context of meeting AB 32 goals. However, this methodology will need substantially more work and is not considered viable for the interim guidance presented in this white paper.

- Divide the total operational GHG emissions by the Service Population (SP) supported by the project (where SP is defined as the sum of the number of residents and the number of jobs supported by the project). This value should be compared to that of the projected statewide GHG emissions inventory from the applicable end-use sectors (electricity generation, residential, commercial/institutional, and mobile-source) in 1990 divided by the projected statewide SP for the year 2020 (i.e., AB 32 requirements), to determine if the project would conflict with legislative goals.

    - If the project's operational GHG/SP falls below AB 32 requirements, then the project's GHG emissions are less than cumulatively considerable.

    - If the project's operational GHG/SP exceed AB 32 requirements (a substantial contribution), then the project's GHG emissions would conflict with legislative requirements, and the impact would be cumulatively considerable and mitigation would be required where feasible.

- New stationary and area sources/facilities: calculate GHG emissions using the CCAR GRP. All GHG emissions associated with new stationary or area sources should be treated as a net increase in emissions, and if deemed significant, should be mitigated where feasible.

- Road or levee construction projects or other construction-only projects: calculate GHG emissions using the RoadMod, which will be updated to contain GHG emission factors from EMFAC and OFFROAD. All construction-generated GHG emissions should be treated as a net increase, and if deemed significant, should be mitigated to the extent feasible.

- Air District rulemaking or air quality management plan-type projects should be evaluated on a case-by-case basis for secondary impacts of increased GHG emissions generation. In most cases, the types of projects that act to reduce regional air pollution simultaneously act to reduce GHG emissions, and would be beneficial, but should be evaluated for secondary effects from GHG emissions.

- Regional transportation plans should also be evaluated on a case-by-case basis for potential to either reduce or increase GHG emissions from the transportation sector. EMFAC can be utilized to determine the net change in GHG emissions

associated with projected vehicle VMT and from operating speed changes associated with additional or alleviated congestion.

To achieve the goals of AB 32, which are tied to GHG emission rates of specific benchmark years (i.e., 1990), California would have to achieve a lower rate of emissions per unit of population and per unit of economic activity than it has now. Further, in order to accommodate future population and economic growth, the state would have to achieve an even lower rate of emissions per unit than was generated in 1990. (The goal to achieve 1990 quantities of GHG emissions by 2020 means that this will need to be accomplished in light of 30 years of population and economic growth in place beyond 1990.) Thus, future planning efforts that would not encourage new development to achieve its fair share of reductions in GHG emissions would conflict with the spirit of the policy decisions contained in AB 32, thus impeding California's ability to comply with the mandate.

Thus, if a statewide context for GHG emissions were pursued, any net increase in GHG emissions within state boundaries would be considered "new" emissions. For example, a land development project, such as a specific plan, does not necessarily create "new" emitters of GHG, but would theoretically accommodate a greater number of residents in the state. Some of the residents that move to the project could already be California residents, while some may be from out of state (or would 'take the place' of in-state residents who 'vacate' their current residences to move to the new project). Some may also be associated with new births over deaths (net population growth) in the state. The out-of-state residents would be contributing new emissions in a statewide context, but would not necessarily be generating new emissions in a global context. Given the California context established by AB 32, the project would need to accommodate an increase in population in a manner that would not inhibit the state's ability to achieve the goals of lower total mass of emissions.

The average net influx of new residents to California is approximately 1.4 percent per year (this value represents the net increase in population, including the net contribution from births and deaths). With population growth, California also anticipates economic growth. Average statewide employment has grown by approximately 1.1 percent over the last 15 years. The average percentage of population employed over the last 15 years is 46 percent. Population is expected to continue growing at a projected rate of approximately 1.5 percent per year through 2050. Long-range employment projection data is not available from the California Department of Finance (DOF) and can be extrapolated in different ways (e.g., linear extrapolation by percentage rate of change, percentage of population employed, mathematical series expansion, more complex extrapolation based on further research of demographic projections such as age distribution). Further study would be needed to refine accurate employment projections from the present to 2050. For developing this framework, employment is assumed to have a constant proportionate relationship with the state's population. The projected number of jobs is assumed to be roughly 46 percent of the projected population.

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In light of the statewide context established by California law, consistency is most important for evaluating GHG emissions from projects. Thus, URBEMIS and the CCAR GRP are the recommended tools for quantification of GHG emissions from most project types in the short term. Over the long term, more sophisticated models that integrate the relationship between GHG emissions and land use, transportation, energy, water, waste, and other resources, and have similar application statewide would have better application to the problem, but may not currently be as accessible or as easily operable. I-PLACE^{3}S and CTG Energetics' Sustainable Communities Model (SCM) are two examples of such models that contain emission factors for GHGs, which could be refined to have applicability statewide and made available to CEQA practitioners. Other models are likely to be developed, given the importance of this issue.

Short-Term and Long-Term Methodologies

The following tools can be used to quantify a project's GHG emissions until tools that are more comprehensive become available statewide:

1. Land development projects: URBEMIS 2007 v. 9.2 and the CCAR GRP v. 2.2 (short-term); further development of I-PLACE^{3}S or CTG's Sustainable Communities Model (long-term).
2. New stationary and area sources/facilities: AP-42 Chapter 4.3, LandGem v. 3.02, and/or CCAR GRP v. 2.2.
3. Road or levee construction projects or other construction-only projects: RoadMod/OFFROAD 2007.

Ideally, I-PLACE^{3}S or CTG's Sustainable Communities Model would be expanded to apply to all regions of the state. These types of models use an integrated approach, which is the best approach for reasonably approximating the emissions that result from interaction between land uses, but neither is available to the public and would create consistency problems in reporting emissions from projects across the state if these were used today. However, a similar model with statewide applicability will likely be developed due to the importance of the issue.Table 10 Summary of Modeling Tools for Estimating GHG Emissions and Project Applicability

Table 10: Summary of Modeling Tools for GHG Emissions

Method/Tool Description	Availability	Applicability	Scope	Ease of Use	Data Input (Requirements and Guidance)	Data Output	Recommendation Comments	Advantages/ Disadvantages
URBEMIS 2007	*Public domain -Download (www.urbemis.com) free of charge*	*Land development and construction projects (construction, mobile- and area-source emissions)*	*Local*	*Fairly Easy*	*Land use information, construction and operational data and assumptions (e.g., jurisdiction, acres of land use type, year of operation, etc.)*	*Mobile-source Construction & Operational CO_2 (lb/day or tons/year)*	*-Recommended for land use development and construction projects -Also recommended for net change in land use (zoning changes)*	*-Does not quantify indirect emissions from energy consumption or other GHGs (except methane from mobile-sources) -Free, available to public, and applicable statewide -Widely used for assessment of other air quality impacts*
California Climate Action Registry General Reporting Protocol v. 2.2	*Public guidance document*	*Indirect emissions from land development projects, stationary- and area-source facilities regulated under AB 32*	*State*	*Easy*	*Energy consumption*	*CO_2e (Metric tons/year)*	*-Recommended for indirect emissions from energy consumption for land use development projects, and for new stationary- or area- sources to be regulated*	*-Contains emission factors for CH_4 and N_2O in addition to CO_2 -Does not contain emission factors broken down by utility provider (statewide average grid only)*
Clean Air and Climate Projection (CACP) Software	*Public agencies (members of ICLEI, NACAA, or similar)*	*Local governments used for emissions inventories*	*Local*	*N/A*	*Energy usage, waste generation/disposal transportation*	*CO_2e (tons/year)*	*-Recommended for inventories of local government entities activities (must be a member of affiliated agency or group)*	*-Not available to public*
CTG Sustainable Communities Model	*Custom model*	*Land development*	*Regional, scalable*	*N/A*	*Land use information, operational (mobile, energy, economic, infrastructure) assumptions*	*CO_2e (tons/year)*	*-An integrated and comprehensive modeling tool, but cannot obtain*	*-Not available to public*

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Method/Tool Description	Availability	Applicability	Scope	Ease of Use	Data Input (Requirements and Guidance)	Data Output	Recommendation Comments	Advantages/ Disadvantages
I-PLACE^{3}S	*Access fee through local COG* *Only available for eight California counties*	*Land use change*	*Regional, scalable*	*Fairly Easy*	*Parcel information*	*CO_2 (lb/day or tons/year)*	*-Recommended for land use development projects and land use changes* *-Especially good for general plans*	*-Not freely available to public* *-Not applicable statewide* *-Actually provides insight into land use interaction* *-Can include very specific project attributes* *-Trip rates are from behavioral survey data, instead of ITE*
EMFAC 2007	*Public domain*	*On-road mobile-sources*	*Statewide, regional*	*Fairly Easy*	*Vehicle fleet information*	*CO_2 (grams/mile)*	*-Not recommended for most projects (URBEMIS preferred)* *-Could be used for certain Air District Rulemaking applications*	*-Can compare emissions based on speed-distribution* *-Emission factors contained in URBEMIS* *-Not a stand-alone model*
OFFROAD 2007	*Public domain*	*Off-road mobile sources (construction equipment)*	*Statewide, regional*	*Fairly Easy*	*Construction fleet information*	*CO_2 (lb/day)*	*-Not recommended (URBEMIS preferred)* *-could be used for certain Air District Rulemaking applications (re: construction equipment)*	*-Emission factors contained in URBEMIS*
RoadMod (to be updated to include CO_2)	*Public domain*	*Off-road and on-road mobile sources (construction equipment and material haul trucks)*	*Statewide*	*Easy*	*Construction information*	*CO_2 (lb/day or tons/project)*	*-Recommended for construction-only projects (linear in nature; i.e., levees, roads, pipelines)*	*-To be updated to support emissions factors from OFFROAD 2007*

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Method/Tool Description	Availability	Applicability	Scope	Ease of Use	Data Input (Requirements and Guidance)	Data Output	Recommendation Comments	Advantages/ Disadvantages
DTIM	*Public domain*	*On-road mobile-sources*	*Statewide, regional*	*Difficult (consists of a series of three programs and requires input files from traffic and emissions modeling)*	*-EMFAC files -Traffic model output files (e.g., link, interzonal, and trip end data) -User options file -Optional files*	*CO_2 (tons/year)*	*-Not recommended*	*-Not updated to support EMFAC 2007 emission factors -Input files include output files from regional transportation models which more accurately reflect VMT*
Southeast Climate Change Partnership Spreadsheet Model (UK)	*Public domain http://www.climatesoutheast.org.uk/*	*UK Local government/ agencies/ organizations used for emissions inventories*	*Local, county, regional*	*Fairly easy*	*Energy usage, waste generation/disposal, transportation*	*CO_2 (tonnes/year)*	*-Not recommended for use in California, but could be a valuable source for building an applicable spreadsheet model*	*-Applicability for UK, but could be updated with CA-specific emission factors*
EPA AP-42; Evaporation Loss Sources Chapter 4.3.5	*Public reference document*	*GHG emissions from waste water treatment facilities*	*Facility level*	*Easy equation; substantial research needed to use*	*Biochemical oxygen demand (BOD) loading, Fraction anaerobically digested*	*CH4 (lb/year)*	*-Recommended for Publicly owned treatment works (POTW) projects*	*-Substantial research needed to determine the "fraction anaerobically digested" parameter, which is dependent on the type of treatment plant/process*
LandGem v. 3.02	*Public domain http://www.epa.gov/ttn/catc/dir1/landgem-v302.xls*	*GHG emissions from anaerobic decomposition associated with landfills*	*Facility Level*	*Moderate*	*Solid waste processing, year of analysis, lifetime of waste in place*	*CO_2, CH_4 (Mega grams/year)*	*-Recommended for landfill emissions*	*-Emission rates change dependent on years of decomposition, waste in place rates of change. -Complex decomposition rate equation, but good first approximation*

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Method/Tool Description	Availability	Applicability	Scope	Ease of Use	Data Input (Requirements and Guidance)	Data Output	Recommendation Comments	Advantages/ Disadvantages
CARROT	*Registry members*	*Stationary source emissions, vehicle fleet mobile sources*	*Facility level*	*Moderate*	*Facility-specific information*	*All GHGs*	*-Recommended for reporting facilities under AB 32 and for indirect emissions from energy consumption (CCAR Protocol)*	*-Estimates all GHGs and normalizes to CO_2e* *-Not publicly available*

Notes:

GHG = greenhouse gas; AB = assembly bill; CO_2e = carbon dioxide equivalent; CH_4 = methane; N_2O = nitrous oxide; COG = council of governments ; ITE = Institute of Transportation Engineers; CCAR = California Climate Action Registry

Source: Data compiled by EDAW and the California Air Pollution Control Officers Association in 2007

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Introduction

This chapter (and Appendix B) identifies existing and potential mitigation measures that could be applied to projects during the CEQA process to reduce a project's GHG emissions that would be identified using the analytical methodologies included in this white paper. The Subcommittee retained the services of EDAW to assist with this effort. EDAW performed a global search of mitigation measures currently in practice and under study that would reduce GHG emissions.

Table 16 (Appendix B) provides a brief description of each measure along with an assessment of their feasibility (from a standpoint of economical, technological, and logistical feasibility, and emission reduction effectiveness), and identifies their potential for secondary impacts to air quality. During the global search performed, EDAW also took note of GHG reduction strategies being implemented as rules and regulation (e.g., early action items under AB 32), which are summarized in Table 18 (Appendix C). It is important to note that though compliance with such would be required by regulation for some sources, such strategies may be applicable to other project and source types.

The recurring theme that echoes throughout a majority of these measures is the shift toward New Urbanism, and research has consistently shown that implementation of Neotraditional Development techniques reduces VMT and associated emissions. The material reviewed assessed reductions from transportation-related measures (e.g., bicycle, pedestrian, transit, and parking) as a single comprehensive approach to land use. This comprehensive approach focuses on development design criteria conducive to enhancing alternate modes of transportation, including transit, walking, and bicycling. Transportation Demand Management (TDM) programs are viewed as a mechanism to implement specific measures. TDM responsibilities may include offering incentives to potential users of alternative modes of transportation and monitoring and reporting mode split changes.

The comprehensive approach makes it more difficult to assess reductions attributable to each measure. Nevertheless, there is a strong interrelationship between many of the measures, which justifies a combined approach. Consider the relationship between bike parking nonresidential, bike parking residential, endtrip facilities, and proximity to bike path/bike lane measures. In reality, these measures combined act as incentives for one individual to bike to work, while implementation of a single measure without the others reduces effectiveness.

The global nature of GHG emissions is an important feature that enables unique mitigation: abatement. When designing a project subject to CEQA, the preferred practice is first to avoid, then to minimize, and finally to compensate for impacts. Where the impact cannot be mitigated on-site, off-site mitigation is often and effectively implemented in several resource areas, either in the form of offsetting the same impact or preserving the resource elsewhere in the region. Frequently, mitigation fee programs or funds are established, where the proponent pays into the program and fees collected

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throughout the region or state are used to implement projects that, in turn, proportionately offset the impacts of the projects to the given resource. It may be more cost-effective to reduce as much GHG on-site as feasible (economically and technologically). Then the proponent would pay into a "GHG retrofit fund" to reduce equivalent GHG emissions off-site. In contrast to regional air pollutant offset programs such as the Carl Moyer Program, it matters greatly where reductions of ozone precursors occur, as ozone affects regional air quality. The GHG retrofit fund could be used to provide incentives to upgrade older buildings and make them more energy efficient. This would reduce demand on the energy sector and reduce stationary source emissions associated with utilities. This program has been successfully implemented in the United Kingdom where developments advertise "carbon neutrality." Of course, some GHG emissions occur associated with operation of the development, but the development would offset the remainder of emissions through off-site retrofit. Avoiding emissions that would otherwise continue to occur at existing development would be a unique opportunity for mitigation of GHG emissions. Reduction of GHG emissions also may have important side benefits including reduction of other forms of pollution.

Depending on the significance threshold concept adopted, projects subject to the CEQA process would either qualitatively or quantitatively identify the amount of GHG emissions associated with their project using the analytical methodologies identified in the previous chapter. The analysis would then apply the appropriate number of mitigation measures listed in Appendix B to their project to reduce their GHG emissions below the significance level. Calculating the amount of GHG emission reductions attributable to a given mitigation measure would require additional research. The examples below illustrate how a project would be mitigated using this approach.

Residential Project Example

Project Attributes:

- 68 detached dwelling units
- 15.9 acres
- Located in unincorporated Placer County PCAPCD jurisdiction)
- Assume URBEMIS defaults for a rural project in Placer County, in absence of a traffic study (This is contrary to the recommendations contained under Task 1; a traffic study is necessary to asses project-specific GHG emissions).
- Analysis year 2009

Table 11: Residential Project Example GHG Emissions Estimates with Mitigation

URBEMIS Output (Unmitigated)	Metric Tons/Year CO_2e	URBEMIS Output (Mitigated)	Metric Tons/Year CO_2e	Percent Reduction
Area-source emissions	252	Area-source emissions	215	14.6
Mobile-source emissions	1,047	Mobile-source emissions	916	12.5
Total direct operational emissions (area + mobile)	1,299	Total operational emissions (area + mobile)	1,131	12.9

Notes:
CO_2e = carbon dioxide equivalent

Sources: Data compiled by EDAW in 2007

Using URBEMIS 2007 and assuming the project would implement the mitigation measures listed below, yearly project-generated emissions of CO_2e would be reduced by approximately 13 percent. Implementation of the following mitigation measures is assumed:

- 100 housing units within one-half-mile radius of project's center, including this project's 68 residential units;
- provision of 80 jobs in the study area;
- retail uses present with one-half-mile radius of project's center;
- 10 intersections per square mile;
- 100% of streets with sidewalks on one side;
- 50% of streets with sidewalks on both sides;
- 30% of collectors and arterials with bike lanes, or where suitable, direct parallel routes exist;
- 15% of housing units deed restricted below market rate;
- 20% energy efficiency increase beyond Title 24; and
- 100% of landscape maintenance equipment electrically powered and electrical outlets in front and rear of units.

Example Project Methodology and Mitigation

Table 12 –Residential Projects Example Methodology and Mitigation

Source	Methodology	Mitigation
Direct Emissions		
Construction	URBEMIS (OFFROAD emission factors)	MM C-1→MM C-4
Mobile Sources	URBEMIS (EMFAC emission factors)	MM T-3→MM T-8, MM T-10→ MM T-14, MM T-16, MM T-19→ MM T-21 MM D-2→MM D-8, MM D-10→ MM D-15, MM D-17 MM S-1→MM S-2 MM M-1→MM M-2
Area Sources	URBEMIS	MM D-13→MM D-15, MM D-17
Indirect Emissions		
Energy Consumption	CCAR GRP & CEC	MM E-1→MM E-8, MM E-10, MM E-12→MM E-23 MM S-1→MM S-2 MM M-1→MM M-2

Table 13 –Commercial Projects Example Methodology and Mitigation

Source	Methodology	Mitigation
Direct Emissions		
Construction	URBEMIS (OFFROAD emission factors)	MM C-1→MM C-4
Mobile Sources	URBEMIS (EMFAC emission factors)	MM T-1→MM T-2, MM T-4→ MM T-15, MM T-17→MM T-21 MM D-1→MM D-3, MM D-5→ MM D-6, MM D-10, MM D-12, MM D-14→MM D-17 MM E-24 MM S-1→MM S-2 MM M-1→MM M-2
Area Sources	URBEMIS	MM D-14→MM D-17
Indirect Emissions		
Energy Consumption	CCAR GRP & CEC	MM E-1, MM E-4→MM E-13, MM E-16→MM E-24 MM S-1→MM S-2 MM M-1→MM M-2

Table 14 –Specific Plans Example Methodology and Mitigation

Source	Methodology	Mitigation
Direct Emissions		
Construction	URBEMIS (OFFROAD emission factors)	MM C-1→MM C-4
Mobile Sources	Short-term: URBEMIS (EMFAC emission factors). Long-term: I-PLACE^{3}S/CTG SCM	MM T-1→MM T-21 MM D-1→MM D-12, MM D-18→ MM D-19 MM E-24 MM S-1→MM S-2 MM M-1→MM M-2
Area Sources	Short-term: URBEMIS (EMFAC emission factors). Long-term: I-PLACE^{3}S/CTG SCM	MM D-13→MM D-19 MM E-1→MM E-24 MM S-1→MM S-2 MM M-1→MM M-2
Indirect Emissions		
Energy Consumption	Short-term: CCAR GRP & CEC. Long-term: I-PLACE^{3}S/CTG SCM	

General Plans

- Include a general plan policy to reduce emissions within planning area to a level consistent with legislative requirements.
- Implementation strategies include preparation of a GHG reduction plan.
- Projects consistent with a general plan could be responsible for complying with such a policy.

Table 15 –General Plans Example Methodology and Mitigation

Source	Methodology	Mitigation
Direct Emissions		
Construction	URBEMIS (OFFROAD emission factors).	MS G-1 MM G-15
Mobile Sources	Short-term: URBEMIS (EMFAC emission factors). Long-term: I-PLACE^{3}S/CTG SCM	MS G-1 MS G-2→MS C-7, MS G-9, MS G-12, MS-13→MS-14, MS-16→MS-23
Area Sources	Short-term: URBEMIS (EMFAC emission factors). Long-term: I-PLACE^{3}S/CTG SCM	MS G-1 MS G-8→MS C-11, MS G-134, MS G-12, MS-15, MS-17, MS-22
Indirect Emissions		
Energy Consumption	Short-term: CCAR GRP & CEC. Long-term: I-PLACE^{3}S/CTG SCM	

Other Project Types

Air District Rules and Regulations

Air district rules and regulations could have the potential to increase or decrease GHG emissions within the respective jurisdiction. In general, air district rules and regulations act to decrease criteria air pollutant or toxic air contaminant emissions, which would usually act to reduce GHG emissions simultaneously. However, this may not always be the case and air district rules and regulations could address emissions from a large variety of different source types. Reductions of GHG emissions associated with implementation of applicable mitigation, which could also vary greatly, would need to be evaluated on a case-by-case basis. However, once applicable mitigation measures are identified, percent reductions based on the best available research to date, such as those specified in Table 15, could be applied to determine mitigated emissions.

Air Quality Plans

Similarly to air district rules and regulations, air quality plans could have the potential to increase or decrease GHG emissions because of criteria air pollutant reduction strategies. In general, strategies implemented by air districts to reduce criteria air pollutants also act to reduce GHG emissions. However, this may not always be the case. Reductions of GHG emissions associated with implementation of applicable mitigation would need to be evaluated on a case-by-case basis. The methodology identified above for determining whether the strategies contained within the GHG reduction plan would adhere to the level specified in general plan policy could also be used to determine the reductions associated with CAP strategies.

Regional Transportation Plans

Regional transportation plans and reductions of GHG emissions associated with implementation of applicable mitigation would also need to be evaluated on a case-by-case basis to determine if a net increase or decrease in GHG emissions would occur. Complex interactions between the roadway network, operating conditions, alternative transportation availability (such as public transit, bicycle pathways, and pedestrian infrastructure), and many other independent parameters specific to a region should be considered. EMFAC 2007 can be used with VMT from the RTP to create an inventory of GHG emissions. Reductions associated with implementation of applicable measures contained in Table 16 could be accomplished by accounting for VMT reductions in the traffic model.

Many states, counties, and cities have developed policies and regulations concerning greenhouse gas emissions that seek to require or promote reductions in GHG emissions through standards for vehicle emissions, fuels, electricity production/renewables, building efficiency, and other means. However, we could only identify three public agencies in the United States that are considering formally requiring the analysis of greenhouse gas emissions and climate change for development projects during their associated environmental processes. There may be others, but they were not identified during research conducted during preparation of this paper.

The following is a summary of those three efforts.

Commonwealth of Massachusetts - MEPA Greenhouse Gas Emissions Policy and Protocol

The Massachusetts Executive Office of Energy and Environmental Affairs (EEA) has determined that the phrase "damage to the environment" as used in the Massachusetts Environmental Policy Act (MEPA) includes the emission of greenhouse gases caused by projects subjects to MEPA Review. EEA has published a Greenhouse Gas Emissions Policy (GGEP) to fulfill the statutory obligation to take all feasible measurers to avoid, minimize or mitigate damage to the environment.

The GGEP concerns the following projects only:

- The Commonwealth or a state agency is the proponent;
- The Commonwealth or a state agency is providing financial assistance;
- The project is privately funded, but requires an Air Quality Permit from the department of Environmental Protection;
- The project is privately funded, but will generate:
    - 3,000 or more new vehicle trips per day for office projects;
    - 6,000 or more new vehicle trips per day for mixed use projects that are 25% or more office space; or
    - 10,000 or more new vehicle trips per day for other projects.

As a comparison, the trip generation amounts correspond as follows:

- 3,000 vehicle trips per day = approximately 250,000 square foot office development;
- 6,000 or more new vehicle trips per day for mixed use projects that are 25% or more office space = if 25% office space, then equivalent to approximately 130,000 square feet of office and either 100,000 square feet of retail or 450 single-family residential units or some combination thereof.
- 10,000 or more new vehicle trips per day = approximately 1,000 single family residential units or 250,000 square feet retail.

The draft policy states it is not intended to create a numerical GHG emission limit or a numerical GHG emissions reduction target, but rather to ensure that project proponents and reviewers have considered the GHG emissions impacts of their projects and taken all feasible means and measure to reduce those impacts.

The draft policy notes that some projects within these categories will have little or no greenhouse gas emission and the policy will not apply to such projects. EEA intends to identify in the scoping certificate whether a project falls within this *de minimis* exception.

The GGEP requires qualifying projects to do the following:

- to quantify their GHG emissions;
- identify measures to minimize or mitigate such emissions;
- quantify the reduction in emissions and energy savings from mitigation.

Emissions inventories are intended to focus on carbon dioxide, but analysis of other GHGs may be required for certain projects. EEA will require analysis of direct GGH emissions and indirect (electricity and transportation) emissions. The GGEP references the protocols prepared by the World Resource Institute as guidance for inventory preparation.

The policy is still in draft form, but the comment period closed on August 10, 2007.

King County, Washington - Executive Order on the Evaluation of Climate Change Impacts through the State Environmental Policy Act (SEPA)

On June 27, 2007, the King County Executive Ron Sims directed all King County Departments, as follows:

> *"...effective September 1, 2007 to require that climate impacts, including, but not limited to those pertaining to greenhouse gases, be appropriately identified and evaluated when such Departments are acting as the lead agency in reviewing the environmental impacts of private or public proposals pursuant to the State Environmental Policy Act".*

The Executive Order does not define what a "climate impact" is. Based on statements of the County Deputy Chief of Staff*

- County agencies will ask project proponents to supply information on transportation, energy usage and other impacts of proposed projects using the County's existing SEPA checklist.

* Marten Law Group: Environmental News, August 1, 2007, "King County (WA) First in Nation to Require Climate Change Impacts to be Considered During Environmental Review of New Projects".

- There is no current plan to require project proponents to take action to mitigate the impacts identifies.
- Development of emissions thresholds and mitigation requirements will be undertaken in connection with the County's upcoming 2008 update of its Comprehensive Plan.

Sacramento Metropolitan Air Quality Management District

The Sacramento Metropolitan Air Quality Management District released an interim guidance on addressing climate change in CEQA documents on September 6, 2007. While very general in nature, the District recommends that CEQA environmental documents include a discussion of anticipated GHG emissions during both the construction and operation phases of the project. This includes assessing the GHG emissions from projects (using readily available models) to determine whether a project may have a significant impact. If so, then the District recommends addressing all of the District's GHG mitigation measures (drawn from comments made by the California Attorney General) – with explanations on how the mitigation will be implemented or providing rationale for why a measure would be considered infeasible. The District provides assistance to agencies in their analysis of GHG emissions and the applicability of specific mitigation measures. The District's guidance can be found at: http://64.143.64.21/climatechange/ClimateChangeCEQAguidance.pdf

Mendocino Air Quality Management District – CEQA Guidelines

The Mendocino AQMD updated its "Guidelines for Use During Preparation of Air Quality Impacts in EIRs or Mitigated Negative Declarations" in May 2007. The guidelines call for preparing estimates of the increased emissions of air contaminations (including GHG) for projects.

The guidelines state that GHG emissions should be presumed to have a significant impact if CO emissions from District-approved modeling exceed either of the following:

- 80% of the level defined as significant for stationary sources in Regulation1, Rule 130 (s2) of the District (which is 550 lbs/day for CO, meaning a threshold of 440 lbs/day for CO for stationary sources); or
- levels established in District Regulation 1 Rule 130 (i2) for indirect sources (which is 690 lbs/day for CO for indirect sources).

If an average passenger vehicle emits 22 grams of CO/mile and 0.8 lb/mile of CO_2, then the 690-lb/day threshold for CO corresponds to approximately 11,400 lb/day CO_2 threshold for passenger vehicle-related emissions. If one assumes that the average passenger vehicle goes 12,500 miles/year (about 35 miles/day), then this is a threshold equivalent to about 420 vehicles. Using an average in California of about 1.77 vehicles/household, this would correspond to about 250 households/dwelling units.

Appendix A

Relevant Citations

Citations from the Public Resources Code (Division 13, §21000 et seq.) as amended through January 1, 2005.

Public Resources Code – Section 21004, MITIGATING OR AVOIDING A SIGNIFICANT EFFECT; POWERS OF PUBLIC AGENCY:
"In mitigating or avoiding a significant effect of a project on the environment, a public agency may exercise only those express or implied powers provided by law other than this division. However, a public agency may use discretionary powers provided by such other law for the purpose of mitigating or avoiding a significant effect on the environment subject to the express or implied constraints or limitations that may be provided by law."

Public Resources Code – Section 21082.2, SIGNIFICANT EFFECT ON ENVIRONMENT; DETERMINATION; ENVIRONMENTAL IMPACT REPORT PREPARATION:
(a) The lead agency shall determine whether a project may have a significant effect on the environment based on substantial evidence in light of the whole record.
(b) The existence of public controversy over the environmental effects of a project shall not require preparation of an environmental impact report if there is no substantial evidence in light of the whole record before the lead agency that the project may have a significant effect on the environment.
(c) Argument, speculation, unsubstantiated opinion or narrative, evidence which is clearly inaccurate or erroneous, or evidence of social or economic impacts which do not contribute to, or are not caused by, physical impacts on the environment, is not substantial evidence. Substantial evidence shall include facts, reasonable assumptions predicated upon facts, and expert opinion supported by facts.
(d) If there is substantial evidence, in light of the whole record before the lead agency, that a project may have a significant effect on the environment, an environmental impact report shall be prepared.
(e) Statements in an environmental impact report and comments with respect to an environmental impact report shall not be deemed determinative of whether the project may have a significant effect on the environment.

Citations from the Guidelines for California Environmental Quality Act, CCR, Title 14, Division 6 (§15000 et seq.) as amended through July 27, 2007.

AG=Attorney General, ARB=California Air Resources Board, ASTM=American Society for Testing and Material; BAAQMD=Bay Area Air Quality Management District; BEES= Building for Environmental and Economic Sustainability; CA=California; Caltrans=California Department of Transportation; CAPs=Criteria Air Pollutants; CCAP=Center for Clean Air Policy; CF=Connectivity Factor; CIWMB=California Integrated Waste Management Board; CO= Carbon Monoxide; CO_2=Carbon Dioxide; DGS=Department of General Services, DOE=U.S. Department of Energy; DPF=Diesel particulate Filter; E85=85% Ethanol; EERE=Energy Efficiency and Renewable Energy; EOE=Encyclopedia of Earth; EPA=U.S. Environmental Protection Agency; ETC=Edmonton Trolley Coalition; EVs/CNG=Electric Vehicles/Compressed Natural Gas; FAR=Floor Area Ratio; GHG=Greenhouse Gas; ITE=Institute of Transportation Engineers; kg/m^2=kilogram per square meter; km=Kilometer; lb=pound; LEED=Leadership in Energy and Environmental Design; M=Million; NA=Not Available; NEV=Neighborhood Electric Vehicle; NIST=National Institute of Standards and Technology; NO_X=Oxides of Nitrogen, NREL=National Renewable Energy Laboratory; N/S=North/South; PG&E=Pacific Gas and Electric, PM=Particulate Matter; SJVAPCD=San Joaquin Valley Air Pollution Control District; SMAQMD=Sacramento Metropolitan Air Quality Management District; SMUD=Sacramento Municipal Utilities District; SO_x=Sulfur Oxides; SRI=Solar Reflectance Index; TACs=Toxic Air Contaminants; TDM=Transportation Demand Management; TMA=Transportation Management Association; THC=Total Hydrocarbon; ULEV=Ultra Low Emission Vehicle; USGBC=U.S. Green Building Council; and VTPI=Victoria Transit Policy.

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State CEQA Guidelines – Section 15064, DETERMINING THE SIGNIFICANCE OF THE ENVIRONMENTAL EFFECTS CAUSED BY A PROJECT:

(a) Determining whether a project may have a significant effect plays a critical role in the CEQA process.

(1) If there is substantial evidence, in light of the whole record before a lead agency, that a project may have a significant effect on the environment, the agency shall prepare a draft EIR.

(2) When a final EIR identifies one or more significant effects, the Lead Agency and each Responsible Agency shall make a finding under Section 15091 for each significant effect and may need to make a statement of overriding considerations under Section 15093 for the project.

(b) The determination of whether a project may have a significant effect on the environment calls for careful judgment on the part of the public agency involved, based to the extent possible on scientific and factual data. An ironclad definition of significant effect is not always possible because the significance of an activity may vary with the setting. For example, an activity which may not be significant in an urban area may be significant in a rural area.

(c) In determining whether an effect will be adverse or beneficial, the Lead Agency shall consider the views held by members of the public in all areas affected as expressed in the whole record before the lead agency. Before requiring the preparation of an EIR, the Lead Agency must still determine whether environmental change itself might be substantial.

(d) In evaluating the significance of the environmental effect of a project, the Lead Agency shall consider direct physical changes in the environment which may be caused by the project and reasonably foreseeable indirect physical changes in the environment which may be caused by the project.

(1) A direct physical change in the environment is a physical change in the environment which is caused by and immediately related to the project. Examples of direct physical changes in the environment are the dust, noise, and traffic of heavy equipment that would result from construction of a sewage treatment plant and possible odors from operation of the plant.

(2) An indirect physical change in the environment is a physical change in the environment which is not immediately related to the project, but which is caused indirectly by the project. If a direct physical change in the environment in turn causes another change in the environment, then the other change is an indirect physical change in the environment. For example, the construction of a new sewage treatment plant may facilitate population growth in the service area due to the increase in sewage treatment capacity and may lead to an increase in air pollution.

(3) An indirect physical change is to be considered only if that change is a reasonably foreseeable impact which may be caused by the project. A change which is speculative or unlikely to occur is not reasonably foreseeable.

(e) Economic and social changes resulting from a project shall not be treated as significant effects on the environment. Economic or social changes may be used, however, to determine that a physical change shall be regarded as a significant effect on the environment. Where a physical change is caused by economic or social effects of a

project, the physical change may be regarded as a significant effect in the same manner as any other physical change resulting from the project. Alternatively, economic and social effects of a physical change may be used to determine that the physical change is a significant effect on the environment. If the physical change causes adverse economic or social effects on people, those adverse effects may be used as a factor in determining whether the physical change is significant. For example, if a project would cause overcrowding of a public facility and the overcrowding causes an adverse effect on people, the overcrowding would be regarded as a significant effect.

(f) The decision as to whether a project may have one or more significant effects shall be based on substantial evidence in the record of the lead agency.

(1) If the lead agency determines there is substantial evidence in the record that the project may have a significant effect on the environment, the lead agency shall prepare an EIR (Friends of B Street v. City of Hayward (1980) 106 Cal.App.3d 988). Said another way, if a lead agency is presented with a fair argument that a project may have a significant effect on the environment, the lead agency shall prepare an EIR even though it may also be presented with other substantial evidence that the project will not have a significant effect (No Oil, Inc. v. City of Los Angeles (1974) 13 Cal.3d 68).

(2) If the lead agency determines there is substantial evidence in the record that the project may have a significant effect on the environment but the lead agency determines that revisions in the project plans or proposals made by, or agreed to by, the applicant would avoid the effects or mitigate the effects to a point where clearly no significant effect on the environment would occur and there is no substantial evidence in light of the whole record before the public agency that the project, as revised, may have a significant effect on the environment then a mitigated negative declaration shall be prepared.

(3) If the lead agency determines there is no substantial evidence that the project may have a significant effect on the environment, the lead agency shall prepare a negative declaration (Friends of B Street v. City of Hayward (1980) 106 Cal.App. 3d 988).

(4) The existence of public controversy over the environmental effects of a project will not require preparation of an EIR if there is no substantial evidence before the agency that the project may have a significant effect on the environment.

(5) Argument, speculation, unsubstantiated opinion or narrative, or evidence that is clearly inaccurate or erroneous, or evidence that is not credible, shall not constitute substantial evidence. Substantial evidence shall include facts, reasonable assumptions predicated upon facts, and expert opinion support by facts.

(6) Evidence of economic and social impacts that do not contribute to or are not caused by physical changes in the environment is not substantial evidence that the project may have a significant effect on the environment.

(7) The provisions of sections 15162, 15163, and 15164 apply when the project being analyzed is a change to, or further approval for, a project for which an EIR or negative declaration was previously certified or adopted (e.g. a tentative subdivision, conditional use permit). Under case law, the fair argument standard does not apply to determinations of significance pursuant to sections 15162, 15163, and 15164.

(g) After application of the principles set forth above in Section 15064(f)(g), and in marginal cases where it is not clear whether there is substantial evidence that a project may have a significant effect on the environment, the lead agency shall be guided by the following principle: If there is disagreement among expert opinion supported by facts

over the significance of an effect on the environment, the Lead Agency shall treat the effect as significant and shall prepare an EIR.
(h)(1) When assessing whether a cumulative effect requires an EIR, the lead agency shall consider whether the cumulative impact is significant and whether the effects of the project are cumulatively considerable. An EIR must be prepared if the cumulative impact may be significant and the project's incremental effect, though individually limited, is cumulatively considerable. "Cumulatively considerable" means that the incremental effects of an individual project are significant when viewed in connection with the effects of past projects, the effects of other current projects, and the effects of probable future projects.
(2) A lead agency may determine in an initial study that a project's contribution to a significant cumulative impact will be rendered less than cumulatively considerable and thus is not significant. When a project might contribute to a significant cumulative impact, but the contribution will be rendered less than cumulatively considerable through mitigation measures set forth in a mitigated negative declaration, the initial study shall briefly indicate and explain how the contribution has been rendered less than cumulatively considerable.
(3) A lead agency may determine that a project's incremental contribution to a cumulative effect is not cumulatively considerable if the project will comply with the requirements in a previously approved plan or mitigation program which provides specific requirements that will avoid or substantially lessen the cumulative problem (e.g., water quality control plan, air quality plan, integrated waste management plan) within the geographic area in which the project is located. Such plans or programs must be specified in law or adopted by the public agency with jurisdiction over the affected resources through a public review process to implement, interpret, or make specific the law enforced or administered by the public agency. If there is substantial evidence that the possible effects of a particular project are still cumulatively considerable notwithstanding that the project complies with the specified plan or mitigation program addressing the cumulative problem, an EIR must be prepared for the project.
(4) The mere existence of significant cumulative impacts caused by other projects alone shall not constitute substantial evidence that the proposed project's incremental effects are cumulatively considerable.

State CEQA Guidelines – Section 15130, DISCUSSION OF CUMULATIVE IMPACTS:
(a)(3). "An EIR may determine that a project's contribution to a significant cumulative impact will be rendered less than cumulatively considerable and thus is not significant. A project's contribution is less than cumulatively considerable if the project is required to implement or fund its fair share of a mitigation measure or measures designed to alleviate the cumulative impact. The lead agency shall identify facts and analysis supporting its conclusion that the contribution will be rendered less than cumulatively considerable.

State CEQA Guidelines – Section 15064.7, THRESHOLDS OF SIGNIFICANCE:
"Each public agency is encouraged to develop and publish thresholds of significance that the agency uses in the determination of the significance of environmental effects. A threshold of significance is an identifiable quantitative, qualitative or performance level

of a particular environmental effect, non-compliance with which means the effect will normally be determined to be significant by the agency and compliance with which means the effect normally will be determined to be less than significant."

Appendix B

Mitigation Measure Summary

Table 16
Mitigation Measure Summary

Mitigation Measure	Applicable Project/Source Type[1]	Effective	Feasible (Yes/No)			Secondary Effects (Yes/No)	Agency/Organization/Other[6]	Description/Comments
		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
Transportation								
Bicycle/Pedestrian/Transit Measures								
MM T-1: Bike Parking	LD (C, M), I, SP, TP, AQP, RR, P/Mobile	1%-5%/High: CCAP presents combined % reductions for a range of mitigation measures (Dierkers et al. 2007). SMAQMD allocates combined reductions among individual measures (e.g., 2.5% reduction for all bicycle-related measures and one-quarter of 2.5% for each individual measure) (TIAX 2005, EDAW 2006, SMAQMD 2007). VTPI presents % reductions for showers and combined measures in the TDM encyclopedia (VTPI	Yes: Lockers ($1,200-$2,950, $700/bike on average), Racks ($70-$2,000, $70/bike on average).	Yes (Caltrans 2005, Dierkers et al. 2007, VTPI 2007)	Yes (Caltrans 2005, Dierkers et al. 2007, VTPI 2007)	Adverse: No Beneficial: CAPs, TACs	Caltrans, Portland Bicycle Master Plan (City of Portland 1998), CCAP Transportation Emissions Guidebook (Dierkers et al. 2007), SMAQMD Recommended Guidance for Land Use Emission Reductions (SMAQMD 2007), VTPI, CA air quality management and control districts, and cities/counties.	Nonresidential projects provide plentiful short- and long-term bicycle parking facilities to meet peak season maximum demand (e.g., one bike rack space per 20 vehicle/employee parking spaces.
MM T-2: End of Trip Facilities	LD (C, M), I, SP, TP, AQP, RR, P/Mobile		Yes	Yes (Caltrans 2005, Dierkers et al. 2007, VTPI 2007)	Yes (Caltrans 2005, Dierkers et al. 2007, VTPI 2007)	Adverse: No Beneficial: CAPs, TACs		Nonresidential projects provide "end-of-trip" facilities including showers, lockers, and changing space (e.g., four clothes lockers and one shower provided for every 80 employee parking spaces, separate facilities for each gender for projects with 160 or more employee parking spaces).
MM T-3: Bike-Parking at Multi-	LD (R, M), SP, AQP, RR,		Yes: Lockers ($1,200-	Yes (Caltrans 2005,	Yes (Caltrans	Adverse: No Beneficial:		Long-term bicycle parking is provided at apartment

AG=Attorney General; ARB=California Air Resources Board; ASTM=American Society for Testing and Material; BAAQMD=Bay Area Air Quality Management District; BEES= Building for Environmental and Economic Sustainability; CA=California; Caltrans=California Department of Transportation; CAPs=Criteria Air Pollutants; CCAP=Center for Clean Air Policy; CF=Connectivity Factor; CIWMB=California Integrated Waste Management Board; CO= Carbon Monoxide; CO_2=Carbon Dioxide; DGS=Department of General Services; DOE=U.S. Department of Energy; DPF=Diesel particulate Filter; E85=85% Ethanol; EERE=Energy Efficiency and Renewable Energy; EOE=Encyclopedia of Earth; EPA=U.S. Environmental Protection Agency; ETC=Edmonton Trolley Coalition; EVs/CNG=Electric Vehicles/Compressed Natural Gas; FAR=Floor Area Ratio; GHG=Greenhouse Gas; ITE=Institute of Transportation Engineers; kg/m^2=kilogram per square meter; km=Kilometer; lb=pound; LEED=Leadership in Energy and Environmental Design; M=Million; NA=Not Available; NEV=Neighborhood Electric Vehicle; NIST=National Institute of Standards and Technology; NO_X=Oxides of Nitrogen; NREL=National Renewable Energy Laboratory; N/S=North/South; PG&E=Pacific Gas and Electric; PM=Particulate Matter; SJVAPCD=San Joaquin Valley Air Pollution Control District; SMAQMD=Sacramento Metropolitan Air Quality Management District; SMUD=Sacramento Municipal Utilities District; SO_x=Sulfur Oxides, SRI=Solar Reflectance Index; TACs=Toxic Air Contaminants; TDM=Transportation Demand Management; TMA=Transportation Management Association; THC=Total Hydrocarbon; ULEV=Ultra Low Emission Vehicle; USGBC=U.S. Green Building Council, and VTPI=Victoria Transit Policy.

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Mitigation Measure Summary

Mitigation Measure	Applicable Project/Source Type[1]	Effective	Feasible (Yes/No)			Secondary Effects (Yes/No)	Agency/Organization/Other[6]	Description/Comments
		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
Unit Residential	P/Mobile	2007). JSA bases estimates on CCAP information (JSA 2004).	$2,950, $700/bike on average), Racks ($70-$2,000, $70/bike on average).	Dierkers et al. 2007, VTPI 2007)	2005, Dierkers et al. 2007, VTPI 2007)	CAPs, TACs		complexes or condominiums without garages (e.g., one long-term bicycle parking space for each unit without a garage). Long-term facilities shall consist of one of the following: a bicycle locker, a locked room with standard racks and access limited to bicyclists only, or a standard rack in a location that is staffed and/or monitored by video surveillance 24 hours per day.
MM T-4: Proximity to Bike Path/Bike Lanes	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile		Yes	Yes (Caltrans 2005, Dierkers et al. 2007, VTPI 2007)	Yes (Caltrans 2005, Dierkers et al. 2007, VTPI 2007)	Adverse: No Beneficial: CAPs, TACs		Entire project is located within one-half mile of an existing/planned Class I or Class II bike lane and project design includes a comparable network that connects the project uses to the existing offsite facility. Project design includes a designated bicycle route connecting all units, on-site bicycle parking facilities, offsite bicycle facilities, site entrances, and primary building entrances to existing Class I or Class II bike lane(s) within one-half mile. Bicycle route connects to all streets contiguous with project site. Bicycle route has minimum conflicts with automobile parking and circulation

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Mitigation Measure Summary

Mitigation Measure	Applicable Project/Source Type[1]	Effective		Feasible (Yes/No)		Secondary Effects (Yes/No)	Agency/Organization/Other[6]	Description/Comments
		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
								facilities. All streets internal to the project wider than 75 feet have Class II bicycle lanes on both sides.

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		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
MM T-5: Pedestrian Network	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	1%-10%/High: CCAP presents combined % reductions for a range of mitigation measures (Dierkers et al. 2007). SMAQMD allocates 1% for each individual measure (TIAX 2005, EDAW 2006, SMAQMD 2007).	Yes	Yes (Dierkers et al. 2007, VTPI 2007)	Yes (Dierkers et al. 2007, VTPI 2007)	Adverse: No Beneficial: CAPs, TACs	CCAP Transportation Emissions Guidebook (Dierkers et al. 2007), SMAQMD Recommended Guidance for Land Use Emission Reductions (SMAQMD 2007), VTPI, CA air quality management and control districts, and cities/counties.	The project provides a pedestrian access network that internally links all uses and connects to all existing/planned external streets and pedestrian facilities contiguous with the project site. Project design includes a designated pedestrian route interconnecting all internal uses, site entrances, primary building entrances, public facilities, and adjacent uses to existing external pedestrian facilities and streets. Route has minimal conflict with parking and automobile circulation facilities. Streets (with the exception of alleys) within the project have sidewalks on both sides. All sidewalks internal and adjacent to project site are minimum of five feet wide. All sidewalks feature vertical curbs. Pedestrian facilities and improvements such as grade separation, wider sidewalks, and traffic calming are implemented wherever feasible to minimize pedestrian barriers. All site entrances provide pedestrian access.
MM T-6: Pedestrian	LD (R, C, M), I, SP, TP,		Yes	Yes (Dierkers et al. 2007,	Yes (Dierkers et	Adverse: No Beneficial:		Site design and building placement minimize barriers to

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Mitigation Measure	Applicable Project/Source Type[1]	Effective		Feasible (Yes/No)		Secondary Effects (Yes/No)	Agency/Organization/Other[6]	Description/Comments
		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
Barriers Minimized	AQP, RR, P/Mobile			VTPI 2007)	al. 2007, VTPI 2007)	CAPs, TACs		pedestrian access and interconnectivity. Physical barriers such as walls, berms, landscaping, and slopes between residential and nonresidential uses that impede bicycle or pedestrian circulation are eliminated.
MM T-7: Bus Shelter for Existing/Planned Transit Service	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	1%-2%/High: CCAP presents these % reductions (Dierkers et al., 2007). SMAQMD assigns from .25%-1%, depending on headway frequency (TIAX 2005, EDAW 2006, SMAQMD 2007).	Yes: $15,000-$70,000.	Yes (Dierkers et al. 2007, VTPI 2007)	Yes (Dierkers et al. 2007, VTPI 2007)	Adverse: No Beneficial: CAPs, TACs	CCAP Transportation Emissions Guidebook (Dierkers et al. 2007), SMAQMD Recommended Guidance for Land Use Emission Reductions (SMAQMD 2007), VTPI, City of Calgary (City of Calgary 2004), CA air quality management and control districts, and cities/counties.	Bus or streetcar service provides headways of one hour or less for stops within one-quarter mile; project provides safe and convenient bicycle/pedestrian access to transit stop(s) and provides essential transit stop improvements (i.e., shelters, route information, benches, and lighting).

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Table 16
Mitigation Measure Summary

Mitigation Measure	Applicable Project/Source Type[1]	Effective	Feasible (Yes/No)			Secondary Effects (Yes/No)	Agency/Organization/Other[6]	Description/Comments
		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
MM T-8: Traffic Calming	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	1%-10%/High: CCAP presents combined % reductions for a range of mitigation measures (Dierkers et al. 2007). SMAQMD allocates .25%-1.0% for each individual measure depending on percent of intersections and streets with improvements (TIAX 2005, EDAW 2006, SMAQMD 2007).	Yes	Yes (Dierkers et al. 2007, VTPI 2007)	Yes (Dierkers et al. 2007, VTPI 2007)	Adverse: No Beneficial: CAPs, TACs	CCAP Transportation Emissions Guidebook (Dierkers et al. 2007), SMAQMD Recommended Guidance for Land Use Emission Reductions (SMAQMD 2007), VTPI, CA air quality management and control districts, and cities/counties.	Project design includes pedestrian/bicycle safety and traffic calming measures in excess of jurisdiction requirements. Roadways are designed to reduce motor vehicle speeds and encourage pedestrian and bicycle trips by featuring traffic calming features. All sidewalks internal and adjacent to project site are minimum of five feet wide. All sidewalks feature vertical curbs. Roadways that converge internally within the project are routed in such a way as to avoid "skewed intersections;" which are intersections that meet at acute, rather than right, angles. Intersections internal and adjacent to the project feature one or more of the following pedestrian safety/traffic calming design techniques: marked crosswalks, count-down signal timers, curb extensions, speed tables, raised crosswalks, raised intersections, median islands, tight corner radii, and roundabouts or mini-circles. Streets internal and adjacent to the project feature pedestrian safety/traffic calming measures such as on-street parking, planter strips with street trees,

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		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
								and chicanes/chokers (variations in road width to discourage high-speed travel).
Parking Measures								
MM T-9: Paid Parking (Parking Cash Out)	LD (C, M), I, SP, TP, AQP, RR, P/Mobile	1%-30%/High: CCAP presents a range of 15%-30% reduction for parking programs (Dierkers et al. 2007). SMAQMD presents a range of 1.0%-7.2%, depending on cost/day and distance to transit (TIAX 2005, EDAW 2006, SMAQMD 2007). Shoupe presents a 21% reduction [$5/day for commuters to downtown LA, with elasticity of -0.18 (e.g., if price increases 10%, then solo driving goes down by 1.8% more)] (Shoupe 2005). Urban Transit Institute	Yes: Vary by location and project size.	Yes (Dierkers et al. 2007, VTPI 2007)	Yes (Dierkers et al. 2007, VTPI 2007)	Adverse: No Beneficial: CAPs, TACs	CCAP Transportation Emissions Guidebook (Dierkers et al. 2007), SMAQMD Recommended Guidance for Land Use Emission Reductions (SMAQMD 2007), VTPI, CA air quality management and control districts, and cities/counties.	Project provides employee and/or customer paid parking system. Project must have a permanent and enforceable method of maintaining user fees for all parking facilities. The facility may not provide customer or employee validations. Daily charge for parking must be equal to or greater than the cost of a transit day/monthly pass plus 20%.

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		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
		presents a range of 1%-10% reduction in trips to central city sites, and 2%-4% in suburban sites (VTPI 2007).						
MM T-10: Minimum Parking	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	1%-30%/High: CCAP presents a range of 15%-30% reduction for parking programs (Dierkers et al. 2007). SMAQMD presents a maximum of 6% (Nelson/Nygaard Consulting Associates, 2005, TIAX 2005, EDAW 2006).	Yes	Yes (Dierkers et al. 2007, VTPI 2007)	Yes (Dierkers et al. 2007, VTPI 2007), Note that in certain areas of the state, the minimum parking required by code is greater than the peak period parking demand for most land uses. Simply meeting minimum code requirements in these areas would not result in an emissions reduction.	Adverse: No Beneficial: CAPs, TACs	CCAP Transportation Emissions Guidebook (Dierkers et al. 2007), SMAQMD Recommended Guidance for Land Use Emission Reductions (SMAQMD 2007), VTPI, Governor's Office of Smart Growth (Annapolis, Maryland) (Zimbler), CA air quality management and control districts, and cities/counties.	Provide minimum amount of parking required. Once land uses are determined, the trip reduction factor associated with this measure can be determined by utilizing the ITE parking generation publication. The reduction in trips can be computed as shown below by the ratio of the difference of minimum parking required by code and ITE peak parking demand to ITE peak parking demand for the land uses multiplied by 50%. Percent Trip Reduction = 50 * [(min parking required by code – ITE peak parking demand)/ (ITE peak parking demand)]

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		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
MM T-11: Parking Reduction Beyond Code/Shared Parking	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	1%-30%/High: CCAP presents a range of 15%-30% reduction for parking programs (Dierkers et al. 2007). SMAQMD presents a maximum of 12% (Nelson/Nygaard, 2005, TIAX 2005, EDAW 2006).	Yes	Yes (Dierkers et al. 2007, VTPI 2007)	Yes (Dierkers et al. 2007, VTPI 2007)	Adverse: No Beneficial: CAPs, TACs		Provide parking reduction less than code. This measure can be readily implemented through a shared parking strategy, wherein parking is utilized jointly among different land uses, buildings, and facilities in an area that experience peak parking needs at different times of day and day of the week.
MM T-12: Pedestrian Pathway Through Parking	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	1%-4%/Moderate: CCAP presents combined % reductions for a range of mitigation measures (Dierkers et al. 2007). SMAQMD allocates 0.5% reduction for this measure (TIAX 2005, EDAW 2006, SMAQMD 2007).	Yes	Yes (Dierkers et al. 2007, VTPI 2007)	Yes (Dierkers et al. 2007, VTPI 2007)	Adverse: No Beneficial: CAPs, TACs		Provide a parking lot design that includes clearly marked and shaded pedestrian pathways between transit facilities and building entrances.

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		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
MM T-13: Off-Street Parking	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	1%-4%/Moderate: CCAP presents combined % reductions for a range of mitigation measures (Dierkers et al. 2007). SMAQMD allocates a range of 0.1%-1.5% for this measure (TIAX 2005, EDAW 2006, SMAQMD 2007).	Yes	Yes (Dierkers et al. 2007, VTPI 2007)	Yes (Dierkers et al. 2007, VTPI 2007)	Adverse: No Beneficial: CAPs, TACs		Parking facilities are not adjacent to street frontage.
MM T-14: Parking Area Tree Cover	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	Annual net CO_2 reduction of 3.1 kg/m^2 canopy cover/Moderate (McPherson 2001).	Yes: $19 per new tree for CA, cost varies for maintenance, removal and replacement (McPherson 2001).	Yes	Yes	Adverse: VOCs Beneficial: CAPs, TACs	AG, State of CA Department of Justice (Goldberg 2007) and cities/counties (e.g., parking lot ordinances in Sacramento, Davis, and Los Angeles, CA).	Provide parking lot areas with 50% tree cover within 10 years of construction, in particular low emitting, low maintenance, native drought resistant trees. Reduces urban heat island effect and requirement for air conditioning, effective when combined with other measures (e.g., electrical maintenance equipment and reflective paving material).
MM T-15: Valet Bicycle Parking	LD (C, M), SP, AQP, TP, RR, P/Mobile	NA/Low	Yes	Yes	Yes: Raley Field (Sacramento, CA)	Adverse: No Beneficial: CAPs, TACs	Raley Field (Sacramento, CA).	Provide spaces for the operation of valet bicycle parking at community event "centers" such as amphitheaters, theaters, and stadiums.
MM T-16: Garage Bicycle Storage	LD (R, M), SP, AQP, TP, RR, P/Mobile	NA/Low	Yes: Less than $200/multiple bike rack.	Yes	Yes	Adverse: No Beneficial: CAPs, TACs	City of Fairview, OR	Provide storage space in one-car garages for bicycles and bicycle trailers.

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		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
MM T-17: Preferential Parking for EVs/CNG Vehicles	LD (C, M), I, SP, TP, AQP, RR, P/Mobile	NA/Low	Yes	Yes	Yes	Adverse: No Beneficial: CAPs, TACs	USGBC, CA air quality management and control districts and cities/counties (e.g., BAAQMD).	Provide preferential parking space locations for EVs/CNG vehicles.
MM T-18: Reduced/No Parking Fee for EVs/CNG Vehicles	LD (C, M), I, SP, TP, AQP, RR, P/Mobile	NA/Low	Yes	Yes	Yes	Adverse: No Beneficial: CAPs, TACs	Hotels (e.g., Argonaut in San Francisco, CA)	Provide a reduced/no parking fee for EVs/CNG vehicles.

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		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
Miscellaneous Measure								
MM T-19: TMA Membership	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	1%-28%/High: CCAP presents a range of 3%-25% for TDMs with complementary transit and land use measures (Dierkers et al. 2007). VTPI presents a range of 6%-7% in the TDM encyclopedia (VTPI 2007). URBEMIS offers a 2%-10% range in reductions for a TDM that has 5 elements that are pedestrian and transit friendly and 1%-5% for 3 elements. SMAQMD presents a reduction of 5% (TIAX 2005, EDAW 2006, SMAQMD 2007).	Yes	Yes (Dierkers et al. 2007, VTPI 2007)	Yes (Dierkers et al. 2007, VTPI 2007)	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Include permanent TMA membership and funding requirement. Funding to be provided by Community Facilities District or County Service Area or other nonrevocable funding mechanism. TDMs have been shown to reduce employee vehicle trips up to 28% with the largest reductions achieved through parking pricing and transit passes. The impact depends on the travel alternatives.
MM T-20: ULEV	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	NA/Low	Yes: Higher than corresponding gasoline models.	Yes	Yes: Fueling stations might not be readily available depending on location. More than 900 E85 fueling	Adverse: No Beneficial: CAPs, TACs	DGS, CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Use of and/or provide ULEV that are 50% cleaner than average new model cars (e.g., natural gas, ethanol, electric).

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		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
					stations in the U.S., 5 in CA. Vehicles available in select regions only			
MM T-21: Flex Fuel Vehicles	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	5466.97 lb GHG/year/Low (DOE Fuel Economy)	Yes: E85 costs less than gasoline per gallon, but results in lower fuel economy.	Yes	Yes: More than 900 E85 fueling stations in the U.S., 5 in CA. Vehicles available in select regions only	Adverse: Yes Issues with the energy intensive ethanol production process (e.g., wastewater treatment requirements). Beneficial: CAPs, TACs	DGS, CA air quality management and control districts and cities/counties (e.g., SJVAPCD).	Use of and/or provide vehicles that utilize gasoline/ethanol blends (e.g., E85).
Design								
Commercial & Residential Building Design Measures								
MM D-1: Office/Mixed Use Density	LD (C, M), SP, TP, AQP, RR, P/Mobile	0.05%-2%/Moderate: This range is from SMAQMD, depending	Yes	Yes (VTPI 2007)	Yes (VTPI 2007)	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties	Project provides high density office or mixed-use proximate to transit. Project must provide

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		on FAR and headway frequencies (Nelson/Nygaard Consulting Associates 2005, EDAW 2006, SMAQMD 2007).					(e.g., SMAQMD).	safe and convenient pedestrian and bicycle access to all transit stops within one-quarter mile.
MM D-2: Orientation to Existing/Planned Transit, Bikeway, or Pedestrian Corridor	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	0.4%-1%/Moderate: CCAP attributes a 0.5% reduction per 1% improvement in transit frequency (Dierkers et al. 2007). SMAQMD presents a range of 0.25%-5% (JSA 2005, EDAW 2006, SMAQMD 2007).	Yes	Yes (Dierkers et al. 2007)	Yes (Dierkers et al. 2007)	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Project is oriented towards existing transit, bicycle, or pedestrian corridor. Setback distance between project and existing or planned adjacent uses is minimized or nonexistent. Setback distance between different buildings on project site is minimized. Setbacks between project buildings and planned or existing sidewalks are minimized. Buildings are oriented towards existing or planned street frontage. Primary entrances to buildings are located along planned or existing public street frontage. Project provides bicycle access to any planned bicycle corridor(s). Project provides pedestrian access to any planned pedestrian corridor(s).
MM D-3: Services Operational	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	0.5%-5%/Moderate	Yes	Yes	Yes	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Project provides on-site shops and services for employees.

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MM D-4: Residential Density (Employ Sufficient Density for New Residential Development to Support the Use of Public Transit)	LD (R, M), SP, TP, AQP, RR, P/Mobile	1%-40%/High: #7, EPA presents a range of 32%-40% (EPA 2006). SMAQMD presents a range of 1%-12% depending on density and headway frequencies (Nelson/Nygaard Consulting Associates 2005, JSA 2005, EDAW 2006, SMAQMD 2007). Nelson/Nygaard presents a trip reduction formula: Trip Reduction = 0.6*(1-(19749*((4.814+ households per residential acre)/(4.814+7.14))^-06.39)/25914).	Yes	Yes (VTPI 2007, Holtzclaw 2007)	Yes (VTPI 2007, Holtzclaw 2007)	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Project provides high-density residential development. Transit facilities must be within one-quarter mile of project border. Project provides safe and convenient bicycle/pedestrian access to all transit stop(s) within one-quarter mile of project border.
MM D-5: Street Grid	LD (R, C, M), I, SP, TP, AQP, RR,	1%/Moderate: SMAQMD presents this % reduction (JSA	Yes	Yes (Dierkers et al. 2007, VTPI 2007)	Yes (Dierkers et al. 2007,	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties	Multiple and direct street routing (grid style). This measure only applies to projects

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		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
	P/Mobile	2005, EDAW 2006, SMAQMD 2007).			VTPI 2007)		(e.g., SMAQMD).	with an internal CF >/= 0.80, and average of one-quarter mile or less between external connections along perimeter of project. [CF= # of intersections / (# of cul-de-sacs + intersections)]. Cul-de-sacs with bicycle/pedestrian through access may be considered "complete intersections" when calculating the project's internal connectivity factor. External connections are bike/pedestrian pathways and access points, or streets with safe and convenient bicycle and pedestrian access that connect the project to adjacent streets, sidewalks, and uses. If project site is adjacent to undeveloped land; streets, pathways, access points, and right-of-ways that provide for future access to adjacent uses may count for up to 50% of the external connections. Block perimeter (the sum of the measurement of the length of all block sides) is limited to no more than 1,350 feet. Streets internal to the project should connect to streets external to the project whenever possible.

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MM D-6: NEV Access	LD (R, C, M), SP, TP, AQP, RR, P/Mobile	0.5%-1.5%/Low: SMAQMD presents this % reduction (EDAW 2006, SMAQMD 2007).	Yes	Yes (Litman 1999, Sperling 1994)	Yes (Litman 1999, Sperling 1994)	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Make physical development consistent with requirements for neighborhood electric vehicles. Current studies show that for most trips, NEVs do not replace gas-fueled vehicles as the primary vehicle.
MM D-7: Affordable Housing Component	LD (R, M), SP, TP, AQP, RR, P/Mobile	0.4%-6%/Moderate: SMAQMD presents this % reduction (Nelson/Nygaard Consulting Associates 2005, EDAW 2006, SMAQMD 2007).	Yes	Yes	Yes	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Residential development projects of five or more dwelling units provide a deed-restricted low-income housing component on-site (or as defined in the code). Developers who pay into In-Lieu Fee Programs are not considered eligible to receive credit for this measure. The award of emission reduction credit shall be based only on the proportion of affordable housing developed on-site because in-lieu programs simply induce a net increase in development. Percentage reduction shall be calculated according to the following formula:

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		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
								% reduction = % units deed-restricted below market rate housing * 0.04
MM D-8: Recharging Area	LD (R, M), SP, TP, AQP, RR, P/Mobile	NA/Low	Yes	Yes	Yes	Adverse: No Beneficial: CAPs, TACs		Provide residential buildings with a "utility" room or space for recharging batteries, whether for use in a car, electric lawnmower, other electric landscaping equipment, or even batteries for small items such as flashlights.
Mixed-Use Development Measures								
MM D-9: Urban Mixed-Use	LD (M), SP, TP, AQP, RR, P/Mobile	3%-9%/Moderate: SMAQMD presents this % reduction (TIAX 2005, EDAW 2006, SMAQMD 2007).	Yes	Yes (EPA 2006)	Yes (EPA 2006)	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Development of projects predominantly characterized by properties on which various uses, such as office, commercial, institutional, and residential, are combined in a single building or on a single site in an integrated development project with functional interrelationships and a coherent physical design.
MM D-10: Suburban Mixed-Use	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	3%/Moderate: SMAQMD presents this % reduction (TIAX 2005, EDAW 2006, SMAQMD 2007).	Yes	Yes (EPA 2006)	Yes (EPA 2006)	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Have at least three of the following on site and/or offsite within one-quarter mile: Residential Development, Retail Development, Park, Open Space, or Office.
MM D-11: Other Mixed-Use	LD (R, M), SP, TP, AQP, RR, P/Mobile	1%/Moderate: SMAQMD presents this % reduction (TIAX 2005, EDAW	Yes	Yes (EPA 2006)	Yes (EPA 2006)	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	All residential units are within one-quarter mile of parks, schools or other civic uses.

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		2006, SMAQMD 2007).						
MM D-12: Infill Development	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	3%-30%/High: Infill development reduces vehicle trips and VMT by 3% and 20%, respectively (Fehr & Peers 2007). CCAP identifies a site level VMT reduction range of 20%-30% (Dierkers et al. 2007).	Yes	Yes (Dierkers et al. 2007)	Yes (Dierkers et al. 2007)	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Project site is on a vacant infill site, redevelopment area, or brownfield or greyfield lot that is highly accessible to regional destinations, where the destinations rating of the development site (measured as the weighted average travel time to all other regional destinations) is improved by 100% when compared to an alternate greenfield site.
Miscellaneous Measures								
MM D-13: Electric Lawnmower	LD (R, M), SP, AQP, RR, P/Area	1%/Low: SMAQMD presents this % reduction (EDAW 2006, SMAQMD 2007).	Yes	Yes	Yes	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Provide a complimentary electric lawnmower to each residential buyer.

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		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
MM D-14: Enhanced Recycling/Waste Reduction, Reuse, Composting	LD (R, C, M), I, SP, AQP, RR, P/Stationary & Area	NA/Low	Yes	Yes	Yes: Association with social awareness.	Adverse: No Beneficial: CAPs, TACs	CIWMB	Provide infrastructure/education that promotes the avoidance of products with excessive packaging, recycle, buying of refills, separating of food and yard waste for composting, and using rechargeable batteries.
MM D-15: LEED Certification	LD (R, C, M), I, SP, AQP, RR, P/Stationary & Area	NA/Moderate	Yes: Receive tax rebates, incentives (e.g., EDAW San Diego office interior remodel cost $1,700,000 for 32,500 square feet) (USGBC 2007)	Yes	Yes: More than 700 buildings of different certifications in CA (USGBC 2007).	Adverse: No Beneficial: CAPs, TACs	USGBC, CA air quality management and control districts and cities/counties (e.g., BAAQMD).	LEED promotes a whole-building approach to sustainability by recognizing performance in five key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality.
MM D-16: Retro-Commissioning	LD (C, M), I, SP, AQP, RR, P/Stationary & Area	8%-10% reduction in energy usage/Moderate: (Mills et al. 2004)	Yes: Average $0.28/square feet, varies with building size (Haasl and Sharp 1999).	Yes	Yes: 27 projects underway in CA, 21 more to be completed in 2007, mostly state buildings owned by DGS (DGS 2007).	Adverse: No Beneficial: CAPs, TACs	DGS, CA air quality management and control districts and cities/counties (e.g., BAAQMD).	The process ensures that all building systems perform interactively according to the contract documents, the design intent and the owner's operational needs to optimize energy performance.
MM D-17 Landscaping	LD (R, C, M), I, SP, AQP, RR,	NA/Low	Yes	Yes	Yes	Adverse: No Beneficial: CAPs, TACs	Alliance for the Chesapeake Bay, EPA Green Landscaping	Project shall use drought resistant native trees, trees with low emissions and high carbon

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	P/Stationary & Area						Resources	sequestration potential. Evergreen trees on the north and west sides afford the best protection from the setting summer sun and cold winter winds. Additional considerations include the use of deciduous trees on the south side of the house that will admit summer sun; evergreen plantings on the north side will slow cold winter winds; constructing a natural planted channel to funnel summer cooling breezes into the house. Neighborhood CCR's not requiring that front and side yards of single family homes be planted with turf grass. Vegetable gardens, bunch grass, and low-water landscaping shall also be permitted, or even encouraged.
MM D-18: Local Farmers' Market	LD (M), SP/Mobile, Stationary, &	NA/Low	Yes	Yes	Yes: Associated with social	Adverse: No Beneficial: CAPs, TACs	Cities/counties (e.g., Davis, Sacramento)	Project shall dedicate space in a centralized, accessible location for a weekly farmers' market.

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	Area				choice and public awareness.			
MM D-19: Community Gardens	LD (M), SP/Mobile, Stationary, & Area	NA/Low	Yes	Yes	Yes: Associated with social choice and public awareness.	Adverse: No Beneficial: CAPs, TACs	Cities/counties (e.g., Davis)	Project shall dedicate space for community gardens.
Energy Efficiency/Building Component								
MM E-1: High-Efficiency Pumps	LD (R, C, M), SP, AQP, RR, P/Stationary & Area	NA/Low	Yes	Yes	Yes	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., BAAQMD).	Project shall use high-efficiency pumps.
MM E-2: Wood Burning Fireplaces/Stoves	LD (R, M), SP, AQP, RR, P/Stationary & Area	NA/Low: EDAW 2006	Yes	Yes	Yes	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Project does not feature fireplaces or wood burning stoves.
MM E-3: Natural Gas Stove	LD (R, M), SP, AQP, RR, P/Stationary & Area	NA/Low: EDAW 2006	Yes: Cost of stove—$350 (gas) and $360 (electric) same brand, total yearly cost of $42.17 as opposed to $56.65 for electric (Saving Electricity 2006).	Yes	Yes	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Project features only natural gas or electric stoves in residences.

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MM E-4: Energy Star Roof	LD (R, C, M), I, SP, AQP, RR, P/Stationary & Area	0.5%-1%/Low: SMAQMD presents this % reduction (EDAW 2006, SMAQMD 2007).	Yes	Yes	Yes: 866 Energy Star labeled buildings in California (Energy Star 2007)	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Project installs Energy Star labeled roof materials.
MM E-5: On-site Renewable Energy System	LD (R, C, M), I, SP, AQP, RR, P/Stationary & Area	1%-3%/Moderate: SMAQMD presents this % reduction (USGBC 2002 and 2005, EDAW 2006, SMAQMD 2007).	Yes	Yes (USGBC 2002 and 2005)	Yes (USGBC 2002 and 2005)	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Project provides onsite renewable energy system(s). Nonpolluting and renewable energy potential includes solar, wind, geothermal, low-impact hydro, biomass and bio-gas strategies. When applying these strategies, projects may take advantage of net metering with the local utility.

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MM E-6: Exceed Title 24	LD (R, C, M), I, GSP, AQP, RR, P/Stationary & Area	1%/Moderate: SMAQMD presents this % reduction (EDAW 2006, SMAQMD 2007).	Yes	Yes (PG&E 2002, SMUD 2006)	Yes (PG&E 2002, SMUD 2006)	Adverse: No Beneficial: CAPs, TACs	PG&E, SMUD, CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Project exceeds title 24 requirements by 20%.
MM E-7: Solar Orientation	LD (R, C, M), I, SP, AQP, RR, P/Stationary & Area	0.5%/Low: SMAQMD presents this % reduction (EDAW 2006, SMAQMD 2007).	Yes	Yes	Yes	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Project orients 75% or more of homes and/or buildings to face either north or south (within 30° of N/S). Building design includes roof overhangs that are sufficient to block the high summer sun, but not the lower winter sun, from penetrating south facing windows. Trees, other landscaping features and other buildings are sited in such a way as to maximize shade in the summer and maximize solar access to walls and windows in the winter.
MM E-8: Nonroof Surfaces	LD (R, C, M), I, GSP, AQP, RR, P/Stationary & Area	1.0%/Low: SMAQMD presents this % reduction (EDAW 2006, SMAQMD 2007).	Yes	Yes (USGBC 2002 and 2005)	Yes (USGBC 2002 and 2005)	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Provide shade (within 5 years) and/or use light-colored/high-albedo materials (reflectance of at least 0.3) and/or open grid pavement for at least 30% of the site's nonroof impervious surfaces, including parking lots, walkways, plazas, etc.; OR place a minimum of 50% of parking spaces underground or covered by structured parking; OR use an open-grid pavement system (less than 50% impervious) for a minimum of

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								50% of the parking lot area. The mitigation measure reduces heat islands (thermal gradient differences between developed and undeveloped areas to minimize impact on microclimate and human and wildlife habitats. This measure requires the use of patented or copyright protected methodologies created by the ASTM. The SRI is a measure of the constructed surface's ability to reflect solar heat, as shown by a small rise in temperature. It is defined so that a standard black (reflectance 0.05, emittance 0.90) is "0" and a standard white (reflectance 0.80, emittance 0.90) is 100. To calculate SRI for a given material, obtain the reflectance value and emittance value for the material. SRI is calculated according to ASTM E 1980-01. Reflectance is measured

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Mitigation Measure	Applicable Project/Source Type[1]	Effective		Feasible (Yes/No)		Secondary Effects (Yes/No)	Agency/Organization/Other[6]	Description/Comments
		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
								according to ASTM E 903, ASTM E 1918, or ASTM C 1549. Emittance is measured according to ASTM E 408 or ASTM C 1371. Default values for some materials will be available in the LEED-NC v2.2 Reference Guide.
MM E-9: Low-Energy Cooling	LD (C, M), I, SP, AQP, RR, P/Stationary & Area	1%-10%/Low: EDAW presents this percent reduction range (EDAW 2006).	Yes	Yes (USGBC 2002 and 2005)	Yes (USGBC 2002 and 2005)	Adverse: No Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Project optimizes building's thermal distribution by separating ventilation and thermal conditioning systems.
MM E-10: Green Roof	LD (R, C, M), I, SP, AQP, RR, P/Stationary & Area	1.0%/Moderate: SMAQMD presents this % reduction (EDAW 2006, SMAQMD 2007).	Yes	Yes (USGBC 2002 and 2005)	Yes (USGBC 2002 and 2005)	Adverse: Increased Water Consumption Beneficial: CAPs, TACs	CA air quality management and control districts and cities/counties (e.g., SMAQMD).	Install a vegetated roof that covers at least 50% of roof area. The reduction assumes that a vegetated roof is installed on a least 50% of the roof area or that a combination high albedo and vegetated roof surface is installed that meets the following standard: (Area of SRI Roof/0.75)+(Area of vegetated roof/0.5) >= Total Roof Area. Water consumption reduction measures shall be considered in the design of the green roof.
MM E-11: EV Charging Facilities	LD (C, M), SP, AQP, RR, P/Stationary & Area	NA/Low	Yes: $500-$5000/ vehicle site (PG&E 1999)	Yes	Yes: 381 facilities in CA (Clean Air Maps 2007).	Adverse: No Beneficial: CAPs, TACs	DOE, EERE, CA air quality management and control districts and cities/counties (e.g., BAAQMD).	Project installs EV charging facilities.
MM E-12:	LD (R, C, M),	NA/Low: Increasing	Yes: Light	Yes	Yes: Apply	Adverse: No		Project provides light-colored

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Light-Colored Paving	I, SP, AQP, RR, P/Stationary & Area	the albedo of 1,250 km of pavement by 0.25 would save cooling energy worth $15M per year.	colored aggregates and white cement are more expensive than gray cement. Certain blended cements are very light in color and may reflect similarly to white cement at an equivalent cost to normal gray cement.		natural sand or gravel colored single surface treatments to asphalt (EOE 2007).	Beneficial: CAPs, TACs		paving (e.g., increased albedo pavement).
MM E-13: Cool Roofs	LD (R, C, M), I, SP, AQP, RR, P/Stationary & Area	NA/Low	Yes: 0.75–1.5/square feet coating (EPA 2007a)	Yes	Yes: Over 90% of the roofs in the United States are dark colored	Adverse: No Beneficial: CAPs, TACs	CEC	Project provides cool roofs. Highly reflective, highly emissive roofing materials that stay 50-60°F cooler than a normal roof under a hot summer sun. CA's Cool Savings

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					(EPA 2007a).			Program provided rebates to building owners for installing roofing materials with high solar reflectance and thermal emittance. The highest rebate went to roofs on air conditioned buildings, while buildings with rooftop ducts and other nonresidential buildings were eligible for slightly less. The program aimed to reduce peak summer electricity demand and was administered by the CEC.
MM E-14: Solar Water Heaters	LD (R, M), SP, AQP, RR, P/Stationary & Area	20%–70% reduction in cooling energy needs/Moderate	Yes: $1675/20 square feet, requires a 50 gallon tank, annual operating cost of $176 (DOE 2007).	Yes	Yes: Based on solar orientation, building codes, zoning ordinances.	Adverse: No Beneficial: CAPs, TACs	Europe	Project provides solar water heaters.
MM E-15: Electric Yard Equipment Compatibility	LD (R, M), SP, AQP, RR, P/Stationary & Area	NA/Low	Yes: $75–$250/outlet from existing circuit (Cost Helper 2007).	Yes	Yes	Adverse: No Beneficial: CAPs, TACs		Project provides electrical outlets at building exterior areas.
MM E-16: Energy Efficient Appliance Standards	LD (R, C, M), SP, AQP, RR, P/Stationary & Area	NA/Low	Yes: Varies for each appliance—higher capital costs, lower operating costs (Energy	Yes	Yes: Major retail stores.	Adverse: No Beneficial: CAPs, TACs		Project uses energy efficient appliances (e.g., Energy Star).

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			Star 2007).					
MM E-17: Green Building Materials	LD (R, C, M), SP, AQP, RR, P/Stationary & Area	NA/Low: 25-30% more efficient on average.	Yes	Yes: BEES software allows users to balance the environmental and economic performance of building products; developed by NIST (NIST 2007).	Yes	Adverse: No Beneficial: CAPs, TACs		Project uses materials which are resource efficient, recycled, with long life cycles and manufactured in an environmentally friendly way.
MM E-18: Shading Mechanisms	LD (R, C, M), I, SP, AQP, RR, P/Stationary, & Area	NA/Low: Up to $450 annual energy savings (Energy Star 2007).	Yes: Higher capital costs, lower operating and maintenance costs (Energy Star 2007).	Yes	Yes: Major retail stores.	Adverse: No Beneficial: CAPs, TACs		Install energy-reducing shading mechanisms for windows, porch, patio and walkway overhangs.

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		Emissions Reduction/Score[2]	Cost (Yes/No)[3]	Technical[4]	Logistical[5]			
MM E-19: Ceiling/Whole-House Fans	LD (R, C, M), I, SP, AQP, RR, P/Stationary, & Area	NA/Low: 50% more efficient than conventional fans (Energy Star 2007).	Yes: $45-$200/fan, installation extra (Lowe's 2007).	Yes	Yes: Major retail stores.	Adverse: No Beneficial: CAPs, TACs		Install energy-reducing ceiling/whole-house fans.
MM E-20: Programmable Thermostats	LD (R, C, M), I, SP, AQP, RR, P/Stationary, & Area	NA/Low: $100 annual savings in energy costs (Energy Star 2007).	Yes: $60/LCD display and 4 settings for typical residential use (Lowe's 2007).	Yes	Yes: Major retail stores.	Adverse: Yes, Mercury Beneficial: CAPs, TACs		Install energy-reducing programmable thermostats that automatically adjust temperature settings.
MM E-21: Passive Heating and Cooling Systems	LD (R, C, M), I, SP, AQP, RR, P/Stationary, & Area	NA/Low	Yes: $800 (wall heaters) to $4,000+ (central systems)	Yes	Yes	Adverse: No Beneficial: CAPs, TACs		Install energy-reducing passive heating and cooling systems (e.g., insulation and ventilation).
MM E-22: Day Lighting Systems	LD (R, C, M), I, SP, AQP, RR, P/Stationary, & Area	NA/Low	Yes: $1,300 to $1,500 depending upon the kind of roof (Barrier 1995), installation extra.	Yes	Yes: Work well only for space near the roof of the building, little benefit in multi-floor buildings.	Adverse: No Beneficial: CAPs, TACs		Install energy-reducing day lighting systems (e.g., skylights, light shelves and interior transom windows).
MM E-23: Low-Water Use Appliances	LD (R, C, M), I, SP, AQP, RR, P/Stationary, & Area	NA/Low: Avoided water agency cost for using water-efficient kitchen pre-rinse spray valves of $65.18 per acre-foot.	Yes: Can return their cost through reduction in water consumption,	Yes	Yes	Adverse: No Beneficial: CAPs, TACs		Require the installation of low-water use appliances.

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			pumping, and treatment.					
MM E-24: Goods Transport by Rail	LD (C, M), I, SP, AQP, RR, P/Mobile	NA/Moderate	Yes	Yes	Yes	Adverse: No Beneficial: CAPs, TACs	ARB Goods Movement Plan (ARB 2007)	Provide a spur at nonresidential projects to use nearby rail for goods movement.
Social Awareness/Education								
MM S-1: GHG Emissions Reductions Education	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile, Stationary, & Mobile	NA/Low	Yes	Yes	Yes: Similar programs currently exist in CA.	Adverse: No Beneficial: CAPs, TACs		Provide local governments, businesses, and residents with guidance/protocols/information on how to reduce GHG emissions (e.g., energy saving, food miles).
MM S-2: School Curriculum	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile, Stationary, & Mobile	NA/Low	Yes	Yes	Yes: Similar programs currently exist in CA.	Adverse: No Beneficial: CAPs, TACs		Include how to reduce GHG emissions (e.g., energy saving, food miles) in the school curriculum.
Construction								
MM C-1: ARB-Certified Diesel Construction Equipment	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	NA/Low	Yes: Oxidation Catalysts, $1,000-	Yes	Yes	Adverse: Yes, NO_x Beneficial: CAPs, TACs	AG, EPA, ARB, and CA air quality management and pollution control districts.	Use ARB-certified diesel construction equipment. Increases CO_2 emissions when trapped CO and carbon particles

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			$2,000. DPF, $5000-$10,000; installation extra (EPA 2007b).					are oxidized (Catalyst Products 2007, ETC 2007).
MM C-2: Alternative Fuel Construction Equipment	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	NA/Low	Yes	Yes	Yes	Adverse: Yes, THC, NO_x Beneficial: CO, PM, SO_x	AG, EPA, ARB, and CA air quality management and pollution control districts.	Use alternative fuel types for construction equipment. At the tailpipe biodiesel emits 10% more CO_2 than petroleum diesel. Overall lifecycle emissions of CO_2 from 100% biodiesel are 78% lower than those of petroleum diesel (NREL 1998, EPA 2007b).
MM C-3: Local Building Materials	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	NA/Low	Yes	Yes	Yes: Depends on location of building material manufacture sites.	Adverse: No Beneficial: CAPs, TACs		Use locally made building materials for construction of the project and associated infrastructure.
MM C-4: Recycle Demolished Construction Material	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile	NA/Low	Yes	Yes	Yes	Adverse: No Beneficial: CAPs, TACs		Recycle/Reuse demolished construction material. Use locally made building materials for construction of the project and associated infrastructure.

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Miscellaneous								
MM M-1: Off-Site Mitigation Fee Program	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile & Area	NA/Moderate-High: Though there is currently no program in place, the potential for real and quantifiable reductions of GHG emissions could be high if a defensible fee program were designed.	Yes	Yes	No: Program does not exist in CA, but similar programs currently exist (e.g., Carl Moyer Program, SJVAPCD Rule 9510, SMAQMD Off-Site Construction Mitigation Fee Program).	Adverse: No Beneficial: CAPs, TACs		Provide/Pay into an off-site mitigation fee program, which focuses primarily on reducing emissions from existing development and buildings through retro-fit (e.g., increased insulation).
MM M-2: Offset Purchase	LD (R, C, M), I, SP, TP, AQP, RR, P/Mobile, Stationary, & Area	NA/Low	Yes	Yes	No: ARB has not adopted official program, but similar programs	No		Provide/purchase offsets for additional emissions by acquiring carbon credits or engaging in other market "cap and trade" systems.

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					currently exist.			
Regional Transportation Plan Measures								
MM RTP-1: Dedicate High Occupancy Vehicle (HOV) lanes prior to adding capacity to existing highways.	RTP		Yes	Yes	Yes	Adverse: possible local CO Beneficial: regional CAPs, TACs	Caltrans, local government	Evaluate the trip reduction (and GHG reduction) potential of adding HOV lanes prior to adding standard lanes.
MM RTP-2: Implement toll/user fee programs prior to adding capacity to existing highways.	RTP		Yes	Yes	Yes	Adverse: possible local CO. Beneficial: regional CAPs, TACs	Caltrans	Evaluate price elasticity and associated trip reduction (and GHG reduction) potential with adding or increasing tolls prior to adding capacity to existing highways.

Note:
[1] Where LD (R, C, M) =Land Development (Residential, Commercial, Mixed-Use), I=Industrial, GP=General Plan, SP=Specific Plan, TP=Transportation Plans, AQP=Air Quality Plans, RR=Rules/Regulations, and P=Policy. It is important to note that listed project types may not be directly specific to the mitigation measure (e.g., TP, AQP, RR, and P) as such could apply to a variety of source types, especially RR and P.
[2] This score system entails ratings of high, moderate, and low that refer to the level of the measure to provide a substantive, reasonably certain (e.g., documented emission reductions with proven technologies), and long-term reduction of GHG emissions.
[3] Refers to whether the measure would provide a cost-effective reduction of GHG emissions based on available documentation.
[4] Refers to whether the measure is based on currently, readily available technology based on available documentation.
[5] Refers to whether the measure could be implemented without extraordinary effort based on available documentation.
[6] List is not meant to be all inclusive.
Source: Data complied by EDAW in 2007

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Table 17
General Planning Level Mitigation Strategies Summary

Strategy	Source Type[1]	Agency/Organization[2]	Description/Comments
MS G-1: Adopt a GHG reduction plan	GP/ Mobile, Stationary, & Area	City of San Bernardino	- Adopt GHG reduction targets for the planning area, based on the current legislation providing direction for state-wide targets, and update the plan as necessary. -The local government agency should serve as a model by inventorying its GHG emissions from agency operations, and implementing those reduction goals.
Circulation			
MS G-2: Provide for convenient and safe local travel	GP/ Mobile	Cities/Counties (e.g., Aliso Viejo, Claremont)	- Create a gridded street pattern with small block sizes. This promotes walkability through direct routing and ease of navigation. -Maintain a high level of connectivity of the roadway network. Minimize cul-de-sacs and incomplete roadway segments. -Plan and maintain an integrated, hierarchical and multi-modal system of roadways, pedestrian walks, and bicycle paths throughout the area. -Apply creative traffic management approaches to address congestion in areas with unique problems, particularly on roadways and intersections in the vicinity of schools in the morning and afternoon peak hours, and near churches, parks and community centers. -Work with adjacent jurisdictions to address the impacts of regional development patterns (e.g. residential development in surrounding communities, regional universities, employment centers, and commercial developments) on the circulation system. -Actively promote walking as a safe mode of local travel, particularly for children attending local schools. -Employ traffic calming methods such as median landscaping and provision of bike or transit lanes to slow traffic, improve roadway capacity, and address safety issues.
MS G-3: Enhance the regional transportation network and maintain effectiveness	GP/ Mobile	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Encourage the transportation authority to reduce fees for short distance trips. -Ensure that improvements to the traffic corridors do not negatively impact the operation of local roadways and land uses.

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			-Cooperate with adjacent jurisdictions to maintain adequate service levels at shared intersections and to provide adequate capacity on regional routes for through traffic. -Support initiatives to provide better public transportation. Work actively to ensure that public transportation is part of every regional transportation corridor. - Coordinate the different modes of travel to enable users to transfer easily from one mode to another. -Work to provide a strong paratransit system that promotes the mobility of all residents and educate residents about local mobility choices. - Promote transit-oriented development to facilitate the use of the community's transit services.
MS G-4: Promote and support an efficient public transportation network connecting activity centers in the area to each other and the region.	GP/ Mobile	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Promote increased use of public transportation and support efforts to increase bus service range and frequency within the area as appropriate. -Enhance and encourage provision of attractive and appropriate transit amenities, including shaded bus stops, to encourage use of public transportation. -Encourage the school districts, private schools and other operators to coordinate local bussing and to expand ride-sharing programs. All bussing options should be fully considered before substantial roadway improvements are made in the vicinity of schools to ease congestion.
MS G-5: Establish and maintain a comprehensive system, which is safe and convenient, of pedestrian ways and bicycle routes that provide viable options to travel by automobile.	GP/ Mobile	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Improve area sidewalks and rights-of-way to make them efficient and appealing for walking and bicycling safely. Coordinate with adjacent jurisdictions and regional agencies to improve pedestrian and bicycle trails, facilities, signage, and amenities. -Provide safe and convenient pedestrian and bicycle connections to and from town centers, other commercial districts, office complexes, neighborhoods, schools, other major activity centers, and surrounding communities. -Work with neighboring jurisdictions to provide well-designed pedestrian and bicycle crossings of major roadways. -Promote walking throughout the community. Install sidewalks where missing and make improvements

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			to existing sidewalks for accessibility purposes. Particular attention should be given to needed sidewalk improvement near schools and activity centers. -Encourage businesses or residents to sponsor street furniture and landscaped areas. - Strive to provide pedestrian pathways that are well shaded and pleasantly landscaped to encourage use. - Attract bicyclists from neighboring communities to ride their bicycles or to bring their bicycles on the train to enjoy bicycling around the community and to support local businesses. - Meet guidelines to become nationally recognized as a Bicycle-Friendly community. - Provide for an education program and stepped up code enforcement to address and minimize vegetation that degrades access along public rights-of-way. -Engage in discussions with transit providers to increase the number of bicycles that can be accommodated on buses
MS G-6: Achieve optimum use of regional rail transit.	GP/ Mobile	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Support regional rail and work with rail authority to expand services. - Achieve better integration of all transit options. -Work with regional transportation planning agencies to finance and provide incentives for multimodal transportation systems. - Promote activity centers and transit-oriented development projects around the transit station.
MS G-7: Expand and optimize use of local and regional bus and transit systems.	GP/ Mobile	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Encourage convenient public transit service between area and airports. -Support the establishment of a local shuttle to serve commercial centers. -Promote convenient, clean, efficient, and accessible public transit that serves transit-dependent riders and attracts discretionary riders as an alternative to reliance on single-occupant automobiles.

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			- Empower seniors and those with physical disabilities who desire maximum personal freedom and independence of lifestyle with unimpeded access to public transportation. -Integrate transit service and amenities with surrounding land uses and buildings.
Conservation, Open Space			
MS G-8: Emphasize the importance of water conservation and maximizing the use of native, low-water landscaping.	GP/Stationary & Area	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Reduce the amount of water used for landscaping and increase use of native and low water plants. Maximize use of native, low-water plants for landscaping of areas adjacent to sidewalks or other impermeable surfaces. -Encourage the production, distribution and use of recycled and reclaimed water for landscaping projects throughout the community, while maintaining urban runoff water quality objectives. -Promote water conservation measures, reduce urban runoff, and prevent groundwater pollution within development projects, property maintenance, area operations and all activities requiring approval. -Educate the public about the importance of water conservation and avoiding wasteful water habits. -Work with water provider in exploring water conservation programs, and encourage the water provider to offer incentives for water conservation.
MS G-9: Improve air quality within the region.	GP/ Mobile, Stationary, & Area	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Integrate air quality planning with area land use, economic development and transportation planning efforts. -Support programs that reduce air quality emissions related to vehicular travel. -Support alternative transportation modes and technologies, and develop bike- and pedestrian-friendly neighborhoods to reduce emissions associated with automobile use. -Encourage the use of clean fuel vehicles. -Promote the use of fuel-efficient heating and cooling equipment and other appliances, such as water

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Table 17
General Planning Level Mitigation Strategies Summary

Strategy	Source Type[1]	Agency/Organization[2]	Description/Comments
			heaters, swimming pool heaters, cooking equipment, refrigerators, furnaces, and boiler units. - Promote the use of clean air technologies such as fuel cell technologies, renewable energy sources. UV coatings, and alternative, non-fossil fuels. -Require the planting of street trees along streets and inclusion of trees and landscaping for all development projects to help improve airshed and minimize urban heat island effects. - Encourage small businesses to utilize clean, innovative technologies to reduce air pollution. - Implement principles of green building. - Support jobs/housing balance within the community so more people can both live and work within the community. To reduce vehicle trips, encourage people to telecommute or work out of home or in local satellite offices.
MS G-10: Encourage and maximize energy conservation and identification of alternative energy sources.	GP/ Stationary & Area	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Encourage green building designs for new construction and renovation projects within the area. -Coordinate with regional and local energy suppliers to ensure adequate supplies of energy to meet community needs, implement energy conservation and public education programs, and identify alternative energy sources where appropriate. -Encourage building orientations and landscaping that enhance natural lighting and sun exposure. -Encourage expansion of neighborhood-level products and services and public transit opportunities throughout the area to reduce automobile use. - Incorporate the use of energy conservation strategies in area projects. - Promote energy-efficient design features, including appropriate site orientation, use of light color roofing and building materials, and use of evergreen trees and wind-break trees to reduce fuel consumption for heating and cooling.

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Table 17
General Planning Level Mitigation Strategies Summary

Strategy	Source Type[1]	Agency/Organization[2]	Description/Comments
			-Explore and consider the cost/benefits of alternative fuel vehicles including hybrid, natural gas, and hydrogen powered vehicles when purchasing new vehicles. -Continue to promote the use of solar power and other energy conservation measures. - Encourage residents to consider the cost/benefits of alternative fuel vehicles. - Promote the use of different technologies that reduce use of non-renewable energy resources. -Facilitate the use of green building standards and LEED in both private and public projects. -Promote sustainable building practices that go beyond the requirements of Title 24 of the California Administrative Code, and encourage energy-efficient design elements, as appropriate. -Support sustainable building practices that integrate building materials and methods that promote environmental quality, economic vitality, and social benefit through the design, construction, and operation of the built environment. - Investigate the feasibility of using solar (photovoltaic) street lights instead of conventional street lights that are powered by electricity in an effort to conserve energy. - Encourage cooperation between neighboring development to facilitate on-site renewable energy supplies or combined heat and power co-generation facilities that can serve the energy demand of contiguous development.

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Table 17
General Planning Level Mitigation Strategies Summary

Strategy	Source Type[1]	Agency/Organization[2]	Description/Comments
MS G-11: Preserve unique community forests, and provide for sustainable increase and maintenance of this valuable resource.	GP/Stationary & Area	Cities/Counties (e.g., Aliso Viejo, Claremont)	- Develop a tree planting policy that strives to accomplish specific % shading of constructed paved and concrete surfaces within five years of construction. -Provide adequate funding to manage and maintain the existing forest, including sufficient funds for tree planting, pest control, scheduled pruning, and removal and replacement of dead trees. -Coordinate with local and regional plant experts in selecting tree species that respect the natural region in which Claremont is located, to help create a healthier, more sustainable urban forest. - Continue to plant new trees (in particular native tree species where appropriate), and work to preserve mature native trees. -Increase the awareness of the benefits of street trees and the community forest through a area wide education effort. -Encourage residents to properly care for and preserve large and beautiful trees on their own private property.
Housing			
MS G-12: Provide affordability levels to meet the needs of community residents.	GP/ Mobile	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Encourage development of affordable housing opportunities throughout the community, as well as development of housing for elderly and low and moderate income households near public transportation services. -Ensure a portion of future residential development is affordable to low and very low income households.
Land Use			
MS G-13: Promote a visually-cohesive urban form and establish connections between the urban core and outlying portions of the	GP/ Mobile, Stationary, & Area	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Preserve the current pattern of development that encourages more intense and higher density development at the core of the community and less intense uses radiating from the central core. -Create and enhance landscaped greenway, trail and sidewalk connections between neighborhoods and to commercial areas, town centers, and parks.

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Table 17
General Planning Level Mitigation Strategies Summary

Strategy	Source Type[1]	Agency/Organization[2]	Description/Comments
community.			-Identify ways to visually identify and physically connect all portions of the community, focusing on enhanced gateways and unifying isolated and/or outlying areas with the rest of the area. -Study and create a diverse plant identity with emphasis on drought-resistant native species.
MS G-14: Provide a diverse mix of land uses to meet the future needs of all residents and the business community.	GP/ Mobile	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Attract a broad range of additional retail, medical, and office uses providing employment at all income levels. -Support efforts to provide beneficial civic, religious, recreational, cultural and educational opportunities and public services to the entire community. -Coordinate with public and private organizations to maximize the availability and use of parks and recreational facilities in the community. -Support development of hotel and recreational commercial land uses to provide these amenities to local residents and businesses.
MS G-15: Collaborate with providers of solid waste collection, disposal and recycling services to ensure a level of service that promotes a clean community and environment.	GP/ Stationary, & Area	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Require recycling, composting, source reduction and education efforts throughout the community, including residential, businesses, industries, and institutions, within the construction industry, and in all sponsored activities.
MS G-16: Promote construction, maintenance and active use of publicly- and privately-operated parks, recreation programs, and a community center.	GP/ Mobile	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Work to expand and improve community recreation amenities including parks, pedestrian trails and connections to regional trail facilities. -As a condition upon new development, require payment of park fees and/or dedication and provision of parkland, recreation facilities and/or multi-use trails that improve the public and private recreation system. -Research options or opportunities to provide necessary or desired community facilities.

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General Planning Level Mitigation Strategies Summary

Strategy	Source Type[1]	Agency/Organization[2]	Description/Comments
MS G-17: Promote the application of sustainable development practices.	GP/ Mobile, Stationary, & Area	Cities/Counties (e.g., Aliso Viejo, Claremont)	- Encourage sustainable development that incorporates green building best practices and involves the reuse of previously developed property and/or vacant sites within a built-up area. - Encourage the conservation, maintenance, and rehabilitation of the existing housing stock. -Encourage development that incorporates green building practices to conserve natural resources as part of sustainable development practices. -Avoid development of isolated residential areas in the hillsides or other areas where such development would require significant infrastructure investment, adversely impact biotic resources. - Provide land area zoned for commercial and industrial uses to support a mix of retail, office, professional, service, and manufacturing businesses.
MS G-18: Create activity nodes as important destination areas, with an emphasis on public life within the community.	GP/ Mobile	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Provide pedestrian amenities, traffic-calming features, plazas and public areas, attractive streetscapes, shade trees, lighting, and retail stores at activity nodes. -Provide for a mixture of complementary retail uses to be located together to create activity nodes to serve adjacent neighborhoods and to draw visitors from other neighborhoods and from outside the area.
MS G-19: Make roads comfortable, safe, accessible, and attractive for use day and night.	GP/ Mobile	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Provide crosswalks and sidewalks along streets that are accessible for people with disabilities and people who are physically challenged. -Provide lighting for walking and nighttime activities, where appropriate. -Provide transit shelters that are comfortable, attractive, and accommodate transit riders.
MS G-20: Maintain and expand where possible the system of neighborhood connections that attach neighborhoods to larger roadways.	GP/ Mobile	Cities/Counties (e.g., Aliso Viejo, Claremont)	- Provide sidewalks where they are missing, and provide wide sidewalks where appropriate with buffers and shade so that people can walk comfortably. -Make walking comfortable at intersections through traffic-calming, landscaping, and designated crosswalks.

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Table 17
General Planning Level Mitigation Strategies Summary

Strategy	Source Type[1]	Agency/Organization[2]	Description/Comments
			-Look for opportunities for connections along easements & other areas where vehicles not permitted.
MS G-21: Create distinctive places throughout the area.	GP/ Mobile	Cities/Counties (e.g., Aliso Viejo, Claremont)	-Provide benches, streetlights, public art, and other amenities in public areas to attract pedestrian activities. -Encourage new developments to incorporate drought tolerant and native landscaping that is pedestrian friendly, attractive, and consistent with the landscaped character of area. -Encourage all new development to preserve existing mature trees. -Encourage streetscape design programs for commercial frontages that create vibrant places which support walking, bicycling, transit, and sustainable economic development. -Encourage the design and placement of buildings on lots to provide opportunities for natural systems such as solar heating and passive cooling. - Ensure that all new industrial development projects are positive additions to the community setting, provide amenities for the comfort of the employees such as outdoor seating area for breaks or lunch, and have adequate landscape buffers.
MS G-22: Reinvest in existing neighborhoods and promote infill development as a preference over new, greenfield development	GP/ Mobile, Stationary, & Area	Cities/Counties (e.g., Aliso Viejo, Claremont)	- Identify all underused properties in the plan area and focus development in these opportunity sites prior to designating new growth areas for development. - Implement programs to retro-fit existing structures to make them more energy-efficient. -Encourage compact development, by placing the desired activity areas in smaller spaces.

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Table 17
General Planning Level Mitigation Strategies Summary

Strategy	Source Type[1]	Agency/Organization[2]	Description/Comments
Public Safety			
MS G-23: Promote a safe community in which residents can live, work, shop, and play.	GP/ Mobile	Cities/Counties (e.g., Aliso Viejo, Claremont)	- Foster an environment of trust by ensuring non-biased policing, and by adopting policies and encouraging collaboration that creates transparency. - Facilitate traffic safety for motorists and pedestrians through proper street design and traffic monitoring.

Note:
[1] Where GP=General Plan.
[2] List is not meant to be all inclusive.
Source: Data complied by EDAW in 2007

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Appendix C

Rule and Regulation Summary

Table 18
Rule and Regulation Summary

Rule/Regulation	Reduction	Implementation Date	Agency	Description	Comments
Low Carbon Fuel Standard	10-20 MMT CO_2e by 2020	January 1, 2010	ARB	This rule/regulation will require fuel providers (e.g., producers, importers, refiners and blenders) to ensure that the mix of fuels they sell in CA meets the statewide goal to reduce the carbon intensity of CA's transportation fuels by at least 10% by the 2020 target.	ARB Early Action Measure
Reduction of HFC-134a Emissions from Nonprofessional Servicing of Motor Vehicle Air Conditioning Systems	1-2 MMT CO_2e by 2020	January 1, 2010	ARB	This rule/regulation will restrict the use of high GWP refrigerants for nonprofessional recharging of leaky automotive air conditioning systems.	ARB Early Action Measure
Landfill Gas Recovery	2-4 MMT CO_2e by 2020	January 1, 2010	IWMB, ARB	This rule/regulation will require landfill gas recovery systems on small to medium landfills that do not have them and upgrade the requirements at landfills with existing systems to represent best capture and destruction efficiencies.	ARB Early Action Measure
Vehicle Climate Change Standards (AB 1493 Pavley, Chapter 200, Statutes of 2002)	30 MMT CO_2e by 2020	2009	ARB	This rule/regulation will require ARB to achieve the maximum feasible and cost effective reduction of GHG emissions from passenger vehicles and light-duty trucks.	ARB Early Action Measure
Reduction of PFCs from the Semiconductor Industry	0.5 MMT CO_2e by 2020	2007–2009	ARB	This rule/regulation will reduce GHG emissions by process improvements/source reduction, alternative chemicals capture and beneficial reuse, and destruction technologies	Underway or to be initiated by CAT members in 2007-2009 period

AB=Assembly Bill; ARB=California Air Resources Board; Calfire=California Fire; CA=California; Caltrans=California Department of Transportation; CAT=California Action Team; CEC=California Energy Commission; CDFA=California Department of Food and Agriculture; CH_4=Methane; CO_2=Carbon Dioxide; CPUC=California Public Utilities Commission; CUFR=California Urban Forestry; DGS=Department of General Services; DWR=Department of Water Resources; GHG=Greenhouse Gas; GWP=Global Warming Potential; IGCC= Integrated Gasification Combined Cycle; IOU= Investor-Owned Utility; IT=Information Technology; IWCB= Integrated Waste Management Board; LNG= Liquefied Natural Gas; MMT CO_2e=Million Metric Tons Carbon Dioxide Equivalent; MW=Megawatts; NA=Not Available; N_2O=Nitrous Oxide; PFC= Perfluorocompound; POU= Publicly Owned Utility; RPS= Renewable Portfolio Standards; RTP=Regional Transportation Plan SB=Senate Bill; SWP=State Water Project; TBD=To Be Determined; UC/CSU=University of California/California State University; ULEV=Ultra Low Emission Vehicle.

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Table 18
Rule and Regulation Summary

Rule/Regulation	Reduction	Implementation Date	Agency	Description	Comments
Restrictions on High GWP Refrigerants	9 MMT CO_2e by 2020	2010	ARB	This rule/regulation will expand and enforce the national ban on release of high GWP refrigerants during appliance lifetime.	ARB Early Action Measure
Cement Manufacture	<1 MMT CO_2e per year (based on 2004 production levels)	2010	Caltrans	This rule/regulation will allow 2.5% interground limestone concrete mix in cement use.	CAT Early Action Measure
Hydrogen Fuel Standards (SB 76 of 2005)	TBD	By 2008	CDFA	This rule/regulation will develop hydrogen fuel standards for use in combustion systems and fuel cells.	CAT Early Action Measure
Regulation of GHG from Load Serving Entities (SB 1368)	15 MMT CO_2e by 2020	May 23, 2007	CEC, CPUC	This rule/regulation will establish a GHG emission performance standard for baseload generation of local publicly owned electric utilities that is no higher than the rate of emissions of GHG for combined-cycle natural gas baseload generation.	CAT Early Action Measure
Energy Efficient Building Standards	TBD	In 2008	CEC	This rule/regulation will update of Title 24 standards.	CAT Early Action Measure
Energy Efficient Appliance Standards	TBD	January 1, 2010	CEC	This rule/regulation will regulate light bulb efficiency	CAT Early Action Measure
Tire Efficiency (Chapter 8.7 Division 15 of the Public Resources Code)	<1 MMT CO_2e by 2020	January 1, 2010	CEC & IWMB	This rule/regulation will ensure that replacement tires sold in CA are at least as energy efficient, on average, as tires sold in the state as original equipment on these vehicles.	CAT Early Action Measure
New Solar Homes Partnership	TBD	January 2007	CEC	Under this rule/regulation, approved solar systems will receive incentive funds based on system performance above building standards.	CAT Early Action Measure

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Rule/Regulation	Reduction	Implementation Date	Agency	Description	Comments
Water Use Efficiency	1 MMT CO_2e by 2020	2010	DWR	This rule/regulation will adopt standards for projects and programs funded through water bonds that would require consideration of water use efficiency in construction and operation.	CAT Early Action Measure
State Water Project	TBD	2010	DWR	This rule/regulation will include feasible and cost effective renewable energy in the SWP's portfolio.	CAT Early Action Measure
Cleaner Energy for Water Supply	TBD	2010	DWR	Under this rule/regulation, energy supply contracts with conventional coal power plants will not be renewed.	CAT Early Action Measure
IOU Energy Efficiency Programs	4 MMT CO_2e by 2020	2010	CPUC	This rule/regulation will provide a risk/reward incentive mechanism for utilities to encourage additional investment in energy efficiency; evaluate new technologies and new measures like encouraging compact fluorescent lighting in residential and commercial buildings	CAT Early Action Measure
Solar Generation	TBD	2007–2009	DGS	3 MW of clean solar power generation implemented in CA last year, with another 1 MW coming up. The second round is anticipated to total additional 10 MW and may include UC/CSU campuses and state fairgrounds.	Underway or to be initiated by CAT members in 2007-2009 period

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Rule/Regulation	Reduction	Implementation Date	Agency	Description	Comments
Transportation Efficiency	9 MMT CO_2e by 2020	2007–2009	Caltrans	This rule/regulation will reduce congestion, improve travel time in congested corridors, and promote coordinated, integrated land use.	Underway or to be initiated by CAT members in 2007-2009 period
Smart Land Use and Intelligent Transportation	10 MMT CO_2e by 2020	2007–2009	Caltrans	This rule/regulation will integrate consideration of GHG reduction measures and energy efficiency factors into RTPs, project development etc.	Underway or to be initiated by CAT members in 2007-2009 period
Cool Automobile Paints	1.2 to 2.0 MMT CO_2e by 2020	2009	ARB	Cool paints would reduce the solar heat gain in a vehicle and reduce air conditioning needs.	ARB Early Action Measure
Tire Inflation Program	TBD	2009	ARB	This rule/regulation will require tires to be checked and inflated at regular intervals to improve fuel economy.	ARB Early Action Measure
Electrification of Stationary Agricultural Engines	0.1 MMT CO_2e by 2020	2010	ARB	This rule/regulation will provide incentive funding opportunities for replacing diesel engines with electric motors.	ARB Early Action Measure
Desktop Power Management	Reduce energy use by 50%	2007–2009	DGS, ARB	This rule/regulation will provide software to reduce electricity use by desktop computers by up to 40%.	Currently deployed in DGS
Reducing CH_4 Venting/Leaking from Oil and Gas Systems (EJAC-3/ARB 2-12)	1 MMT CO_2e by 2020	2010	ARB	This rule/regulation will reduce fugitive CH_4 emissions from production, processing, transmission, and distribution of natural gas and oil.	ARB Early Action Measure
Replacement of High GWP Gases Used in Fire Protection Systems with Alternate Chemical (ARB 2-10)	0.1 MMT CO_2e by 2020	2011	ARB	This rule/regulation will require the use of lower GWP substances in fire protection systems.	ARB Early Action Measure
Contracting for Environmentally Preferable Products	NA	2007–2009	DGS	New state contracts have been or are being created for more energy and resource efficient IT goods, copiers, low mercury fluorescent lamps, the CA Gold Carpet Standard and office furniture.	Underway or to be initiated by CAT members in 2007-2009 period
Hydrogen Fuel Cells	NA	2007–2009	DGS	This rule/regulation will incorporate clean hydrogen fuel cells in stationary applications	Underway or to be initiated by CAT members in 2007-2009

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Table 18 Rule and Regulation Summary					
Rule/Regulation	**Reduction**	**Implementation Date**	**Agency**	**Description**	**Comments**
				at State facilities and as back-up generation for emergency radio services.	period
High Performance Schools	NA	2007–2009	DGS	New guidelines adopted for energy and resource efficient schools; up to $100 million in bond money for construction of sustainable, high performance schools.	Underway or to be initiated by CAT members in 2007-2009 period
Urban Forestry	1 MMT CO_2e by 2020	2007–2009	Calfire, CUFR	This rule/regulation will provide five million additional trees in urban areas by 2020.	Underway or to be initiated by CAT members in 2007-2009 period
Fuels Management/Biomass	3 MMT CO_2e by 2020	2007–2009	Calfire	This rule/regulation will provide biomass from forest fuel treatments to existing biomass utilization facilities.	Underway or to be initiated by CAT members in 2007-2009 period
Forest Conservation and Forest Management	10 MMT CO_2e by 2020	2007–2009	Calfire, WCB	This rule/regulation will provide opportunities for carbon sequestration in Proposition 84 forest land conservation program to conserve an additional 75,000 acres of forest landscape by 2010.	Underway or to be initiated by CAT members in 2007-2009 period
Afforestation/Reforestation	2 MMT CO_2e by 2020	2007–2009	Calfire	This rule/regulation will subsidize tree planting.	Underway or to be initiated by CAT members in 2007-2009 period
Dairy Digesters	TBD	January 1, 2010	CDFA	This rule/regulation will develop a dairy digester protocol to document GHG emission reductions from these facilities.	ARB Early Action Measure

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Rule and Regulation Summary

Rule/Regulation	Reduction	Implementation Date	Agency	Description	Comments
Conservation Tillage and Enteric Fermentation	1 MMT CO_2e by 2020	2007–2009	CDFA	This rule/regulation will develop and implement actions to quantify and reduce enteric fermentation emissions from livestock and sequester soil carbon using cover crops and conservation tillage.	Underway or to be initiated by CAT members in 2007-2009 period
ULEV	TBD	2007–2009	DGS	A new long term commercial rental contract was released in March 2007 requiring a minimum ULEV standard for gasoline vehicles and requires alternative fuel and hybrid-electric vehicles.	Underway or to be initiated by CAT members in 2007-2009 period
Flex Fuel Vehicles	370 metric tons CO_2, 0.85 metric tons of CH_4, and 1.14 metric tons of N_2O	2007–2009	DGS	Under this rule/regulation, DGS is replacing 800 vehicles with new, more efficient vehicles.	Underway or to be initiated by CAT members in 2007-2009 period
Climate Registry	TBD	2007–2009	DGS	Benchmarking and reduction of GHG emissions for state owned buildings, leased buildings and light duty vehicles.	Underway or to be initiated by CAT members in 2007-2009 period
Municipal Utilities Electricity Sector Carbon Policy	Included in SB 1368 reductions	2007–2009	CEC, CPUC, ARB	Under this rule/regulation, GHG emissions cap policy guidelines for CA's electricity sector (IOUs and POUs).	Underway or to be initiated by CAT members in 2007-2009 period
Alternative Fuels: Nonpetroleum Fuels	TBD	2007–2009	CEC	State plan to increase the use of alternative fuels for transportation; full fuel cycle assessment.	Underway or to be initiated by CAT members in 2007-2009 period
Zero Waste/High Recycling Strategy	5 MMT CO_2e by 2020	2007–2009	IWMB	This rule/regulation will identify materials to focus on to achieve GHG reduction at the lowest possible cost; Builds on the success of 50% Statewide Recycling Goal.	Underway or to be initiated by CAT members in 2007-2009 period
Organic Materials Management	TBD	2007–2009	IWMB	This rule/regulation will develop a market incentive program to increase organics diversion to the agricultural industry.	Underway or to be initiated by CAT members in 2007-2009 period
Landfill Gas Energy	TBD	2007–2009	IWMB	Landfill Gas to Energy & LNG/biofuels	Underway or to be initiated by CAT members in 2007-2009 period

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Table 18 Rule and Regulation Summary					
Rule/Regulation	**Reduction**	**Implementation Date**	**Agency**	**Description**	**Comments**
Target Recycling	TBD	2007–2009	IWMB	This rule/regulation will focus on industry/public sectors with high GHG components to implement targeted commodity recycling programs.	Underway or to be initiated by CAT members in 2007-2009 period
Accelerated Renewable Portfolio Standard	Included in SB 1368 reductions	2007–2009	CPUC	This rule/regulation will examine RPS long term planning and address the use of tradable renewable energy credits for RPS compliance.	Underway or to be initiated by CAT members in 2007-2009 period
CA Solar Initiative	1 MMT CO_2e by 2020	2007–2009	CPUC	Initiative to deliver 2000 MWs of clean, emissions free energy to the CA grid by 2016.	Underway or to be initiated by CAT members in 2007-2009 period
Carbon Capture and Sequestration	TBD	2007–2009	CPUC	Proposals for power plants with IGCC and/or carbon capture in the next 18 months.	Underway or to be initiated by CAT members in 2007-2009
Source: Data complied by EDAW in 2007					

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U.S. Department of Transportation

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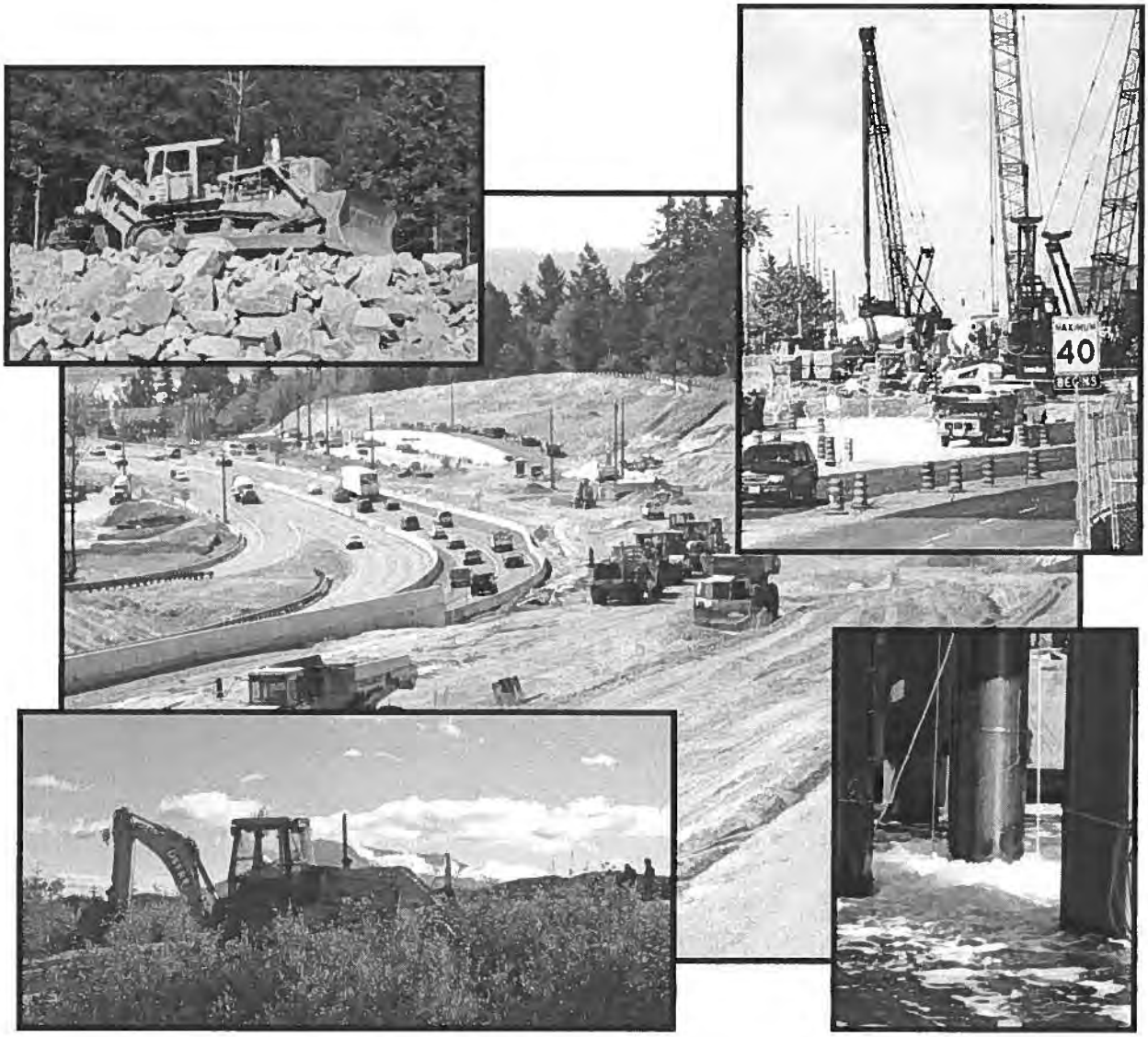
FHWA HIGHWAY CONSTRUCTION NOISE HANDBOOK

Final Report
August 2006



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3.0 EFFECTS OF CONSTRUCTION NOISE

3.1 Introduction

Construction noise in the community may not pose a health risk or damage peoples' sense of hearing, but it can adversely affect peoples' quality of life. To some degree, construction noise can be a contributing factor to the degradation of someone's health in that it can cause people to be irritated and stressed and can interrupt their ability to sleep – all of which may lead to higher blood pressure, anxiety, and feelings of animosity toward the people or agencies responsible for producing the noise.

In fact, several of the traditional definitions of "noise" (i.e. unwanted or undesirable sound) can be associated with construction noise. Construction noise can be perceived or considered to:

- be too loud;
- be impulsive;
- be uncontrollable;
- contain annoying pure tones;
- occur unexpectedly;
- occur at undesirable times of day; and/or
- interrupt people's activities.

Construction noise has the potential to disturb people at home in their residences, in office buildings or retail businesses, in public institutional buildings, at locations of religious services, while attending sporting events, or when on vacation.

Figure 3.1 Construction in residential area
(Photo #924)

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Figure 3.2 Construction in business district
(Photo #714)

Figure 3.3 Construction in vicinity of sporting event venue
(Photo #718)

Figure 3.4 Construction in paradise
(Photo #1033)

While construction noise can be unwelcome during nighttime periods in residential areas when people are trying to sleep, it can be equally unwelcome during the daytime in commercial areas if it interferes with peoples' ability to conduct business. In short, construction noise has the potential to disturb people 24 hours a day, 7 days a week. If not properly addressed, specific public concerns related to a project could result in actions affecting the progress and/or cost of a project.

There is nothing particularly unique about construction noise – it's a fluctuation in air pressure oscillating above and below atmospheric pressure that is produced by construction equipment or activities with sufficient magnitude (loudness) and within a certain frequency range (audible spectrum) such that human beings can hear it – just like any other noise. Being a physical parameter, it can be measured, quantified, modeled, predicted, and in certain instances, abated to some degree.

Noise from construction-related activities can also affect non-human species such as aquatic life and land and airborne animals in a variety of ways. The non-human category includes domestic, farm-based, and creatures living in the wild. In assessing the effects of noise on non-humans, it is essential that noise analysts closely coordinate with qualified biologists in the assessment and mitigation of noise impacts.

Issues related to vibration may also be raised during project development. This is particularly true when blasting operations occur. There are no FHWA requirements directed specifically to traffic-induced or construction-related vibration. Most studies that State DOTs have done to assess the impact of operational traffic-induced vibrations have shown that both measured and predicted vibration levels are less than any known criteria for structural damage to buildings, although levels may be such as to cause various degrees of annoyance. Analysis of construction-related vibration effects is beyond the scope of this Handbook.

The intent of this Handbook is not to provide detailed discussion of the above-listed effects, but rather to summarize them and refer the reader to more detailed information regarding specific effects of construction-related noise.

3.2 Types of Effects

3.2.1 Physical Effects

Physical effects related to humans are probably most applicable to the operators of construction equipment as opposed to people residing adjacent to construction projects. An exception to this would be unique situations such as scuba diving or swimming activities occurring in the vicinity of a water-based pile driving or blasting operation. The potential for hearing loss or physical damage to the human hearing mechanism is protected by Occupational Safety and Health Administration (OSHA) criteria, and as such, is not discussed herein. While resulting in the potential to annoy or disturb humans, construction noise is typically not a danger to people's hearing.

Knowledge related to the physical effects of construction noise on non-human species such as land-based animals, birds, and owls is limited. It is recognized that aquatic mammals and fish can be physically damaged by water-born sound and vibration waves caused by construction activities such as underwater blasting and pile driving. In lieu of detailed discussions within this Handbook of the variety of specialized studies related to the physical effects of construction noise on such species, references to such studies are provided in a list at the end of this chapter.

3.2.2 Speech Interference

Loud noises from construction activities can create situations where people cannot effectively communicate, as documented in Tables 3.1 and 3.2. While such situations may be merely an annoyance or inconvenience in certain situations, they could be construed as a safety issue if such noises prevent people from hearing important local noises such as approaching traffic, emergency warning devices, alerts from other people, etc.

3.2.3 Activity Interference

Noise from construction activities can affect humans, land-based animals, aquatic wildlife, and airborne wildlife in a variety of ways. Humans are most affected in terms of sleep deprivation and the carrying on of normal daily activities such as watching television, listening to the radio, recreational activities, and activities requiring concentration, such as reading. Special activities such as those associated with

churches, schools, and libraries can also be negatively affected by construction noise. Water-based activities such as scuba diving, swimming, and boating can also be affected.

3.2.4 Annoyance

While non-humans are most likely annoyed by construction noise, there is little known about the related effects. However, the annoyance of noise on humans has been studied for some time and is documented in a 1974 EPA report commonly referred to as the "Levels Document"[ref033]. It is complementary to the 1979 EPA document, "Protective Noise Levels"[ref052].

3.2.5 Examples of Data from Previous Studies (Effects on Humans)

A variety of studies have attempted to quantify the effects of noise on humans. An example is provided in the following table contained in the "Levels Document" referred to above. Note that all noise levels referred to in the "Levels Document" are A-weighted.

Table 3.1 Summary of Human Effects in Terms of Speech Communication, Community Reactions, Annoyance, and Attitude toward Area Associated with an Outdoor Day/Night Sound Level of 55 dB re 20 Micropascals.

Type of Effect	Magnitude of Effect
Speech - Indoors	100% sentence intelligibility (average) with a 5 dB margin of safety
Speech - Outdoors	100% sentence intelligibility (average) at 0.35 meters
	99% sentence intelligibility (average) at 1.0 meters
	95% sentence intelligibility (average) at 3.5 meters
Average Community Reaction	None evident; 7 dB below level of significant "complaints and threats of legal action" and at least 16 dB below "vigorous action" (attitudes and other non-level related factors may affect this result)
Complaints	1% dependent on attitude and other non-level related factors
Annoyance	1% dependent on attitude and other non-level related factors
Attitude Toward Area	Noise essentially the least important of various factors

Table 3.2. Steady A-weighted Sound Levels that Allow Communication with 95 Percent Sentence Intelligibility over Various Distances Outdoors for Different Voice Levels.

Communication Distance (meters)	0.5	1	2	3	4	5
Normal Voice (dB)	72	66	60	56	54	52
Raised Voice (dB)	78	72	66	62	60	58

3.2.6 Effects on Non-Humans

The effects of construction-related noise on non-humans are less understood and probably most related to mating, nesting, migration, and feeding activities. While data on such effects is limited as compared with information on humans, some research is available[ref031 and ref032].

For a more detailed discussion of the general effects of noise on wildlife and other non-human species, the reader is directed to references dealing with the following:

- Effects on wildlife and other animals: ref031 and ref 032;
- Effects on marine mammals: ref 102;
- Effects on fish: ref030, ref036, ref046, ref054, ref060, and ref061; and
- Effects on owls: research underway as of the publication date of this Handbook by Washington State DOT (WSDOT); when available, any published reports will be available through the WSDOT webpage (see Table 10.1).

In determining noise impacts and possible mitigation measures for construction projects involving non-human species, noise analysts should closely coordinate with qualified biologists.

4.0 CONSTRUCTION NOISE CRITERIA AND DESCRIPTORS

4.1 Criteria

Construction noise levels may be evaluated in terms of human response and considered in the assessment of effects on wildlife and other non-human species. Noise levels and criteria are expressed in English, metric, or both conventions, depending upon the geographic area or the policies of the controlling agency. Typically, the English convention is used mostly in the United States, with the metric convention used in Canada and other countries.

While the issue of construction noise must be addressed as part of the planning of any transportation project, there are no standardized criteria on the federal level for assessing construction noise impacts related to transportation projects. Where project-specific construction noise criteria have been developed by individual agencies or municipalities, they typically consider the following factors which form the fundamentals for defining construction noise impact:

- Difference between existing noise levels prior to construction startup and expected noise levels during construction: This takes into account specific construction operations and/or individual pieces of equipment.

- Absolute level of expected construction noise: This may constitute the combined levels of all equipment and operations at a given time or be specifically related to the absolute noise level of a specific operation and/or piece of equipment.

- Adjacent land uses: Consideration of this factor provides an indicator of the degree of sensitivity that may be expected and will likely have a major effect on the operational time restraints and the noise level increases tolerated. For example, residential areas may typically have a restriction on night operations and possibly a noise level restriction during the day. Industrial areas may have no restrictions at all, and offices may or may not have a restriction on the noise levels during the day, with possibly no restriction for night operations. Examples of absolute and relative construction noise level criteria are provided in Table 7.1.

- Duration of construction/operation: The duration of high noise levels may play a significant role in how a noise impact is perceived and/or mitigated. If the levels are of a brief nature, possibly only occurring once or twice during the project, the perceived impact could be quite different than that associated with a constant noise source. Similarly, any related noise mitigation techniques employed could be substantially different in terms of type and/or duration of application.

4.1.1 History of Construction Noise Criteria

4.1.1.1 United States

While noise impact and abatement criteria have been established for the operation of transportation facilities in the United States, standardized criteria have not yet been established related to noise associated with the construction of such facilities. However, since the publication of the original 1977 Report[ref001], additional guidance has been disseminated (through agencies such as FHWA and FTA) and

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analysis tools developed to better address construction noise. For example, the FTA Transit Noise and Vibration Impact Assessment document[ref014] presents guidelines that "can be considered reasonable criteria for assessment" of construction noise impacts. In addition, a number of agencies, municipalities, and other entities have developed procedures for addressing construction noise impacts and implementing related noise mitigation for their areas of jurisdiction or on a project-specific basis.

In some instances, local entities may have developed noise ordinances that contain restrictions associated with construction noise levels. Noise practitioners and others involved in the project development process are encouraged to become familiar with such ordinances and their relationship to other State and/or municipal ordinances. In certain instances, the State jurisdiction may supersede any local noise ordinances.

Figure 4.1 Local noise ordinance
(Photo #314)

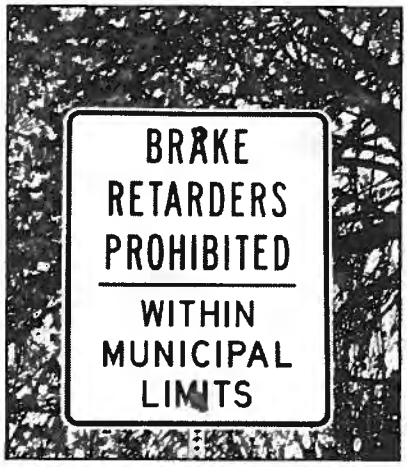

Figure 4.2 Local noise restrictions
(Photo #1206)

Noise restrictions may also be imposed by local and/or State authorities to deal with specific activities or operations. An example is the growing practice of restricting the use of engine compression brakes on heavy trucks in residential areas.

Noise restrictions may also be applied within the workplace associated with employee/worker exposure to noise levels over varying durations. These criteria have been established by OSHA. However, such criteria are typically not relevant or applicable to the transportation-related project construction noise levels experienced by people residing or working in areas adjacent to such projects. As such, they are not discussed within this Handbook.

Construction noise criteria within the United States vary considerably in terms of both scope and specificity and can be broadly categorized as follows, in order of complexity:

- No criteria specified;
- Qualitative criteria, e.g. "Noise levels shall not cause a disturbance";

- Relative criteria, e.g. "Noise levels shall not exceed existing (or ambient, or background) noise levels by more than x dB";
- Absolute criteria, e.g. "Maximum noise levels shall not exceed xx dB";
- Criteria containing a combination absolute and relative noise level limits; and
- Combinations of the above criteria elements with additional restrictions placed on time periods and types of land uses or activities.

An example of more complex criteria is that associated with the Central Artery/Tunnel Project in Boston, MA. Data related to these criteria are discussed in Reference 023 and illustrated in Table 7.1 of this Handbook. This project established criteria that include both L_{10} and L_{max} absolute noise level limits for defined noise sensitive locations (residences, institutions, hotels, etc.) for daytime, evening, and nighttime periods. In addition, the criteria established maximum noise level increases relative to established baseline noise levels. Relative and absolute noise level limits were also established for commercial and industrial areas.

From the standpoint of construction noise criteria, the intent of this Handbook is not to address all State and local noise ordinances and/or criteria, but rather, to address the approaches and techniques that may be contained in such criteria. As such, the discussions contained within this Handbook are meant to provide a summary of considerations related to all aspects of construction noise. The reader is encouraged to refer to specific references in Table 10.1 for more detailed information on noise criteria and other factors related to construction noise.

4.1.1.2 Canada

Similar to the United States, no standardized Canadian criteria exist related to transportation project construction noise. Where project-specific analysis techniques have been employed to address and/or mitigate construction-related noise and its impacts, such methods have been similar to those employed in the United States. Examples of such efforts may be found in References 010 and 019.

4.1.1.3 Other International

While an exhaustive survey of international criteria was not conducted, several criteria are discussed here for informational use only. More specifics may be found by accessing the relative links found in the Reference Database in Chapter 10.

- The Official Journal of the European Communities' Directive 2000/14/EC of the European Parliament and of the Council of 8 May 2000[ref017] establishes legislation dictating specific noise levels for individual pieces of construction equipment. It also contains specifics related to the measurement locations and equipment operating conditions relative to the testing of individual pieces of equipment.
- The Australian EPA's Environmental Noise Control Manual[ref015] establishes the following criteria which officers may specify related to construction noise:
    - For a construction period of four (4) weeks or less, the maximum L_{10} noise level measured over a period of not less than 15 minutes when the construction site is operating must not exceed the background noise level by more than 20 dBA;

- For a construction period greater than four (4) weeks, the maximum L_{10} noise level measured over a period of not less than 15 minutes when the construction site is operating must not exceed the background noise level by more than 10 dBA;
- Construction limited to 0700 to 1800 time period on Monday through Friday;
- Construction limited on Saturdays to 0700 to 1300 time period if inaudible on residential premises; otherwise, 0800 to 1300;
- No construction work may take place on Sundays or public holidays; and
- All possible steps should be taken to silence construction site equipment. It is particularly important that silenced equipment should be used on road or rail works where 24-hour operation is necessary.

4.2 Descriptors

While it is not the intent of this Handbook to establish criteria for evaluating construction noise impacts, it is important to stress that reasonable and defensible noise descriptors must be used to describe construction noise levels. The following are important elements related to selecting a workable noise descriptor for use in measuring and analyzing construction noise:

- Suitable for practical measuring methods;
- Accounts for temporal variations in equipment noise levels;
- Accounts for temporal variations in overall site noise level;
- Suitable for prediction modeling;
- Suitable for combining noise levels from various source types; and
- Relative to subjective responses.

The descriptor most commonly chosen for use is the A-weighted equivalent sound level (energy basis), L_{Aeq}. In many cases, the time average period applied to the L_{Aeq} value is one hour (designated L_{Aeq1h}). For certain projects and operations, the time period over which the L_{Aeq} is applied may need to be examined on a case-by-case basis. For several major construction projects in the United States and Canada, the L_{10} (applied generally during daytime periods) and L_{max} (applied for specific equipment and/or nighttime operations) descriptors have been used over varying time periods.

The L_{dn} descriptor has been used to assess annoyance and community reaction to construction noise. L_{dn} is an L_{Aeq}-based descriptor that applies a 10 dBA penalty to nighttime noise levels.

The L_{Aeq}-based and L_{10}-based descriptors satisfy the first four elements listed above. The L_{Aeq} satisfies the fifth element and may also satisfy the sixth element (relative to subjective responses). However, the L_{Aeq}, L_{10}, and L_{max} descriptors may not be suited for determining responses by some aquatic wildlife (where using an un-weighted sound pressure level may be more suitable) or for owls (where use of a different weighting category such as dBO or a descriptor such as SEL may be more suitable to account for effects such as air blasts associated with blasting). More detailed information related to these specific conditions might be found in documents listed in Section 3.2.6 of this document.

9.0 CONSTRUCTION EQUIPMENT NOISE LEVELS AND RANGES

9.1 Equipment Type Inventory and Related Emission Levels

Noise levels generated by individual pieces of construction equipment and specific construction operations form the basis for the prediction of construction-related noise levels. A variety of information exists related to sound emissions related to such equipment and operations. This data transcends the period beginning in the 1970s thru 2006. This information exists for both stationary and mobile sources and for steady, intermittent, and impulse type generators of noise.

9.1.1 Stationary Equipment

Stationary equipment consists of equipment that generates noise from one general area and includes items such as pumps, generators, compressors, etc. These types of equipment operate at a constant noise level under normal operation and are classified as non-impact equipment. Other types of stationary equipment such as pile drivers, jackhammers, pavement breakers, blasting operations, etc., produce variable and sporadic noise levels and often produce impact-type noises. Impact equipment is equipment that generates impulsive noise, where impulsive noise is defined as noise of short duration (generally less than one second), high intensity, abrupt onset, rapid decay, and often rapidly changing spectral composition. For impact equipment, the noise is produced by the impact of a mass on a surface, typically repeating over time.

9.1.2 Mobile Equipment

Mobile equipment such as dozers, scrapers, graders, etc., may operate in a cyclic fashion in which a period of full power is followed by a period of reduced power. Other equipment such as compressors, although generally considered to be stationary when operating, can be readily relocated to another location for the next operation.

9.2 Sources of Information

Construction-related equipment and operation noise level data may be provided by numerous sources, including suppliers, manufacturers, agencies, organizations, etc. Some information is included in this document, and many web-based links are given for equipment manufacturers.

9.3 Specifics of Construction Equipment and Operation Noise Inventories

Details included in each specific inventory of construction equipment and operation noise emission levels are often variable in terms of how data is represented. Some inventories include ranges of noise levels while others present single numbers for each equipment type. Others provide levels for specific models of each type of construction equipment. Often, different noise descriptors are used, such as L_{Aeq}, L_{max}, L_{10}, sound power level, etc. As such, the array of data does not readily lend itself to being combined into a single table or easily compared. As such, this Handbook attempts to summarize a variety of such inventories and provide links to each, thereby providing the reader with a variety of sources from which to choose the appropriate levels for use in his or her respective analysis.

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9.4 Summaries of Referenced Inventories

Included below are examples of several inventories of construction-related noise emission values. These and additional inventories are included on the companion CD-ROM.

9.4.1 RCNM Inventory

Equipment and operation noise levels in this inventory are expressed in terms of L_{max} noise levels and are accompanied by a usage factor value. They have been recently updated and are based on extensive measurements taken in conjunction with the Central Artery/Tunnel (CA/T) Project. Table 9.1 summarizes the equipment noise emissions database used by the CA/T Project. While these values represent the "default" values for use in the RCNM, user-defined equipment and corresponding noise levels can be added.

Table 9.1 RCNM Default Noise Emission Reference Levels and Usage Factors.

Equipment Description	Impact Device?	Acoustical Usage Factor (%)	Spec. 721.560 L_{max} @ 50 feet (dBA, slow)	Actual Measured L_{max} @ 50 feet (dBA, slow) (Samples Averaged)	Number of Actual Data Samples (Count)
All Other Equipment > 5 HP	No	50	85	N/A	0
Auger Drill Rig	No	20	85	84	36
Backhoe	No	40	80	78	372
Bar Bender	No	20	80	N/A	0
Blasting	Yes	N/A	94	N/A	0
Boring Jack Power Unit	No	50	80	83	1
Chain Saw	No	20	85	84	46
Clam Shovel (dropping)	Yes	20	93	87	4
Compactor (ground)	No	20	80	83	57
Compressor (air)	No	40	80	78	18
Concrete Batch Plant	No	15	83	N/A	0
Concrete Mixer Truck	No	40	85	79	40
Concrete Pump Truck	No	20	82	81	30
Concrete Saw	No	20	90	90	55
Crane	No	16	85	81	405
Dozer	No	40	85	82	55
Drill Rig Truck	No	20	84	79	22
Drum Mixer	No	50	80	80	1
Dump Truck	No	40	84	76	31
Excavator	No	40	85	81	170
Flat Bed Truck	No	40	84	74	4
Front End Loader	No	40	80	79	96
Generator	No	50	82	81	19
Generator (<25KVA, VMS Signs)	No	50	70	73	74
Gradall	No	40	85	83	70
Grader	No	40	85	N/A	0
Grapple (on backhoe)	No	40	85	87	1

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Equipment Description	Impact Device?	Acoustical Usage Factor (%)	Spec. 721.560 L_{max} @ 50 feet (dBA, slow)	Actual Measured L_{max} @ 50 feet (dBA, slow) (Samples Averaged)	Number of Actual Data Samples (Count)
Horizontal Boring Hydraulic Jack	No	25	80	82	6
Hydra Break Ram	Yes	10	90	N/A	0
Impact Pile Driver	Yes	20	95	101	11
Jackhammer	Yes	20	85	89	133
Man Lift	No	20	85	75	23
Mounted Impact Hammer (hoe ram)	Yes	20	90	90	212
Pavement Scarifier	No	20	85	90	2
Paver	No	50	85	77	9
Pickup Truck	No	40	55	75	1
Pneumatic Tools	No	50	85	85	90
Pumps	No	50	77	81	17
Refrigerator Unit	No	100	82	73	3
Rivit Buster/Chipping Gun	Yes	20	85	79	19
Rock Drill	No	20	85	81	3
Roller	No	20	85	80	16
Sand Blasting (single nozzle)	No	20	85	96	9
Scraper	No	40	85	84	12
Sheers (on backhoe)	No	40	85	96	5
Slurry Plant	No	100	78	78	1
Slurry Trenching Machine	No	50	82	80	75
Soil Mix Drill Rig	No	50	80	N/A	0
Tractor	No	40	84	N/A	0
Vacuum Excavator (Vac-Truck)	No	40	85	85	149
Vacuum Street Sweeper	No	10	80	82	19
Ventilation Fan	No	100	85	79	13
Vibrating Hopper	No	50	85	87	1
Vibratory Concrete Mixer	No	20	80	80	1
Vibratory Pile Driver	No	20	95	101	44
Warning Horn	No	5	85	83	12
Welder/Torch	No	40	73	74	5

For each generic type of equipment listed in Table 9.1, the following information is provided:

- an indication as to whether or not the equipment is an impact device;
- the acoustical usage factor to assume for modeling purposes;
- the specification "Spec" limit for each piece of equipment expressed as an L_{max} level in dBA "slow" at a reference distance of 50 foot from the loudest side of the equipment;
- the measured "Actual" emission level at 50 feet for each piece of equipment based on hundreds of emission measurements performed on CA/T work sites; and
- the number of samples that were averaged together to compute the "Actual" emission level.

A comparison of the "Spec" emission limits against the "Actual" emission levels reveals that the Spec limits were set, in general, to realistically obtainable noise levels based on the equipment used by contractors on the CA/T Project. When measured in the field, some equipment such as pile drivers, sand

blasting, demolition shears, and pumps tended to exceed their applicable emission limit. As such, these noisy devices needed to have some form of noise mitigation in place in order to comply with the Spec emission limits. Other equipment, such as clamshell shovels, concrete mixer trucks, truck-mounted drill rigs, man-lifts, chipping guns, ventilation fans, pavers, dump trucks, and flatbed trucks, easily complied. Therefore, the Spec emission limits for these devices could have been reduced somewhat further. It is recommended that the user review the RCNM User's Guide contained in Appendix A for detailed guidance regarding application of values contained in Table 9.1.

9.4.2 FHWA Special Report Inventories

Appendix A of the 1977 Handbook provides tables of construction equipment noise levels and ranges. The majority of the data were provided by the American Road Builders Association. These data were taken during a 1973 survey in which member contractors were asked to secure readings of noise exposure to operators of various types of equipment. Additionally, the contractors were asked to take readings at 50 feet from the machinery. These 50-foot peak readings are provided in Tables 9.2 through 9.8. Though the data were produced under varying conditions and degrees of expertise, the values are relatively consistent.

Table 9.2 Construction Equipment Noise Levels Based on Limited Data Samples - Cranes.

Manufacturer	Type or Model	Peak Noise Level (dBA)	Remarks
Northwestern	80D	77	Within 15m 1958 mod
Northwestern	8	84	Within 15m 1940 mod
Northwestern	6	72	Within 15m 1965 mod
American	7260	82	Within 15m 1967 mod
American	599	76	Within 15m 1969 mod
American	5299	70	Within 15m 1972 mod
American	4210	82	Within 15m 1968 mod
Buck Eye	45C	79	Within 15m 1972 mod
Buck Eye	308	74	Within 15m 1968 mod
Buck Eye	30B	73	Within 15m 1965 mod
Buck Eye	30B	70	Within 15m 1959 mod
Link Belt	LS98	76	Within 15m 1956 mod
Manitowoc	4000	94	Within 15m 1956 mod
Grove	RF59	82	Within 15m 1973 mod
Koehr	605	76	Within 15m 1967 mod
Koehr	435	86	Within 15m 1969 mod
Koehr	405	84	Within 15m 1969 mod

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Table 9.3 Construction Equipment Noise Levels Based on Limited Data Samples - Backhoes.

Manufacturer	Type or Model	Peak Noise Level (dBA)	Remarks
Link Belt	4000	92	Within 15m 1971 mod
John Deere	609A	85	Within 15m 1971 mod
Case	680C	74	Within 15m 1973 mod
Drott	40 yr.	82	Within 15m 1971 mod
Koehr	1066	81 & 84	Within 15m 2 tested

Table 9.4 Construction Equipment Noise Levels Based on Limited Data Samples - Front Loaders.

Manufacturer	Type or Model	Peak Noise Level (dBA)	Remarks
Caterpillar	980	84	Within 15m 1972 mod
Caterpillar	977K	79	Within 15m 1969 mod
Caterpillar	977	87	Within 15m 1971 mod
Caterpillar	977	94	Within 15m 1967 mod
Caterpillar	966C	84	Within 15m 1973 mod
Caterpillar	966C	85	Within 15m 1972 mod
Caterpillar	966	81	Within 15m 1972 mod
Caterpillar	966	77	Within 15m 1972 mod
Caterpillar	966	85	Within 15m 1966 mod
Caterpillar	955L	90	Within 15m ;1973 mod
Caterpillar	955K	79	Within 15m 1969 mod
Caterpillar	955H	94	Within 15m 1963 mod
Caterpillar	950	78 & 80	Within 15m 1972 mod
Caterpillar	950	75	Within 15m 1968 mod
Caterpillar	950	88	Within 15m 1967 mod
Caterpillar	950	86	Within 15m 1965 mod
Caterpillar	944A	80	Within 15m 1965 mod
Caterpillar	850	82	Within 15m 1968 mod
Michigan	75B	90	Within 15m 1969 mod
Michigan	475A	96	Within 15m 1967 mod
Michigan	275	85	Within 15m 1971 mod

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Manufacturer	Type or Model	Peak Noise Level (dBA)	Remarks
Michigan	125	87	Within 15m 1967 mod
Hough	65	82	Within 15m 1971 mod
Hough	60	91	Within 15m 1961 mod
Hough	400B	94	Within 15m 1961 mod
Hough	H90	86	Within 15m 1961 mod
Trojan	3000	85	Within 15m 1956 mod
Trojan	RT	82	Within 15m 1965 mod
Payloader	H50	85	Within 15m 1963 mod

Table 9.5 Construction Equipment Noise Levels Based on Limited Data Samples - Dozers.

Manufacturer	Type or Model	Peak Noise Level (dBA)	Remarks
Caterpillar	D5	83	Within 15m 1967 mod
Caterpillar	D6	85	Within 15m 1967 mod
Caterpillar	D6	86	Within 15m 1964 mod
Caterpillar	D6	81	Within 15m 1967 mod
Caterpillar	D6B	83	Within 15m 1967 mod
Caterpillar	D6C	82	Within 15m 1962 mod
Caterpillar	D7	85	Within 15m 1956 mod
Caterpillar	D7	86	Within 15m 1969 mod
Caterpillar	D7	84	Within 15m 1969 mod
Caterpillar	D7	78	Within 15m 1970 mod
Caterpillar	D7	78	Within 15m 1972 mod
Caterpillar	D7E	86	Within 15m 1965 mod
Caterpillar	D7E	78	Within 15m 1970 mod
Caterpillar	D7E	84	Within 15m 1973 mod
Caterpillar	D7F	80	Within 15m 1972 mod
Caterpillar	D8	92	Within 15m 1954 mod
Caterpillar	D8	95	Within 15m 1968 mod
Caterpillar	D8	86	Within 15m 1972 mod
Caterpillar	D8H	88	Within 15m 1966 mod
Caterpillar	D8H	82	Within 15m 1972 mod

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Manufacturer	Type or Model	Peak Noise Level (dBA)	Remarks
Caterpillar	D9	85	Within 15m 1972 mod
Caterpillar	D9	94	Within 15m 1972 mod
Caterpillar	D9	90	Within 15m 1963 mod
Caterpillar	D9	87	Within 15m 1965 mod
Caterpillar	D9	90	Within 15m 1965 mod
Caterpillar	D9	88	Within 15m 1968 mod
Caterpillar	D9	92	Within 15m 1972 mod
Caterpillar	D9G	85	Within 15m 1965 mod
Allis Chambers	HD41	93	Within 15m 1970 mod
International	TD15	79	Within 15m 1970 mod
International	TD20	87	Within 15m 1970 mod
International	TD25	90	Within 15m 1972 mod
International	TD8	83	Within 15m 1970 mod
Case	1150	82	Within 15m 1972 mod
John Deer	350B	77	Within 15m 1971 mod
John Deer	450B	65	Within 15m 1972 mod
Terex	8230	70	Within 15m 1972 mod
Terex	8240	93	Within 15m 1969 mod
Michigan	280	85	Within 15m 1961 mod
Michigan	280	90	Within 15m 1962 mod
Caterpillar	824	90	Within 15m 1968 mod

Table 9.6 Construction Equipment Noise Levels Based on Limited Data Samples - Graders.

Manufacturer	Type or Model	Peak Noise Level (dBA)	Remarks
Caterpillar	16	91	Within 15m 1969 mod
Caterpillar	16	86	Within 15m 1968 mod
Caterpillar	140	83	Within 15m 1970 mod
Caterpillar	14E	84	Within 15m 1972 mod
Caterpillar	14E	85	Within 15m 1971 mod
Caterpillar	14C	85	Within 15m 1971 mod
Caterpillar	14B	84	Within 15m 1967 mod

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Manufacturer	Type or Model	Peak Noise Level (dBA)	Remarks
Caterpillar	12F	82	Within 15m 1961-72 mod
Caterpillar	12F	72-92	Within 15m 1961-72 mod
Caterpillar	12E	81.3	Within 15m 1959-67 mod
Caterpillar	12E	80-83	Within 15m 1959-67 mod
Caterpillar	12	84.7	Within 15m 1960-67 mod
Caterpillar	12	82-88	Within 15m 1960-67 mod
Gallon	T500	84	Within 15m 1964 mod
Allis Chambers		87	Within 15m 1964 mod

Table 9.7 Construction Equipment Noise Levels Based on Limited Data Samples - Scrapers.

Manufacturer	Type or Model	Peak Noise Level (dBA)	Remarks
Caterpillar	660	92	Within 15m
Caterpillar	641B	85	Within 15m 1972 mod
Caterpillar	641B	86	Within 15m 1972 mod
Caterpillar	641	80 & 84	Within 15m 1972 mod
Caterpillar	641	83 & 89	Within 15m 1965 mod
Caterpillar	637	87	Within 15m 1971 mod
Caterpillar	633	87	Within 15m 1972 mod
Caterpillar	631C	89	Within 15m 1973 mod
Caterpillar	631C	83	Within 15m 1972 mod
Caterpillar	631B	94	Within 15m 1969 mod
Caterpillar	631B	84-87	Within 15m 1968 mod
Caterpillar		85 avg.	Within 15m 1968 mod
Caterpillar	621	90	Within 15m 1970 mod
Caterpillar	621	86	Within 15m 1967 mod
Caterpillar	613	76	Within 15m 1972 mod
Terex	TS24	87	Within 15m 1972 mod
Terex	TS24	84-91	
Terex	TS24	82	Within 15m 1971 mod
Terex	TS24	81-83	Within 15m 1971 mod
Terex	TS24	94	Within 15m 1966 mod

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Manufacturer	Type or Model	Peak Noise Level (dBA)	Remarks
Terex	TS24	92-98	Within 15m 1966 mod
Terex	TS24	94.7	Within 15m 1963 mod
Terex	TS24	94-95	Within 15m 1963 mod
Terex	TS14	82	Within 15m 1969 mod
Terex	S35E	84	Within 15m 1971 mod

Table 9.8 Noise Levels of Standard Compressors.

Manufacturer	Model	Silenced or Standard	Type Eng.	Type Comp.	Test Avg. Cond. (cfm.psi)	Avg. Cond. Noise Lev. (cfm.psi) (dBA) at 7m*
Atlas	ST-48	Standard	Diesel	Reciprocal	160,100	83.6
Atlas	ST-95	Standard	Diesel	Reciprocal	330,105	80.2
Atlas	VSS-170Dd	Silenced	Diesel	Reciprocal	170,850	70.2
Atlas	VT-85M	Standard	Gas	Reciprocal	85,100	81.4
Atlas	VS-85Dd	Silenced	Gas	Reciprocal	85,100	75.5
Atlas	VSS-125Dd	Silenced	Diesel	Reciprocal	125,100	70.1
Atlas	STS-35Dd	Silenced	Diesel	Reciprocal	125,100	73.5
Atlas	VSS-170Dd	Silenced	Diesel	Reciprocal	170,100	
Gardner-Denver	SPWDA/2	Silenced	Diesel	Rotary-Screw	1200,000	73.3
Gardner-Denver	SPQDA/2	Silenced	Diesel	Rotary-Screw	750,000	78.2
Gardner-Denver	SPHGC	Silenced	Gas	Rotary-Screw	185,000	77.1
Ingersoll-Rand	DXL 1200	Standard	Diesel	Rotary-Screw	1200,125	92.6
Ingersoll-Rand	DXL 1200 (doors open)	Standard	Diesel	Rotary-Screw	1200,125	
Ingersoll-Rand	DXL 900S	Silenced	Diesel	Rotary-Screw	900,125	76.0
Ingersoll-Rand	DXL 900S	Silenced	Diesel	Rotary-Screw	900,125	75.1
Ingersoll-Rand	DXLCU1050	Standard	Diesel	Rotary-Screw	1050,125	90.2
Ingersoll-Rand	DXL 900S	Silenced	Diesel	Rotary-Screw	900,125	75.3
Ingersoll-Rand	DXL 900S	Silenced	Diesel	Rotary-Screw	900,125	75.0
Ingersoll-Rand	DXL 900	Standard	Diesel	Rotary-Screw	900,125	89.9
Ingersoll-Rand	DXL 750	Standard	Diesel	Rotary-Screw	750,125	87.7
Jaeger	A	Standard	Gas	Rotary-Screw	175,100	88.2
Jaeger	A(doors	Standard	Gas	Rotary-	175,100	

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Manufacturer	Model	Silenced or Standard	Type Eng.	Type Comp.	Test Avg. Cond. (cfm.psi)	Avg. Cond. Noise Lev. (cfm.psi) (dBA) at 7m*
	open)			Screw		
Jaeger	E	Standard	Gas	Vane	85,100	81.5
Jaeger	E(doors open)	Standard	Gas	Vane	85,100	
Worthington	60 G/2Qt	Silenced	Gas	Vane	160,100	74.2
Worthington	750-QTEX	Silenced	Diesel	Rotary-Screw	750,100	74.7

*Data taken from EPA Report - EPA 550/9-76-004.

9.4.3 FTA Noise and Vibration Assessment Procedure

Chapter 12 of the FTA Transit Noise and Vibration Guidance Handbook discusses construction noise evaluation methodology and contains the noise emission levels for construction equipment displayed in Table 9.9.

Table 9.9 FTA Construction Equipment Noise Emission Levels.

Equipment	Typical Noise Level (dBA) 50 ft from Source*
Air Compressor	81
Backhoe	80
Ballast Equalizer	82
Ballast Tamper	83
Compactor	82
Concrete Mixer	85
Concrete Pump	82
Concrete Vibrator	76
Crane Derrick	88
Crane Mobile	83
Dozer	85
Generator	81
Grader	85
Impact Wrench	85
Jack Hammer	88
Loader	85
Paver	89
Pile Driver (Impact)	101
Pile Driver (Sonic)	96
Pneumatic Tool	85
Pump	76
Rail Saw	90
Rock Drill	98
Roller	74
Saw	76
Scarifier	83
Scraper	89
Shovel	82
Spike Driver	77
Tie Cutter	84

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Equipment	Typical Noise Level (dBA) 50 ft from Source*
Tie Handler	80
Tie Inserter	85
Truck	88

*Table based on EPA Report, measured data from railroad construction equipment taken during Northeast Corridor improvement project and other measured data.

9.5 Links to Equipment Manufacturers

Table 9.10 contains web-based links to manufacturers of construction equipment. While few of these links contain noise-related data associated with the equipment, they provide descriptions and/or specifications related to the equipment, as well as sources for possibly obtaining additional information related to the equipment. Information in this table is by no means all-inclusive and does not represent any type of endorsement of the manufacturers, suppliers, or equipment. Users are hereby advised that the referenced websites may have certain restrictions, copyrights, etc., associated with any use of data contained therein.

Table 9.10 Equipment Manufacturers and Websites.

Equipment	Manufacturer	Website Address
Arrow Boards		
	North Star	http://northstar-traffic.com/index.cfm?SC=14&PT=1
	Trafcom	http://www.trafcon.com
	Allmand	http://www.allmand.com/MB%20AB%20page.htm
Articulated Trucks		
	Case	http://www.casece.com/products/products.asp?RL=NAE&id=196
	Hitachi	http://www.hitachi-c-m.com/global/products/articulate/index.html
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=182b2104d7a1ce2c68b57b49f8c1436c&nav=prod#nb_0fb692066603522ee229a7ff28293d18
	Caterpillar	http://www.cat.com/cda/layout?m=37840&x=7
	Volvo	http://www.volvo.com/constructionequipment/na/en-us/products/articulatedhaulers/
Asphalt Saws		
	Allied	http://www.alliedcp.com/products/rotocut.asp
Augers – See Drills / Augers		
Backhoes – See Loaders/Backhoes		
Boring Equipment – See Pile Drivers/Boring Equipment		
Compaction Equipment		
	Allied	http://www.alliedcp.com/products/compactor.asp
Compressors		

Equipment	Manufacturer	Website Address
	Sullair	http://www.sullair.com/corp/details/0,10294,CLI1_DIV61_ETI5714,00.html
	Compair	http://www.compair.com/Products/Portable_Compressors.aspx
Concrete and Asphalt Batch/Mixing Plants and Equipment		
	Con-E-Co	http://www.con-e-co.com/products.cfm
	Terex	http://www.terex.com/main.php?obj=prod&action=VIEW&id=a253f234f9c3bd69195320d1fe6e1cd9&nav=prod&cid=7713bf85ccb5a97458457e944ca4ed76
	Gunter &	http://www.guntert.com/concrete_mobilebatching.asp
	Rex Con	http://www.rexcon.com/products.html
Concrete Breakers/ Hydraulic Hammers/Hydraulic Breakers		
	Drillman	http://www.drillmanindia.com/concrete-breaker.html
	Hydro Khan	http:/www.sangi.co.kr/english/e_product1_2.php
	Stanley	http://www.stanley-hydraulic-tools.com/Hand%20Held/NoAmbreakers.htm
	Lynx	http://www.stanley-hydraulic-tools.com/Lynx/breakers.htm
Concrete Chain Saws		
	Lynx	http://www.stanley-hydraulic-tools.com/Lynx/concrete-saws.htm
Concrete Core Drilling Machines		
	Multiquip	http://www.multiquip.com/multiquip/318_ENU_HTML.htm
Concrete Cutters		
	Vermeer	http://www.vermeermfg.com/vcom/TrenchingEquipment/Line.jsp?PrdlnID=3618
Concrete/Material Pumps		
	Multiquip	http://www.multiquip.com/multiquip/309_ENU_HTML.htm
	Reed	http://www.reedpumps.com/
Concrete Mixer Trucks		
	Oshkosh	http://www.oshkoshtruck.com/concrete/products~overview~home.cfm
	London	http://www.lmi.ca/mixers.cfm
	Terex/Advance	http://www.advancemixer.com/trucks.asp
Concrete Saws		
	Multiquip	http://www.multiquip.com/multiquip/315_ENU_HTML.htm
	Diamond Core Cut	http://www.diamondproducts.com/dp_home.htm
Concrete Screeds		
	Multiquip	http://www.multiquip.com/multiquip/317_ENU_HTML.htm

Equipment	Manufacturer	Website Address
Concrete Vibrators		
	Multiquip	http://www.multiquip.com/multiquip/313_ENU_HTML.htm
	Sullair	http://www.sullair.com/corp/details/0,10294,CLI1_DIV61_ETI5722,00.html
Cranes		
	Malcolm Drilling	www.malcolmdrilling.com
	Link-Belt	http://www.linkbelt.com/lit/products/frameproducthome.htm
	Casagrande	http://www.casagrandegroup.com/home_fond.php
	Liebherr	http://www.liebherr.com/em/en/35381.asp
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=487c16c8ff145d0843f57512eafb8592&nav=prod
Crawler Tractors – See Dozers/Crawler Tractors		
Crushing and Screening Equipment		
	Cedarapids	http://www.cedarapids.com/crushscr.htm
	Hitachi	http://www.hitachi-c-m.com/global/products/crusher/index.html
	Komatsu	http://www.komatsu.com/ce/products/mobile_crushers.html
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=e75ed9c85681b27ffcfe5cadbd68c04e&nav=prod
Crushers/Pulverizers		
	Hydro Khan	http://www.sangi.co.kr/english/e_product3.php
Cutoff Saws		
	Multiquip	http://www.multiquip.com/multiquip/309_ENU_HTML.htm
	Lynx	http://www.stanley-hydraulic-tools.com/Lynx/cutoff%20saw.htm
Dozers/CrawlerTractors		
	John Deere	http://www.deere.com/en_US/cfd/construction/deere_const/crawlers/deere_dozer_selection.html
	Caterpillar	http://www.cat.com/cda/layout?m=37840&x=7
	Case	http://www.casece.com/products/products.asp?RL=NAE&id=2
	Komatsu	http://www.komatsu.com/ce/products/crawler_dozers.html
Dewatering Pumps		
	Multiquip	http://www.multiquip.com/multiquip/371_ENU_HTML.htm
Drills / Augers		
	Malcolm Drilling	www.malcolmdrilling.com
	Casagrande	www.casagrandegroup.com/home_fond.php
	Soilmec	http://www.soilmec.com/_vti_g1_techno.aspx?rpstry=4_

Equipment	Manufacturer	Website Address
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=702f2c2ab1d75e021729f249258879f4&nav=prod#nb_cd8eeb0c300ecd6c7df8a7462718172d
Excavators		
	Hitachi	http://www.hitachi-c-m.com/global/products/excavator/index.html
	Caterpiller	http://www.cat.com/cda/layout?m=37840&x=7
	Volvo	http://www.volvo.com/constructionequipment/na/en-us/products/compactexcavators/
		http://www.volvo.com/constructionequipment/na/en-us/products/wheeledexcavators/
		http://www.volvo.com/constructionequipment/na/en-us/products/crawlerexcavators/
	John Deere	http://www.deere.com/en_US/cfd/construction/deere_const/excavators/deere_excavator_selection.html
	Liebherr	http://www.liebherr.com/em/en/18891.asp
	Soilmec	http://www.soilmec.com/_vti_g1_t02.aspx?rpstry=29_
	Gehl	http://www.gehl.com/const/prod_sl.html
	Case	http://www.casece.com/products/products.asp?RL=NAE&id=216
	Komatsu	http://www.komatsu.com/ce/products/crawler_excavators.html
		http://www.komatsu.com/ce/products/wheel_excavators.html
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=477c69a0ac11ed40efe034eb1420b8c6&nav=prod
	Link-Belt	http://www.lbxco.com/lx_series.asp
	Gradall	http://www.gradall.com/
	Badger Daylighting	http://www.badgerinc.com/
Fork Lifts – See Lifts / Variable Reach Fork Lifts/ Material Handlers		
Generators		
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=6cde2dee72c250aafbd68c5b8c8d028b&nav=prod
	Multiquip	http://www.multiquip.com/multiquip/212_ENU_HTML.htm
	Sullair	http://www.sullair.com/corp/details/0,10294,CLI1_DIV61_ETI5714,00.html
	Baldor	http://www.baldor.com/products/generators/ts.asp
Graders		
	Case	http://www.casece.com/products/products.asp?RL=NAE&id=190
	Volvo	http://www.volvo.com/constructionequipment/na/en-us/products/MotorGraders/

Equipment	Manufacturer	Website Address
	Komatsu	http://www.komatsu.com/ce/products/motor_graders.html
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=b71fa964f478a2243ebbbbafa04bf814&nav=prod
Hand Compaction Equipment		
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=4c93fdc86b1c7733c1564fc8c41ee691&nav=prod#nb_cbcf35494fa399b7350f8edf5bc27373
	Multiquip	http://www.multiquip.com/multiquip/56_ENU_HTML.htm
Hydraulic Hammers/Hydraulic Breakers – See Concrete Breakers/ Hydraulic Hammers/Hydraulic Breakers		
Jackhammers – See Rock Drilling Equipment/Jackhammers		
Lifts / Variable Reach Fork Lifts/ Material Handlers		
	Genie Lift	www.genielift.com
	Sky Track	www.kirby-smith.com/
	Ingersol-Rand	www.ingersollrand.com
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=6d18d9a15fdb6da73f44a893c21c0fb4&nav=prod
	Roadtec	http://www.roadtec.com/products/mtv/default.htm
Light Towers		
	Baldor	http://www.baldor.com/products/generators/mlt.asp
	Multiquip	http://www.multiquip.com/multiquip/293_ENU_HTML.htm
	Allmand	http://www.allmand.com/Night%20Lite%20Pro%20page.htm
Loaders/Backhoes		
	Case	http://www.casece.com/products/products.asp?RL=NAE&id=54
	Caterpillar	http://www.cat.com/cda/layout?m=37840&x=7
	Volvo	http://www.volvo.com/constructionequipment/na/en-us/products/backhoeloaders/
	John Deere	http://www.deere.com/en_US/cfd/construction/deere_const/backhoes/deere_backhoe_selection.html
	Komatsu	http://www.komatsu.com/ce/products/backhoe_loaders.html
Material Handlers – See Lifts / Variable Reach Fork Lifts/ Material Handlers		
Milling Machines		
	Wirtgen	https://www.wirtgenamerica.com/noflash.html
Mining Trucks – See Rigid Dump Trucks/Mining Trucks		
Pans – See Scrapers/Pans		
Pavers/Paving Equipment		

Equipment	Manufacturer	Website Address
	Caterpillar/ Barber Greene	http://www.cat.com/cda/layout?m=37840&x=7
	Rosco	http://www.leeboy.com/rosco/
	Bomag	http://www.bomag.com/americas/index.aspx?&Lang=478
	Gehl	http://www.gehl.com/const/prodpg_ap.html
	Leeboy	http://www.leeboy.com/leeboy/
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=7713bf85ccb5a97458457e944ca4ed76&nav=prod#nb_70af03a93dfc933f83a7e6afdc2dc833
	Ingersoll-Rand	http://www.road-development.irco.com/Default.aspx?MenuItemID=12
	Vogele	http://www.vogeleamerica.com/noflash.html
	GOMACO	http://www.gomaco.com/index.html
	Roadtec	http://www.roadtec.com/products/asphalt_pavers/default.htm
Pile Drivers/Boring Equipment		
	Soilmec	http://www.soilmec.com/_vti_g1_t09.aspx?rpstry=29_
	Leffer	http://www.leffer.com/hme.html
	Bauer	http://www.bauer.de/en/maschinenbau/produkte/drehbohrgeraete/bg_reihe/usbg15h.htm
Pipelayers/Trenchers		
	Liebherr	http://www.liebherr.com/em/en/18908.asp
	Caterpillar	http://www.cat.com/cda/layout?m=37840&x=7
	Case	http://www.casece.com/products/products.asp?RL=NAE&id=28&archived=1
	Vermeer	http://www.vermeermfg.com/vcom/TrenchingEquipment/trenching-equipment.htm
	Ditchwitch	http://www.ditchwitch.com/dwcom/Product/ProductView/115
	Eagle	http://www.guntert.com/trenchers_home.asp
Profilers – See Roadway Planers/Profilers		
Rammers		
	Multiquip	http://www.multiquip.com/multiquip/56_ENU_HTML.htm
Rebar Benders/Cutters		
	Multiquip	http://www.multiquip.com/multiquip/1316_ENU_HTML.htm
Recyclers – See Stabilizers/Recyclers		
Rigid Dump Trucks/Mining Trucks		
	Hitachi	http://www.hitachi-c-m.com/global/products/rigid/index.html
	Caterpillar	http://www.cat.com/cda/layout?m=37840&x=7
	Liebherr	http://www.liebherr.com/em/en/18898.asp
	Komatsu	http://www.komatsu.com/ce/products/dump_trucks.html

Equipment	Manufacturer	Website Address
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=182b2104d7a1ce2c68b57b49f8c1436c&nav=prod#nb_d97e204d5e73962e595735d68fad8ae3
Roadway Planers/Profilers		
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=7713bf85ccb5a97458457e944ca4ed76&nav=prod#nb_c9b8a083c7d9ebb936cd1e4f642eba59
	Roadtec	http://www.roadtec.com/products/cold_planers/default.htm
Rock Drilling Equipment/Jackhammers		
	Drillman	http://www.drillmanindia.com/rock-drilling-machine.html
	Whaker	http://www.wackergroup.com/webapp/wcs/stores/servlet/ViewAllModels?storeId=10051&prodgrpId=10070&langId=-1
	Sullair	http://www.sullair.com/corp/details/0,10294,CLI1_DIV61_ETI5721,00.html
	Allied	http://www.alliedcp.com/products/hammers.asp
Rollers – See Tampers/Rollers		
Scrapers/Pans		
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=e3959eefdc65adcc4e0e616b833694b1&nav=prod
Screening Equipment – See Crushing and Screening Equipment		
Slabbuster		
	Allied	http://www.alliedcp.com/products/slabbuster.asp
Slip Form Pavers		
	Huron	http://www.huronmanufacturing.com/
	Guntert & Zimmerman	http://www.guntert.com/concreteSlipformPavers.asp
Stabilizers/Recyclers		
	Bomag	http://www.bomag.com/americas/index.aspx?&Lang=478
	Komatsu	http://www.komatsu.com/ce/products/mobile_crushers.html
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=7713bf85ccb5a97458457e944ca4ed76&nav=prod#nb_d920dd8094cc1af5cb5d82359f8f227b
	Wirtgen	https://www.wirtgenamerica.com/noflash.html
	Roadtec	http://www.roadtec.com/products/cir/default.htm
Sweepers		
	Elgin	http://www.elginsweeper.com/index.asp
	Johnston	http://www.johnstonsweepers.com/
Tampers/ Rollers		

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Equipment	Manufacturer	Website Address
	Bomag	http://www.bomag.com/americas/index.aspx?&Lang=478
	Komatsu	http://www.komatsu.com/ce/products/vibratory_rollers.html
	Whaker	http://www.wackergroup.com/webapp/wcs/stores/servlet/ViewAllModels?storeId=10051&prodgrpId=10070&langId=-1
	Lynx	http://www.stanley-hydraulic-tools.com/Lynx/tamper.htm
	Multiquip	http://www.multiquip.com/multiquip/181_ENU_HTML.htm
	Ingersoll-Rand	http://www.road-development.irco.com/Default.aspx?MenuItemID=15
Trenchers – See Pipelayers/Trenchers		
Trucks – See Articulated Trucks, Concrete Mixer Trucks, Rigid Dump Trucks/Mining Trucks		
Vacuum Units		
	Advanced Recycling Systems	www.arsrecycling.com/
	Vacmasters	http://www.vacmasters.com/airsystm.htm
	Vector	http://www.vector-vacuums.com/
Variable Message Signs		
	Allmand	http://www.allmand.com/MB%20only%20page.htm
	North Star	http://northstar-traffic.com/index.cfm?SC=13&PT=1
	Trafcom	http://www.trafcon.com
	Daktronics	http://www.daktronics.com/vms_prod/dak_vms_products.cfm
Vibratory Rammers		
	Whaker	http://www.wackergroup.com/webapp/wcs/stores/servlet/ViewAllModels?storeId=10051&prodgrpId=10070&langId=-1
Welders/Welding Equipment		
	Airgas	www.airgas.com
	Multiquip	http://www.multiquip.com/multiquip/408_ENU_HTML.htm
	Miller	http://www.millerwelds.com/products/
	Lincoln	http://www.mylincolnelectric.com/Catalog/equipmentseries.asp?browse=101|400|
Wheel Loaders		
	Hitachi	http://www.hitachi-c-m.com/global/products/loader/index.html
	Case	http://www.casece.com/products/products.asp?RL=NAE&id=30
	Caterpillar	http://www.cat.com/cda/layout?m=37840&x=7
	Volvo	http://www.volvo.com/constructionequipment/na/en-us/products/wheelloaders/
	Terex	http://www.terex.com/main.php?obj=category&action=BROWSE&cid=ad8a2ae2f52f113b6d143bfd7765b165&nav=prod

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Equipment	Manufacturer	Website Address
	Komatsu	http://www.komatsu.com/ce/products/wheel_loaders.html
	TCM	http://www.tcmglobal.net/products/main02.html

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Ms. #306

Construction Noise: Exposure, Effects, and the Potential for Remediation; A Review and Analysis

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More than one-half million construction workers are exposed to potentially hazardous levels of noise, yet federal and state Occupational Safety and Health Administration (OSHA) programs provide little incentive to protect them against noise-induced hearing loss. Construction noise regulations lack the specificity of general industry noise regulations. In addition, problems that characterize the construction industry, such as worker mobility and the large proportion of small businesses, make implementing hearing conservation measures more difficult. The apparent severity of exposure depends greatly on the measurement method, with the 3-dB exchange rate almost always showing higher average exposure levels than the 5-dB (OSHA) rule. Construction workers demonstrate hearing threshold levels that generally conform to those expected in manufacturing. The prevalence of hearing protection device (HPD) use among U.S. construction workers is very poor, partly because of perceived difficulties in hearing and understanding speech communication and warning signals. In addition, masking by noise of necessary communication and warning signals is of particular concern in construction, where recent research demonstrated the association between fatalities and the failure to hear reverse alarms. Judicial use of HPDs is of the utmost importance, along with avoiding overattenuation, selecting HPDs with uniform attenuation, and using noise-attenuating communication systems when possible. A successful hearing conservation program in British Columbia can serve as a model for the United States, with a long-standing positive safety culture, a high percentage of HPD use, improvement in average hearing threshold levels over the last decade, and a centralized record-keeping procedure, which helps solve the problem of worker mobility. However, controlling construction noise at the source is the most reliable way to protect worker hearing. U.S. manufacturers and contractors should benefit from the activities of the European Community, where noise control and product labeling in construction has been carried out for more than 20 years.

Keywords: construction workers, hearing conservation, noise exposure

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The fact that U.S. construction workers are exposed to hazardous levels of noise and sustain significant hearing impairments is not news. That these impairments are at least as great as would be expected from an industrial population became evident during the 1960s and 1970s.[1,2] Estimated numbers of construction workers exposed to potentially hazardous levels of noise range from about half a million to 750,000.[3,4] In 1988 the National Institute for Occupational Safety and Health (NIOSH) recommended that the Occupational Safety and Health Administration's (OSHA's) noise regulation, including the hearing conservation provisions, be extended to construction workers as well as to other occupations not then covered.[5] A 1995 conference jointly sponsored by NIOSH and the National

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TABLE I. Construction Employment Data (1995) and NIOSH Estimates (1981–1983) of Numbers Exposed at or Above 85 dBA (Adapted from Hattis[4])

SIC	Industry Description	1995 1000s Employees	NIOSH % Exposed >85 dBA[A,B]
152	Residential builders	609	12
154	Nonresidential builders	567	12
161	Highway and street construction	223	27
162	Other heavy construction	526	17
171	Plumbing, heating, and air conditioning	712	7
172	Painting and paper hanging	179	20
173	Electrical work	593	13
174	Masonry, stonework, and plastering	409	8
175	Carpentry and floor laying	219	32
176	Roofing, siding, and sheet metal	208	11
177	Concrete work	248	40
179	Miscellaneous special trade contractors	548	14
Total (in 1000s)		5041	

[A]Percentages were rounded to the nearest integer.
[B]Total number exposed >85 = 754,174.[4]

Hearing Conservation Association identified construction workers as an "underserved" population.[6]

In the United States there are separate noise regulations for construction (29 CFR 1926.52 and 1926.101) and general industry (29 CFR 1910.95). The permissible exposure limits (PEL) and requirements for noise control are essentially the same, an 8-hour time-weighted average exposure level (TWA) of 90 dBA with a 5-dB exchange rate between allowable duration and noise level. Engineering or administrative controls are required to be implemented above this level, and hearing protection devices (HPDs) must be issued and worn when exposures exceed the PEL. Both regulations require hearing conservation programs (HCPs) for overexposed workers, but there are two essential differences: (1) the noise regulation for general industry requires the initiation of HCPs at an action level of 85 dBA, whereas the construction regulation does not use an action level; and (2) the general industry regulation gives detailed requirements for noise exposure monitoring, audiometric testing, (HPDs), worker training and education, and record keeping, whereas the construction regulation (1926.52) has only a general requirement for "continuing effective hearing conservation programs" above the PEL. Construction regulation 1926.101 merely mandates the use of hearing protection above the PEL and requires insert devices to be fitted or determined individually by "competent persons."

Current enforcement of these noise regulations is not rigorous, particularly in construction. Neither the noise reduction nor the hearing conservation provisions are well enforced in construction. For example, of more than 18,000 federal construction inspections during fiscal year 1998, only 63 inspections were conducted for the noise regulations, resulting in a total of 79 citations.[7] Lack of enforcement characterizes state as well as federal programs. Even those states that have adopted the general industry noise regulation for construction, such as the state of Washington, have failed to enforce the hearing conservation provisions.

Part of the problem has been a perceived lack of information about the noise exposures of construction workers, although several studies have been conducted over recent decades in the United States and Canada. A more salient reason for the lack of activity in this area is the impracticality of the usual approaches to HCPs in the construction arena. Mobility among construction workers, short periods of employment, and the consequent difficulty in record keeping and follow-up present daunting obstacles. This report attempts to address these issues and offer possible solutions.

NOISE EXPOSURE LEVELS OF CONSTRUCTION WORKERS

Evidence of Overexposure

Several studies conducted in the 1960s and 1970s indicated that construction workers were overexposed. In the early 1980s NIOSH estimated the numbers of workers in various occupations, including construction, exposed to noise levels above 85 dBA.[8] Table I gives the estimated percentage of workers in various construction trades exposed to noise levels above 85 dBA. Although the percentages were derived in the early 1980s, the data on numbers of employees in the various trades has been updated to 1995.[4]

The highest percentages of overexposed workers occur in highway and street construction, carpentry, and concrete work. Of the approximately 5 million construction workers in 1995, the total number exposed to noise levels of 85 dBA and above was about 754,000. Because NIOSH sampled noise levels rather than exposures, these are not TWAs, and the actual numbers would be somewhat lower when using TWA, but these numbers are useful for ranking the extent of the hazard by trade and to estimate the upper bound of the total number exposed.

Studies of Noise Exposure in Construction Workers

Recent studies have supplemented the earlier ones with noise dosimetry, providing a more precise and comprehensive picture of construction workers' exposures. Table II, containing information from Sinclair and Haflidson,[9] shows average daily noise exposures of construction workers by type of construction. The authors obtained samples of up to 5 hours in 27 construction projects during 1991–1992, which, due to the repetitive nature of the work, they considered representative of a full shift. They measured according to the proposed Ontario Noise Regulation, which specifies a 3-dB exchange rate.[10] TWA sound levels using the 3-dB exchange rate

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TABLE II. Average Noise Exposure Levels (Daily L_{eq}) by Type of Construction (Adapted from Sinclair and Haflidson[9])

Type of Construction	Number Samples	Average dBA[A]	Range dBA[A]
Residential	7	93	87–96
Roads/bridges	16	93	84–100
Shop work[B]	26	95	85–104
Maintenance	2	95	91–97
ICI[C]	23	96	81–108
Sewer/water	17	99	85–108
Plant work[D]	6	101	87–106
Power station	6	108	93–113
Total	103	99	81–113

[A]Rounded to the nearest integer
[B]Shop work = work in a contractor's fabrication shop.
[C]ICI = industrial, commercial, or institutional.
[D]Plant work = work in a construction contractor's plant.

are sometimes referred to as "equivalent continuous sound levels" or L_{eq}. Of the 103 workers sampled, the average noise exposure level was approximately 99 dBA.

Table III, also from data gathered by Sinclair and Haflidson,[9] shows daily average noise exposure levels by trade, activity, or equipment. The authors caution that in many cases the samples are too small to state definitively which sectors of construction have the greatest risk, but, in their words, "the magnitude of the problem is obvious."[p. 459] From Table III it is clear that boilermakers and iron workers, at least those studied here, are heavily exposed, with average exposure levels of 108 and 105 dBA, respectively. The authors concluded that pneumatic tools were largely responsible.

In another Canadian study, Legris and Poulin[11] reported on the noise exposure of heavy equipment operators and laborers. The data were collected in Quebec in the late 1980s and the measurements used a 5-dB exchange rate. The average duration of the work shift was 9.5 hours with a range of 8–12 hours, and the data were normalized to an 8-hour shift. Of the 250 samples taken, 65 were from laborers and 185 from heavy equipment operators.

TABLE III. Average Noise Exposure Levels (Daily L_{eq}) by Trade, Activity, or Equipment (Adapted from Sinclair and Haflidson[9])

Trade, Activity, or Equipment	Number of Samples	Average dBA[A]	Range dBA[A]
Install rebar	2	89	88–90
Carpenter	3	90	82–94
Mason	14	91	84–97
Framer	7	93	87–96
Sprinkler	6	94	86–97
Forming	5	94	87–97
Refractory	2	95	91–97
Sheet metal	17	96	85–104
Ironworker	2	105	98–108
Boilermaker	6	108	93–113
Paver	6	90	84–92
Front-end loader	2	90	87–92
Scraper	5	90	88–91
Curb machine	3	93	86–96
Roller	2	98	93–100
Crane	3	99	95–102
Dozer	6	102	85–108
Heavy equipment	4	90	86–94
Gravel plant	4	102	88–106
Other	4	88	81–90
Total	103	99	81–113

[A]Rounded to the nearest integer

TABLE IV. Average Daily Noise Exposure Levels (8-Hour TWA) of Heavy Equipment Operators and Associated Laborers in dBA (Adapted from Legris and Poulin[11])

Operator or Task	Mean TWA	SD	Range
Heavy-duty bulldozer	99	5	91–107
Vibrating road roller	97	4	91–104
Light-duty bulldozer	96	2	93–101
Asphalt road roller	95	4	85–103
Wheel loader	94	4	87–100
Asphalt spreader	91	3	87–97
Light-duty grader	89	1	88–91
Power shovel	88	3	80–93
Laborers	90	6	78–107
Crawler crane >35 ton			
Noninsulated cab	97	2	93–101
Crawler crane <35 ton			
Noninsulated cab	94	3	90–98
Insulated cab	84	3	80–89
Rubber tired cane >35 ton			
Noninsulated cab	84	5	78–90
Insulated cab	74	9	59–87
Rubber tired crane <35 ton			
Insulated cab	81	4	77–87
Truck-mounted crane	79	2	76–83
Tower crane	74	2	70–76

Table IV gives 8-hour average noise exposure levels for heavy equipment operators and laborers according to Legris and Poulin. The authors explained the variations in exposures by such factors as the location and type of muffler, amount of time the equipment was idling or under load, the power rating of the engine, and the nature of the task. Of particular importance were the presence or absence of an insulated cab and the design of the equipment. Note the 10-dB difference between insulated and noninsulated cabs and the 13-dB difference between crawler and rubber-tired cranes weighing more than 35 tons with noninsulated cabs.

The results of another, smaller study of operating engineers and laborers are in general agreement with those of Legris and Poulin. Greenspan et al.[12] found 8-hour TWAs ranging from about 68 to 103 dBA, with a mean TWA of 89 dBA, although five of the eight samples were above 90 dBA. The study should not be considered conclusive because of the small sample size (N=8) and the wide range of exposures, but it gives a clear example of the benefits of noise reduction in machinery design. The 68-dBA exposure was achieved in a Caterpillar 980 front-end loader with an enclosed, sound insulated cab.

Data from the Worker Compensation Board of British Columbia[13] are also in general agreement with the above data, although such factors as occupations, sample sizes, and the exchange rate vary from study to study.

Several factors make it difficult to draw comparisons between these kinds of studies. First, the exchange rate has an effect, with the 3-dB exchange rate almost always producing higher exposure levels than the 5-dB exchange rate. Second, the length of the work shift, of course, increases the exposure level; and third, the amount of time each worker spends on each piece of equipment also has an effect.

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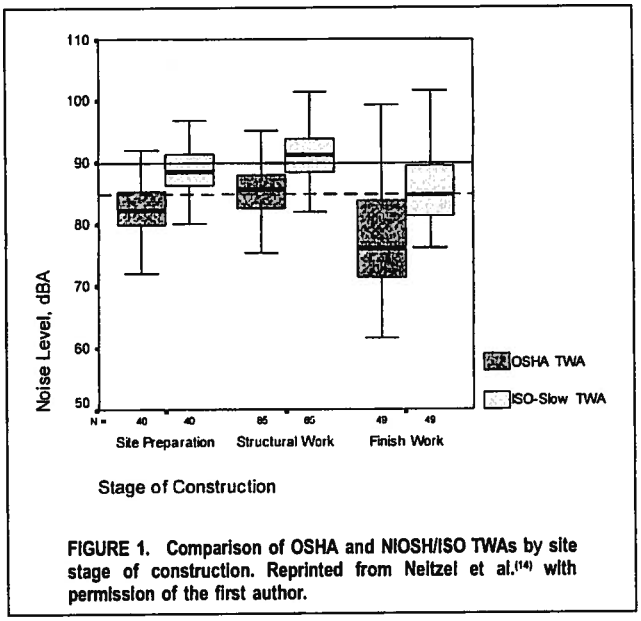

FIGURE 1. Comparison of OSHA and NIOSH/ISO TWAs by site stage of construction. Reprinted from Neitzel et al.[14] with permission of the first author.

Effect of the Exchange Rate

Varying and intermittent noise environments are typical of the construction industry, unlike many manufacturing industries in which the noise is relatively continuous. Much of the construction process takes place outdoors, without the reverberant buildup typical of factories, and it is often characterized by the high-level short-duration sounds of hand tools. When noise from heavy equipment predominates, however, the sound tends to be more continuous. Thus, the differences between measurements using the 3- and the 5-dB exchange rate become more pronounced as the type of construction moves from site preparation, which involves much use of heavy equipment, to finishing work involving carpentry and the use of hand tools.

Neitzel, Seixas, and their colleagues at the University of Washington measured the noise exposure levels of 133 carpenters, laborers, ironworkers, and operating engineers with data-logging dosimeters.[14,15] They found that using the 5-dB exchange rate ("OSHA TWA"), 13% of their samples exceeded the 90-dBA criterion and 40% exceeded the 85-dBA criterion. Using the 3-dB exchange rate ("ISO-slow TWA"), 45% exceeded the 90-dBA criterion and 80% exceeded the 85-dBA criterion. These large differences, according to stage of construction, are presented graphically in Figure 1.[14] The boxes represent the range of noise exposure between the 25th and 75th centiles, the brackets show the entire range of exposures, and the horizontal lines within the boxes represent medians. One can see that the differences are larger in finish work than in site preparation and structural work. The authors found the differences to be statistically significant for both finish work and structural work, although not for site preparation.

Figure 2, also from Neitzel et al., compares noise exposure levels using the 3- and 5-dB exchange rates by construction trade. The differences are smallest for the operating engineers and greatest for carpenters, but they are also substantial for ironworkers and laborers. In this case all of the differences were significant at the 0.05 level. The authors found an overall difference between the 3- and 5-dB exchange rates of about 7 dB.

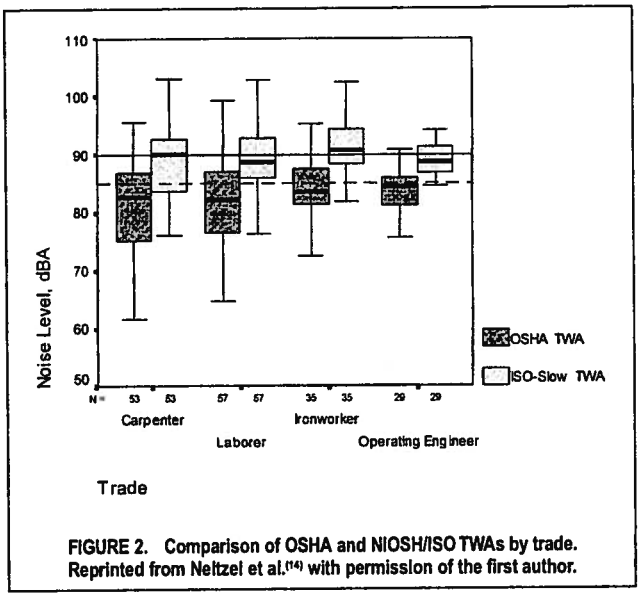

FIGURE 2. Comparison of OSHA and NIOSH/ISO TWAs by trade. Reprinted from Neitzel et al.[14] with permission of the first author.

TABLE V. Median 1-Min Sound Levels in L_{eq} by Equipment/Tool (Adapted from Neitzel et al.[14] Using Additional Data Supplied by Neitzel[16])

Tool Name	Tool Drive Type	Minutes	Median dBA	SD dBA	Range dBA
Air compressor	pneumatic	255	96	11.2	70–114
Backhoe	gasoline	1908	86	6.0	70–108
Bulldozer	gasoline	494	89	8.2	70–104
Chipping gun	pneumatic	1151	93	13.1	70–120
Chopsaw	electric	631	80	8.6	70–106
Crane	electric	3059	78	7.7	70–110
Forklift	gasoline	3727	85	5.8	62–125
Hand hammer	mechanical	4443	85	8.0	56–110
Jackhammer	pneumatic	267	104	11.4	70–112
Lejeune gun	pneumatic	390	89	8.4	70–120
Truck	gasoline	970	78	8.0	70–123
Welding torch	other	1923	84	8.9	70–118

Relative Hazard of Construction Equipment

Because construction workers often use several different pieces of equipment, Neitzel and Seixas developed a method by which the average noise contribution of the various tools and equipment could be assessed. Table V gives "1-min sound levels" of construction equipment. This term represents an average of the 1-min dosimeter readings in L_{eq} (3-dB exchange rate) that came from periods when workers reported using a particular piece of equipment. For example, there was a total of 255 min during which workers reported using an air compressor, and the median sound level, integrated during each 1-min period, was 96 dBA, with a range of 70 to 114 dBA and a standard deviation of 11.2 dBA. The large standard deviations for most pieces of equipment reflect the variations of sound levels and conditions of use.

These 1-min average noise levels do not represent noise doses or 8-hour time-weighted exposures, but they do provide a means for estimating the relative hazard of the various pieces of equipment. The reason they may be somewhat lower than measurements taken with a sound level meter is that they tend to incorporate some amount of time when the equipment is either idling or actually turned off. Although it would be useful to have data on additional types of equipment, as well as various models of the

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TABLE VI. Job Specialties Showing Incidence of Hearing Loss (Adapted from Ohlin[25])

Job Title	No. Audiograms In Specialty	No. with Hearing Loss[A]	Percentage with Hearing Loss[A]
Crane operator	116	38	33
Welder	602	176	29
Carpenter	811	214	26
Engineering equipment operator	340	84	24
Wood worker	258	61	24
Motor vehicle operator	983	185	19
Electrician	495	92	19

[A]HTLs greater than an average of 25 dB at 1000, 2000, and 3000 Hz.

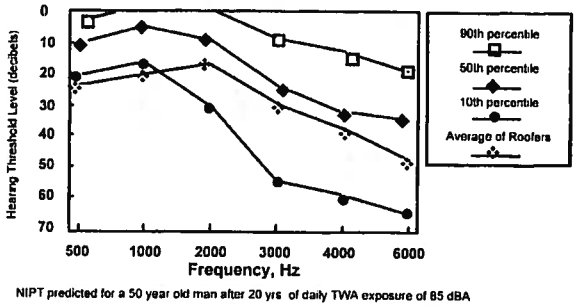

FIGURE 3. Average hearing threshold levels among roofers compared with those of a hypothetical 50-year-old population exposed to 85 dBA for 20 years as predicted by ISO 1999 using Annex B. Reprinted from Schneider and Tennenbaum[27] with permission of the first author.

same type of equipment, these data show that pneumatic tools, such as jackhammers and chipping guns, pose a greater risk than those powered by other means.

Chemical and Combined Exposures

In recent years there has been a substantial increase in information on the adverse auditory effects of chemicals, especially when combined with high levels of noise. OSHA estimates nearly one million construction workers are occupationally exposed to lead,[17] a substance known to be ototoxic.[18,19] Solvents, such as toluene and xylene, have been implicated as causes of occupational hearing loss, and, particularly when combined with noise, appear to exacerbate the hazard to hearing.[20–23] In a report on construction laborers, Burkhart et al.[24] placed toluene and xylene high on the list of hazardous chemicals and physical agents in terms of estimated number of exposed workers. Until more details are known about the combined exposures of construction workers, the existing data in this area should be used as added incentive for diligence in protecting workers, both from noise and from potentially hazardous chemicals.

HEARING THRESHOLD LEVELS OF CONSTRUCTION WORKERS

Although there is not nearly as much information on hearing threshold levels of construction workers as there is on noise exposure levels, fortunately, some data do exist. Studies as early as the 1960s and 1970s pointed out the problem. LaBenz et al.[1] measured the hearing of 66 operators of earth-moving vehicles and found considerably more hearing loss than in a population not exposed to noise for all age groups. Kenney and Ayer,[2] with more sophisticated audiometric equipment, measured hearing threshold levels of 33 sheet metal construction workers who regularly used hand-held power tools. They found noise-induced threshold shifts that were significant for every age group and greatly exceeded expected hearing threshold levels for the older age groups.

Ohlin[25] prepared an inventory of civilian job specialties giving the number and percentage of workers in each specialty with hearing loss, defined as hearing threshold levels (HTLs) greater than an average of 25 dB at 1000, 2000, and 3000 Hz. The list, found in Table VI, includes several jobs that are associated with construction activity.

Waitzman and Smith[26] performed a multivariate regression analysis based on the combined data from the Public Health Service and Health Examination Surveys of 1960–1961 and 1971–1975. The authors divided industrial workers into three categories: construction, manufacturing/mining, and other. They found that the construction category showed the greatest amount of hearing loss for all degrees of severity and at all ages, demonstrating the magnitude of the problem in construction and indicating that the onset of noise-induced hearing loss starts early. The relative risk for blue-collar construction workers was three times that of white-collar workers. In addition, white-collar construction workers also had more hearing loss than their counterparts in other industries.

A recent study of hearing loss among 66 roofers was conducted by Schneider and Tennenbaum.[27] Subjects completed a questionnaire that included information on other hazards, such as exposure to vibration, fuels, thinners/solvents, paints, glues, lead, extreme heat, and extreme cold, as well as information on hypertension and shooting habits. The average age was 48 years with 20 years on the job. Subjects reported that they generally worked slightly more than half time and they wore hearing protection infrequently (2 always, 7 often, 11 sometimes, and 46 never). The only confounding variables that showed an effect were hypertension and shooting. The authors adjusted the data for shooting by using only the right ear of the 18 subjects that reported use of weapons.

Figure 3, from Schneider and Tennenbaum,[27] shows the average hearing threshold levels of roofers compared with the median, 90th, and 10th centiles predicted by ISO 1999 for the same age group exposed for 20 years to average levels of 85 dBA. The roofers' hearing threshold levels fall between the median and 10th centiles of the ISO prediction.

Two factors might cause these thresholds to be overestimates of the true hearing thresholds of roofers. First, the audiometric room was quiet but not soundproofed, which would be likely to produce elevated thresholds in the low and middle frequencies, although lack of soundproofing is unlikely to affect thresholds above 1000 Hz, where the major differences manifest. Secondly, a self-selection bias could occur because these subjects were volunteers at a convention. The bias could, however, work the other way in that some roofers might not volunteer because they did not want to confront the fact of hearing loss. One factor that would cause these thresholds to be underestimates is that they are part-time exposures that are compared with full-time exposures in

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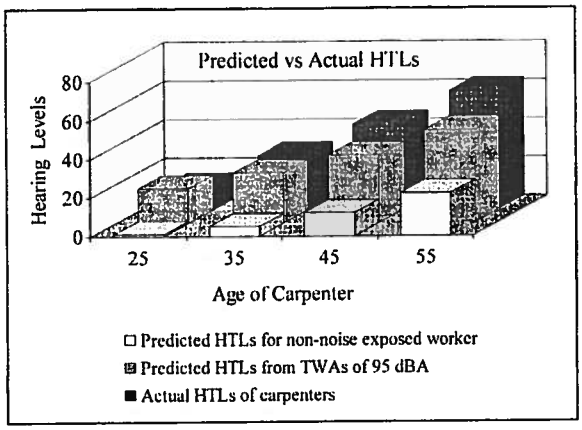

FIGURE 4. Predicted compared with actual hearing threshold levels at 4000 Hz for carpenters. Reprinted from Stephenson[28] with permission of the author.

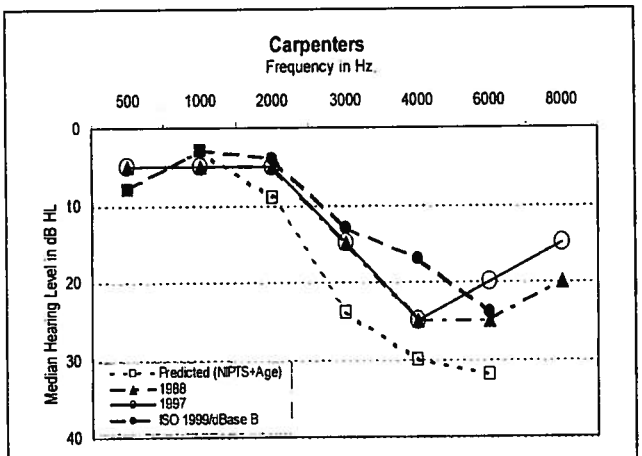

FIGURE 5. Hearing threshold levels of British Columbia carpenters (triangles, 1988; open circles, 1997) plotted against a population not exposed to noise (closed circles) and predictions of expected hearing threshold levels due to average measured exposures of carpenters of L_{eq} 91.3 dBA (dashed line). Reprinted from Gillis and Harrison[29] with permission of the first author.

the ISO method. Thus, to the extent that other roofers work longer hours their hearing losses could be more severe.

Figure 4, from Stephenson,[28] shows predicted compared with actual hearing threshold levels at 4000 Hz for carpenters. The data were collected by NIOSH personnel at a convention, so once again, self-selection may have introduced a bias, either to higher or lower hearing threshold levels. The results are interesting, however, because the author compares mean hearing levels of carpenters with a control group not exposed to noise (Annex A of ISO 1999 or ANSI S3.44, which comprises hearing threshold levels of an ontologically normal [highly screened] population) and to median hearing levels predicted by ISO 1999 (or ANSI S3.44) of persons exposed to average daily levels of 95 dBA for the same age groups. One can see that the carpenters' hearing threshold levels are considerably greater than those of the subjects not exposed to noise in all age groups, and worse than the 95-dBA populations in the older age groups. These data would indicate, to the extent that this is a representative sample, that the exposures of carpenters equal or exceed an average L_{eq} of 95 dBA.

Undoubtedly, the most comprehensive HCPs for construction workers are those of the Worker's Compensation Board (WCB) in British Columbia. Figure 5, supplied by the WCB, shows HTLs of carpenters dating from 1988 and 1997.[29] These HTLs are plotted against a population from ISO 1999 Annex B (hearing threshold levels listed in Annex B of ISO 1999 [and ANSI S3.44] are for an unscreened population in an industrialized country) not exposed to noise and predictions of expected hearing threshold levels (noise-induced permanent threshold shift plus age) calculated from the measured exposures of a group of 63 carpenters in British Columbia. The carpenters' data are for the right ear and Annex B data are for the better ear, although any effect caused by this difference should be minimal. The average exposure of the measured group was an L_{eq} of 91.3 dBA. One can see that the carpenters' HTLs were slightly worse than that of the population not exposed to noise but somewhat better than the predictions based on ISO 1999. Also, there is a slight improvement between the measured thresholds in 1997 and those from 1988 in the 6000- and 8000-Hz frequencies.

Figure 6 shows the same kind of data for equipment operators.[29] The ISO 1999 estimates of HTL are based on the measured noise exposures of 46 workers with an average L_{eq} of 91.6 dBA. Once again the 1988 HTLs are worse than those of the control population not exposed to noise and better than would be predicted according to the ISO standard. HTLs of the 1997 population, however, mimic the nonexposed curve and are substantially better than would be predicted by the average exposure level of a similar group of equipment operators. The reasons for these improvements are most likely attributable to the success of HCPs, which will be discussed further in the following sections. It is possible that some of the improvements may be due to the learning effect, an artifactual improvement in HTLs that occurs when people take several audiometric tests over a period of time. However, one cannot dispute the large differences between HTLs of these workers and the HTLs that would be predicted from their noise exposures.

HEARING PROTECTOR USE AMONG CONSTRUCTION WORKERS

Prevalence of Use

The use of HPDs by U.S. construction workers has been notoriously poor, although it has improved slightly in recent years. For example, a 1967 study of occupational health in California noted that HPDs were not considered practical because of heat, dust, dirt, and lack of washing and fitting facilities on job sites.[30] This attitude was probably typical of construction in the United States until fairly recently. Even today, the use of HPDs in construction is not widespread. Greenspan et al.[12] found that only one individual out of the group of operating engineers and laborers they studied used HPDs, and this individual reported that he already had a hearing loss. Most of the group was older than 50 years and most reported that HPDs interfered with communication.

Table VII gives estimated numbers of workers exposed to noise levels of 85 dBA and above in various segments of the construction industry and the reported percentage using HPDs. The numbers of exposed workers are based on NIOSH estimates from 1981–1983, updated to reflect 1995 construction employment data.[4] The percentages are based on NIOSH observations from

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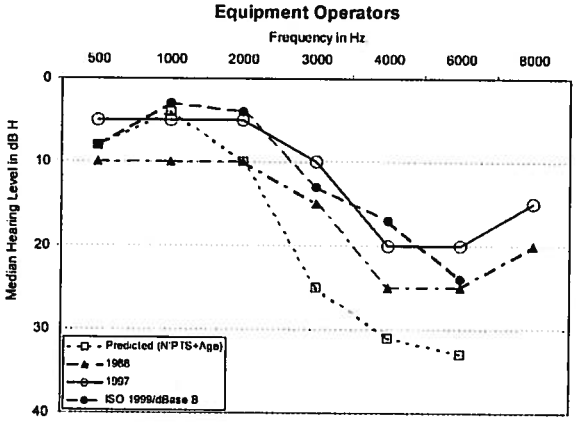

FIGURE 6. Hearing threshold levels of British Columbia equipment operators (triangles, 1988; open circles, 1997) plotted against a population not exposed to noise (closed circles) and predictions of expected hearing threshold levels due to average measured exposures of equipment operators of L_{eq} 91.6 dBA (dashed line). Reprinted from Gillis and Harrison[29] with permission of the first author.

1981–1983. One should keep in mind that the numbers exposed include all of those exposed to levels, not TWAs, of 85 dBA and above. Even so, the percentage observed using HPDs is quite low, and virtually nonexistent in certain trades.

The information in Table VIII summarizes the prevalence of HPD use according to various studies. In their survey of operating engineers, carpenters, and plumbers/pipefitters, Lusk and her colleagues found that overall, 24% of those surveyed never used HPDs when exposed to high levels of noise, and only 5.3% always wore them when exposed.[32]

By contrast, the majority of British Columbia construction workers regularly used HPDs, even in 1988, when hearing conservation efforts were formally initiated in construction. According to Harrison,[33] British Columbia has required the use of HPDs since 1967, and a positive safety culture has existed there since the early 1970s, when hard hats and HPDs were fairly widely accepted. Enforcement of hearing conservation requirements was stepped up in the early 1970s, mainly in the forestry industry, but compliance appeared to spread into other sectors at that time. The widespread use of HPDs by 1988 is likely to be the primary reason for the better-than-expected hearing threshold levels of the carpenters and equipment operators shown in Figures 5 and 6.

Practical Considerations

The need for construction workers to communicate with each other is as great or greater than in most manufacturing industries. This is particularly true of personnel operating heavy and mobile equipment, such as loaders, dozers, and cranes, as well as personnel on the ground or in structures who need to communicate with them. Unless these workers are fitted with effective two-way or multiway communication systems, HPDs are likely to be viewed as a hindrance to communication and the perception of warning signals. This is especially true of workers who have already incurred a noise-induced hearing loss.

Most of these noise-induced hearing losses occur in the frequencies above 1000 Hz, which is the area most critical for the understanding of speech. Unfortunately, HPDs attenuate most effectively in this same frequency range. Consequently, spoken communication and indeed many warning signals become more difficult to perceive and understand when the person with noise-induced hearing impairment wears HPDs. There is a considerable body of research indicating that persons with noise-induced hearing loss are at an increased disadvantage in the perception of speech and warning signals when they wear HPDs.[34]

By contrast, a recent laboratory study of the effects of HPDs and hearing loss on the ability to perceive a common back-up signal indicated that persons with fairly severe losses could still detect a common reverse alarm at a signal-to-noise ratio of 0 dB.[35] These results are not definitive, however, because of the small size of the experimental population and because the subjects had no additional demands on their attention. It does suggest that even hearing-impaired persons wearing HPDs are able to perceive warning signals under certain favorable conditions.

There is also a body of research on listeners with normal hearing that shows that the use of HPDs can actually improve the perception of speech and warning signals in high-noise conditions. This is especially true when the noise is continuous. It appears that the point at which HPDs no longer provide an advantage for normal-hearing listeners is between about 80 and 90 dBA.[34]

However, much of construction noise tends to be intermittent or varying. Intermittent noise, which is typical of carpentry and

TABLE VII. Estimated Numbers of Workers Exposed at or Above 85 dBA and Percentage Using HPDs (NIOSH Percentage Estimates [1981–1983] Using 1995 Construction Employment Data. Adapted from Hattis[4])

SIC	Industry Description	NIOSH Est. No. Exposed >85 dBA	Reported % Using Hearing Protection
152	Residental builders	75,500	1
154	Nonresidental builders	66,300	15
161	Highway and street construction	60,400	11
162	Other heavy construction	90,500	44
171	Plumbing, heating, and air conditioning	52,700	16
172	Painting and paper hanging	35,100	0
173	Electrical work	74,100	0
174	Masonry, stonework, and plastering	33,500	11
175	Carpentry and floor laying	70,700	0
176	Roofing, siding, and sheet metal	22,300	3
177	Concrete work	98,500	19
179	Miscellaneous special trade contractors	74,500	35
Total		754,100	avg. 15%

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TABLE VIII. Summary of Prevalence of HPD Use According to Various Studies

NIOSH (NOES) (1981–1983)[A]		
Highway and street construction, 11%		
Carpentry and floor laying, 0%		
Plumbing, heating, and air conditioning, 16%		
Overall average, 15%		
Lusk et al.[31]		
Operating engineers, 49%		
Carpenters, 18%		
Plumbers/pipefitters, 32%		
Overall average, 33%		
British Columbia WCB[29]	1988	1998
Equipment operators	74%	90%
Carpenters	49%	77%
Electricians	55%	87%
Laborers	64%	64%
Truck drivers	46%	73%
Welders	76%	94%
Overall average	56%	75%

[A]Examples from Table VII

finishing operations, is characterized by large differences in sound level and periodic interruptions at relatively low levels. Varying noise, which is more typical of the heavy equipment noise generated during site preparation, is characterized by ample differences between maximum and minimum levels, but low-to-moderate levels in between are present for a considerable amount of time.[36,37] Although HPDs may benefit communication during high noise periods, they are likely to be an impediment during the periods of intermittency when noise is below 80–90 dBA, and yet construction workers need to communicate and hear warning sounds during these periods.

This problem would suggest the need for HPDs that can be easily put on and taken off, such as muffs or semiaurals. There are, however, drawbacks to both of these protectors in the construction environment. First, muffs are sometimes incompatible with hard hats and safety glasses. Some muffs can be worn with the headband under the chin, but this position may be awkward. Muffs that are actually attached to the helmet are a popular alternative, but the attenuation is not always as great as with standard muffs because of difficulties in proper orientation and fit. The temple bars of safety glasses will often break an earmuff's seal and attenuation will be reduced. Semiaurals may be useful as they are very easy to don and doff, but workers often find them uncomfortable and dislike the effects on the perception of their own voices due to the "occlusion effect" they sometimes generate.[38]

Interestingly, most workers in the British Columbia program, where the rate of use is highest, prefer to wear earplugs rather than earmuffs or semiaurals. In 1997, 64% of the construction workers reported using plugs, 13% used muffs, 1% used a combination of plugs and muffs, and 22% used no HPD. The use of plugs in British Columbia has greatly increased since a previous survey in 1981, and the use of muffs has decreased.[39]

Earplugs also have their disadvantages, aside from the fact that they require more time and effort to put on and take off than muffs or semiaurals. User-molded plugs, which have become by far the most popular type of plug, require clean hands to roll down and insert. The dust and dirt typical of construction sites can become imbedded in the plug and therefore a possible hygiene problem.

Localization of the sound source can be very important in construction. Workers need to be aware of warning signals, shouts from co-workers, and back-up alarms from moving vehicles. Both plugs and muffs degrade the ability to localize in the horizontal plane (left-right) and muffs have a devastating effect on localization in the vertical plane.[34,40,41] This fact has particular implications for the safety of iron workers and others who depend on communication in the up-down dimension.

It is true that hearing loss itself degrades the ability to localize[42] and to perceive speech and warning signals,[34] and one of the best ways to prevent hearing loss is the effective use of HPDs. This presents a difficult paradox because one is reluctant to generate safety problems in the effort to reduce an adverse effect on both safety and health.

The most recent noise regulation in British Columbia, which applies to construction as well as general industry, requires the posting of noise hazard areas when average exposure levels exceed 85 dBA (L_{eq}) or peak sound levels exceed 135 dBA. Employers must supply HPDs and workers must wear them in areas that have been posted.[43] This would presume that construction workers would be obliged to wear HPDs during the quiet periods and in noise levels between 80 and 90 dBA, even if they should pose a safety hazard. The regulation does state, however, that workers must wear HPDs "in accordance with instructions provided by the employer." Hopefully, employers would see fit to allow, even encourage workers to remove protectors when noise levels drop below about 85 dBA, but such flexibility on the part of both contractors and workers may not be easy to achieve. Employers often have the idea that bigger is better, and seek out HPDs with the most attenuation, regardless of an employee's noise environment and job needs. This practice can lead to overprotection, when too much attenuation can prevent workers from hearing sounds that are necessary to their job performance and safety. HPDs with only mild or moderate levels of attenuation can be quite adequate, as long as they are worn properly.

The British Columbia noise regulation requires certain selection criteria for HPDs, which are based on the Canadian Standards Association Standard, Z94.2–94, "Hearing Protectors" and its appendix. These criteria include communication demands on the worker as well as the worker's hearing ability and daily noise exposure.[43] The requirements should have the effect of encouraging employers not to overprotect.

In the United States the ANSI standard (S12.6) for estimating the attenuation of HPDs has recently been revised to include a subject-fit protocol (Method B) in addition to the traditional experimenter-fit method (Method A).[44] Using the new subject-fit procedure results in noise reduction ratings (NRRs) that are somewhat lower, but considerably more realistic than those derived by the earlier method, which is still printed on the HPD's package. U.S. employers should be encouraged to use the newer Method B values whenever available, and to understand that they are more reflective of real-world use. In other words, employers should understand that hearing protector attenuation needs to be adequate but not excessive, and that overkill is a bad idea.

Regardless of whether HPDs improve or interfere with the perception and identification of warning sounds in specific cases, many construction workers believe that they will be a hindrance and therefore resist wearing them. A survey of carpenters' attitudes showed that nearly 50% believed they would be unable to hear warning sounds when wearing HPDs, and an additional 17% was unsure.[45] This problem calls not only for improved training, but an educated sensitivity on the part of those who dispense and supervise the wearing of HPDs.

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Potential Solutions

Over recent decades, certain HPDs have been developed with speech communication and warning signal detection in mind. They may be classified as passive attenuators, attenuators aided by electronics, and communication systems. (For a comprehensive review of technology advances in HPDs, see Casali and Berger.[46])

Passive attenuation is characteristic of conventional plugs and muffs that do not use electronic systems. An example of a relatively new passive device is the Ultra 9000 (Acaro Co. Indianapolis, Ind.), a level-dependent earmuff that uses a valve system to achieve low levels of attenuation in low noise levels, with substantial attenuation in impulsive noise conditions.[47] Although this muff provides somewhat less attenuation in the low frequencies than in the middle and high frequencies, the slope between 500 and 8000 Hz is relatively flat (when worn correctly), which is desirable for speech communication. Other earmuffs without the level-dependent characteristic are currently being marketed for their communication advantages. An example is the Bilsom NST (Bacou-Dalloz Inc., Reading, Pa.), which has a relatively uniform attenuation between 250 and 6000 Hz.

Another promising development in the passive category are the ER-15 and the ER-25 plugs (Etymōtic Research, Elk Grove Village, Ill.). The former provides a uniform attenuation of approximately 15 dB throughout nearly the entire frequency range, and the latter 25 dB of attenuation, although it rolls off slightly in the low frequencies. According to Killion et al.,[48] the acoustics of the ER-15 plug were developed to mirror the natural response of the open ear while providing some amount of attenuation. It has become known as the "musician's earplug" because of its popularity among musicians, who require spectral "fidelity." Because its official NRR is only 7 dB, it is not appropriate for all occupational uses. The ER-25, however, does provide more attenuation, with an NRR of 16. The major drawback to these HPDs is that they must be custom molded to the user's ear, which adds considerably to the cost.

There are some conventional earplugs that attempt to achieve a flat attenuation at much lower cost. For example, Acaro's Ultratech plugs, with NRRs of 12 or 16 dB, are premolded plugs that have a slope of only 10 dB between 125 and 8000 Hz when worn correctly. Even though the NRRs of these devices are not as impressive as the 25-to-30 dB of many other HPDs, their attenuation would be sufficient for many construction activities, as long as they are inserted and worn properly.

There are two types of earmuffs that employ electronics. One uses noise cancellation to achieve attenuation. The other uses amplification to permit the passage of low and moderate levels of sound, maintaining a constant level at the ear. It then acts as a passive attenuator at high levels. An example of the latter is the Peltor Tactical 7-S (Acaro Co., Indianapolis, Ind.). This type of HPD offers promise of protection against high-level impulses superimposed against a background of relative quiet.[46]

Noise canceling earmuffs use electronics to generate an "antinoise" signal that reduces incoming noise levels by 20 dB or so in the low frequencies. An example of this HPD would be the ProActive 3000 muff (Noise Cancellation Technologies Inc., Stamford, Conn.), with an NRR of 21 dB assessed in the passive mode. These devices are useful mainly in environments characterized by high levels of low-frequency noise, where C-weighted levels exceed A-weighted levels by at least 10 dB. Because the electronics take up considerable room in the earcup, they cannot achieve as much passive attenuation as certain other protectors. However, they can produce a flatter attenuation curve when the active noise reduction feature is activated by boosting attenuation in the low frequencies and they can also reduce the troublesome masking properties of low-frequency noise. As of 1989, at least seven different companies had working models of active noise reduction headsets using noise cancellation technology,[49] but that number is probably lower today. Cost is a drawback, with prices ranging from $150 up to $1000 per set.[46]

It appears that there has been little laboratory or field testing of speech recognition with either type of electronically aided muffs. These HPDs may indeed be of benefit to speech communication and warning signal detection, but further evaluation is indicated before they are relied on in situations when speech communication is critical.

Communication headsets, however, have been used successfully over the years when communication at a distance is necessary. Although they cost anywhere from $200 to over $600, the expense can be more than offset by the benefits of clear and necessary communication. Noise cancellation may be used in these devices as an added benefit in the reduction of low-frequency noise, as in the Aviation Headset X (Bose Corp., Framingham, Mass.). Passive attenuating muffs may be plugged into existing radio systems, or self-contained units are also available for communication at distances of up to 2 miles. Several companies manufacture HPDs as communication headsets, with NRRs ranging from 21 to 29 dB.[50]

With the passage of the Americans with Disabilities Act in 1990, it is within reason to speculate that employers, including construction contractors, may need to provide workers who have hearing losses with HPDs that are suited to their communication needs, both in terms of spoken communication and the perception of warning signals.[51]

Clearly, the only practical, long-term solution to the many problems of hearing protector use in construction is noise control, both in the design and manufacture of construction equipment and at the construction work site.

AUDIOMETRIC MONITORING/ RECORD KEEPING

Audiometric testing is of little value unless serial audiograms can be compared, threshold shifts detected, and measures taken to halt the progression of noise-induced hearing loss. Single audiograms may indicate hearing loss, but unless a series of audiograms imply an occupational cause, the process is only one of documentation rather than conservation of hearing.

Barriers to Successful Audiometric Monitoring and Record Keeping

There are several reasons why meaningful audiometric testing and the proper keeping of records are difficult in the construction industry. These include (1) mobility of construction workers, (2) the temporary and seasonal nature of employment, (3) the small size of construction companies, and (4) the prevalence of self-employment.

The Center for the Protection of Workers Rights has compiled a substantial amount of information about the construction industry and its workers from the Bureau of Labor Statistics, the Bureau of the Census, and other sources, which can illuminate these issues.[52]

Mobility. Depending on the size and nature of the project, construction workers may work for one company for only a matter of weeks or months, or up to many years. The average duration, however, is less than in the manufacturing industries. Job

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tenure in construction also depends on whether an employee belongs to a union. In 1993 the median job tenure in construction for union employees was 5 years and for nonunion employees, 3 years.[52, chart 20b] However, nearly 80% of construction employees are not unionized.[52, chart 14a]

Temporary and Seasonal Nature of Employment. Temporary unemployment is common among construction workers, and seasonal breaks are particularly common in the northern states. Unemployment ranges from 5 to 10% higher in construction than in the general population[52, chart 20c] and the rate of failure in construction companies has been consistently greater than in other industries as a whole.[52, chart 11a]

Small Size of Construction Companies. Small businesses are less likely to conduct audiometric testing, and those with 10 employees or fewer are generally exempt from record-keeping requirements. Nearly 82% of construction establishments have less than 10 employees and less than 1% have more than 100 employees.[52, chart 3c]

Prevalence of Self-Employment. Construction workers who are self-employed are less likely to be part of an employer's safety and health program, and are unlikely to have their own hearing tested. About 2 million of the estimated 5 million construction workers list themselves as self-employed, and 75% of these are unincorporated.[52, page 21]

Potential Solutions

Centralized Systems

British Columbia. The most successful HCP for construction workers is the program conducted by the Worker Compensation Board (WCB) of British Columbia. One measure of its success can be seen in the better-than-expected hearing threshold levels of construction workers and the improvements between the thresholds in 1988 and those measured in 1997. The examples given in Figures 5 and 6 are representative of all of the trades measured.[29] This program has the advantage of being centralized in the WCB, which is supported from fees taken out of the worker compensation premiums of British Columbia employers.

The program has been in effect for construction workers since 1987, when audiometric tests were initiated, and since then tests have been conducted annually. An updated noise regulation specifies a PEL of 85 dBA, a 3-dB exchange rate, a peak sound level limit of 135 dBA, and engineering controls above these limits whenever practicable.[43] Noise exposure monitoring and training and education are required at an action level of 0.5 (an L_{eq} of 82 dBA), but these latter requirements are not rigorously enforced in the construction industry.[53]

The WCB trains and certifies all technicians, who then provide audiometric testing, training, and counseling to construction workers. Audiometric information, including a medical history, is collected by the technicians on an optical-read form and scanned onto a WCB mainframe. In addition, workers carry with them a "WorkSafe" card, which contains a record of their hearing test, the date of the test, and boxes in which the technician may check whether the worker has received an explanation of the results, a fit test of hearing protection, or whether the requirement to wear HPDs has been discussed. Workers are advised to show the card at the next test in one year. The regulation requires also that the employer maintain, "in a manner acceptable to the board,"[sec. 13.120] a record of the hearing tests for each worker as long as the worker is employed by that employer.[43]

Information about noise control and other aspects of hearing conservation is made available to employers through a WCB newsletter as well as through the technicians. Roberts[53] reports that compliance with the regulations is fairly good in heavy construction, commercial building, and road construction, but poorer in housing construction and among small-business contractors (which is not surprising). Also, because the regulation requires hearing tests "not later than 6 months after the start of employment,"[sec. 13.116] workers on short jobs are likely to be overlooked.

European Programs. Bygghälsan, the Swedish Foundation for Industrial Safety and Health in the Construction Industry, was founded in 1968. Its support was generated by assessing contractors for fees based on hours worked, and, like the British Columbia program, provided a central repository for hearing test data and other types of information. Its activities in recent years have been severely curtailed because of government cutbacks. The CPWR Chart Book, however, does contain data showing the decreased prevalence of "severe high-tone hearing loss" in Swedish construction workers between 1971–1974 and 1986–1990.[52, chart 40c]

In Germany, Arbeitsmedizinischer Dienst, state-run occupational health centers assist small companies with audiometric testing and the retention of audiometric records.[54]

Requirements of Other OSHA Regulations. Welch and Roto[55] report that of the 21 OSHA regulations requiring medical monitoring, 13 apply to construction. Both lead and asbestos have their own construction versions, although lead is, at this time, a final interim rule. The lead standard, 29 CFR 1926.62, requires a full medical examination when blood-lead or air sampling levels exceed certain criteria. The asbestos standard, 29 CFR 1926.1101, requires medical monitoring for all employees who are exposed above the PEL or an "excursion limit" for a combined total of 30 days or more per year. A medical exam must be given at least annually. It should include pulmonary function tests and may include a chest X-ray at the discretion of the physician. An exam is not required if records show that an employee has been examined within the past year.

The general industry regulation for hazardous waste operations, 29 CFR 1910.120, also requires medical examinations, and the revised respirator standard, 1910.134, requires physician clearance for workers to wear continuous-flow respirators. These standards also apply to construction.

Employers, including construction contractors, are required to ensure that these tests are performed and must pay for them. The problem is that the many complex characteristics of construction mentioned above (mobility, seasonal and short-term nature of the work, prevalence of self-employment, etc.) work against efficient medical monitoring programs, especially the keeping of records. OSHA's record-keeping rules, which have the same provisions for construction as for general industry, limit the requirements for short-term employment and for companies with 10 or fewer employees, except in cases of fatalities or multiple hospitalization accidents. Clearly, great numbers of construction workers are falling through the cracks.

Even for those companies that would be responsible for keeping records of medical monitoring, the question remains as to what to do when employees move on. The construction regulation for access to medical records (29 CFR 1926.33), which is identical to the general industry regulation (29 CFR 1910.1020), states that employers need not retain records after an employee's termination, but may simply give the records to the employee, provided that the employee has not worked there for more than 1 year.

But the question of effective follow-up remains open, especially in the case of audiometric testing, which is so dependent on the

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comparison of serial audiograms. There appears to be little experience with effective records management for construction employees for any health hazard outside of British Columbia. The one exception may be joint labor-management programs.

Joint Programs. Several of the unions whose members perform construction work have negotiated medical monitoring, testing, and training programs through the collective bargaining process. Examples of these are ironworkers, painters, carpenters, laborers, and sheet metal workers. All of these unions have centralized funds used mainly for training, but that also pay for some medical testing, such as asbestos exams, lead, and clearance for working with hazardous waste.[56]

A good example of this type of program is the MOST (Mobilization Optimization, Stabilization, and Training) program run by the boilermakers union.[57] The program covers drug, pulmonary function, and respirator fit testing, as well as safety glasses and safety training for some 20,000 boilermakers at this time, and it will soon involve 26,000 construction workers in Michigan. In addition, it is now open to all crafts in the nation. One of its most interesting aspects is the Employee Verification System, the ability of employers to call in to the program headquarters and obtain information on pulmonary function levels, as well as the dates on which all testing and training occurred. The program used to include full medical exams, including audiometric testing, but that segment was discontinued due to expense.

Unfortunately, there is no evidence in the United States of joint labor-management programs for construction workers that include audiometric testing and record keeping.

Even though these joint programs may be very successful, there are two principle disadvantages. First, union members are understandably reluctant to pay for medical monitoring and training when OSHA regulations have mandated these as employer responsibilities. Even though it is actually the employer who pays, workers may be reluctant to use collective bargaining to achieve benefits that are their right by law. The second and most obvious disadvantage is that 80% of the construction work force is not organized and therefore would not benefit from this type of arrangement.

There is no reason, however, why contractors could not pay into a fund for purposes of medical monitoring, including audiometric testing and record keeping, which would be managed by a public or private agency. This fund would then cover all construction workers, whether or not they were unionized.

State-Run Programs. There are, in fact, some states that have adopted OSHA's hearing conservation amendment for construction workers. For example, the State of Washington's Department of Labor and Industry is divided into a worker compensation section and an occupational safety and health section, the latter having jurisdiction over noise regulations. However, there has been virtually no enforcement or compliance with the construction noise standard, so merely adopting the federal hearing conservation standard for construction workers is not necessarily the answer unless the state is willing and able to enforce it.

It appears that the best solution would be a program like that of the WCB. Here, a centralized agency, in this case the WCB of the Province of British Columbia, not only keeps the records but trains the technicians, ensures follow-up, and provides quality control. This function could be carried out within the United States by state agencies, such as health departments.

There is a program called the Adult Blood Lead Surveillance program, funded by NIOSH and the Centers for Disease Control and Prevention, in which 26 states keep a register of the effects of lead and other heavy metals. These data are generally used for epidemiological purposes, but in some cases for individual follow-up. In New York, for example, all blood lead levels are sent to the State Department of Health and high levels can trigger follow-up phone calls to lead-exposed individuals.[58] In addition, some states have cancer or silicosis registries.

Although a state-run program is likely to be the most efficient solution for HCP elements such as audiometric testing and record keeping, these programs are always susceptible to the whims of state legislatures or federal funding sources. The perfect solution is elusive.

Credit-Card Type Storage Devices

Contemporary technology could make the problem of construction worker mobility somewhat more tractable. These devices, like optical cards, may be carried in one's wallet and are capable of storing considerable amounts of information. Evidently they are already being used for documenting safety training. According to Stephenson,[59] any audiometer that can communicate with a personal computer (which is a great many audiometers nowadays) can handle these devices. All that is needed is the appropriate software and a special drive. NIOSH has this capability at this time.

An example of the effective use of these "smart" cards is the program that allows travelers to cross the U.S./Canadian border by inserting a card encoded with the individual's fingerprint into an optical reader. According to a press release issued by Canon USA in 1995, these cards can store the equivalent of 1600 pages of text or other digital data, and they are already widely used in the health care field as a portable clinical record.[60] No doubt the technology has advanced considerably since then.

NOISE, HEARING LOSS, AND ACCIDENTS IN CONSTRUCTION

Accidents in Construction

Traditionally there has been a high rate of occupational injuries in the construction industry. Sweeney and her colleagues collected the following data from the Bureau of Labor Statistics and various other sources:[61] Construction workers represent 6.5% of the work force, but 18% of the fatal injuries occur in construction. After mining and agriculture, construction ranks third for workplace fatalities and injuries. The leading causes of construction fatalities include falls (31%) and transportation incidents (27%). Contact with or being struck by an object and musculoskeletal disorders account for more than 50% of all traumatic injuries. Construction workers are twice as likely as the average worker to be killed by a motor vehicle, and 40% of worker fatalities from motor vehicle accidents are pedestrians. Nearly 2000 machine-related deaths in construction occurred between 1980 and 1992 and in nearly one-third of the cases the worker was struck by a moving mobile machine. Laborers (23.5%) and operating engineers (22.6%) accounted for nearly half of the machine-related deaths.

Possible Contribution of Noise and Hearing Loss

There is little objective information linking noise exposure or hearing loss with accidents specific to construction, but common sense would suggest that many of these accidents might have been prevented had workers been able to perceive warning shouts or signals. The high incidence of fatalities from being struck by objects, of transportation incidents, and the frequency of fatal accidents from moving machines (especially with pedestrians as victims) all suggest a breakdown in communication.

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Noise and hearing loss have been implicated in studies of other industries. For example, noise and hearing loss were found to be accountable for 43% of the injuries in a shipyard setting.[62] The authors considered other possible causes, such as alcohol consumption, cigarette smoking, and the use of earplugs, and found that alcohol consumption was the only significant factor besides noise and hearing loss. It appears that the authors controlled for age and job hazard.

Zwerling et al.[63] assessed the likelihood of occupational injuries in a large sample of workers drawn from the National Health Interview Survey. These workers had listed themselves as having some kind of preexisting impairment: visual or hearing impairment, back conditions, upper or lower extremity conditions, diabetes, epilepsy, and arthritis. The authors found that the highest risk of job-related injuries came from workers having sensory impairments with odds ratios for blindness of 3.21, deafness 2.19, hearing impairment 1.55, and visual impairment 1.37 (which was not statistically significant). Of the seven occupational groups studied, laborers represented about 8% of the total cohort, and approximately 36,000 in this group (13%) were construction laborers.[64] The remainder of the group included material handlers, as well as operators of various kinds of vehicles and equipment, some of whom might also be considered construction workers. The category titled laborers was one of three blue-collar categories, the others being mechanics/repairers, and operators/assemblers. The odds ratio for injury among laborers was 4.16, the highest of any of the groups.

Another study of a large industrial population compiled accident data from factories over a 2-year period.[65] The authors found that the frequency of accidents and illness-related absences increased with increasing noise exposure levels for both men and women. The relationship between noise exposure and accidents was significant for men but not for women. Unfortunately, it can be very difficult to control for the hazardous nature of various jobs in this kind of study, and it is possible that high levels of noise may be related to jobs that are inherently hazardous.

Reverse Alarms

In recent years there has been some attention to the questionable effectiveness of back-up alarms in mobile machinery. A study by Laroche et al.[66] demonstrated that the audibility of back-up alarms on dump trucks is compromised because of the ineffectiveness of their acoustic signals. Laroche and Lefebvre[67] traced 22 fatalities to faulty back-up alarms in the Province of Quebec over a 15-year period. Table IX provides an updated version of these data, giving the cause of each accident and comments about noise levels and the back-up alarm specific to each situation.[68]

Laroche and Lefebvre[67] concluded that there are at least five principle causes for these types of accidents: (1) hearing loss among construction workers, (2) high noise levels on some sites, (3) worker attentional demand or complacency, (4) inadequate placement of alarms, and (5) deficient acoustic features of the alarms.

The adverse effect of hearing loss should be self-evident, as with high noise levels, because they both would degrade the ability to perceive back-up alarms as well as warning shouts. Worker attentional demand from complex tasks or stimuli could cause the failure not so much to hear but to attend to the warnings produced by back-up alarms (see review of this subject by Suter, Ref. 34, Chapter 4). Inattention caused by habituation also could reduce the ability to react appropriately to the sound of warning alarms.

Laroche and Lefebvre[67] reported that placement of the back-up alarm is often problematical. For example, some owners position the alarm underneath the vehicle to protect it against weather, which placement has an attenuating effect. With regard to deficient acoustic features, the authors found that most back-up alarms produce pure-tone signals around 1400 Hz or modulations of two neighboring sounds, 1250 and 1350 Hz. Reflections of these sound waves on the ground or diffraction by the sides of vehicles have the effect of reducing or even canceling them before reaching the listener. Within spaces of less than a few inches, Laroche and Lefebvre found variations in sound pressure level of more than 15 dB behind vehicles. Finally, the use of a pure tone in the 1500–3000 Hz range is not efficient for purposes of auditory localization.[69]

There are several reasonable solutions to these problems. First would be to prevent hearing loss through noise control, the judicial use of HPDs, and training. Second, noise levels on the construction site should be reduced through the manufacture and purchase of quieter equipment and the proper maintenance of all noise-producing equipment. Third, workers should be trained in the awareness of warning signals as well as all aspects of hearing conservation. Fourth, back-up alarms should be placed for optimal reception by the intended listener. Fifth, greater attention should be given to the workers' sound environment and sound propagation in the design of the alarm, as well as the psychoacoustics of audition. Laroche and Lefebvre[67] caution that back-up alarms should not emit just one pure tone because of the considerable risk of sound cancellation, but instead should produce several frequencies in the 500 to 2000 Hz range that are not harmonically related.

In optimal conditions the sound level of an alarm should exceed the background noise by 10–15 dB. However, this can pose a problem to the residents neighboring construction sites, who often complain about the noise of back-up alarms. A partial solution could be found in the form of an auto-adjusting alarm, which senses noise in the environment and adjusts its signal to a level 10 dB above that of the background noise. An example is the Starmatic 63–000 (Star Warning Systems Co., Avon, N.Y.), an auto-adjusting back-up alarm, with a range of 87–112 dB.

One final recommendation came from a safety workshop attended by laborers, and that is that personnel backing heavy vehicles should use an additional worker as a "spotter."[56] This worker is presumably in a place where the operator can see him or her, and it is important that the worker is trained and alert because Laroche and her colleagues found that the "signalman" was sometimes the one who was fatally hit.[66]

NOISE CONTROL IN CONSTRUCTION

There is a considerable amount of information available on the control of noise in the various aspects of construction, and a detailed discussion of this topic is beyond the scope of this report. A brief overview, however, would be useful. Noise control solutions include the efficient operation and maintenance of construction equipment, retrofit of existing equipment, and the design of quieter new equipment.

Feasibility

It appears that noise reduction in most construction sites and for most construction equipment is feasible. Although some tools will still require the use of HPDs for adequate protection, there is a great deal that can be done. Figure 7, from the Bureau of Mines,

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TABLE IX. Deadly Accidents Involving Heavy Vehicles and Noise (After Laroche et al.;[69] Updated, Expanded Version Translated into English Provided by Laroche[68])

Case No.	Date of Accident	Employee	Vehicle Involved	Cause of Accident	Comments
1	08-29-91		tow truck		noise level exceeded alarm
2	06-02-88	splitter/operator (aluminum co.)	forklift	poor visibility, plus backup alarm not detected	
3	04-28-88	water system installer	dump truck (?)	backup alarm not detected	poor synchronization of maneuvers
4	09-04-87	flag person (construction site)	dump truck (10 wheeler) backup alarm: DAP	backup alarm not detected	alarm: 90 dBA; noise from streamroller: 87 dBA
5	07-01-87	quality control attendant (construction site)	dump truck (10 wheeler) Kenworth 1974	backup alarm not detected	backup alarm in front of the 2 back axles and directed toward the left. alarm : 80–85 dBA; noise: 105–107 dBA
6	01-09-87	flag person (construction site)	dump truck (10 wheeler)	misjudgment by worker	alarm level greater than noise levels
7	08-08-86	marine docker	forklift	backup alarm not detected, plus driver's vision obstructed	noise: 84–96 dBA; alarm: +2 dBA
8	08-15-85	flag person (road repair)	5-ton truck backup alarm: DAP 50	backup alarm not detected, plus poor planning of operations	noise: 92 dBA; alarm: 75 dBA
9	11-21-83	shipping and receiving clerk (interior site of a pharmaceutical co.)	delivery truck	noise from truck was not detected	high noise level because of construction
10	10-06-82		loaded dump truck, Mack 76 (10 wheeler) (28,800 kg)		poor judgment or noise level same as alarm
11	09-24-82	docker (port)	road hauler	noise from hauler was not detected	high noise level, poor lighting; one-way circulation
12	09-17-82		10 wheeler dump truck		alarm was not functioning, high noise level
13	01-20-82	general foreman (James Bay site)	loaded cement mixer (82,000 kg)	backup alarm not detected	alarm: 83 dBA at 1 ft noise: 107 dBA at 3 ft
14	11-23-81	welder (railroad)	grinder, LORAM	horn was not detected	horn: 97 dBA welding noise: 90.5 dBA
15	08-10-81		loader		lack of good work method, no backup alarm
16	12-06-78	garbage collector assistant	garbage truck	backup alarm or noise not detected (?)	surrounding noise greater than truck noise
17	08-21-78	flag person (road repair)	dump truck (10 wheeler) Ford 8000	backup alarm not detected	noise level greater than alarm
18	01-08-76	digger operator (Miron)	dump truck (8 wheeler) (10 tons)	noise from truck was not detected	no backup alarm
19	12-29-75	flag person (snow removal)	leveler	noise from leveler was not detected	no backup alarm
20	07-08-75	flag person (steel works site)	dump truck (19 tons)	noise from truck was not detected	worker was walking with his back to the truck
21	08-14-75	crane operator	platform type tow truck	noise from truck was not detected	no backup alarm

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TABLE IX. Continued

Case No.	Date of Accident	Employee	Vehicle Involved	Cause of Accident	Comments
22	07-08-75	truck driver (road repair)	dump truck (7 tons)	noise from truck was not detected, also subject was very close to the back of the truck	high noise level
23	03-18-75	pedestrian (construction site)	dump truck	noise from truck was not detected	high noise level, no backup alarm
24	03-12-75	engineer (road excavation)	loader (2.5 tons)	noise from loader was not detected	high noise level

gives examples of how noise control could be applied to surface mining machines, several of which are used in construction.[70] Note the dramatic reductions achieved in haulage trucks, front-end loaders, and graders. Although some of these noise problems may have been mitigated in contemporary equipment, undoubtedly many have not yet been sufficiently quieted.

Maintenance

One of the least expensive and most rewarding noise control practices is the proper operation and maintenance of equipment. This includes keeping noisy operations away from workers who are not involved in that process, lubricating parts, keeping saw blades sharpened, and replacing worn bearings and other parts as needed. It also involves keeping the doors and windows of noisy vehicles closed to the extent possible to protect the operator from the engine and exhaust noise. Like any vulnerable part, noise control measures, such as gaskets and mufflers, need to be maintained and replaced when necessary to provide the desired attenuation.

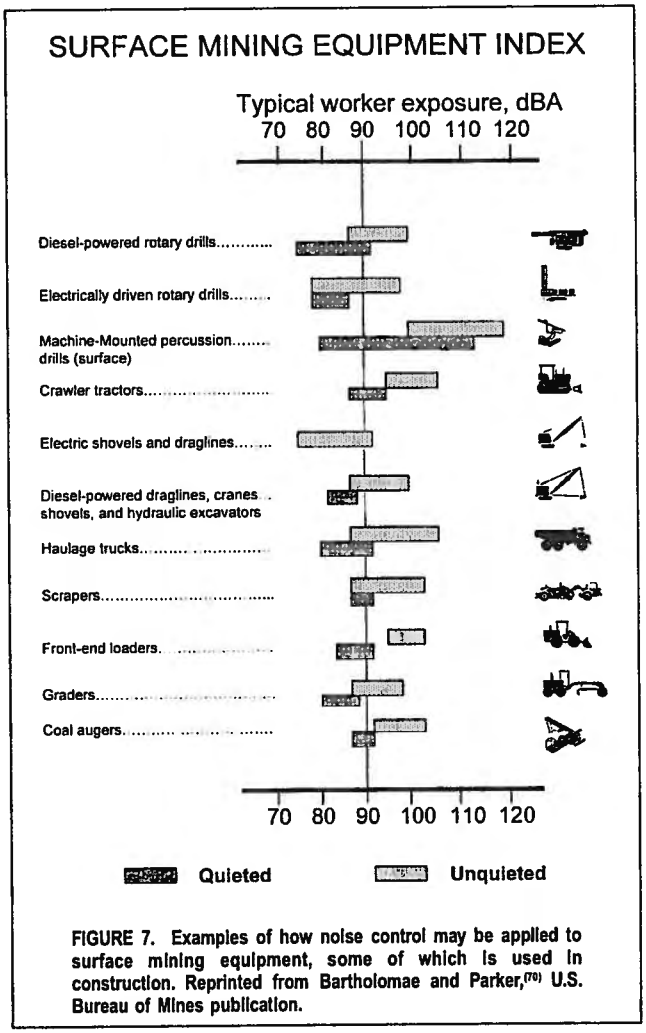

FIGURE 7. Examples of how noise control may be applied to surface mining equipment, some of which is used in construction. Reprinted from Bartholomae and Parker,[70] U.S. Bureau of Mines publication.

Retrofit

Retrofit applications, such as those advocated in the Bureau of Mines Handbook,[70] include installing mufflers, enclosing and insulating the cabs of noisy vehicles, and enclosing parts of noisy machines. Table X, from Schneider et al.[51] lists types of construction equipment and suggested retrofit controls. The authors give references for each control measure. For example, they cite a report by the Society of Automotive Engineers, which found that changing from an inadequate to a better muffler could make a difference of 1–3 dB, and installing a muffler where one had been lacking could make a difference of 10–12 dB.[71]

There may be times when retrofits yield only small improvements in noise level and HPDs are still necessary to prevent hearing loss. Researchers at the Mine Safety and Health Administration found that retrofit controls tend to reduce high-frequency noise more readily than low-frequency noise, often resulting in differences between C-weighted and A-weighted noise levels that exceed the nonretrofit condition, even though A-weighted levels had been reduced.[72] Although this finding should not discourage the use of retrofit measures, it does provide additional support for choosing HPDs with good low-frequency attenuation and careful training in their effective use.

Design

The most efficient and economical stage at which to control noise is in the design phase. This is true both in the design of a potentially noisy work space and in the design of equipment. For example, changes in the pathways of ductwork can reduce fan noise,[73] and changing low-frequency jet noise to high-frequency can make it easier to control.[74]

At an Environmental Protection Agency (EPA) hearing many years ago, George Diehl, an acoustical engineer with the Ingersoll-Rand Co. (Woodcliff Lake, N.J.), reported on a "whisperized" air compressor, in which the noise level had been reduced from 110 dBA to 85 dBA.[75] At that time the company was also working on noise from rock drills (pavement breakers and jackhammers), and had reduced the noise between 8 and 10 dB, while simultaneously reducing vibration. Mr. Diehl also discussed another type of demolition tool called a "hobgoblin," which was

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TABLE X. Noise Controls for Construction Equipment (from Schneider et al.[51])

Equipment	Noise Controls
Pile driver	Enclosure, muffler
Stone cutting saw	Noise control pad with water
Handheld impact drills	Reduction of reflected sound
Circular saw blades	15° tooth angle, new tooth configuration, slotted saw blades, viscoelastic damping
Pneumatic tools	Muffler
Pavement breaker/Rock drill	Muffler, enclosure of cylinder case and front head, moil damping
Portable air compressor	Muffler, acoustic enclosures
Bulldozer	Cab-liner material, enclosure, sound absorption in canopy, sealing of all openings
Wheeled loader	Absorption of sound cooling air route
Vibratory roller	Flexible mounting for pump compartment
Joint cutter	Antivibration mounting fixtures

mounted on a backhoe. Because it was hydraulically operated it had no air exhaust, and therefore, the major source of noise was reduced. He reported that it could do the work of 10 to 24 regular paving breakers while producing considerably less noise.[75] It appears that this kind of push for the control of construction noise in the United States has diminished, but it continues to progress in Europe.

There is, however, an interesting innovation being developed called the Raptor (Brookhaven National Laboratory, Upton, N.Y.), a machine that fractures concrete by firing steel nails from silencer-equipped guns. It is reported to work more rapidly than the conventional jackhammer, does not rely on an air compressor, and the noise level is projected to be below 80 dB.[76]

Resources

There are many such reports on noise control solutions in the construction industry. Some of them are consolidated in booklets or a series of articles. In addition to the sources cited by Schneider et al.,[51] the following are some examples.

Mining Machinery Noise Control Guidelines, 1983, a Bureau of Mines Handbook.[70] This publication contains information on the noise levels of surface and underground mining equipment, some of which is used in construction, particularly in the site preparation phase of large construction projects. For each piece of equipment the booklet lists typical noise levels, along with recommended treatments, quieted noise levels, costs in dollars and labor in hours, and the availability of treatments. These descriptions include sources for commercially available noise control products and materials, technical reports on the development and demonstration of noise control treatments, and case histories.

Noise Control, Proceedings: Bureau of Mines Technology Transfer Seminars.[77] This book of proceedings contains specific articles covering some of the same types of information as above, with more text.

Constructional Noise: A Survey of Noise on Building Sites, Bygghälsan, Stockholm.[78] This booklet gives octave band and A-weighted noise measurement data for more than 30 examples of construction noise sources, along with information on the work operation, cause of the noise, and suggested control measures for each type of equipment or setting. Although these data are more than 25 years old, many are undoubtedly still applicable. It includes comments about controls and the need for hearing protection.

Noise Control: A Guide for Workers and Employers, U.S. Department of Labor.[79] Although this guide pertains to general noise problems and their solutions, some of the principles of noise control also apply to construction. It was originally published by the Swedish Work Environment Fund, translated, then edited and adapted by OSHA.

"Noise Control: Principles and Practice," published in *Noise News International* between June 1994 and June 1999, form a series of 15 articles by Stig Ingemansson, the original author of the Swedish guide previously cited.[80] The articles represent an edited and updated version of the older guide.

Many papers and articles on noise control, some of which deal with construction, are available in the publications of the Institute of Noise Control Engineering, which has headquarters in Poughkeepsie, N.Y. These include *Noise Control Engineering Journal, Noise News International,* and the proceedings of annual conferences, both U.S. and international.

In addition to the preceding suggestions, there are other publications, such as those cited by Neitzel and Seixas:[15] Alfredson and May,[81] Kessler,[82] and Mulholland and Attenborough.[83]

EPA

The Office of Noise Abatement in the U.S. EPA, which functioned between 1972 and 1982, made significant efforts to control noise in the general environment, including construction noise. Funding for the program was terminated in 1982 by the Reagan administration, and the office was closed. However, the statutory requirements still stand because Congress has never rescinded them: the Noise Control Act of 1972 and the Quiet Community Act of 1988 (P.L. 92–574, 1972 as amended at U.S.C. 4901–4918, 1988).

Of interest in the area of construction are the regulations for medium- and heavy-duty trucks, air compressors, and regulations for the existing motor carrier fleet. These regulations are still in effect but are not being enforced. Two pieces of construction equipment, pavement breakers and rock drills, were identified as major sources of noise and set on the path toward regulation, but were "disidentified" when the program closed in 1982. The agency also considered the regulation of wheel and crawler tractor noise emission. The Noise Control Act required EPA to regulate the labeling of products that emitted or reduced noise, but EPA only promulgated one regulation in this category, the attenuation of HPDs.

A considerable amount of information about construction noise was generated by the agency, most of which is listed in EPA's *Bibliography of Noise Publications.*[84] Some titles pertaining to construction noise are listed in Appendix A. In addition, EPA has microfilmed much of the materials from the Office of Noise Abatement, and many of its contractor reports are still obtainable.

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EUROPEAN STANDARDS AND DIRECTIVES

Activities of the European Community

Undoubtedly the most interesting developments in noise standards and regulations are currently occurring in the European Community (EC), now known as the European Union (EU). With the economic unification of European countries, the effort to harmonize existing standards and to develop a unified approach to new standards has been taking place for nearly two decades. There are now a great many European standards and directives in the field of noise measurement, effects, permissible limits, and control, including some that are specific to construction.

Although publications in this area tend to use the terms "standard" and "directive" interchangeably, the word "standard" is usually applied to measurement procedures or proposals set forward by consensus groups such as the International Organization for Standardization (ISO) or the International Electrotechnical Commission (IEC). The term "directive" usually applies to an order issued by the Council of the European Community (CEC), and this order is generally mandatory for implementation by the member states of the EU.

The EU speaks in terms of the "old approach" and the "new approach" to the issuance of directives. The old approach, taken prior to 1985, applied to one product at a time and was very time-consuming. The new approach resembles enabling legislation, in that these directives apply to broad categories of products. Under the new approach, the CEN prepares nonmandatory technical specifications, the purpose of which is to assist manufacturers in the design of products so that these products will meet mandatory directives. Although the new approach was followed for directives issued in 1985 and thereafter, directives issued under the old approach still apply. Some of the old approach directives are being revised, and some new directives are still being issued under the old approach.[85]

Construction Directives

One of the earliest directives issued by the EC specified measurement methods for determining the A-weighted sound power levels of construction plants and equipment.[86] This directive was followed in 1984 by several specific directives,[85] which stipulated measurement methods and permissible sound power levels for air compressors (84/553/EEC; 85/406/EEC), tower cranes (84/84/534/EEC), welding generators (84/553/EEC; 85/407/EEC), power generators (84/536/EEC; 85/408/EEC), and concrete breakers and picks (84/537/EEC; 85/409/EEC). In 1986 the EC issued a directive on hydraulic and rope-operated excavators, dozers, loaders, and excavator-loaders (86/662/EEC; 89/514/EEC). Several of these directives have been revised (indicated by the second date). Tables 3–8 in Ref. 85 present a summary of the sound power level limit values for the construction equipment listed above. The permissible sound power levels range from 100 dBA to 118 dBA, depending on size, weight, and type of equipment. (One needs to keep in mind that the sound power level can be some 25 dB greater than the sound pressure level at the operator's position.)

1986 Directive to Protect Workers Against Noise

In 1986 the CEC issued directive 86/188/EEC "on the protection of workers from the risks related to exposure to noise at work."[87] This directive required all employers to reduce TWA noise exposure levels (using the 3-dB exchange rate) to 90 dBA or "to the lowest level reasonably practicable, taking account of technical progress and the availability of measures to control the noise, in particular at source."[article 5 1] This means that employers must reduce noise to levels below 90 dBA whenever "reasonably practicable."[article 5 2] Other measures, such as information and training, the provision of HPDs, and hearing testing must be instituted at an L_{eq} of 85 dBA. Those countries comprising the EC were required to have regulations that conformed to the CEC directive, or were at least as stringent, by January 1, 1990. Article 8 of the directive states that the design, building, and/or construction of new plants must comply with the 90-dBA exposure limit, and tools or machines that expose workers to daily average levels greater than 85 dBA must provide adequate information "about the noise produced in conditions of use to be specified."

Machinery Directive

In 1989 the CEC issued the Machinery Directive, under the procedures of the new approach.[88] This directive, 89/392/EEC, requires manufacturers of a wide variety of machines, including many that are used in construction, to make noise reduction an integral part of machinery design by implementing state-of-the art design methods.[85] Manufacturers must include information on noise levels when any machinery exceeds exposure levels of 70 dBA or 130 dBC at the operator's work station, or when sound power levels exceed 85 dBA.[88] Both the sound pressure and sound power level information are to be based on durations representative of the typical work-cycle of the machine. Noise emission information must be included in the instruction handbook of the machine (for the user's benefit) and in the technical information describing the machine (for the benefit of the purchaser.)

Since the promulgation of the machinery directive, several safety standards have been issued specific to certain machines. These standards contain a description of the hazard, the safety objectives to be achieved, measures for reducing the hazards, test methods to establish compliance, and user information. Lazarus and Zimmerman[89] present a discussion of these standards, along with some of their limitations.

Draft standard EN 1746 gives the noise provisions that should be included in machine safety standards: the identification of a machine's main noise sources; reference to principles of low-noise design, along with examples of design for noise control; a compilation of ranges of noise emission values; and the development of information necessary for user instructions to allow for low-noise operation. The authors report that the majority of "framework" standards necessary for the preparation of machine-specific safety standards already exist for noise, but they need to be developed further and adapted to the practical problems of manufacturers and operators. For example, typical operating conditions still need to be agreed on and differences between the conditions specified in the standards and actual use need to be resolved.[89]

Labeling

Another interesting provision of the machinery directive is its requirement for compliant machinery to carry the "CE" mark. An amendment to the machinery directive gives the form in which the CE mark is to be displayed (93/68/EEC). In addition, the construction noise directive (79/113/EEC) requires manufacturers to display labels in the form of plates showing either the sound power level (L_{WA}) or sound pressure level (L_{pA}) at the operator's position. The specifications for these labels are shown in Figure 8.

There is an ISO standard pertaining to the noise labeling of

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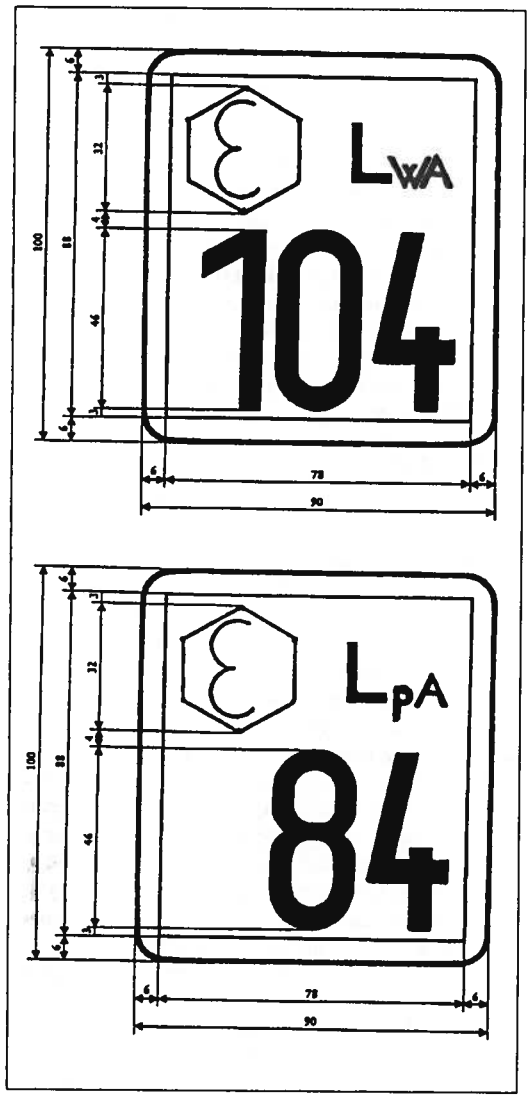

FIGURE 8. Models of plates showing the sound power level (L_{WA}) and sound pressure levels (L_{pA}) at the operator's position required by the European Community's construction noise directive (79/113/EEC). Reprinted from Higginson et al.[85] with permission from *Noise News International*.

machinery and equipment, ISO 4871.[90] This standard prescribes the labeling of machines, or families of machines, with the A-weighted sound power level in more than one mode of operation, preferably the mode resulting in the highest value. Although the labeled sound power level may be useful for deciding which machine to purchase, it gives relatively little information on the worker's exposure in actual use.

A draft American National Standard is currently being prepared by an ANSI working group[91] that adopts the provisions of ISO 4871, with the addition of a series of annexes. Proposed Annex E gives the option of including A-weighted sound pressure levels and C-weighted peak sound pressure instead of or along with sound power levels. A proposed modification to Annex B gives examples of declarations for both sound power level and sound pressure level in the "idle" and "operating" modes. It is important to remember, however, that the operating mode means under load but not necessarily in actual working conditions, as in the case of a tool contacting a work piece.

Evaluation of Noise Limits and Labeling Requirements

The success of these programs is bound to be variable because enforcement of the EC directives is carried out by the individual member states, some of which are likely to be more zealous than others. Also, the problems raised above by Lazarus and Zimmerman have been mentioned by other researchers. Kyttala and Airo[92] found that although a majority of the hand-held power tools they surveyed carried noise declarations (labels), the authors questioned whether the information provided would apply to the tools as they were being used. They found that the declared noise levels were usually lower and sometimes considerably lower than those measured in actual use.

Irmer and Fischer-Sheikh Ali[93] pointed out that the primary purpose of the machinery noise directives was to enhance the functioning of the common market by eliminating trade barriers. Thus, noise limits were set high enough so that very few products would be excluded from the market. They maintain that setting an easily achieved upper limit for construction equipment removes any pressure to produce products with lower noise emission levels. They do mention, however, that the EC has recently published a proposal on the noise emission of equipment used outdoors, which will replace existing directives and revise existing noise limits in such a way as to give a higher priority to environmental concerns like construction noise.[93,94]

INCENTIVES FOR QUIET

Disincentives of the Last Two Decades

With the demise of EPA's Office of Noise Abatement in 1982 and along with it the regulatory program for construction equipment, the incentive for noise control has declined. This is true of equipment manufacturers as well as contractors. Some small incentive has been supplied by municipalities and local groups seeking to mitigate the noise exposure of communities, but the noise abatement capabilities of local governments were adversely impacted by the closing of the national noise office. Within the last few years there has been a rekindling of interest in environmental noise abatement, both on the national and local levels, but Congress has still not seen fit to appropriate funds for the implementation of the Noise Control Act. There are now two self-sustaining national organizations concerned with noise abatement: the Noise Pollution Clearinghouse and the League for the Hard of Hearing. There also has been considerable media attention to the problem in recent years, as well as increased interest in local ordinances throughout the nation.

Efforts to control noisy products and workplaces have been severely curtailed by OSHA's compliance directive of 1983,[95] which effectively raised the PEL to a TWA of 100 dBA and discouraged noise control even above that level due to extremely permissive enforcement procedures.[96] To the extent that manufacturers of construction equipment concerned themselves with the prospect of noise regulation from either EPA or OSHA, that incentive has disappeared.

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FIGURE 9. The "Blue Angel" label. Reprinted from Irmer and Fischer-Sheikh Ali[93] with permission from *Noise News International*.

The Blue Angel Program

Europe, however, does provide some incentive for noise reduction by the manufacturers of construction machinery, even in the United States. First, there are the directives for noise limits and labeling, with which American manufacturers must comply if they wish to sell their products on the European market. The advent of the ANSI standard on labeling of machinery for noise could possibly encourage U.S. manufacturers to reduce product noise levels, even though the standard will not be mandatory.

The most promising development is Germany's "Blue Angel" program, which could have beneficial spillover for construction workers in the United States and which could also be used as a model in this country. The Blue Angel refers to a program for the voluntary designation of products as favorable to the environment. It was developed in Germany in 1977 and is flourishing today. The program's two main purposes are to assist customers in the choice of products and to encourage manufacturers to develop and market environmentally friendly products. Figure 9 shows the Blue Angel label with the environmental logo of the United Nations, the inscription "Umweltzeichen" (environmental label) above, the words "weil lärmarm" (because low-noise) below, and the words "Jury Umweltzeichen" (Environmental Label Jury) underneath.

Blue Angel awards for low-noise construction equipment were established in 1988. Irmer and Fischer-Sheikh Ali[93] reported that more than 40 companies had applied for the award with about 200 products displaying the label. Differences in sound levels between the existing noise limits in EC directives and those emitted by the Blue Angel products range from 5 to 14 dBA. In the early days of low-noise construction equipment the Federal Environmental Agency gave some financial support to interested manufacturers, but the authors report that the Blue Angel proved to be a good advertising tool and financial incentives are no longer needed.

Some local governments in Germany have given preference to Blue Angel construction products and are allowing them to be used in noise-sensitive areas, where the use of noisier products would be proscribed. Irmer and Fischer-Sheikh Ali[93] also mention that the number of non-German applicants is steadily increasing, with about 15% of the Blue Angel manufacturers coming from outside Germany. A 1997 publication of the German government gives an overview of construction machinery bearing the Blue Angel label.[97] The Caterpillar Co. is one of 14 manufacturers of excavators, with four types of machines displaying the Blue Angel. Their sound pressure levels range from 72 to 77 dBA. Of the 12 manufacturers of loaders, Caterpillar manufactures six models with sound pressure levels ranging from 68 to 78 dBA. Other products listed include compressors, power generators, welding generators, paver-finishers, concrete mixers, and tower cranes. Additional products and companies are undoubtedly certified today. Current information on the Blue Angel program is available at http://www.blauer-engel.de.

Buy Quiet Programs

EPA's Office of Noise Abatement and Control initiated an ambitious Buy Quiet program during the 1970s.[98] Its purpose was to leverage the multibillion dollar public sector market to buy quiet products. This would be done by organizing government purchasing cooperatives and working through professional purchasing organizations. The agency's program included the Government Services Administration, the National Institute of Governmental Purchasing, the National League of Cities, and various federal, state, and local purchasing agencies and cooperatives.

The EPA's Buy Quiet program consisted of four parts: (1) a series of conferences to develop quiet product purchase descriptions, (2) local Buy Quiet programs in which governments and purchasing cooperatives agree to buy quiet products as an ongoing activity, (3) a data bank for quiet purchasing operated by the National Institute of Governmental Purchasing, and (4) demonstrations of quiet products loaned by the EPA to local governments. Bids were evaluated on the basis of both noise level and price. In 1981, 64 governments had either committed themselves to a Buy Quiet program or were considering doing so.

EPA's Buy Quiet program had a short life because the agency was closed in 1982. At present there are no data on the number of government agencies (federal, state, or local) with these kinds of programs, but it is likely to be relatively few.

There is evidence, however, that these programs may continue in some places. Haag[99] reported that the 1987 edition of the National Fire Protection Association (NFPA) Standard on Fire Department Occupational Safety and Health Program contained noise specifications. Section A-5–8.1 stated that "new fire apparatus should provide maximum sound requirements that would allow members to ride in those vehicles without hearing protective devices. A maximum limit of 85 dBA without audible warning devices and 90 dBA with warning devices in operation is recommended."[99, p. F-22]

CONCLUSIONS

Approximately one-half million construction workers are exposed to hazardous levels of noise. Studies of construction workers' HTLs in the United States reflect excessive exposure, and it appears that the onset of noise-induced hearing loss starts early and continues throughout the career.

The prevalence of HPD use in the U.S. construction industry is very poor and only recently has begun to improve. Anxiety concerning the ability to perceive and understand warning signals and

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communication is an important factor in resisting HPDs, and research over recent years supports the validity of this anxiety. In British Columbia, however, the use of HPDs is significantly higher than in the United States, which is related to the success of its overall HCP. Today's broad range of HPDs, with several models designed specifically to mitigate the problems of hearing and understanding communication and warning signals in noise, points toward the necessity of careful selection and fitting of HPDs.

Audiometric testing in industry is of virtually no value unless serial audiograms can be compared. The problem of audiometric record keeping is especially difficult in construction because of the mobility of construction workers and the small size of many construction companies. Some kind of centralization, such as that found in the British Columbia program, would appear to be the best solution. Credit card storage devices or "smart cards" could make audiometric record keeping considerably more efficient for mobile employees because workers could easily carry them from job to job.

Although there has been relatively little investigation into the effects of noise, hearing loss, and HPDs on accidents in the construction industry, the existing research, along with evidence from studies of other industries, demonstrates the likelihood of adverse effects in construction. There are several steps that can be taken to reduce this hazard.

Noise control is the most effective way to prevent noise-induced hearing loss in construction, and very possibly reduce the incidence of serious accidents. Although maintenance and retrofit are viable approaches, control at the design stage is most desirable. Considerable information in this area is available, although some of it may be dated.

European standards and directives have focused attention on noise emission in European countries. These directives, which limit noise exposure and mandate labeling and provision of information, must provide some incentive to manufacturers, even though these requirements need to be made more relevant to the workplace in some cases.

Incentives for noise control on construction sites in the United States have diminished over the last two decades. The most likely reasons are the closing of EPA's Office of Noise Abatement and the issuance of OSHA's compliance directive for general industry, which effectively raised the PEL to 100 dBA. European directives may provide some incentives to U.S. manufacturers, especially in the form of programs like Germany's Blue Angel. Governmental Buy Quiet programs could also provide some incentive for noise control.

RECOMMENDATIONS

Professionals in industrial hygiene and hearing conservation should make every effort to control excessive noise on construction sites through the purchase of quieter equipment, as well as retrofit and proper maintenance of existing equipment. These efforts would not only conserve hearing but also aid in the prevention of noise-related accidents and fatalities.

Training programs should be developed for workers and contractors that include the importance of communication in the construction workplace, the dangers of overfitting HPDs, and how to tailor HPDs to communication needs. Contractors should be warned that they may have to spend more money on HPDs than they anticipated to ensure worker safety and efficiency, as well as the prevention of noise-induced hearing loss.

Manufacturers of reverse alarms and other warning devices should be encouraged to design their products for maximum audibility in the noise conditions most typical of their use, and to be perceived and understood by workers with noise-induced hearing loss, workers wearing HPDs, and workers under varying degrees of attentional demand. Contractors should be encouraged to purchase warning devices that are suitable for the work environments for which they are intended.

Pressure should be brought to bear on OSHA to move as rapidly as possible to extend the general industry noise regulation, including its amendment for HCPs, to cover construction workers. Although sections of the regulation would need to be tailored specifically to construction, it appears that the necessary knowledge and technology are available.

The agency should also be encouraged to rescind its instruction of Nov. 8, 1983, CPL 2–2.35 and all references to a TWA of 100 dBA in its directives and manuals. This policy was not subject to public notice and comment and provides a powerful disincentive for noise control and the conservation of workers' hearing in all industries, including construction.

Additional noise measurement data are needed on the sound levels of various types of construction equipment and various models within the same type. These data would facilitate the identification of low-noise and high-noise equipment, both for OSHA to assess the technological capabilities of the industry and for the sake of contractors who wish to purchase quieter equipment.

Consideration should be given to the identification and use of a centralized agency (or agencies) in which audiometric test results could be kept on a permanent basis.

The use of "smart cards" to store and transfer audiometric data should be further investigated.

A noise control database for the construction industry needs to be developed. It should include noise sources and levels, recommended treatments, quieted noise levels, estimated costs, and the availability of materials for treatments. The database should be made available electronically as well as on paper, and should be targeted to contractors, worker representatives, professionals in industrial hygiene and noise control, and federal and state compliance officers.

Government agencies should make financial and technical assistance available to organizations that could renew interest in Buy Quiet programs.

Organizations within the United States should obtain information about and publicize the achievements of all companies that currently display Germany's Blue Angel label for quiet equipment.

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APPENDIX A

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- "Availability of Workplace Noise Control Technology of Selected Machines" (1981)
- "A Comparison of Sound Power Levels for Portable Air Compressors Based Upon Test Methodologies Adopted by U.S. EPA and the CEC" (1980)
- "Construction Noise Control Technology Initiatives" (1980)
- "Noise Technology Research Needs and the Relative Roles of the Federal Government and the Private Sector" (1979)
- "Foreign Noise Research in Machinery/Construction Equipment" (1978)
- "Federal Research, Development and Demonstration Programs: Machinery and Construction Noise" (1978)
- "Understanding Noise and Noise Control Instruction Units for Operating Engineers in Apprenticeship Programs" (1978)
- "Proposed Wheel and Crawler Tractor Noise Emission Regulation: Part I, Draft Environmental Impact Statement. Part II, Background Document" (1977)
- "Background Document for Portable Air Compressors" (1976)
- "Background Document for Medium and Heavy Truck Noise Emission Regulations" (1976)
- "Medium and Heavy Truck Noise Emission Standards" (1976)
- "Noise from Construction Equipment and Operations, Building Equipment, and Home Appliances" (1971)

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U.S. Department of Housing and Urban Development
Office of Community Planning and Development

The Noise Guidebook

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The Noise Guidebook

A Reference Document for Implementing the Department of Housing and Urban Development's Noise Policy

Prepared By The Environmental Planning Division,
Office of Environment and Energy

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Preface

Introduction

This *Noise Guidebook* has been prepared to serve as the basic reference document for all HUD field staff who are responsible for implementing the Department's noise policy. It brings together in one place all the various reports, informational papers and other items that have been put out by the Department over the past several years. It also contains several new items designed to make your job easier.

This *Guidebook* is designed to serve not only the experienced HUD staff member but also the new employee or the old employee who is new to the noise field. Because of this, the *Guidebook* contains some fairly basic background material as well as quizzes and other material specifically geared for the "learner."

Chapter 1

Basic Overview of the Environmental Noise Problem

Introduction

Background

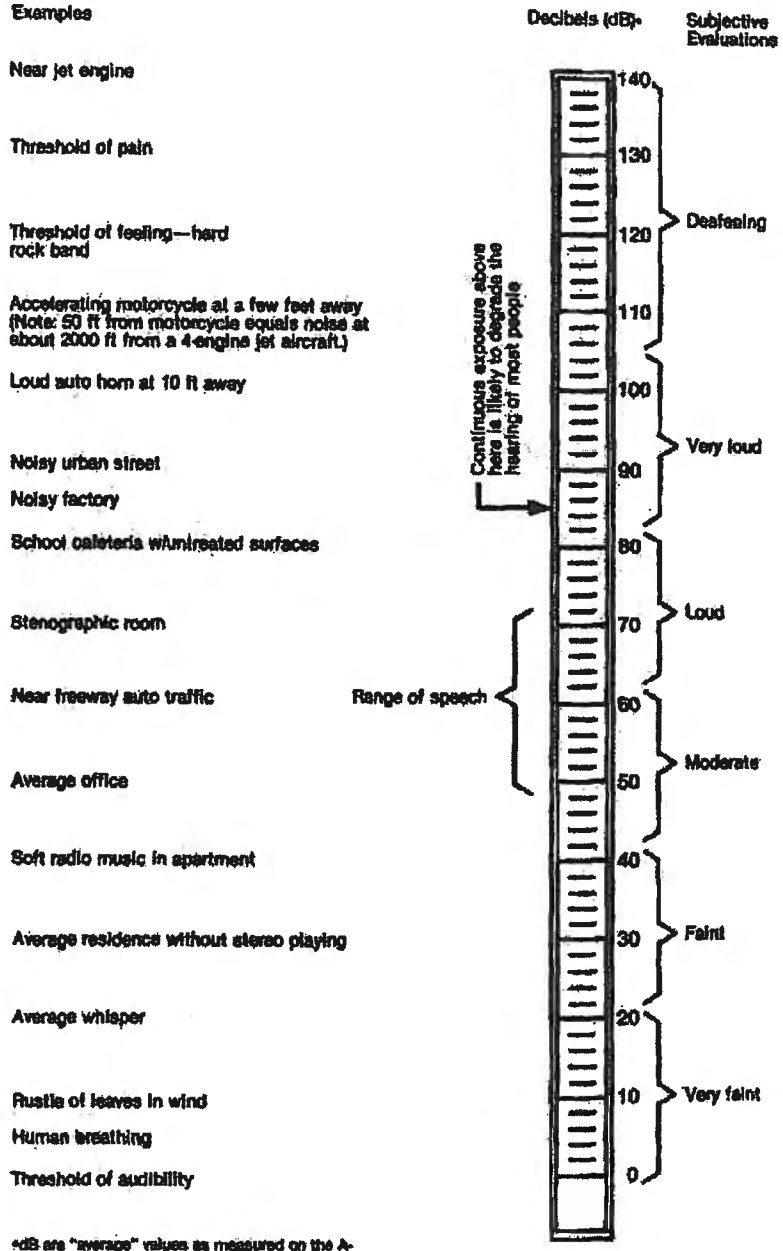
Definition and Scope of the Noise Problem

The air around us is constantly filled with sounds, yet most of us would probably not say we are surrounded by noise. What then is the difference between ordinary sound and what we call noise? The traditional definition of noise is that it is "unwanted sound." Sound becomes unwanted when it either interferes with our normal activities such as sleeping, conversation or recreation, when it causes actual physical harm such as hearing loss or has adverse effects on mental health. As we have become a more urbanized country and as technology has advanced, the level of sound in our environment has reached the point when it sometimes does cause interference and does cause physical and psychological harm, and thus we have developed a noise problem. (See Figure 1 for a listing of common sounds.)

The dimensions of the noise problem have grown larger and larger over the past few decades. In its 1979 Annual Report, The Council on Environmental Quality stated that "nearly half the US population is regularly exposed to levels of noise that interfere with ...normal activities" and about "1 in 10 ...are exposed to noises of duration and intensity sufficient to cause a permanent reduction in their ability to hear."

Figure 1
Common Sounds
Basic Theory: Common Sounds in Decibels (dB)

Some common, easily recognized sounds are listed below in order of increasing sound intensity levels in decibels. The sound levels shown for occupied rooms are typical general activity levels only and do *not* represent criteria for design.



*dB are "average" values as measured on the A-scale of a sound-level meter
(From *Concepts in Architectural Acoustics*: M. David Egan, McGraw Hill, 1972.)

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The Dynamics of the Noise Problem

There are basically two types of noise problems. There is the specific, job related, occupational noise problem created by extremely loud machinery. Then there is the community noise problem where the combined effect of many individual noise sources creates an overall noise level that is unacceptable. In the following pages we will be addressing the community noise problem only.

The main contributors to a community noise problem are transportation sources such as highways, railroads and airports. These sources are the most pervasive and continuing of the noise sources within the community. Of course, at any given site, there may be other noise sources which add to the problem, sources such as jackhammers at a construction site. But in general, and for the purposes of this section, the main concern is with the transportation sources.

The dynamics of a noise problem are based on the relationship between the noise source, the person or place exposed to the noise (hereafter called the receiver) and the path the noise will travel from source to receiver.

The source generates a given amount of noise which travels along the path and arrives at the receiver. The amount of noise will be reduced to some extent as a result of how long that path is or whether there are any barriers along the path. The severity of the impact on the receiver is a function of what type of activity is taking place, whether it is indoors or outdoors, and what type of building it is in if the activity is indoors. Figure 3 contains some basic compatibility guidelines.

The impact of the noise can be altered or mitigated by changing the characteristics of any of the three elements: source, path or receiver. Later on we will look at the various mitigation measures that are possible. Our concern however will be primarily with the receiver and the path. Control of the sources themselves is the specific responsibility of agencies such as the Environmental Protection Agency (EPA) or the Federal Aviation Administration (FAA).

Figure 2
Dynamics of a Noise Problem

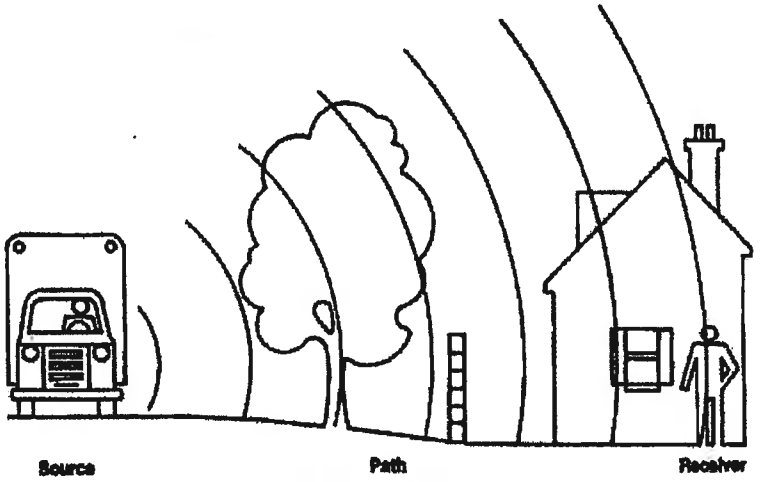

Figure 3
Land Use Compatibility Guidelines

LAND USE CATEGORY	LAND USE INTERPRETATION FOR NEF VALUE* 20	30	40	50
Residential — Single Family, Duplex, Mobile Homes				
Residential — Multiple Family, Dormitories, etc.				
Transient Lodging				
School Classrooms, Libraries, Churches				
Hospitals, Nursing Homes				
Auditoriums, Concert Halls, Music Shells				
Sports Arena, Outdoor Spectator Sports				
Playgrounds, Neighborhood Parks				
Golf Courses, Riding Stables, Water Rec., Cemeteries				
Office Buildings, Personal, Business and Professional				
Commercial — Retail, Movie Theaters, Restaurants				
Commercial — Wholesale, Some Retails, Ind., Mfg., Util.				
Manufacturing, Communication (Noise Sensitive)				
Livestock Farming, Animal Breeding				
Agriculture (except Livestock), Mining, Fishing				
Public Right-of-Way				
Extensive Natural Recreation Areas				

65 75 85
Ldn VALUES

*Ldn = NEF Value + 35

Clearly Acceptable
Normally Unacceptable
Normally Acceptable
Clearly Unacceptable

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The ideal solution to a potential problem is to reduce the noise being produced by the source. The best solution available to HUD, or the community, however, is to make sure that noise sensitive uses are located where they will not be exposed to high noise levels. The next best approach to mitigating noise impact is to attempt to reduce the amount of noise that reaches the receiver. This can be accomplished through the use of barriers such as walls or earthen berms, or combinations of both, along the noise path. If the use of barriers is not possible then the only alternative available is to provide noise reduction measures in any structures associated with the activity so that at least the interior spaces are not exposed to high noise levels. This approach is considered the least desirable because most of the land uses we are concerned about, such as residential, do have outdoor areas and activities associated with them which would remain exposed to high noise levels.

A Note on Descriptors

A key factor in the growth of our ability to evaluate and reduce noise impacts has been the development of better tools to measure and describe the noise levels generated by various sources. The development of better tools (called noise descriptors or metrics) has been particularly important for dealing with community noise problems. Many of the older descriptor systems could only be used for one or two sources such as cars and railroads, but not airplanes. Since the community noise problem very often includes noise from all these sources the lack of an adequate descriptor made it difficult to do an adequate evaluation.

The most advanced descriptor currently in general use is the day night average sound level system, abbreviated as DNL and symbolized mathematically as L_{dn}. The day night average sound level is the 24 hour average sound level, expressed in decibels, obtained after the addition of a 10 decibel penalty for sound levels which occur at night between 10 PM and 7 AM. This nighttime penalty is based on the fact that many studies have shown that people are much more disturbed by noise at night than at any other time. This is not unusual in that background noise is often much less at night and also people tend to be doing very noise sensitive things at night, such as trying to sleep.

Another feature of the DNL system that is very important is that it can be used to describe noise from all sources. Thus, using the DNL system, we can describe the total noise exposure at a site, something many other descriptor systems couldn't do.

The DNL system has been adopted by the EPA, the Department of Defense (DOD) and HUD, and more recently by the FAA, specifically for describing environmental impacts for airport actions. We expect that very soon it will be in almost universal use in the U.S.

Issues

The main issues involved in any noise analysis can be summarized briefly.

- How much noise is a site exposed to
- What types of activities are being affected and how severely
- Is it reasonable to redesign the site to relocate noise sensitive activities
- And, if not, how much protection can be provided through various attenuation measures.

Your approach to these issues will be affected in many ways by the location of the project in question. Projects in suburban or rural areas can be approached differently because the available mitigation options are greater and often the noise exposure itself is not so severe. In urban situations, however, the noise exposure is often more severe but at the same time the options for mitigation or resiting are more limited. In the urban setting innovative design and the use of advanced attenuation measures becomes critical. Fortunately our experience has shown that good design and construction can relieve or substantially reduce major noise problems.

Legal Provisions

General Legislation and Background

The Federal legislation which addresses noise issues is somewhat different from other environmental legislation. The Clean Air Act, for example, required the Environmental Protection Agency to set up actual mandatory standards for air quality which were supposed to be met by all jurisdictions. EPA even has the authority to take punitive steps against cities which are not making "reasonable further progress" towards achieving these air quality goals. There is no similar legislation that covers noise. The approach has been to tackle the noise problem at the source by controlling the amount of noise that can be emitted by the individual airplane engine or the individual jackhammer. Agencies like HUD or the Farmers Home Administration have developed regulations which are related to the overall community noise level, but they only affect their own programs and are not binding on local communities. The Veterans Administration program only relates to aircraft noise and also only affects its own programs.

The major pieces of Federal legislation related to noise include:

The Noise Control Act of 1972 directed EPA to promote an environment for all Americans free from noise that jeopardizes their health and welfare. It also included a requirement for EPA to set a criterion for noise level adequate to protect health and welfare with an adequate margin of safety but without regard to cost or feasibility.

Quiet Communities Act of 1978 amended The Noise Control Act of 1972 to encourage noise control programs at the State and community level.

Federal Aid Highway Act of 1970 established the requirement that noise control be a part of the planning and design of all federally aided highways.

Aviation Safety and Noise Abatement Act of 1979 requires FAA to develop a single system for measuring noise at airports and under certain conditions to prepare and publish noise maps.

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HUD Regulations

While the Department of Housing and Urban Development has no specific responsibility to try to reduce the noise problem at the source the way the Environmental Protection Agency and the Federal Aviation Administration do, it does have the responsibility to be aware of the noise problem and its impact on the housing environment. The most basic mandate which drives the Department's involvement with the noise issue is the Housing Act of 1949 (Public Law 81-171) which sets forth the national goal of "a decent home and suitable living environment for every American family." This goal was affirmed by the Housing and Urban Development Act of 1968 (Public Law 90-448). The Department was tasked by the Housing and Urban Development Act of 1965 (Public Law 89-117) "to determine feasible methods of reducing the economic loss and hardships suffered by homeowners as a result of the depreciation in the value of their properties following the construction of airports in the vicinity of their homes." The Noise Control Act of 1972, in addition to its specific tasking to EPA, tasked all Federal agencies to administer their programs in ways which reduce noise pollution. Finally, the Department is tasked by Federal Management Circular 75-2: *Compatible Land Uses at Federal Airfields* to make sure that its actions do not promote incompatible land uses around Federal airfields.

All of these legislative and regulatory mandates combine to create a serious requirement for the Department of Housing and Urban Development to be aware of the problem of noise and to take positive steps to protect residential and other sensitive land uses from high noise levels.

The Department of Housing and Urban Development first issued formal requirements related specifically to noise in 1971 (HUD Circular 1390.2). These requirements contained standards for exterior noise levels along with policies for approving HUD supported or assisted housing projects in high noise areas. In general the requirements established three zones: an acceptable zone where all projects could be approved, a normally unacceptable zone where mitigation measures would be required and where each project would have to be individually evaluated for approval or denial, and an unacceptable zone in which projects would not, as a rule, be approved.

In 1979, the Department issued revised regulations (24 CFR Part 51B) which kept the same basic standards but adopted new descriptor systems which were considerably advanced over those in use under the old requirements.

HUD's regulations also require that recipients of Community Development Block Grants (CDBG) and Urban Development Action Grants (UDAG) take into consideration the noise criteria and standards in the environmental review process and consider ameliorative actions when noise sensitive land developments are proposed in noise exposed areas. If CDBG or UDAG activities are planned in a noisy area, and HUD assistance is contemplated later for housing and/or other noise sensitive activities, the HUD standards must be met for those activities.

Project Analysis

General

While most of the analysis for noise focuses on noise sources located around the project site, there are some characteristics of the project itself that you should know about. These characteristics will help you to determine what is called the noise assessment location (NAL) for site analysis. (The NAL is a representative point (or points) on the site where significant noise exposure is expected. All distances, etc. are measured from the NAL). This information will also be helpful later in evaluating the potential for mitigating or reducing the impact of noise. All of this data should be available from preliminary plans and specifications. If not, a quick phone call to the developer/sponsor should get you all the information you need.

Data Required

- Location of outdoor noise sensitive uses relative to the noise source.
- Location of buildings containing noise sensitive activities.
- Location of other buildings, particularly ones which might serve to shield sensitive buildings or areas from the noise source.
- Design and construction features of buildings, particularly features such as use of central air conditioning which could provide noise reduction benefits by permitting windows to be kept closed.

Analysis of Site and Environs

General

The primary focus of this impact analysis is on noise sources and the primary item to be determined is the noise level created by those sources. In many instances, particularly with airports, data on the noise levels generated by the source will have already been prepared by another agency such as the airport operator, the local or State highway/transportation department or other similar agency. (Figure 4 shows typical airport noise contours.) In those cases no site or environs analysis is necessary and one can proceed directly to impact analysis. For those instances where there are no current data already prepared, the Department of Housing and Urban Development has developed a handbook called the *Noise Assessment Guidelines* which contains a detailed desk top methodology for use by individuals to determine noise impacts (see Chapter 5). Included in the handbook is a complete listing of the data about the site and its environs that are necessary to conduct an analysis. We don't want to repeat all the detailed requirements here, but the following are some of the types of information you would have to collect if you were to do your own analysis. You might note that most of the information is related to the noise sources themselves.

For the purpose of analysis, the *Noise Assessment Guidelines* require that you consider all military/civilian airports within 15 miles of the project, all significant roads within 1000 feet and basically all railroads within 3000 feet.

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Types of Data Required

- Number and type of vehicles
- Operational data:
  — speed
  — daytime/nighttime split
- Conditions where the vehicles are operated, i.e., freely flowing traffic versus stop and go, level versus hilly, welded railroad track versus bolted railroad track.

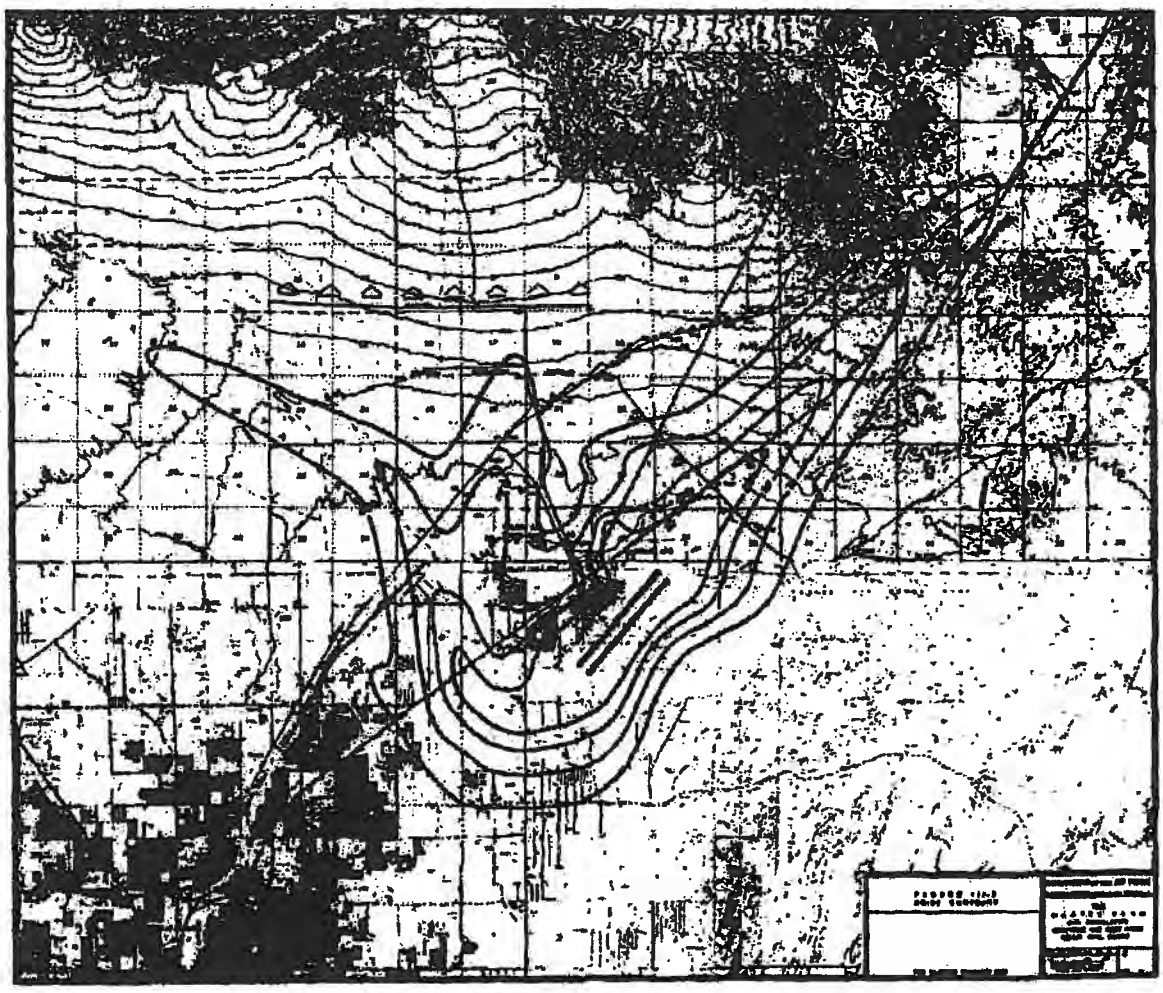
The *Noise Assessment Guidelines* contain guidance on sources for this data. Most of them are obtained from the "operator" of the transportation source. The *Guidelines* also contains model figures which can be used when actual data is unavailable. For example, if the actual number of vehicles traveling at night is not available then the *Guidelines* state that a figure of 15% should be used. Thus it is possible to make reasonably accurate noise level determinations even if some information is not available.

Determination of Impact

General

The specific procedures for determining the noise exposure levels for a site are clearly spelled out in the *Noise Assessment Guidelines*. The process is a fairly simple one in which the noise level from each source affecting the site is calculated and then combined to derive the overall exposure. If some kind of barrier exists or is proposed, the noise levels can be adjusted to reflect the mitigation provided by the barrier. The overall noise level is then compared to HUD's standards and the appropriate action, as spelled out in the regulations, is taken.

Figure 4
Noise Contours



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Evaluation of Impact

HUD Regulations set forth the following exterior noise standards for new housing construction assisted or supported by the Department:

65 L_{dn} or less – Acceptable

Exceeding 65 L_{dn} but not exceeding 75 L_{dn} – Normally Unacceptable – appropriate sound attenuation measures must be provided: 5 decibels attenuation above the attenuation provided by standard construction required in 65 L_{dn} to 70 L_{dn} zone; 10 decibels additional attenuation in 70 L_{dn} to 75 L_{dn} zone.

Exceeding 75 L_{dn} – Unacceptable

HUD's regulations do not contain standards for interior noise levels. Rather a goal of 45 decibels is set forth and the attenuation requirements are geared towards achieving that goal. It is assumed that with standard construction any building will provide sufficient attenuation so that if the exterior level is 65 L_{dn} or less, the interior level will be 45 L_{dn} or less.

Once you have determined the overall noise exposure for the site you compare it to the above standards. If the overall site exposure is 65 L_{dn} or less the project is acceptable. If the exposure is between 65 L_{dn} and 75 L_{dn} you should consider alternative locations or providing adequate attenuation with the first preference, as we've noted, being for the construction of some kind of barrier to prevent noise from reaching the site. If providing adequate attenuation is impossible or impractical then the project should be considered unacceptable.

Suggested Mitigation

General Considerations

As discussed briefly earlier, there are three basic approaches for mitigating the high noise exposures. The first and best is to relocate noise sensitive uses out of the high noise area. The second is to prevent noise from reaching the noise sensitive user through some sort of barrier. And the third, and least desirable approach, is to provide attenuation for at least the interiors of any buildings located in the high noise areas.

Specific Considerations

Relocating Noise Sensitive Uses

By far the most desirable mitigation approach is to relocate noise sensitive uses out of the high noise area although. If the site is large enough it may be possible to locate non-noise sensitive uses between the source and the sensitive use, for example a parking lot might be located between a road and a park (see Figure 6). The workcharts in the *Noise Assessment Guidelines* can be used in reverse to tell you exactly how far away from the noise source you need to be.

When sites are small, very dense or when the source affects the entire site it is very difficult to mitigate by changing the site plan. Then the next option must be considered: erecting some type of barrier between the source and the receiver.

Barriers

Barriers are most effective for at or below ground level sources. They have no effect on noise from aircraft overflights and are limited in practical application with elevated sources such as elevated trains. The key to the effectiveness of a barrier is whether or not it breaks the line of sight between the source and the receiver. If a barrier does not completely break the line of sight either because it is not high enough, or not long enough then its effectiveness is greatly reduced.

Barriers can be actual walls, earthen mounds (called berms) or even other buildings. The use of other non-noise sensitive buildings as barriers is a particularly good approach in that it need not add to the cost of the project and may not create the aesthetic problem a large wall might create (see Figure 6).

Figure 6
The Audible Landscape

In cluster development, open space can be placed near the highway to reduce noise impacts on residences

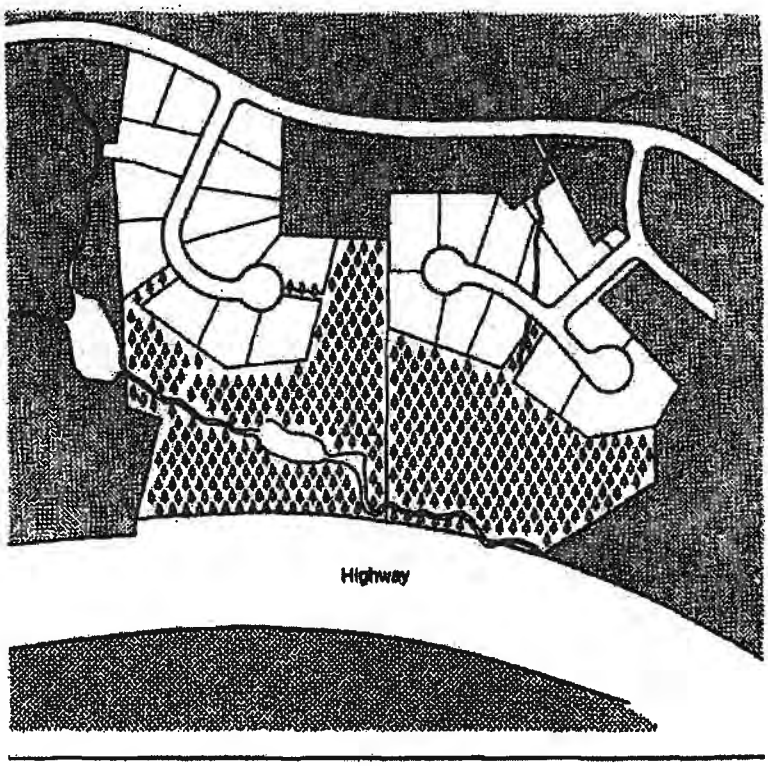

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Figure 6
The Audible Landscape

Placement of noise compatible land uses near highway in Planned Unit Development

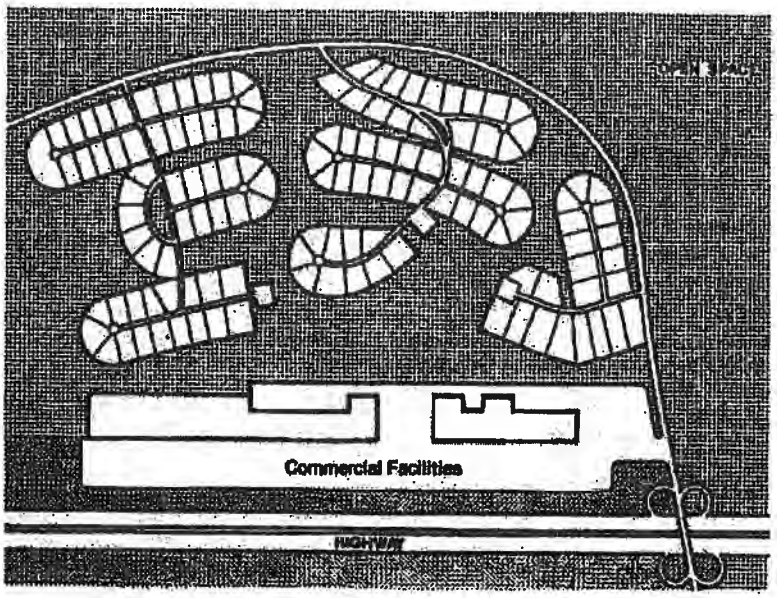
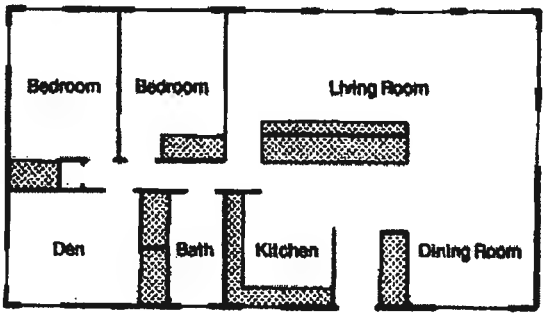


Figure 7
The Audible Landscape

Use of acoustical architectural design to reduce noise impacts on more noise sensitive living spaces



Highway

As pointed out earlier, the effectiveness of a barrier is determined in large part by its height and length. Some studies have shown that the effectiveness of a barrier can be reduced by as much as 50% if it isn't long enough. Again, the *Noise Assessment Guidelines* contain procedures for determining the effectiveness of barriers.

Incorporating Noise Attenuation Measures into the Building

If neither relocation or barriers is a reasonable noise attenuation option, the last resort is to incorporate noise attenuation measures into the buildings themselves. This is not considered the best solution because it leaves the outdoor areas, some of which may be for quiet recreation, exposed to high noise levels. But if development must take place and barriers are impossible, then the noise attenuation measures should be employed in building design and construction.

Without going into great technical detail, noise attenuation construction measures generally fall into four categories.

(1) Reducing the total area of windows or other acoustically weaker building elements

(2) Sealing off "leaks" around windows, doors, vents.

(3) Improving the actual sound attenuating properties of small building elements such as windows, doors, etc.

(4) Improving the actual sound attenuating properties of major building elements such as roof and wall construction.

In addition, noise attenuation in buildings can be provided by designing interior spaces so that "dead" spaces such as closets or corridors act as buffer zones (see Figure 7). And finally noise attenuation can be provided by reducing the need for open windows by providing air conditioning.

Many of the steps that would be taken to provide noise attenuation also help conserve energy. Good weatherstripping around windows and doors is one example. Another might be reducing window areas in walls if the noise source is to the north or west. Because many of these measures serve two purposes, they should not necessarily be considered a burdensome requirement but rather just good design and construction.

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Information Resources

Publications

HUD Regulation 24 CFR Part 51 Subpart B – Noise Abatement and Control.

Noise Assessment Guidelines, HUD 1983, basic technical procedural resource.

Aircraft Noise Impact, HUD 1972, a bit dated but good overview of problem.

The Audible Landscape, DOT (FHWA) 1974, an excellent discusson of mitigation measures including land use planning and building design and construction.

Information on Levels of Environmental Noise Requisite to Protect Public health and Welfare With an Adequate margin of Safety, EPA, 1974. The "levels document" that explains basis for EPA standards.

Noise Barrier Design Handbook, Federal Highway Administration 1976. Good discussion of barriers, technical but readable.

Handbook of Noise Control, 2nd edition, 1979, McGraw Hill. A basic technical handbook covering all aspects of noise for those who wish to go into the subject further.

Experts

HUD environmental officers have been trained in the use of the *Noise Assessment Guidelines* and can help you work with them. Many architects are trained in acoustics and can help in development of noise attenuation strategies.

Quiz

Questions

1. Why is noise considered "unwanted sound"?
2. What is a community noise problem?
3. What are the three main contributors to a community noise problem?
4. What are the three components of a noise problem?
5. What are two key characteristics of the day-night average sound level descriptor system?
6. What are HUD's noise standards?
7. How do HUD's standards apply to CDBG recipients?
8. What are the three general mitigation measures available to HUD and the community and in what order of preference?
9. When are barriers effective and when are they not effective?
10. Describe how the *Noise Assessment Guidelines* can be used to determine appropriate mitigation measures.

Quiz

Answers

1. because it interferes with normal activities or causes physical or psychological damage
2. a community noise problem is where the combined effect of many individual sources creates an overall noise level that is unacceptable
3. highways, railroads and aircraft
4. the source, the path, the receiver
5. it is an average sound level and it can be used for all sources
6. 65 L_{dn} or below: Acceptable
   65 to 75 L_{dn}: Normally unacceptable, noise attenuation measures required,
   above 75 L_{dn}: Unacceptable
7. CDBG recipients must take into consideration the standards in their planning and environmental review, if they expect to use HUD assistance later for housing or other noise sensitive activities the standards must be met for those activities.
8. 1st relocate noise sensitive uses
   2nd reduce noise reaching receiver
   3rd redesign buildings
9. barriers are effective for at or below ground level sources. Are not effective for aircraft overflights or most elevated sources
10. can be used to determine separation distance required for relocation and the height and length of barriers required

Chapter 2

The Noise Regulation

Introduction

The basic foundation for and structure of the HUD noise program is set out in the noise regulation, 24 CFR 51B. The regulation establishes the actual standards, assigns implementation responsibilities, describes review and approval procedures, and identifies special situations which may warrant waivers of procedures or standards. Therefore, the key to your understanding and implementation of the HUD noise program is a clear understanding of the regulation.

There is no way to escape the task of sitting down and simply reading the regulations, over and over until you thoroughly understand them. We have however done two things that will help you apply the regulations. First, for quick reference, we have prepared a list of the key sections in the regulation and second we have prepared an annotated copy of the regulation.

The list of key sections was prepared to help you find the specific section you need for a specific question or issue. While the regulation itself is not really long, an index is always useful. We caution you, however, against using the index to avoid learning the regulations. The list was prepared for your convenience in applying the regulation once you have come to understand it.

We prepared the annotated regulation because, try as we might, it was impossible to anticipate all the questions, implementation problems and special situations that might arise and to address them in the regulation. So, now that we have had a few years' experience with the regulation, we have gathered together the important questions, notes, second thoughts etc. and prepared this annotated regulation. We hope it will give you further insight into what the regulation means when it is applied in the field.

Key Sections in Noise Regulation

Section	Subject
51.101(a)(2)	Application of Policy to Block Grants
51.101(a)(3)	Policy for New Construction
51.101(a)(4)	Policy for Existing Construction
51.101(a)(5)	Policy for Modernization and Rehabilitation
51.101(a)(8)	The Exterior Noise Goal
51.101(a)(9)	The Interior Noise Goal
51.102(a)	Authority to Approve Projects
51.103(a)	Identification of DNL as *The* Noise Descriptor to be Used
51.103(b)	How to Measure Loud Impulsive Noises
51.103(c)	The Noise Standards
51.104(a)	Attenuation Requirements Discussed
51.104(b)(1)	Special Approval and Environmental Review Requirements for the Normally Unacceptable Zone
51.104(b)(2)	Special Approval and Environmental Review Requirements for the Unacceptable zone
51.105(a)	Flexibility for Non-acoustic Benefits Provisions
51.106(a)	How to Tell if Existing Data on Noise Are Acceptable
51.106(a)(4)	Specific Review and Approval Procedures For Airport Noise Contours
51.106(d)	When Noise Measurements May be Used Instead of Calculated Levels
51.106(f)	When to Give Credit for Proposed Barriers

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Federal Register / Vol. 44, No. 235 / Thursday, July 12, 1979 / Rules and Regulations 40861

Part 51—Environmental Criteria and Standards

Subpart A—General Provisions

Sec.
§51.1 Purpose.
§51.2 Authority.
§51.3 Responsibilities.
§51.4 Program coverage.
§51.5 Coordination with environmental clearance requirements.
§51.6 [Reserved]

Subpart B—Noise Abatement and Control

§51.100 Purpose and authority.
§51.101 General policy.
§51.102 Responsibilities.
§51.103 Criteria and standards.
§51.104 Special requirements.
§51.105 Exceptions.
§51.106 Implementation.

Appendix to Subpart B

Authority: Sec. 7(d), Department of HUD Act (42 U.S.C. 3535(d)).

Subpart B—Noise Abatement and Control

This regulation replaces HUD Circular 1390.2, Noise Abatement and Control, 1971, which is now cancelled, along with all instructions and clarifying memoranda pertaining to the circular.

§51.100 Purpose and authority.

(a) *Purpose.* The Department of Housing and Urban Development finds that noise is a major source of environmental pollution which represents a threat to the serenity and quality of life in population centers and that noise exposure may be a cause of adverse physiological and psychological effects as well as economic losses.

It is the purpose of this Subpart to:

(1) Call attention to the threat of noise pollution;

(2) Encourage the control of noise at its source in cooperation with other Federal departments and agencies;

(3) Encourage land use patterns for housing and other noise sensitive urban needs that will provide a suitable separation between them and major noise sources;

(4) Generally prohibit HUD support for new construction of noise sensitive uses on sites having unacceptable noise exposure;

(5) Provide policy on the use of structural and other noise attenuation measures where needed; and

(6) Provide policy to guide implementation of various HUD programs.

(b) *Authority.* Specific authorities for noise abatement and control are contained in:

(1) The Noise Control Act of 1972 (Pub. L. 92-574) which directs Federal agencies to administer their programs in ways which reduce noise pollution.

(2) The Quiet Communities Act of 1978 (Pub. L. 95-609) which amended Pub. L. 92-574.

(3) The General Services Administration, Federal Management Circular 75-2: *Compatible Land Uses at Federal Airfields* prescribes the Executive Branch's general policy with respect to achieving compatible land uses on either public or privately owned property at or in the vicinity of Federal airfields.

(4) Section 1113 of the Housing and Urban Development Act of 1965 (Pub. L. 89-117) directs the Secretary "* * * to determine feasible methods of reducing the economic loss and hardships suffered by homeowners as a result of the depreciation in the value of their properties following the construction of airports in the vicinity of their homes, including a study of feasible methods of insulating such homes from the noise of aircraft."

§51.101 General policy.

(a) It is HUD's general policy to provide minimum national standards applicable to HUD programs to protect citizens against excessive noise in their communities and places of residence.

(1) *Comprehensive planning assistance.* HUD requires that grantees give adequate consideration to noise exposures and sources of noise as an integral part of the urban environment in HUD assisted comprehensive planning, as follows:

(i) Particular emphasis shall be placed on the importance of compatible land use planning in relation to airports, highways and other sources of high noise.

(ii) Applicants shall take into consideration HUD environmental standards impacting the use of land as required in 24 CFR Part 600.

(iii) Environmental studies, including noise assessments, are allowable costs.

(2) *Community Development Block Grants.* Recipients of community development block grants under the Housing and Community Development Act of 1974 (Pub. L. 93-383), as amended by the Housing and Community Development Act of 1977 (Pub. L. 95-128), must take into

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consideration the noise criteria and standards in the environmental review process and consider ameliorative actions when noise sensitive land development is proposed in noise exposed areas. Grant recipients shall address deviations from the standards in their environmental reviews as required in 24 CFR Part 58.

Where CDBG activities are planned in a noisy area, and HUD assistance is contemplated later for housing and/or other noise sensitive activities, the CDBG grantee risks denial of the HUD assistance unless the HUD standards are met. Environmental studies, including noise assessments, are allowable costs.

(3) *HUD support for new construction.* HUD assistance for the construction of new noise sensitive uses is prohibited generally for projects with Unacceptable noise exposures and is discouraged for projects with Normally Unacceptable noise exposure. (Standards of acceptability are contained in §51.103(c).) This policy applies to all HUD programs providing assistance, subsidy or insurance for housing, college housing, mobile home parks, nursing homes, hospitals, and all programs providing assistance or insurance for land development, new communities, redevelopment or any other provision of facilities and services which are directed to make land available for housing or noise sensitive development. The policy does not apply to research demonstration projects which do not result in new construction or reconstruction, flood insurance, interstate land sales registration, or any action or emergency assistance under disaster assistance programs which are provided to save lives, protect property, protect public health and safety, remove debris and wreckage, or assistance provided that has the effect of restoring facilities substantially as they existed prior to the disaster.

(4) *HUD support for existing construction.* Noise exposure by itself will not result in the denial of HUD support for the resale and purchase of otherwise acceptable existing buildings. However, environmental noise is a marketability factor which HUD will consider in determining the amount of insurance or other assistance that may be given.

Existing construction means units which are either more than 1 year old or for which this is the second or subsequent purchaser.

The old definition of major or substantial rehabilitation and modernization as being any project where cost is 75% or more of replacement cost no longer applies. Now the criteria contained in individual program guidance applies.

(5) *HUD support of modernization and rehabilitation.* For modernization projects located in all noise exposed areas, HUD shall encourage noise attenuation features in alterations. For major or substantial rehabilitation projects in the Normally Unacceptable and Unacceptable noise zones, HUD actively shall seek to have project sponsors incorporate noise attenuation features, given the extent of the rehabilitation being undertaken and the level of exterior noise exposure. In Unacceptable noise zones, HUD shall strongly encourage conversion of noise-exposed sites to land uses compatible with the high noise levels.

(6) *Research, guidance and publications.* HUD shall maintain a continuing program designed to provide new knowledge of noise abatement and control to public and private bodies, to develop improved methods for anticipating noise encroachment, to develop noise abatement measures through land use and building construction practices, and to foster better understanding of the consequences of noise. It shall be HUD's policy to issue guidance documents periodically to assist HUD personnel in assigning an acceptability category to projects in accordance with noise exposure standards, in evaluating noise attenuation measures, and in advising local agencies about noise abatement strategies. The guidance documents shall be updated periodically in accordance with advances in the state-of-the-art.

(7) *Construction equipment, building equipment and appliances.* HUD shall encourage the use of quieter construction equipment and methods in population centers, the use of quieter equipment and appliances in buildings, and the use of appropriate noise abatement techniques in the design of residential structures with potential noise problems.

(8) *Exterior noise goals.* It is a HUD goal that exterior noise levels do not exceed a day-night average sound level of 55 decibels. This level is recommended by the Environmental Protection Agency as a goal for outdoors in residential areas. The levels recommended by EPA are not standards and do not take into account cost or feasibility. For the purposes of this regulation and to meet other program objectives, sites with a day-night average sound level of 65 and below are acceptable and are allowable (see Standards in §51.103(c)).

(9) *Interior noise goals.* It is a HUD goal that the interior auditory environment shall not exceed a day-night average sound level of 45 decibels. Attenuation measures to meet these interior goals shall be employed where feasible. Emphasis shall be given to noise sensitive interior spaces such as bedrooms. Minimum attenuation requirements are prescribed in §51.104(a).

(10) *Acoustical privacy in multifamily buildings.* HUD shall require the use of building design and acoustical treatment to afford acoustical privacy in multifamily buildings pursuant to requirements of the Minimum Property Standards.

§51.102 Responsibilities.

(a) *Authority to approve projects.* (1) Decisions on proposed projects with acceptable noise exposures shall be delegated to the program personnel within field offices, including projects where increased noise levels are considered acceptable because of non-acoustic benefits under §51.105(a). Field office program personnel may also approve projects in normally unacceptable noise exposed areas where adequate sound attenuation is provided and where the project does not require an Environmental Impact Statement under §51.104(b).

(2) Other approvals in normally unacceptable noise exposed areas require the concurrence of the Regional Administrator.

(3) Requests for approvals of projects or portions of projects with unacceptable noise exposures shall be referred through the Regional Office to the Assistant Secretary for Community Planning and Development for approval pursuant to §51.104(b).

The Noise Control Act of 1972 required EPA to "publish information on the levels of environmental noise. . .which. . .are requisite to protect the public health and welfare with an adequate margin of safety." EPA has interpreted this to mean that the levels should not reflect technical feasibility or economic costs. "Health and welfare" is defined as being "complete physical, mental and social well-being and not merely the absence of disease and infirmity."

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(4) In cases where the Regional Administrator determines that an important precedent or issue is involved, such cases shall be referred with recommendations to the Assistant Secretary for Community Planning and Development.

(b) *Surveillance of noise problem areas.* Appropriate field staff shall maintain surveillance of potential noise problem areas and advise local officials, developers, and planning groups of the unacceptability of sites because of noise exposure at the earliest possible time in the decision process. Every attempt shall be made to insure that applicants' site choices are consistent with the policy and standards contained herein.

(c) *Notice to applicants.* At the earliest possible stage, HUD program administrators shall:

(1) Determine the suitability of the acoustical environment of proposed projects;

(2) Notify applicants of any adverse or questionable situations; and

(3) Assure that prospective applicants are apprised of the standards contained herein so that future site choices will be consistent with these standards.

(d) *Technical assistance.* Technical assistance in the measurement, estimation, interpretation, or prediction of noise exposure is available from the Office of Community Planning and Development and the Office of Policy Development and Research. Field office questions shall be forwarded through the Regional Office to the Assistant Secretary for Community Planning and Development or his designee.

(e) *Interdepartmental coordination.* Regional Administrators shall foster appropriate coordination between field offices and other departments and agencies, particularly the Environmental Protection Agency, the Department of Transportation, Department of Defense representatives, and the Veterans Administration. HUD staff shall utilize the acceptability standards in commenting on the prospective impacts of transportation facilities and other noise generators in the Environmental Impact Statement review process.

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§51.103 Criteria and standards.

These standards apply to all programs as indicated in §61.101.

(a) *Measure of external noise environments.* The magnitude of the external noise environment at a site is determined by the value of the day-night average sound level produced as the result of the accumulation of noise from all sources contributing to the external noise environment at the site. Day-night average sound level, abbreviated as DNL and symbolized as L_{dn}, is the 24-hour average sound level, in decibels, obtained after addition of 10 decibels to sound levels in the night from 10 p.m. to 7 a.m. Mathematical expressions for average sound level and day-night average sound level are stated in the Appendix.

(b) *Loud impulsive sounds.* On an interim basis, when loud impulsive sounds, such as explosions or sonic booms, are experienced at a site, the day-night average sound level produced by the loud impulsive sounds alone shall have 8 decibels added to it in assessing the acceptability of the site (see Appendix). Alternatively, the C-weighted day-night average sound level (L_{Cdn}) may be used without the 8 decibel addition, as indicated in Section 51.106(a)(3).

Methods for assessing the contribution of loud impulsive sounds to day-night average sound level at a site and mathematical expressions for determining whether a sound is classed as "loud impulsive" are provided in the Appendix.

(c) *Exterior standards.* The degree of acceptability of the noise environment at a site is determined by the sound levels external to buildings or other facilities containing noise sensitive uses. The standards shall usually apply at a location 2 meters (6.5 feet) from the building housing noise sensitive activities in the direction of the predominant noise source. Where the building location is undetermined, the standards shall apply 2 meters (6.5 feet) from the building setback line nearest to the predominant noise source. The standards shall also apply at other locations where it is determined that quiet outdoor space is required in an area ancillary to the principal use on the site.

The noise environment inside a building is considered acceptable if (a) the noise environment external to the building complies with these standards, and (b) the building is constructed in a manner common to the area or, if of uncommon construction, has at least the equivalent noise attenuation characteristics.

This is because the reverberation effect of sound waves hitting the wall will increase the noise levels at the site. You won't pick this up unless you back off from the wall to measure.

Site Acceptability Standards

	Day-night average sound level (in decibels)	Special approvals and requirements
Acceptable	Not exceeding 65 dB(1)	None
Normally Unacceptable	Above 65 dB but not exceeding 75 dB	Special Approvals (2) Environmental Review (3) Attenuation (4)
Unacceptable	Above 75 dB	Special Approvals (2) Environmental Review (3) Attenuation (5)

Notes.—(1) Acceptable threshold may be shifted to 70 dB in special circumstances pursuant to Section 51.105(a)

(2) See Section 51.104(b) for requirements.

(3) See Section 51.104(b) for requirements.

(4) 5 dB additional attenuation required for sites above 65 dB but not exceeding 70 dB and 10 dB additional attenuation required for sites above 70 dB but not exceeding 75 dB. (See Section 51.104(a).)

(5) Attenuation measures to be submitted to the Assistant Secretary for CPD for approval on a case-by-case basis.

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§51.104 Special requirements.

(a) *Noise attenuation.* Noise attenuation measures are those required in addition to attenuation provided by buildings as commonly constructed in the area, and requiring open windows for ventilation. Measures that reduce external noise at a site shall be used wherever practicable in preference to the incorporation of additional noise attenuation in buildings. Building designs and construction techniques that provide more noise attenuation than typical construction may be employed also to meet the noise attenuation requirements.

(1) *Normally Unacceptable noise zone.* Approvals in this zone require a minimum of 5 decibels additional sound attenuation for buildings having noise-sensitive uses if the day-night average sound level is greater than 65 decibels but does not exceed 70 decibels, or a minimum of 10 decibels of additional sound attenuation if the day-night average sound level is greater than 70 decibels but does not exceed 75 decibels.

(2) *Unacceptable noise zone.* Noise attenuation measures require the approval of the Assistant Secretary for Community Planning and Development (See §51.104(b)(2).)

(b) *Special Approvals and Environmental Review Requirements.* Environmental clearances shall be conducted pursuant to the requirements of HUD's Departmental Policies, Responsibilities and Procedures for Protection and Enhancement of Environmental Quality (38 FR 19182 as amended) or other environmental regulations which may be issued by the Department. The Special Clearance and Environmental Impact Statement (EIS) threshold requirements are hereby modified for all projects proposed in the Normally Unacceptable and Unacceptable noise exposure zones as follows:

(1) *Normally Unacceptable noise zone.* (i) All projects located in the Normally Unacceptable Noise Zone require a Special Environmental Clearance except an EIS is required for a proposed project located in a largely undeveloped area, or where the HUD action is likely to encourage the establishment of incompatible land use in this noise zone.

Berms and barriers are our first choice because they provide protection for yards, playgrounds, etc. Since outdoor activity is often very important to residents we want to protect the outdoor areas as much as possible.

By definition a barrier must be separate from the building or area it is providing attenuation for. After all barriers are preferred because they improve exterior as well as interior levels. Non-noise sensitive buildings can, however, be used as barriers for noise sensitive buildings or exterior areas.

Assumption is that standard construction provides an average of 20 L_{dn} attenuation. At 65 L_{dn} or below this amount of attenuation would be sufficient to meet interior level of 45 L_{dn}. Additional requirements are designed to meet this goal even when exterior noise levels are higher.

Substitute Environmental Assessment (with ECO concurrence) wherever you see Special Clearance.

(ii) When an EIS is required, the concurrence of the Regional Administrator is also required before a project can be approved. For the purposes of this paragraph, an area will be considered as largely undeveloped unless the area within a 2-mile radius of the project boundary is more than 50 percent developed for urban uses and infrastructure (particularly water and sewers) is available and has capacity to serve the project.

(iii) All other projects in the Normally Unacceptable zone require a Special Environmental Clearance, except where an EIS is required for other reasons pursuant to HUD environmental policies.

(2) *Unacceptable noise zone.* An EIS is required prior to the approval of projects with unacceptable noise exposure. Projects in or partially in an Unacceptable Noise Zone shall be submitted through the Regional Administrator to the Assistant Secretary for Community Planning and Development for approval. The Assistant Secretary may waive the EIS requirement in cases where noise is the only environmental issue and no outdoor sensitive activity will take place on the site. In such cases, a Special Environmental Clearance is required.

When the area in question is in a small community outside an SMSA and the application of the 2 mile radius rule would be unreasonable, an area can be considered largely developed if it is contiguous to existing development and infrastructure is available and has capacity to serve the project. The Assistant Secretary will review them on a case-by-case basis. In all other cases the 2 mile radius/50% rule still applies.

§51.105 Exceptions.

(a) *Flexibility for non-acoustic benefits.* Where it is determined that program objectives cannot be achieved on sites meeting the acceptability standard of 65 decibels, the Acceptable Zone may be shifted to L_{dn} 70 on a case-by-case basis if all the following conditions are satisfied:

(1) The project does not require an Environmental Impact Statement under provisions of section 104(b)(1) and noise is the only environmental issue.

(2) The project has received a Special Environmental Clearance and has received the concurrence of the Environmental Clearance Officer.

(3) The project meets other program goals to provide housing in proximity to employment, public facilities and transportation.

(4) The project is in conformance with local goals and maintains the character of the neighborhood.

(5) The project sponsor has set forth reasons, acceptable to HUD, as to why the noise attenuation measures that would normally be required for new construction in the L_{dn} 65 to L_{dn} 70 zone cannot be met.

Caution—every effort should be made to get official contours—particularly for military installations and large air carrier airports rather than trying to use the *Noise Assessment Guidelines*.

What this really means is that the 5db attenuation requirement for the 65–70 L_{dn} zone is waived. Primarily intended for urban areas where alternative sites are not available. Note that *all* conditions must be met.

These requirements are very important. Be careful with design hour values.

(6) Other sites which are not exposed to noise above L_{dn} 65 and which meet program objectives are generally not available.

The above factors shall be documented and made part of the project file.

§51.106 Implementation.

(a) *Use of available data.* HUD field staff shall make maximum use of noise data prepared by others when such data are determined to be current and adequately projected into the future and are in terms of the following:

(1) *Sites in the vicinity of airports.* The noise environment around airports is described sometimes in terms of Noise Exposure Forecasts, abbreviated as NEF or, in the State of California, as Community Noise Equivalent Level, abbreviated as CNEL. The noise environment for sites in the vicinity of airports for which day-night average sound level data are not available may be evaluated from NEF or CNEL analyses using the following conversions to DNL:

DNL = NEF + 35

DNL = CNEL

(2) *Sites in the vicinity of highways.* Highway projects receiving Federal aid are subject to noise analyses under the procedures of the Federal Highway Administration.

Where such analyses are available they may be used to assess sites subject to the requirements of this standard. The Federal Highway Administration employs two alternate sound level descriptors: (a) The A-weighted sound level not exceeded more than 10 percent of the time for the highway design hour traffic flow, symbolized as L_{10}; or (b) the equivalent sound level for the design hour, symbolized as L_{eq}. The day-night average sound level may be estimated from the design hour L_{10} or L_{eq} values by the following relationships, provided heavy trucks do not exceed 10 percent of the total traffic flow in vehicles per 24 hours and the traffic flow between 10 p.m. and 7 a.m. does not exceed 15 percent of the average daily traffic flow in vehicles per 24 hours:

DNL = L_{10} (design hour)—3 decibels

DNL = L_{eq} (design hour) decibels

Where the auto/truck mix and time of day relationships as stated in this Section do not exist, the HUD Noise Assessment Guidelines or other noise analysis shall be used.

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(3) *Sites in the vicinity of installations producing loud impulsive sounds.* Certain Department of Defense installations produce loud impulsive sounds from artillery firing and bombing practice ranges. Noise analyses for these facilities sometimes encompass sites that may be subject to the requirements of this standard. Where such analyses are available they may be used on an interim basis to establish the acceptability of sites under this standard.

The Department of Defense uses day-night average sound level based on C-weighted sound level, symbolized L_{Cdn}, for the analysis of loud impulsive sounds. Where such analyses are provided, the 8 decibel addition specified in 51.103(b), is not required, and the same numerical values of day-night average sound level used on an interim basis to determine site suitability for non-impulsive sounds apply to the L_{Cdn}.

(4) *Use of areawide acoustical data.* HUD encourages the preparation and use of areawide acoustical information, such as noise contours for airports. Where such new or revised contours become available for airports (civil or military) and military installations they shall first be referred to the Regional Office (Environmental Clearance Officer) for review, evaluation and decision on appropriateness for use by HUD. The Regional Office shall submit revised contours to the Assistant Secretary of Community Planning and Development for review, evaluation and decison whenever the area affected is changed by 20 percent or more, or whenever it is determined that the new contours will have a significant effect on HUD programs, or whenever the contours are not provided in a methodology acceptable under §51.106(a)(1) or in other cases where the Regional Office determines that Headquarters review is warranted. For other areawide acoustical data, review is required only where existing areawide data are being utilized and where such data have been changed to reflect changes in the measurement methodology or underlying noise source assumptions.

Contours for future noise levels based on new construction, mission changes etc. which become available as part of the Environmental Impact Statement process shall not be used until the NEPA process is complete and a decision on the proposed action is made.

When new or revised contours are approved, make sure all interested people in local area are informed that HUD will be using different contours. Make a special effort to inform the most active developers in area or developers who have worked with HUD before.

This is also required for noise studies for developers by consultants, whether to provide original data, or to contest existing data or a HUD analysis. It is particularly important to make sure the same traffic, vehicle or operational data were used for each study, when one study is being contested.

Requests for determination on usage of new or revised areawide data shall include the following:

(i) Maps showing old, if applicable, and new noise contours, along with brief description of data source and methodology.

(ii) Impact on existing and prospective urbanized areas and on development activity.

(iii) Impact on HUD-assisted projects currently in processing.

(iv) Impact on future HUD program activity. Where a field office has determined that immediate approval of new areawide data is necessary and warranted in limited geographic areas, the request for approval should state the circumstances warranting such approval. Actions on proposed projects shall not be undertaken while new areawide noise data are being considered for HUD use except where the proposed location is affected in the same manner under both the old and new noise data.

(b) *Site assessments.* Compliance with the standards contained in §51.103(c) shall, where necessary, be determined using noise assessment guidelines, handbooks, technical documents and procedures issued by the Department.

(c) *Variations in site noise levels.* In many instances the noise environment will vary across a site, with portions of the site being in an Acceptable noise environment and other portions in a Normally Unacceptable noise environment. The standards in §51.103(c) shall apply to the portions of a building or buildings used for residential purposes and for ancillary noise sensitive open spaces.

(d) *Noise measurements.* Where noise assessments result in a finding that the site is borderline or questionable, or is controversial, noise measurements may be performed. Where it is determined that noise measurements are required, such measurements will be conducted in accordance with methods and measurement criteria established by the Department. Locations for noise measurements will depend on the location of noise sensitive uses that are nearest to the predominant noise source (see §51.103(c)).

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(e) *Projections of noise exposure.* In addition to assessing existing exposure, future conditions should be projected. To the extent possible, noise exposure shall be projected to be representative of conditions that are expected to exist at a time at least 10 years beyond the date of the project or action under review.

(f) *Reduction of site noise by use of berms and/or barriers.* If it is determined by adequate analysis that a berm and/or barrier will reduce noise at a housing site, and if the barrier is existing or there are assurances that it will be in place prior to occupancy, the environmental noise analysis for the site may reflect the benefits afforded by the berm and/or barrier.

In the environmental review process under §51.104(b), the location height and design of the berm and/or barrier shall be evaluated to determine its effectiveness, and impact on design and aesthetic quality, circulation and other environmental factors.

This provision should be used with caution. Very clear and strong assurances that berms or barriers will be constructed should be obtained in writing before approval.

Again also note that by definition a barrier must be physically separate from the building or area it is providing attenuation for.

The *Noise Assessment Guidelines* contain procedures for evaluating barrier effectiveness.

When projections for airports are based on new construction or similar actions the likelihood that such major action will actually take place should be carefully evaluated. This is particularly important if local funding is required. Check to see if initial actions such as land purchases, bonds etc. been taken. If projections are just based on expanded traffic levels make sure they are reasonable for the area. Projections for smaller communities are often overly optimistic.

Appendix to Subpart B—definition of acoustical quantities

1. *Sound Level.* The quantity in decibels measured with an instrument satisfying requirements of American National Standard Specification for Type 1 Sound Level Meters S1.4–1971. Fast time-averaging and A-frequency weighting are to be used, unless others are specified. The sound level meter with the A-weighting is progressively less sensitive to sounds of frequency below 1,000 hertz (cycles per second), somewhat as is the ear. With fast time averaging the sound level meter responds particularly to recent sounds almost as quickly as does the ear in judging the loudness of a sound.

(2) *Average Sound Level.* Average sound level, in decibels, is the level of the mean-square A-weighted sound pressure during the stated time period, with reference to the square of the standard reference sound pressure of 20 micropascals.

$$L_{dn} = 10 \log_{10} \left[\frac{1}{86400} \left(\int_{0000}^{0700} 10^{[L_A(t)+10]/10}\, dt + \int_{0700}^{2200} 10^{L_A(t)/10}\, dt + \int_{2200}^{2400} 10^{[L_A(t)+10]/10}\, dt \right) \right]$$

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Time t is in seconds, so the limits shown in hours and minutes are actually interpreted in seconds. $L_A(t)$ is the time varying value of A-weighted sound level, the quantity in decibels measured by an instrument satisfying requirements of American National Standard Specification for Type 1 Sound Level Meters S1.4–1971.

3. *Loud Impulsive Sounds.* When loud impulsive sounds such as sonic booms or explosions are anticipated contributors to the noise environment at a site, the contribution to day-night average sound level produced by the loud impulsive sounds shall have 6 decibels added to it in assessing the acceptability of a site.

A loud impulsive sound is defined for the purpose of this regulation as one for which:

(i) The sound is definable as a discrete event wherein the sound level increases to a maximum and then decreases in a total time interval of approximately one second or less to the ambient background level that exists without the sound; and

(ii) The maximum sound level (obtained with slow averaging time and A-weighting of a Type 1 sound level meter whose characteristics comply with ANSI S1.4–1971) exceeds the sound level prior to the onset of the event by at least 6 decibels; and

(iii) The maximum sound level obtained with fast averaging time of a sound level meter exceeds the maximum value obtained with slow averaging time by at least 4 decibels.

Issued at Washington, D.C., on July 5, 1979.

Patricia Roberts Harris,
Secretary of Housing and Urban Development.

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Quiz on the Noise Regulations

Questions

1. What is the HUD policy on support for existing construction in high noise areas?
2. What is the definition of "major or substantial rehabilitation"?
3. What is HUD's interior noise goal?
4. What project approval authority does the Field Office have?
5. Who approves projects in the Unacceptable Zone?
6. What noise descriptor is used to express noise levels in the regulation?
7. How are loud impulsive sounds to be evaluated?
8. At what point on a building's exterior are sound levels to be determined?
9. What is the basic assumption behind the attenuation levels required?
10. What type of attenuation measures are preferred?
11. When should building attenuation measures be considered?
12. When are EIS's required?
13. When is an area considered "largely undeveloped"?
14. What is "Flexibility for Non-Acoustic Benefits"?
15. Six conditions are listed for waiving the attenuation requirement under the Flexibility for Non-Acoustic Benefits provision, how many must be met for the waiver to be granted?
16. Who has the authority to grant the attenuation requirements waiver under the "flexibility" provision?
17. What noise descriptors other than DNL are acceptable for aircraft noise contours?
18. Who normally approves areawide noise data such as airport noise contours?
19. If a site is partially in the Unacceptable Zone and partially in the Normally Unacceptable Zone, which review and approval procedures apply?
20. When should noise measurements be used in lieu of areawide data or *Noise Assessment Guidelines* calculations?

Quiz on the Noise Regulations

Answers

1. Noise exposure can not, by itself, be the basis for denying support for resale and purchase of existing buildings. (Section 51.101(a)(4))
2. "Major or substantial rehabilitation" is defined in individual program guidance. There is no single definition. (51.101(a)(5) marginal note)
3. 45 L_{dn} (Section 51.101(a)(9))
4. projects in Acceptable Zone; also projects in Normally Unacceptable Zone provided that
   - adequate sound attenuation is provided
   - no EIS is required

   (Section 51.102(a)(1))
5. The Assistant Secretary for Community Planning and Development.

   (Section 51.102(a)(2) and 51.104(b))
6. The day night average sound level system (DNL). (Section 51.103(a))
7. Two ways:
   - If plain DNL levels have been calculated or measured, add a 8 decibel penalty.
   - Alternatively, the C weighted day night average sound level system (L_{CDN}) can be used as is.

   (Section 51.103(b))
8. Two meters (6.5 feet) away from the building exterior, moving towards the predominant noise source. (Section 51.103(c))
9. That current construction practices provide about 20 db attenuation. Thus in a 65 L_{dn} or lower area the interior goal of 45 L_{dn} would be met with standard construction. The additional attenuation required is the increment over that provided by standard construction necessary to achieve the interior goal of 45 L_{dn}. (Section 51.104(a) marginal note)
10. Measures which reduce exterior noise levels. (51.104(a))
11. Only after it has been determined that berms and barriers or site redesign are not practical alternatives. (Section 51.104(a))
12. When the project is located in the Unacceptable Zone or the project is located in a largely undeveloped area and the project is in the Normally Unacceptable Zone. (Section 51.104(b))
13. When the area within a 2 mile radius of the project is less than 50% developed for urban uses and infrastructure is not in place and available to serve the project. (Section 51.104(b)(1)(ii))
14. A provision in the regulations which allows the attenuation requirements for the 65–70 L_{dn} zone to be waived. (Section 51.105(a) and marginal note)
15. All six conditions must be met. (Section 51.105(a))
16. The field office. (Section 51.102(a))
17. NEF and CNEL. (Section 51.106(a)(1))
18. The Regional Office. (Section 51.106(a)(4))
19. The review and approval procedures for projects in the Unacceptable Zone apply. (Section 51.104(b)(2))
20. Only when the noise assessment indicates that the site is on the bordering between Acceptable and Unacceptable, or when the site is controversial. (Section 51.106(d))

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Chapter 3

Major Policy and Implementation Questions Related to the Noise Regulation

As regulations are applied in the field, it is inevitable that questions will arise. It is, after all, very difficult to anticipate every situation when preparing a regulation. Sometimes the questions relate to specific and unique situations of limited interest to anyone but the office involved. Other questions, however, raise issues of more general concern. In this section we have brought together the most important and most relevant questions that have arisen since the noise regulation went into effect in August of 1979. We have used a question and answer format for your convenience.

The following are the topics included:

1. Noise projections for civil airports
2. Definition of infill for small towns
3. Areawide EIS waivers
4. Requirements for modernization and rehabilitation projects
5. Use of berms and barriers as attenuation measures
6. New and revised airport noise contours

Questions and Answers

1. How valid and useful are civil airport noise projections that show significant reductions in the amount of land exposed to high noise levels? Should we be suspicious?

Contours that show significant reductions in the area exposed to high noise levels may seem questionable, but, according to the Environmental Protection Agency, they may be quite accurate. The EPA does expect to see some significant reductions in the number of people exposed to high levels of aircraft noise over the next 15 years. In their report *Aviation Noise: The Next Twenty years*, EPA stated that they expected to see the number of people exposed to levels of 65 Ldn or greater to drop from a 1975 figure of 5,550,000 to about 2,650,000 in the year 2000. Much of this reduction would occur during the period 1980–1985 with more modest decreases thereafter. The reductions are expected to result from the Federal Aviation Administration's current noise certification requirements, even with up to 100% increases in aircraft operations. (Current certification requirements are for all new aircraft to achieve stage three noise levels and all older aircraft to achieve stage two levels by 1985. Progress has been good in meeting these requirements.)

In general then, you should not be surprised to see significant reductions in contour size if the following conditions are met:

- the decrease in size is no more than 50%;
- the increase in operations is no more than 100%; and
- FAR stage 3 aircraft, such as the B757 and B767, are included in the fleet mix, but not to the total exclusion of all other aircraft.

Assuming that the contours are otherwise technically correct, significantly smaller contours should be acceptable.

2. Many small towns aren't big enough for a project to meet the definition of infill contained in section 51.104 (b)(1)(ii). However, a project located in the heart of town can hardly be considered to be in a largely undeveloped area. Must an EIS be prepared?

Not necessarily. If the jurisdiction in which the project is located is not part of a standard metropolitan area, a project may be considered infill if it is within or contiguous to the already developed area and infrastructure (particularly water and sewer) is available and has the capacity to serve the project. It must also be clear that the project will not encourage the establishment of other incompatible land uses in the normally unacceptable noise zone.

If you believe a project meets these criteria, submit documentation to the Office of Environment and Energy for their review and determination.

3. What can we do to reduce the procedural burden when, for a variety of reasons, the Department expects to be considering a number of projects in an unacceptable noise zone? Most of the projects would probably qualify for an EIS waiver, but how can we avoid filling repetitive, individual requests?

While the number of cases where the Department would be seriously considering a number of projects exposed to unacceptable noise levels in the same jurisdiction is likely to be limited, there is an alternative to individual processing in those situations. The alternative is to issue an areawide waiver for the entire affected jurisdiction. Such a waiver can be useful when the unacceptable noise zone heavily impacts a substantially developed community with limited site alternatives. (In most cases we would expect that the noise source would be aircraft, but in very small towns it is possible that a heavily used rail line could create a large unacceptable noise zone.)

An areawide EIS waiver would, of course, have to have a more detailed environmental assessment than an individual project request, and there are other special processing steps.

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But if you have a situation where you think the Department has a good reason to expect to process a number of projects within the unacceptable noise zone, there is an alternative to individual EIS waivers: Contact the Office of Environment and Energy for details on how to request the areawide waiver.

4. What exactly are the processing requirements and general policies for modernization and rehabilitation projects? Does secton 51.104 apply to them as well as to new construction? The noise regulation is a bit confusing on this.

Yes, the noise regulation is a bit confusing on this question. We have seen several instances where field offices have mistakenly applied the provisions of Section 51.104 to modernization and rehabilitation projects. We believe that this happens because section 51.104 is not as clearly titled as it might have been. It would be better if it read "special requirements for new construction" rather than simply "special requirements".

The only parts of the regulation that apply to modernization and rehabilitation projects are sections 51.101 (a)(5) and the definitions of normally unacceptable and unacceptable noise zones contained in the table in section 51.103. None of the other processing or policy provisions of the table or of sections 51.102 and 51.104 apply. Therefore:

- modernization and rehabilitation projects are to be processed by the field offices regardless of the noise zone.
- EIS's are not required for modernization and rehabilitation projects unless mandated by other applicable environmental regulations.

You must however continue to encourage attenuation features in modernization and rehabilitation projects, in accordance with the general policy stated in section 51.101(a)(5).

5. We know that berms and barriers are the preferred type of noise attenuation because of the protection they provide for outdoor living areas, but we need some further guidance on when they are really the best choice.

While barriers can be an effective noise attenuation technique, they must, indeed, be used with caution and common sense because they can create more problems than they solve. Very high noise barriers can create significant aesthetic and financial problems relative to the noise benefit to be achieved. Barriers can block light, hinder natural ventilation, create an unpleasant sense of being walled in, and can be very unattractive. In addition, barriers do require continuing maintenance and can be very costly to build.

It is important to remember that the noise regulation says that "measures that reduce external noise at a site shall be used wherever practicable." Is it practicable to propose a 20 foot high barrier only 15 feet from the rear of a two-story building? Granted it would certainly protect the building from noise, but what about the blocked light, the reduced ventilation, the visual impact, and the cost? The purpose of a barrier is primarily to reduce the noise levels in those outdoor areas that people use. The secondary purpose is to reduce the need for structural attenuation. Therefore, the barrier should only be as high as is necessary to protect those areas. Structural attenuation should be required for the parts of the building not protected by the barrier. And if there aren't any outdoor areas where low noise levels are important, barriers shouldn't be required unless they would be more cost effective than building attenuation measures.

6. What should we be doing once we have processed new or revised aircraft noise contours and they have been approved for use?

The most important thing you can do once new or revised aircraft noise contours have been approved for use is to tell the people who are most likely to be affected by the change. If you have a newsletter that you regularly publish, that is one way to get the word out. At the very least you should specifically notify the affected jurisdictions and the builders/developers who are known to be active in the vicinity of the noise impacted areas. Make sure you notify builders and developers who have large scale projects that you have been processing in sections. Go back and check your files to find them. Even though you should have done an overall environmental review of the project at the time the first section was submitted, the approval of individual sections is dependent on the noise levels at the time that section is submitted.

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Chapter 4

Noise Attenuation

Introduction

HUD's noise policy (24 CFR 51B) clearly requires that noise attenuation measures be provided when proposed projects are to be located in high noise areas. The requirements set out in Section 51.104(a) are designed to insure that interior levels do not exceed the 45 L_{dn} level established as a goal in Section 51.101(a)(9). Thus, in effect, if the exterior noise level is 65 L_{dn} to 70 L_{dn}, 25 db of noise attenuation must be provided; if the exterior noise level is between 70 and 75 L_{dn}, then 30 db of attenuation is required. Likewise, for projects proposed for areas where noise levels exceed 75 L_{dn}, sufficient attenuation must be provided to bring interior levels down to 45 L_{dn} or below.

There are three basic ways to provide the noise attenuation required:

1. the use of barriers or berms
2. site design
3. acoustical construction

Of these, only the first two provide any improvement in the exterior environment. Because HUD considers a quiet exterior environment to be important, we prefer the use of those measures that reduce exterior levels as well as interior levels. The use of acoustical construction by itself is, therefore, the least preferred alternative since it only affects the interior levels. While we recognize that in many cases barriers or site design cannot provide all the attenuation necessary, you should combine them with acoustical construction whenever possible.

Your responsibility as a HUD staff member is to:

- make sure the project sponsor or developer is aware of the attenuation requirements for the project.
- make the sponsor aware of the options available

and

- review attenuation proposals to make sure they are adequate.

While it is not your responsibility to provide detailed design assistance to the sponsor or developer, you should know enough about the attenuation options to give him or her a basic understanding of what must be done. In many cases, you may be able to reassure the sponsor or developer that the necessary attenuation can be achieved through the use of common construction techniques or materials. Or you may be able to point out how a simple site design change can achieve the desired result without additional cost.

The following sections are designed to provide you with the information you will need to fulfill your responsibilities. Each attenuation approach is discussed both in terms of basic concepts and in terms of what to look for in reviewing attenuation proposals. The discussion does assume that you have a working knowledge of the *Noise Assessment Guidelines*. If you have not worked with the *Guidelines* before or not recently you may want to go back and review them, particularly the section on calculating the effects of barriers.

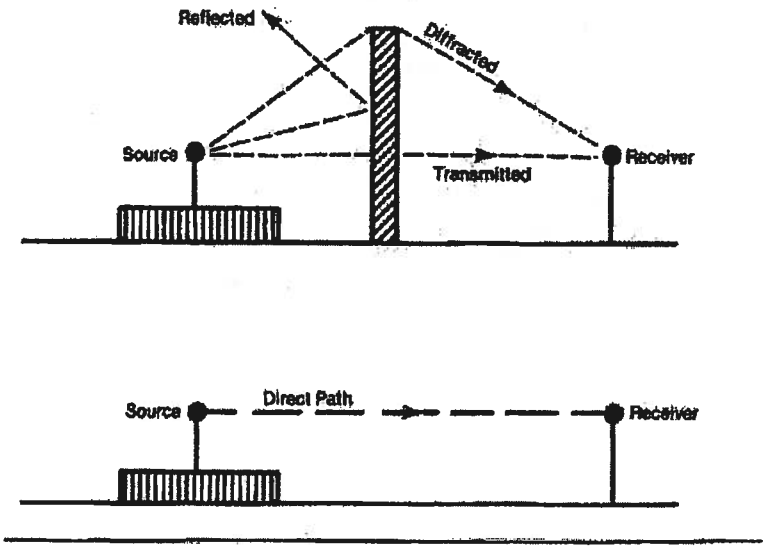
Barrier Noise Reduction Concepts

(The following, with some editing and with some additional graphics, is taken from the Federal Highway Administration's *Noise Barrier Design Handbook*.[1])

When no obstacles are present between [a source] and adjoining areas, sound travels by a direct path from the "sources" ... to [the] "receivers"..., as shown in Figure 1. Introduction of a barrier between the source and receiver redistributes the sound energy into several [indirect] paths: a diffracted path, over the top of the barrier; a transmitted path, through the barrier; and a reflected path, directed away from the receiver. These paths are also illustrated in Figure 1.

[1] *Noise Barrier Design Handbook* US Department of Transportation, Federal Highway Administration, February 1978. (FHWA-RD-76-58).

Figure 1
Alteration of Noise Paths by a Barrier



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Barrier Diffraction and Attenuation

Consider an infinitely long, infinitely massive noise barrier placed between a highway and the receiver. Figure 2 illustrates a cross-section through such a configuration. [In] this example, the only way that sound can reach the receiver is by bending over the top of the barrier; as shown in the figure. The bending of sound waves in this manner over an obstacle is known as diffraction. The area in which diffraction occurs behind the barrier is known as the "shadow zone." The straight path from the source over the top of the barrier forms the boundary of this zone.

All receivers located in the shadow zone will experience some sound attenuation; the amount of attenuation is directly related to the magnitude of the diffraction angle ϕ. As ϕ increases, the barrier attenuation increases. The angle ϕ will increase if the barrier height increases, or if the source or receiver are placed closer to the barrier. Clearly then the barrier attenuation is a function of the geometrical relationship between the source, receiver, and barrier. One way of relating these parameters to the barrier attenuation is to define the path-length difference as shown in Figure 3. This parameter is the difference in distance that the sound must travel in diffracting over the top of the barrier rather than passing directly through it.

In the preceding discussion it was assumed that the barrier was "infinite"; i.e., long enough to shield the receiver from all sound sources up and down the highway. For short barriers, the attenuation can be seriously limited by the sound from sections of highway beyond the barrier's ends, which are unshielded from the receiver, as shown in Figure 4. Similarly, when there are large gaps in the barrier (to permit access, for example), sound from the unshielded section of highway adjacent to the gap can greatly compromise barrier attenuation, especially for those receivers close to the opening.

Figure 2
Barrier Diffraction

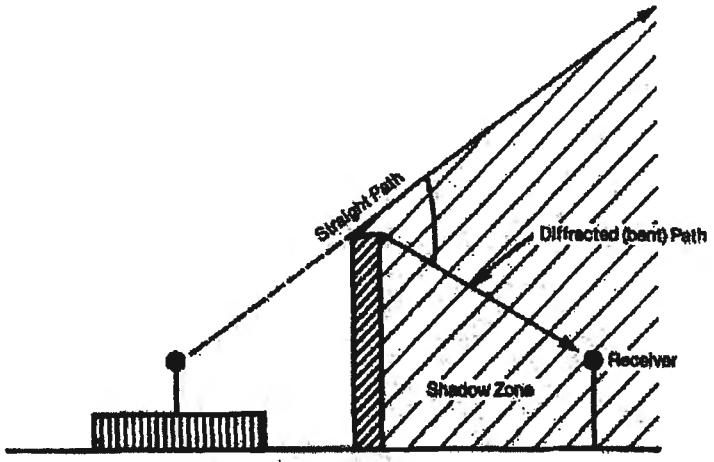


Figure 3
Path Length Difference $\delta = A + B - d$

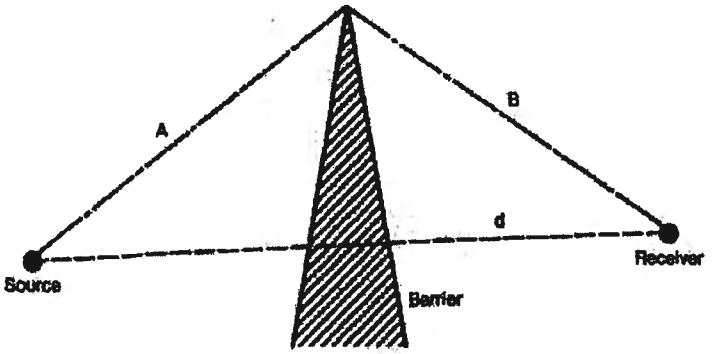
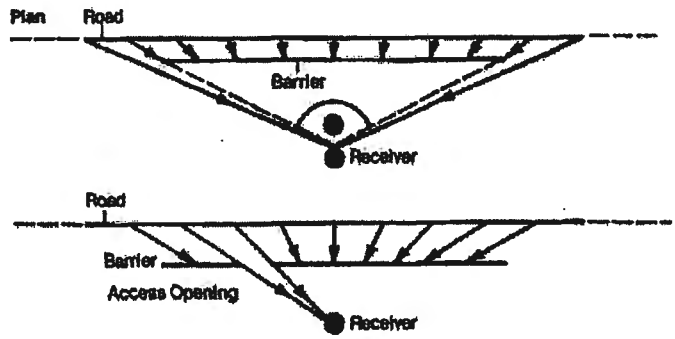


Figure 4
Short-circuit of Barrier Around Ends and Through Openings



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Barrier Transmission

In addition to the sound that travels over the top of the barrier to reach the receiver, sound can travel through the barrier itself. The amount of sound "transmission" through the barrier depends upon factors relating to the barrier material (such as its weight and stiffness), the angle of incidence of the sound, and the frequency spectrum of the sound. One way of rating a material's ability to transmit noise is by the use of a quantity known as the transmission loss, TL. The TL is related to the ratio of the incident noise energy to the transmitted noise energy. Transmission loss values are normally expressed in decibels and represent the amount noise levels will be reduced when the sound waves pass through the material. The higher the TL value the less noise transmitted through the material. Typically, the TL value improves with increasing surface weight of the material.

The noise reduction provided by a barrier can be severely compromised if the TL value of the material permits too much noise to pass through the barrier. This is due to the fact that when attenuation is a function of two or more factors, the noise level at the measurement point is actually the combination of the reduced noise levels resulting from each attenuation factor. For example, with a typical barrier the noise levels are reduced by (1) sound waves being diffracted over the barrier and (2) sound waves passing through the barrier. The noise level at the receiver point is the combination of the attenuated levels resulting from each attenuation step. If the starting noise level is 65 db and the noise level is reduced 10 db when the sound waves pass through the barrier then the attenuated level reaching the receiver is 55 db. If the attenuation provided by the sound waves being diffracted over the barrier is also 10 db then the attenuated level reaching the receiver along that path is 55 db as well. Using the table in the *Noise Assessment Guidelines* to combine the two individual attenuated levels, one finds that the combined attenuated level is actually 58 db. Thus even though the attenuation value of each attenuation step was 10 db, the actual reduction for the receiver is only 7 db. It is, however, a function of the way noise levels combine that if the difference between levels is greater than 10 db it does not affect the levels. As a general rule, therefore, if the TL value is at least 10 dB above the attenuation value resulting from diffraction over the top of the barrier, the barrier noise reduction will not be significantly affected by transmission through the barrier (decreased by less than 0.5 dB). For many common materials used in barrier construction, such as concrete and masonry blocks, TL values are usually more than adequate. For less massive materials such as steel, aluminum and wood, TL values may not be adequate, particularly for those cases where large attenuations are required. (See Table 1 for a list of typical TL values.)

Even if a barrier material is massive enough to prevent significant sound transmission, the barrier noise reduction can be severely compromised if there are holes or openings in the barrier. For large openings, sound energy incident on the barrier will be directly transmitted through the opening to the receiver. When the opening is small an additional phenomenon occurs: upon striking the barrier wall the sound pressure will increase, resulting in an amplification of the transmitted sound to the receiver. Thus, the presence of openings or holes may seriously degrade the noise reduction provided by otherwise effective barriers.

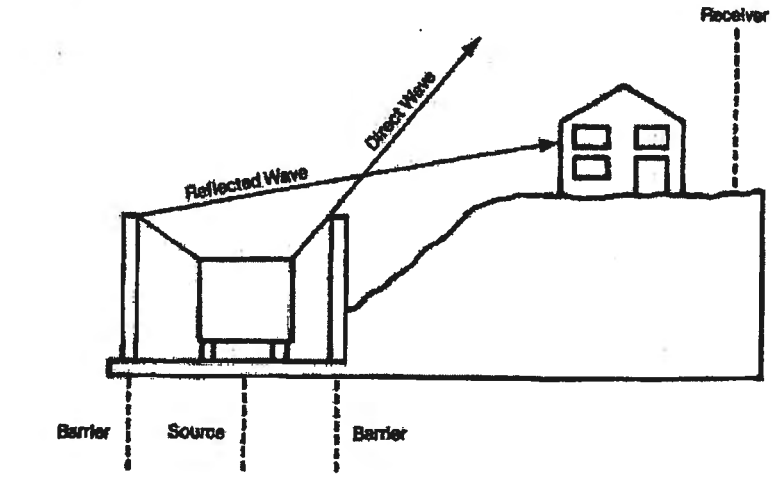
Barrier Reflections

As shown in Figure 1, sound energy can be reflected by a barrier wall. For the configuration shown in that figure, the reflected energy does not affect the receiver, but may affect receivers located to the left of the highway. However the increase in noise level for these receivers would be less than 3 dB, because this single reflection can at most double the sound energy. (Remember how you combine noise levels? The most you add is 3 db when levels are the same.)

The situation is entirely different, however, when a double barrier situation is involved (refer to Figure 5). In addition to the energy that reaches the receiver by diffraction over the top of the barrier, if the barrier walls are reflective, additional sound energy can reach the receiver by a reflection from the left wall as illustrated in the figure. The same principles apply when there is a vertical retaining wall opposite a noise barrier; similarly, in a deep vertical cut the opposite walls will create multiple reflections.

If the barrier walls are not perfectly reflecting but absorb some of the sound energy, the contributon of each reflection is decreased by an amount that depends upon the absorptive characteristics of the barrier. For very hard, reflective surfaces, the absorption characteristics are very poor. Although a serious degradation in barrier performance may result for the double barrier situation, use of materials with good absorption values will usually recover all of the lost noise reduction.

Figure 5.
Reflections from an Opposing Barrier



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It should be mentioned that the use of barrier walls with sloped sides (forming angles of grater than 10–15 degrees from the vertical) will also generally eliminate multiple reflections. Use of earth berms is particularly appropriate to accomplish this. Sloped barrier walls will require more material to achieve a desired height than a vertical wall, while berms will require greater right-of-way than a thin wall.

Ground Effects

Consider again the direct path of sound from the source to receiver as illustrated in Figure 1 in the absence of any obstacles. For sources and receivers located close to the ground, in addition to this direct path sound energy may reach the receiver by reflecting off the ground. When the terrain is relatively hard and flat, such a reflection will add to the noise from the direct path to increase the level at the receiver. However, when the ground is soft, there may be a phase reversal upon reflection such that the noise from the ground reflection path will destructively interfere with the noise from the direct path resulting in a significant reduction in noise levels at the receiver.

This reduction in level, known as ground-effect attenuation, is in excess of the 3 dB per doubling of distance propagation loss for a line source of noise and occurs only above soft absorptive ground (such as normal earth and most ground with vegetation). Over hard ground (such as concrete, stone and very hard-packed earth) these effects do not occur. These effects are most apparent for receivers on the ground floor, and decrease rapidly as receiver height above ground increases.

While ground absorption effects are not completely understood, it is generally believed that these effects account for the 4.5 dB per doubling of distance propagation loss observed over soft ground, as compared to the 3 dB propagation loss observed over hard ground. The implication with regard to barrier design is that placement of a barrier over soft ground between source and receiver will re-direct the sound over the top of the barrier, thus destroying the ground reflection and the additional 1.5 dB per doubling of distance attenuation. Thus, the barrier must be designed to provide more reduction than would otherwise be necessary, to compensate for the lost ground effects over absorptive ground.

Summary
(From: *Design Guide*, National Bureau of Standards[1])

In summary, the following can be said about noise barriers.

- If a barrier does not block the line-of-sight between the source and receiver, the barrier will provide little or no attenuation.
- If a barrier is constructed of a material with a surface weight density greater than 4 lb/ft^2 and there are no openings through the barrier, transmitted sound will usually be negligible.
- If there are openings totaling over 10 percent or more of the barrier area, barrier attenuation will be negligible.
- Diffracted sound is usually the most important aspect in estimating barrier attenuation.
- Reflected sound can be important for receivers on the source side of a barrier, but it normally is not a factor for receivers on the side opposite from the source. Hence reflected sound is usually not important to your building and site.
- Transmission of sound around the ends of the barrier can be critical if the barrier included angle is less than 170°.
- Barrier attenuations greater than an A-weighted sound level difference of 10 dB are difficult to obtain.
- For two or more barriers "in series," consider only the "dominant" barrier.
- Assume no attenuation for a receiver located beyond the end of a barrier.

Reviewing Barrier Proposals

An effective barrier is one which reduces the noise level behind the barrier to 65 L_{dn} or lower. If a barrier can reduce the exterior noise level to 65 L_{dn}, then standard construction techniques should be sufficient to insure an interior level of 45 L_{dn} or below. Therefore, if you determine that a proposed barrier is adequate to reduce the exterior noise level to 65 L_{dn} then no additional attenuation measures should be necessary.

There are four things to check when determining the adequacy of a proposed barrier:

1. Is it high enough?
2. Is it long enough?
3. Is it made of the right materials?
4. Is it properly constructed?

Is It High Enough?

In order for a barrier to be effective it must be at least high enough to break the line of sight between the source and the receiver. In the *Noise Assessment Guidelines* you will find the procedure for determining how much attenuation is provided by a barrier of a given height.

In general, barriers and berms are most effective for one and two story buildings because a relatively low barrier can often provide the attenuation needed. The height that might be required to provide attenuation for much taller buildings is often not feasible for either cost or aesthetic reasons. However, even if a barrier can not be made high enough to attenuate the upper floors of a multistory building, it may still be able to provide some protection for outdoor recreational areas. Before discarding the barrier idea check for this possibility.

If you find that the barrier as proposed is too short to be effective but the sponsor or developer tells you that he or she can not make the barrier any higher, there are some alternatives you can suggest. There are ways to get more attenuation out of each foot of overall height.

As a general rule, barriers work better the closer they are to the source. Figure 6 shows a barrier that does not block the line of sight at all when it is located next to the receiver, yet is quite tall enough when located next to the source. Thus, if the sponsor or developer can not make the barrier any taller, perhaps he or she can move it closer to the source.

Another way to get more attenuation without increasing overall barrier height is to bend the top of the barrier towards the source. Figure 7 shows a case where a barrier built perfectly straight provides 8 dB of attenuation. A barrier with the same overall height but with a 45 degree bend towards the source provides 9.5 dB of attenuation. Thus if the project sponsor or developer wants to keep the overall height of the barrier down, he or she can still increase the attenuation provided simply by bending the top.

[1] *Design Guide for Reducing Transportation Noise in and Around Buildings*, US Department of Commerce, National Bureau of Standards, April 1978. (Building Science Series 84)

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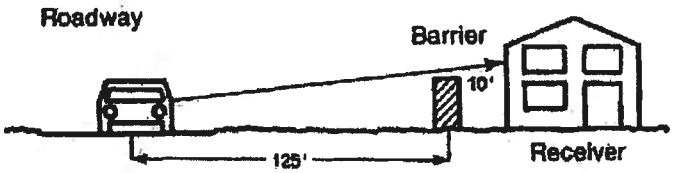
Figure 6
Effect of Moving the Barrier Closer to the Source



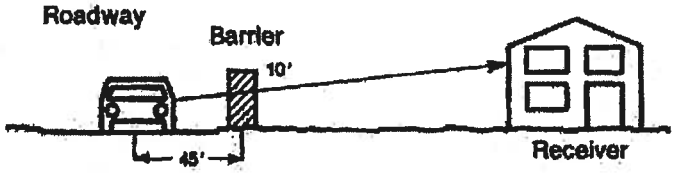
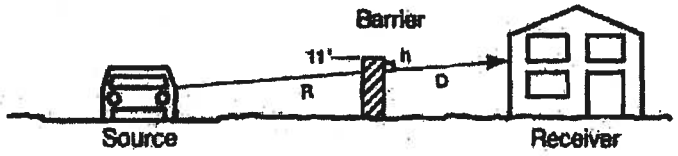
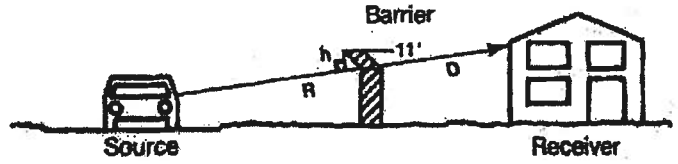


Figure 7
Effect of Bending the Top of the Barrier Towards the Source



Barrier Attenuation Value: 8db
h equals 3'
R equals 45.5'
D equals 40.0



Barrier Attenuation Value: 9.5db
h equals 4'
R equals 42.0'
D equals 43.5'

Thus, if your review of a proposed barrier shows it to be too short, but it can not be made any higher, suggest that the barrier be moved closer to the source or that it be bent at the top, or both.

Is It Long Enough?

Once you have established how much attenuation the barrier provides due to its height, you must determine if the length of the barrier compromises that attenuation level. Again, *the Noise Assessment Guidelines* contain a procedure for calculating the effect of barrier length.

If you find that the barrier is too short but that there are limitations on how long it can be made, there are, as there were with barrier heights, some recommendations you can make on how to improve the effectiveness of the barrier.

Again, if you bend the edges of the barrier, this time towards the receiver not the source, you will increase the effectiveness of the barrier. Figure 8 shows how much a barrier's effectiveness can be improved by bending the edges.

You can also improve the effectiveness of the barrier by moving it closer to the receiver. Figure 9 shows how much a barrier's effectiveness can be increased by moving it closer to the receiver. Now obviously, this creates a conflict with what we said earlier about moving the barrier closer to the source. Clearly each case will require a different compromise. If height is not a limiting factor but length is, you might recommend to the project sponsor or developer that the barrier be moved closer to receiver and the height increased as necessary. If the reverse is true, you would want to recommend the opposite. If both height and length are limited, then the sponsor or developer must find that optimum point where the effectiveness of both the barrier height and the barrier length is as high as possible.

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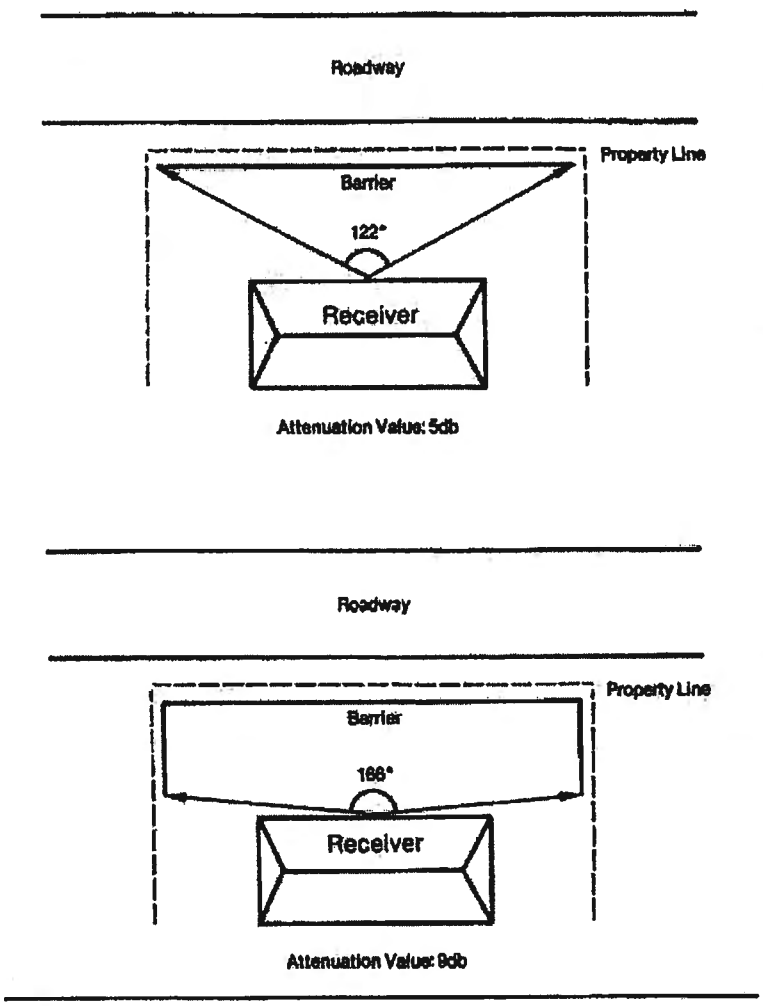
Figure 8
Effect of Bending the Edges of Barrier Towards Receiver
(Both Barriers have Potential Value of 10db)



Is It Made of The Right Materials?

Even if a barrier is high enough and long enough, its effectiveness can be severely reduced if it is made up of lightweight materials that easily transmit sound waves. In the preceding section on barrier concepts we talked about how if the transmission loss value for the barrier material was not at least 10 db higher than the attenuation value of the barrier based on length and height there would be a significant reduction in the effectiveness of the barrier.

Therefore, once you have calculated the basic attenuation potential of the barrier, you must check to make sure the proper material is being used to build the barrier. Table 1 lists the transmission loss values for materials commonly used in barrier construction. Once you have found the transmission loss value for the material being used, go to Table 2. Read down the column with the transmission loss for the material at its top and across the line that has the attenuation potential for the barrier listed. Where the two intersect you will find the actual attenuation capability of the barrier.

If you find that the choice of material has severely reduced the effectiveness of the barrier, you should recommend that the sponsor or developer select another material.

Is It Properly Constructed?

Holes or openings can substantially reduce the effectiveness of a barrier. A barrier that has openings totaling 50% or more of its total area will provide no attenuation. A barrier that has openings totaling 10% of its total area has a maximum attenuation value of approximately 4db. That is 4db no matter how high, how long or how thick the barrier. So you can see that it is very important that the barrier is made of solid materials and that it is tightly constructed. In general the intended openings in a barrier should equal no more than 1% of total area and the construction specifications should require that all joints are tightly sealed.

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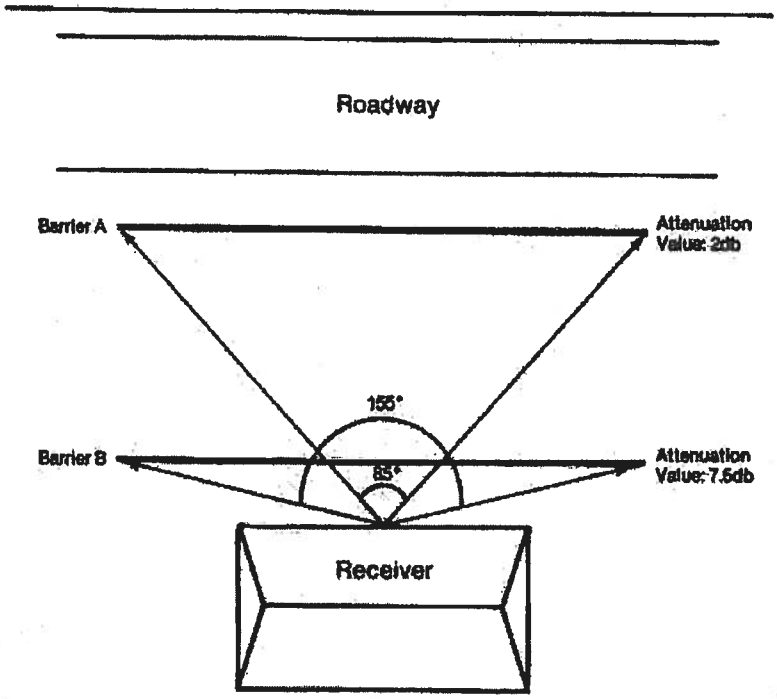
Figure 9
Effect of Moving Barrier Closer to Receiver



A Final Note

One thing should have become clear to you as you have been reading this section, and that is that in order for you to adequately review a project sponsor or developer's proposed barrier you must be given fairly specific information about the exact dimensions of the proposed barrier, the type and thickness of the barrier material, and the exact design of the barrier including construction specifications. Without this information you will be unable to do any more than a cursory evaluation, an evaluation that could be far from accurate. Make sure you make it clear to the developer or sponsor what you need to have.

Table 1
Transmission Loss Value for Common Barrier Materials

Material	Thickness, (inches)	Transmission Loss, dBA (1)
Woods		
Fir	1/2	17
	1	20
	2	24
Pine	1/2	16
	1	19
	2	23
Redwood	1/2	16
	1	19
	2	23
Cedar	1/2	15
	1	18
	2	22
Plywood	1/2	20
	1	23
Particle Board	1/2	20
Metals		
Aluminum	1/16	23
	1/8	25
	1/4	27
Steel	24 ga	18
	20 ga	22
	16 ga	15
Lead	1/16	28
Concrete, Masonry, etc.		
Light Concrete	4	36
	6	39
Dense Concrete	4	40
Concrete Block	4	32
	6	36
Cinder Block (Hollow Core)	6	28
Brick	4	33
Granite	4	40
Composites		
Aluminum Faced Plywood	3/4	21-23
Aluminum Faced Particle Board Plastic	3/4	21-23
Lamina on Plywood Plastic	3/4	21-23
Lamina on Particle Board	3/4	21-23
Miscellaneous		
Glass (Safety Glass)	1/8	22
	1/4	26
Plexiglass (Shatterproof)		22-25
Masonite	1/2	20
Fiberglass/ Resin	1/8	20
Stucco on Metal Lath	1	32
Polyester with Aggregate Surface	3	20-30

[1] A-weighted TL based on generalized truck spectrum. Source: *Noise Barrier Design Handbook*, FHWA

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Table 2
Noise Reduction of a Barrier as a Function of Its Transmission Loss

Designed Attenuation, dB (from height) and length)	Tramission Loss, dB of Materials				
	10	15	20	25	30
5	3.8	4.6	4.9	5.0	5.0
6	4.5	5.5	5.8	6.0	6.0
7	5.2	6.4	6.8	6.9	7.0
8	5.9	7.2	7.7	7.9	8.0
9	6.5	8.0	8.7	8.9	9.0
10	7.0	8.8	9.6	9.9	10.0
11	7.5	9.5	10.5	10.8	11.0
12	7.9	10.2	11.4	11.8	11.9
13	8.2	10.9	12.2	12.7	12.9
14	8.5	11.5	13.0	13.7	13.9
15	8.8	12.0	13.8	14.6	14.9
16	9.0	12.5	14.5	15.5	15.8
17	9.2	12.9	15.2	16.7	16.8
18	9.4	13.2	15.9	17.2	17.7
19	9.5	13.5	16.5	18.0	18.7
20	9.6	13.8	17.0	18.8	19.6

Source: *Noise Barrier Design Handbook, FHWA*

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Acoustical Site Planning Concepts

(This section, with some editing, is from *The Audible Landscape*, FHWA.[1])

The arrangement of buildings on a site can be used to minimize noise impacts. If incompatible land uses already exist, or if a noise sensitive activity is planned, acoustical site planning often provides a successful technique for noise impact reduction.

Many site planning techniques can be employed to shield a residential development from noise. These can include:

1. increasing the distance between the noise source and the receiver;
2. placing noise compatible land uses such as parking lots, maintenance facilities, and utility areas between the source and the receivers. Playgrounds and parks are not necessarily noise compatible activities.
3. locating barrier-type buildings parallel to the noise source or the highway; and
4. orienting the residences away from the noise.

The implementation of many of the above site planning techniques can be combined through the use of cluster and planned unit development techniques.

Distance

Noise can be effectively reduced by increasing the distance between a residential building and a highway. Distance itself reduces sound: doubling the distance from a noise source can reduce its intensity by as much as 3 dBA. In the case of highrise buildings, distance may be the only means, besides acoustical design and construction, of reducing noise impacts. This is because it is nearly impossible to provide physical shielding for the higher stories from adjacent noise.

Noise Compatible Land Uses as Buffers

Noise protection can be achieved by locating noise-compatible land uses between the highway and residential units. Whenever possible, compatible uses should be nearest the noise source. Figure 10 shows a proposed parking garage along two sides of a development in Boston. Both the

[1] *The Audible Landscape: A Manual for Highway Noise and Land Use*, US Department of Transportation, The Federal Highway Administration, November 1974. (GPO Stock Number: 5000-00079.)

Figure 10
Use of a Parking Garage to Shield a Residential Area

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Fitzgerald Expressway and the entrance to the Callahan Tunnel which are shown on the site plan are major and noisy traffic routes. In addition to protecting the residential development from the noise and dirt of highway traffic, the parking garage provides needed facilities for the residents.

Buildings as Noise Shields

Additional noise protection can be achieved by arranging the site plan to use buildings as noise barriers. A long building, or a row of buildings parallel to a highway can shield other more distance structures or open areas from noise.

If the building being used as a barrier is sensitive to highway noise, the building itself must first be soundproofed. This technique was used in a housing project in England where a 3,900 foot long, 18 foot wide and 45-70 foot high wall (depending on the terrain) serves as both residence and a sound shield. The wall/building will contain 387 apartments in which the kitchens and bathrooms are placed towards the noise, and the bedrooms and living rooms face away from the highway. The wall facing the highway will be soundproofed and windows, when they exist, are sealed. Substantial noise reductions are expected.

Orientation

The orientation of buildings or activities on a site affects the impact of noise, and the building or activity area may be oriented in such a way as to reduce this impact.

Noise impacts can be severe for rooms facing the roadway since they are closest to the noise source. The noise impact may also be great for rooms perpendicular to the roadway because (a) the noise pattern can be more annoying in perpendicular rooms and (b) windows on perpendicular walls do not reduce noise as effectively as those on parallel walls because of the angle of the sound. Road noise can be more annoying in perpendicular rooms because it is more extreme when it suddenly comes in and out of earshot as the traffic passes around the side of the building, rather than rising and falling in a continuous sound, as it would if the room were parallel to passing vehicles.

Whether the noise impact is greater on the perpendicular or the parallel wall will depend on the specific individual conditions. Once the most severely impacted wall or walls are determined, noise impacts may be minimized by reducing or eliminating windows from these walls.

Buildings can also be oriented on a site in such a way as to exploit the site's natural features. With reference to noise, natural topography can be exploited and buildings placed in low noise pockets if they exist. If no natural noise pockets exist, it is possible to create them by excavating pockets for buildings and piling up earth mounds between them and the noise. Such a structure would obstruct the sound paths and reduce the noise impacts on the residences.

Cluster and Planned Unit Development

A cluster subdivision is one in which the densities prescribed by the zoning ordinance are adhered to but instead of applying to each individual parcel, they are aggregated over the entire site, and the land is developed as a single entity. A planned unit development, or P.U.D., is similar but changes in land use are included, such as apartments and commercial facilities in what would otherwise be a single-family district.

From Figure 11 it can be seen how the conventional grid subdivision affords no noise protection from the adjacent highway. The first row of houses bears the full impact of the noise. In contrast, the cluster and P.U.D. techniques enable open space and commercial uses respectively to serve as noise buffers. Examples of this are shown in Figures 12 and 13. A word of caution is necessary: in a cluster development, the required open space can be located near the highway to minimize noise to the residences. However, many recreation uses are noise sensitive, and when one takes advantage of the flexibility of cluster development to minimize noise, care must be taken not to use all of the available open space in

Figure 11
Conventional Grid Subdivision

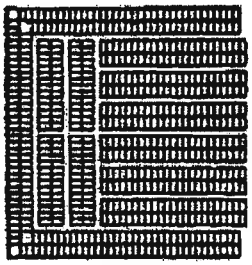
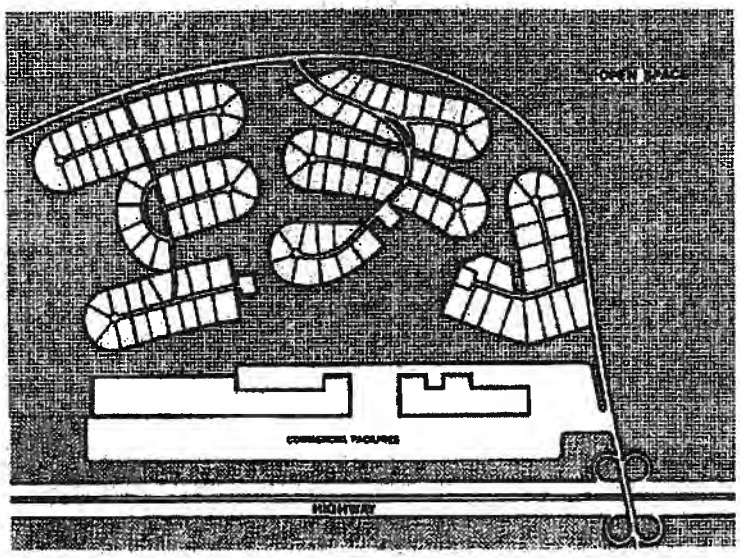


Figure 12
Placement of Noise Compatible Uses Near a Highway in a PUD



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buffer strips, thus depriving the development of a significant open space area. Where high noise levels exist, a combination of buffer strips and other techniques (such as berms and acoustical sound proofing) can be employed.

The flexibility of the cluster and planned unit development techniques allows many of the above site planning techniques to be realized and effective noise reduction achieved.

Reviewing Site Plans

There are two main things to check when reviewing site plan changes to determine if the revised site plan provides adequate attenuation for the noise sensitive uses:

1. Is the separation between the source and the receiver great enough?
2. If noise-compatible buildings are being used as barriers for other buildings, are they adequate barriers, i.e., are they long enough and are they high enough? (And, if the buildings being used as barriers contain noise sensitive activities, have the buildings been properly soundproofed.)

In order to determine whether the proposed site plan changes will provide adequate separation between the source and the receiver, you simply go back to the *Noise Assessment Guidlines* procedures. You can use the *Guidelines* both to determine if the proposed separation distance is sufficient or to determine the necessary separation distance. You should at this point check to make sure that the uses being located in the "buffer zone" between the source and the receiver are indeed noise compatible uses. If parks or playgrounds are located in the buffer zone, make sure they are not the only ones associated with the project.

To determine whether the noise compatible buildings being proposed as barriers are adequate, you simply use the procedures outlined in the preceding section. Determine whether the building is high enough to properly break the line of sight between the receiver and the source. Then determine if the building is long enough. It is not necessary to check to make sure it is made of the proper materials or that it is properly constructed since the building will be inherently thick enough not to have any problems. Again, however, if the building being proposed as a barrier contains noise sensitive uses you must first verify that it is properly soundproofed. (See the next section for guidance on acoustical construction.) If the building is not properly soundproofed then it can not be used as a barrier for other buildings.

As you review the site plan check to see that the building locations will not aggravate noise problems. Figure 14 shows how building arrangement can make the noise problem worse.

Figure 13
Open Space Placed Near a Highway in a Cluster Development

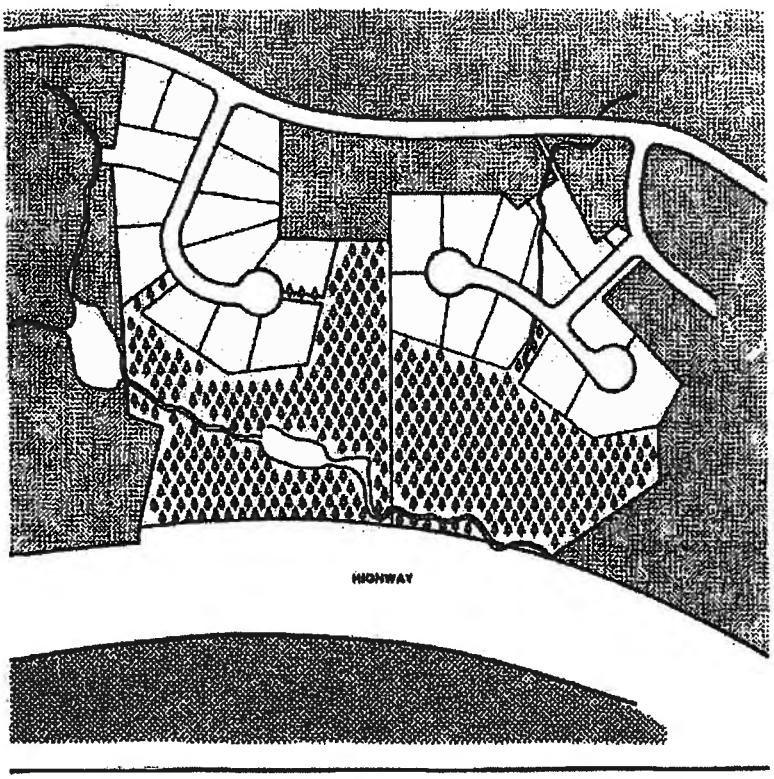

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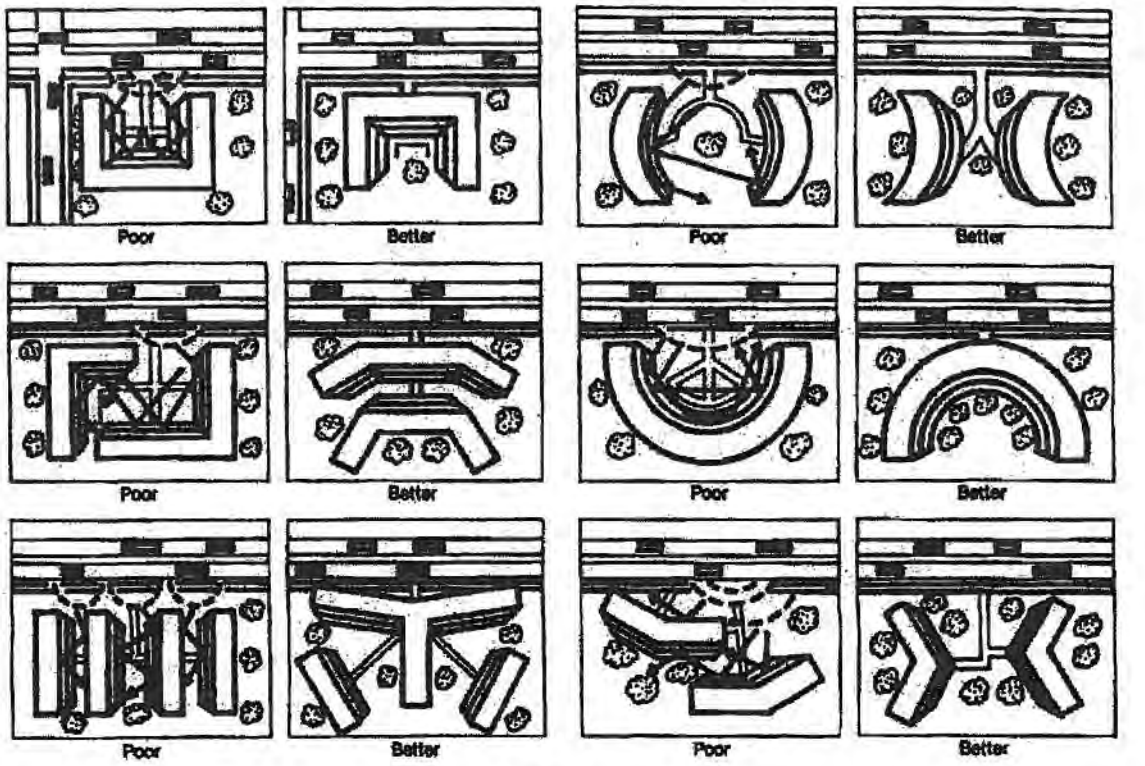
Figure 14
Orientation of Buildings on Sites



Acoustical Construction Concepts

(This section, with some editing is taken from the *Audible Landscape, FHWA.*[1])

Noise can be intercepted as it passes through the walls, floors, windows, ceilings, and doors of a building. Examples of noise reducing materials and construction techniques are described in the pages that follow.

To compare the insulation performance of alternative constructions, the Sound Transmission Class (STC) is used as a measure of a material's ability to reduce sound. Sound Transmission Class is equal to the number of decibels a sound is reduced as it passes through a material. Thus, a high STC rating indicates a good insulating material. It takes into account the influence of different frequencies on sound transmission, but essentially the STC is the difference between the sound levels on the side of the partition where the noise originates and the side where it is received. For example, if the external noise level is 85 dB and the desired internal level is 45 dB, a partition of 40 STC is required. The Sound Transmission Class rating is the official rating endorsed by the American Society of Testing and Measurement. It can be used as a guide in determining what type of construction is needed to reduce noise.

The use of the STC rating system for transportation noise is a subject of some debate. The STC rating was originally intended primarily for use with interior partitions and relates to the "subjective impressions of the sound insulation provided against the sounds of speech, radio, television, music, and similar sources of noise in offices and dwellings."[2] However, since it remains the only widely used noise reduction rating system for materials the STC system is very often used even with transportation noise. When STC ratings are used for transportation noise you should be aware that the STC ratings may be a few dB too high. For example, the STC rating for a standard frame 2 x 4 wall with exterior siding, and sheathing and interior sheetrock may be 37 dB.[3] If rated specifically for transportation noise the dB reduction rating might drop to 34 dB.[4] All this really means, however, is that you should use the STC ratings with a bit of caution and remain aware of the possible 2-3 dB overstating that you may get with the STC rating system. Throughout this text we will be talking in terms of STC ratings for materials and assemblies.

[1] *The Audible Landscape: A Manual for Highway Noise and Land Use*, US Department of Transportation, the Federal Highway Administration, November 1974, (GPO Stock #5000-00078).

[2] *Acoustical and Thermal Performance of Exterior Residential Walls, Doors, and Windows*, US Department of Commerce, National Bureau of Standards, November 1975. (NBS Building Science Series 77) page 21.

[3] Ibid., p. 29

[4] *Design Guide for Reducing Transportation Noise in and Around Buildings*, p. 137.

Walls

Walls provide building occupants with the most protection from exterior noise. Different wall materials and designs vary greatly in their sound insulating properties. Figure 15 provides a visual summary of some ways in which the acoustical properties can be improved:

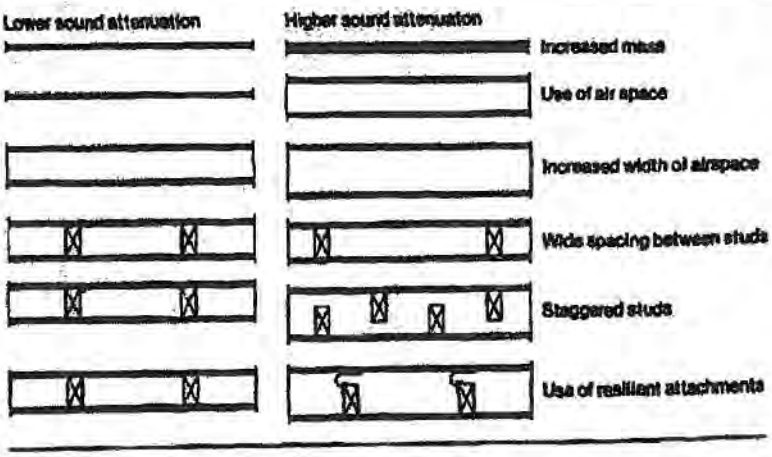
Increase the mass and stiffness of the wall. In general, the denser the wall material, the more it will reduce noise. Thus, concrete walls are better insulators than wood walls of equal thickness. Increasing the thickness of a wall is another way to increase mass and improve sound insulation. Doubling the thickness of a partition can result in as much as a 6 dB reduction in sound.[1] However, the costs of construction tend to limit the feasibility of large increases in wall mass.

The relative stiffness of the wall material can influence its sound attenuation value. Care must be taken to avoid wall constructions that can vibrate at audible frequencies and transmit exterior sounds.

[1] R. K. Cooke and P. Chrzanowski, "Transmission of Noise Through Walls and Floors," Cyril Harris, ed., Handbook of Noise Control, McGraw-Hill Book Company, Inc. (New York, 1957).

Figure 15
The Audible Landscape

Factors which influence sound attenuation of walls



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Use cavity partitions. A cavity wall is composed of two or more layers separated by an airspace. The airspace makes the cavity wall a more effective sound insulator than a single wall of equal weight, leading to cost savings.

Increase the width of the airspace. A three inch airspace provides significant noise reduction, but increasing the spacing to six inches can reduce noise levels by an additional 5 dBA. Extremely wide airspaces are difficult to design.

Increase the spacing between studs. In a single stud wall, 24 inch stud spacing gives a 2-5 dB increase in STC over the common 16 inch spacing.[2]

Use staggered studs. Sound transmission can be reduced by attaching each stud to only one panel and alternating between the two panels.

[2]Leslie T. Doelle, Environmental Acoustics (New York, McGraw-Hill Book Company, 1972), pp. 232-233.

Use resilient materials to hold the studs and panels together. Nails severely reduce the wall's ability to reduce noise. Resilient layers such as fiber board and glass fiber board, resilient clips, and semi-resilient attachments are relatively inexpensive, simple to insert, and can raise the STC rating by 2-5 dB.[1]

Use dissimilar layers. If the layers are made of different materials and/or thickness, the sound reduction qualities of the wall are improved.[2]

Add acoustical blankets. Also known as isolation blankets, these can increase sound attenuation when placed in the airspace. Made from sound absorbing materials such as mineral or rock wool, fiberglass, hair felt or wood fibers, these can attenuate noise as much as 10 dB.[3] They are mainly effective in relatively lightweight construction.

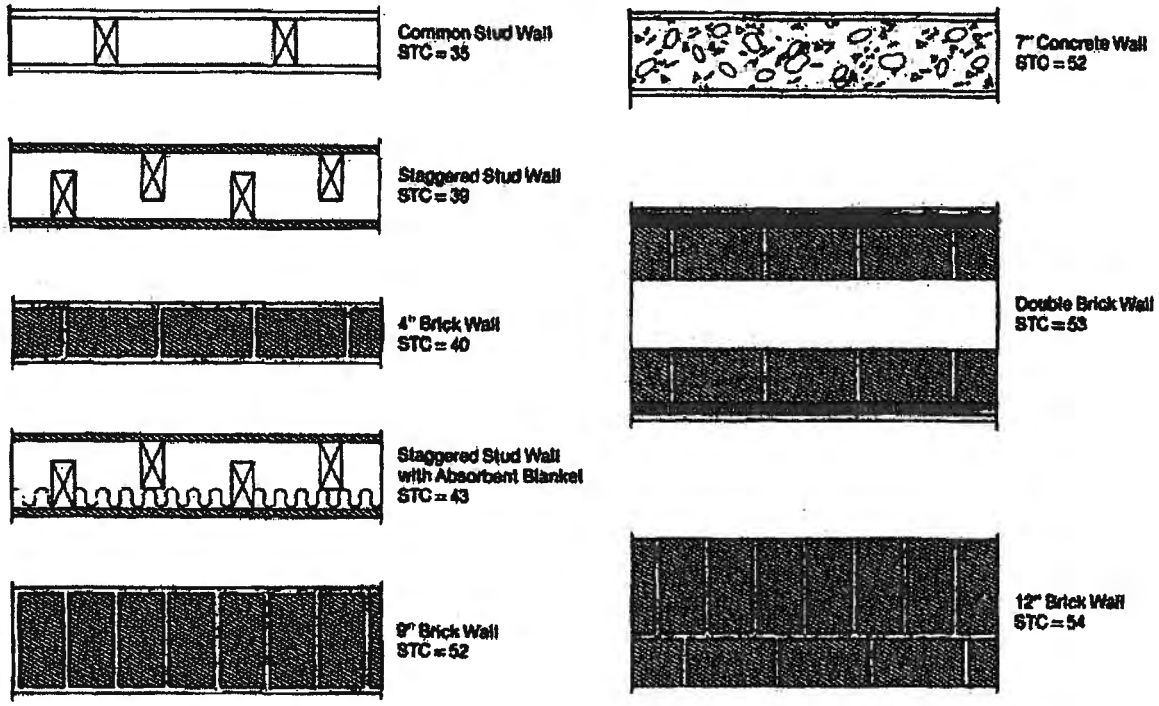
Seal cracks and edges. If the sound insulation of a high performance wall is ever to be realized, the wall must be well sealed at the perimeter. Small holes and cracks can be devastating to the insulation value of a wall. A one-inch square hole or a 1/16 inch crack 16 inches long will reduce a 50 STC wall to 40.[4]

Figure 16 shows a sample of wall types ranging from the lowest to the highest sound insulation values.

Remember that the effectiveness of best wall construction will be substantially reduced if you permit vents, mail slots or similar openings in the walls. If vents are permitted the ducts must be specially designed and insulated to make sure noise does not reach the inside. The best approach is simply to eliminate all such openings on impacted walls.

[1]Ibid, p. 172
[2]Ibid, p. 162
[3]Doelle, p. 20
[4]United States Gypsum, Sound Control Construction, Principles and Performance (Chicago, 1972), p. 65

Figure 16
Walls



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Windows

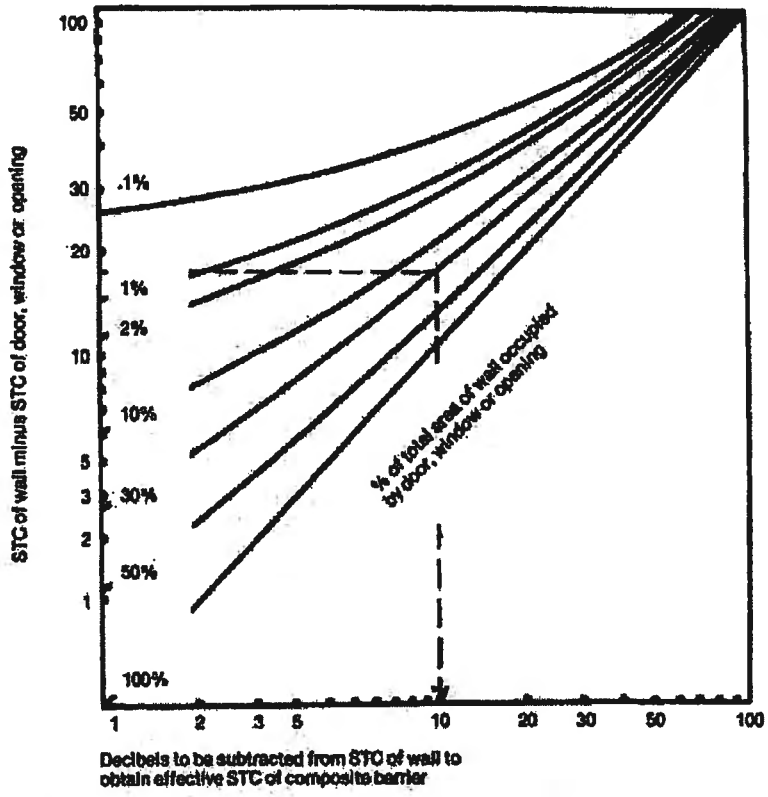
Sound enters a building through its acoustically weakest points, and windows are one of the weakest parts of a wall. An open or weak window will severely negate the effect of a very strong wall. Whenever windows are going to be a part of the building design, they should be given acoustical consideration. Figure 17 illustrates the effects of windows on the sound transmission of walls. For example, if a wall with an STC rating of 45 contains a window with an STC rating of 26 covering 30% of its area, the overall STC of the composite partition will be 35, a reduction of 10 dB.

The following is a discussion of techniques that can be used to reduce noise in a building by means of its windows. These techniques range from a blocking of the principal paths of noise entry to a blocking of the most indirect paths.

Close windows. The first step in reducing unwanted sound is to close and seal the windows. The greatest amount of sound insulation can be achieved if windows are permanently sealed. However, openable acoustical windows have been developed which are fairly effective in reducing sound.[1] Whether or not the sealing is permanent, keeping windows closed necessitates the installation of mechanical ventilation systems. If you are dealing with single family houses and some of the windows are facing away from all noise sources, a whole house fan may be better and cheaper than air conditioning. In multifamily housing or where all windows are exposed to the noise sources you will have to go with the air conditioning. If windows must be openable, special seals are available which allow windows to be opened.[2]

Reduce window size. The smaller the windows, the greater the transmission loss of the total partition of which the window is a part. Reducing the window size is a technique that is used because (a) it precludes the cost of expensive acoustical windows, and (b) it saves money by cutting down the use of glass. The problems with this technique are (a) it is not very effective in reducing noise; e.g., reducing the proportion of window to wall size from 50% to 20% reduces noise by only 3 decibels; and (b) many building codes require a minimum window to wall size ratio.

Figure 17
STC



Instructions on use of graph

1. Subtract the STC value of the door, window or opening from the STC value of the wall.
2. Enter the vertical axis of the graph at the point that matches the value from step 1.
3. Read across to the curve that represents the percentage of the total area of the wall that is taken up by the door, window, or opening.
4. Read down to the horizontal axis.
5. Subtract the value on the horizontal axis from the original STC value of the wall. The result is the composite STC value of the wall and the door, window or opening.

Increase glass thickness. If ordinary windows are insufficient in reducing noise impacts in spite of sealing techniques, then thicker glass can be installed. In addition, this glass can be laminated with a tough transparent plastic which is both noise and shatter resistant. Glass reduces noise by the mass principle; that is, the thicker the glass, the more noise resistant it will be. A 1/2-inch thick glass has a maximum STC rating of 35 dB compared to a 25 dB rating for ordinary 3/16 inch glass.

[1] U.S. Department of Housing and Urban Development, A Study of Techniques to Increase the Sound Insulation of Building Elements, Report No. WR 73-5, Washington, D.C., June 1973.

[2] Los Angeles Department of Airports, *Guide to the Soundproofing of Existing Homes Against Exterior Noise*. Report No. WRC 70-2, March 1970, pp. 9-11, 22-30. In this report, the function and performance of a number of operable seals are described.

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However, glass thicknesses are only practical up to a certain point, when STC increases become too insignificant to justify the cost. For example, a 1/2 inch thick glass can have an STC of 35; increasing the thickness to 3/4 inch only raises the STC to 37. However, a double glass acoustical window consisting of two 3/16 inch thick panes separated by an airspace will have an STC of 51 and can cost less than either solid window.

In addition to thickness, proper sealing is crucial to the success of the window. To prevent sound leaks, single windows can be mounted in resilient material such as rubber, cork, or felt.

Install Double-Glazed Windows. Double-glazed windows are paired panes separated by an airspace or hung in a special frame. Generally, the performance of the double-glazed window may be increased with:

- increased airspace width
- increased glass thickness
- proper use of sealings
- slightly dissimilar thicknesses of the panes
- slightly non-parallel panes

In general the airspace between the panes should not be less than 2-4 inches if an STC above 40 is desired. If this is not possible, a heavy single-glazed window can be used. The use of slightly non-parallel panes is a technique employed when extremely high sound insulation is required, such as in control rooms of television studios.

The thickness of double-glazed panes may vary from 1/8 to 1/4 inch or more per pane. Although thickness is important, the factors which most determine the noise resistance of the window is the use of sealant and the width of the airspace.

As in the case of all windows, proper sealing is extremely important. To achieve an STC above 43, double-glazed windows should be sealed permanently. If the windows must be openable, there are available special frames and sealers for openable windows which allow a maximum STC of 43.[1]

Permanently sealed double-glazed windows often require an air pressure control system to maintain a constant air pressure and minimal moisture in the airspace. Without this system, the panes may deflect, and, in extremely severe cases, pop out of the frames.

[1]Ibid.

To further insure isolation of noise between double-glazed panes, the panes could be of different thicknesses, different weights, and slightly non-parallel to each other. This prevents acoustical coupling and resonance of sound waves.

Doors

Acoustically, doors are even weaker than windows, and more difficult to treat. Any door will reduce the insulation value of the surrounding wall. The common, hollow core wood door has an STC rating of 17 dB. Taking up about 20% of the wall, this door will reduce a 48 STC wall to 24 STC. To strengthen a door against noise, the hollow core door can be replaced by a heavier solid core wood door that is well sealed[1] and is relatively inexpensive. A solid core wood door with vinyl seal around the edges and carpeting on the floor will reduce the same 48 STC wall to only 33 dB.[2] An increased sound insulation value can be achieved if gasketed stops or drop bar threshold closers are installed at the bottom edge of the door. (See Figure 18)

The alternative solution to doors is to eliminate them whenever possible from the severely impacted walls and place them in more shielded walls.

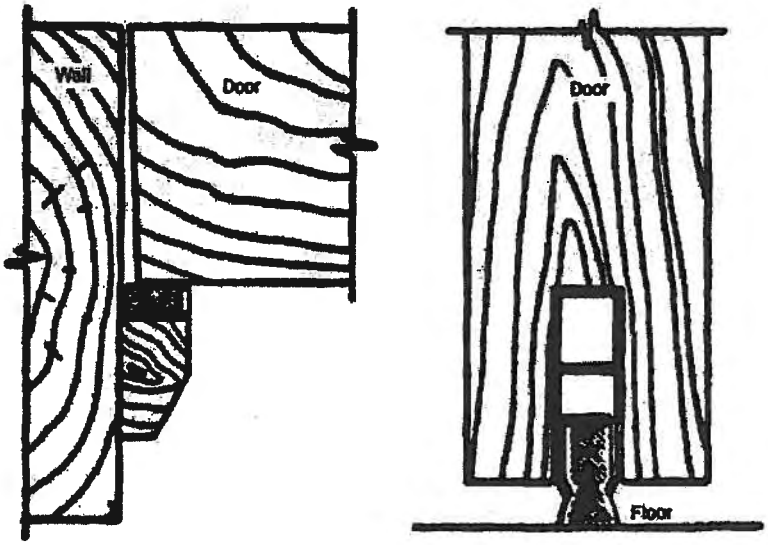
In any case no mail slots or similar openings should be allowed in exterior doors.

Roofs

Acoustical treatment of roofs is not usually necessary unless the noise is extremely severe or the noise source is passing over the building. The ordinary plaster ceiling should provide adequate sound insulation except in extremely severe cases. An acoustically weak roof which is likely to require treatment is the beamed ceiling.[3] Beamed ceilings may be modified by the addition of a layer of fiberglass or some other noise resistent material. Suspended ceilings are the most effective noise reducers but they are also the most expensive.

[1]D.E. Bishop and P.W. Hirtle, "Notes on the Sound Transmission Loss of Residential-Type Windows and Doors," Journal of the Acoustical Society of America, 43:4 (1968).
[2]U.S. Gypsum, Sound Control.., p. 100.
[3]Ibid p. 15.

Figure 18



Gasketed door stop

Drop bar threshold closer

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Floors

In the case of highway noise, floors would only require acoustical treatment if the highway were passing under the building. In this case, flooring would have to provide protection against structural vibrations as well as airborne sound.

Two ways to insulate a floor from noise are to install a solid concrete slab at least 6 inches thick or install a floating floor. In general, the floating floor gives the greatest amount of sound and vibration insulation; however, it is extremely expensive. Basically, a floating floor consists of a wood or concrete slab placed over the structural slab, but separated by a resilient material. The resilient material isolates the surface slab from the structural slab and the surrounding walls.

What to Look for When Reviewing Plans

The number of possible combinations of the building materials that go into walls, ceilings, windows and doors, is, no doubt, considerably short of infinite. It is however still a very large number, large enough that it would be impossible to compile a list of all the possible combinations. Therefore, do not expect to find in this section, or anywhere else for that matter, a neat table showing the STC ratings for all the types of construction you may encounter. In fact, it is not really your responsibility to determine the precise STC ratings for the walls, ceilings, windows and doors in the projects you review. Your job is simply to review the attenuation levels claimed by the sponsor/developer and determine whether or not they are reasonable.

To enable you to perform the above described task, we have prepared a list of the most common types of construction for which we have STC ratings. By comparing the type of construction proposed to one of these "model" types you should be able to tell whether the claimed STC rating is reasonable. For example, the sponsor/developer submits a description of his building stating that a 2 x 6 stud wall with standard sheathing, insulation, wood siding, and 1/2" gypsum board achieves a STC rating of 48. You look at Table 3 and find that the closest "model" wall is a 2 x 4 stud wall with wood siding, sheathing, insulation, and 1/2" gypsum board. This wall has a STC rating of 39. An 9 dB difference is quite significant considering that the walls are really quite similar. You would probably want to go back to the developer/sponsor and ask for some supporting data that proves that the 2 x 6 wall he proposes will indeed provide 48 dB of noise attenuation.

In order to make it easier to review the attenuation levels provided by the proposed construction, we suggest that you ask the developer/sponsor to complete a form such as shown in Figure 19. Such a form will give you all the information you need in a properly organized format that will facilitate your review. You could fill in the first part and simply have the developer/sponsor fill out the second part and return it with the developer certification or other project documents.

As you will recall from the previous section, most walls provide pretty good attenuation by themselves. It is the presence of windows and doors and openings such as vents that reduces the attenuation capability of the wall. Thus, after you have determined whether the basic wall itself has a reasonable STC, you must review the impact of the windows and doors. You do this by using Figure 17. First you determine the difference between the STC ratings for the wall and the windows. You enter the vertical axis of Figure 17 with that number. You read across until you intersect the line that represents the percentage of the wall taken up by the windows. Then you read down to the horizontal axis where you will find the value to be subtracted from the basic STC value of the wall. The resulting number is the combined STC value for the wall. If the wall also contains a door, repeat the same procedure, only start out with the modified STC rating for the wall. If the wall has doors only, then obviously you start with the basic wall STC rating. Finally you compare the number you have derived with that listed by the developer/sponsor. If they are fairly close, you need not pursue it further. If there is a substantial difference, you should ask for an explanation or documentation from the developer.

Once again, we caution you about borderline cases. If the attenuation required is 30 dB and the STC rating for the proposed construction is exactly 30 dB, you may want to ask the developer to provide even more attenuation. Remember that we discussed how the STC rating may overstate the actual attenuation provided by as much as 3 dB. If an additional 3 dB can be achieved at minimum cost, we would strongly urge that you seek it from the developer/sponsor.

Finally check to make sure the developer has provided some form of mechanical ventilation. If it's a single family house and a whole house fan is the means of ventilation being provided make sure that there are operable windows on walls which do not face the noise source(s) nor are perpendicular to the source(s). Otherwise the residents will have to open windows on the exposed wall, thus cancelling out much of the attenuation achieved.

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Table 3
STC Ratings for Typical Building Components[1]

Building Component	Description	STC Rating
Frame Wall	a. 5/8" × 10" Redwood Siding b. 1/2" Insulation Board Sheathing c. 2 × 4 studs 16" o.c. d. Fiberglass Building Insulation e. 1/2" Gypsum Board attached directly to studs	39 dB
Stucco/Frame Wall	a. 7/8" Stucco b. No. 15 felt Building Paper and 1" Wire Mesh c. 2 × 4 Studs 16" o.c. d. Fiberglass Building Insulation e. 1/2" Gypsum Board attached directly to studs	46
Brick Veneer Wall	a. Face Brick b. 1/2" Airspace with metal ties c. 3/4" Insulation Board Sheathing d. 2 × 4 Studs 16" o.c. e. Fiberglass Building Insulation f. 1/2" Gypsum Board attached directly to studs	56
Masonry Wall	a. 1" Stucco b. 8" thick Hollow Concrete Block c. 1/2" Gypsum Board attached to furring strips	49 (estimated)
Windows	Wood double hung, closed but unlocked, single glazing	23
	Aluminum sliding, latched, single glazing	24
	Wood double hung, closed but unlocked, glazed with 7/16" insulating glass	22
	Aluminum single hung, closed, glazed with 7/16" insulating glass	25
	Wood, double hung, sealed, glazed with 7/16" insulating glass with single glazed storm sash–2 1/8" separation	35
	Aluminum sliding, closed, single glazed with single glazed storm sash, 1/8" separation	22
Exterior Doors	Wood, flush solid core, with brass weather stripping	27
	Wood, flush solid core, plastic weather stripping, aluminum storm door	34
	Wood, French door, brass weather stripping	26
	Steel, flush, with urethane foam core, with magnetic weather stripping	28
Roof	Shingle Roof with attic, 1/2" gypsum wall board ceiling framed independently of roof	43 (estimated)

[1]Except as noted, all STC ratings are from: *Acoustical and Thermal Performance of Exterior Residential Walls, Doors and Windows*, National Bureau of Standards.

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Figure 19
Description of Noise Attenuation Measures
(Acoustical Construction)

Part I

Project Name _____

Location _____

Sponsor/Developer _____

Noise Level (From NAG) _____ Attenuation Required _____

Primary Noise Source(s) _____

Part II

1. For Walls (s) facing and parallel to the noise source(s) (or closest to parallel):
   a. Description of wall construction* _____

   b. STC rating for wall (rated for no windows or doors): _____

   c. Description of Windows: _____

   d. STC rating for window type _____

   e. Description of doors _____

   f. STC rating for doors _____

   g. Percentage of wall (per wall, per dwelling unit) composed of windows _____ and doors _____

   h. Combined STC rating for wall component _____

2. For walls perpendicular to noise source(s):
   a. Description of wall construction* _____

   b. STC rating for wall (rated for no windows or doors) _____

   c. Description of windows _____

   d. STC rating for windows _____

   e. Description of doors _____

f. STC rating for doors _____

g. Percentage of wall (per wall, per dwelling unit) composed of windows _____ and doors _____

h. Combined STC rating for wall component _____

3. Roofing component (if overhead attenuation is required due to aircraft noise):
   a. Description of roof construction _____

   _____

   b. STC rating (rated as if no skylights or other openings) _____

   c. Description of skylights or overhead windows _____

   _____

   d. STC rating for skylights or overhead windows _____

   e. Percentage of roof composed of skylights or windows (per dwelling unit) _____

   f. Percentage of roof composed of large uncapped openings such as chimneys _____

   g. Combined STC rating for roof component _____

4. Description of type of mechanical ventilation provided _____

   _____

Prepared by _____

Date: _____

*If walls contain vents or similar openings, attach a description of duct arrangement and insulation and a statement of how much the wall STC is reduced by the presence of the vent.

Figure 19
Description of Noise Attenuation Measures
(Acoustical Construction)

Part I

Project Name PARADISE HOMES

Location ANYTOWN

Sponsor/Developer JOHN DOE & ASSOC. INC.

Noise Level (From NAG) 73 Attenuation Required 30dB

Primary Noise Source(s) HIGHWAY

Part II

1. For Walls (a) facing and parallel to the noise source(s) for closest to parallel):
   a. Description of wall construction* 3/8" FIR PLYWOOD SIDING, 2x4 STUDS 16" o.c. 3½" FIBERGLASS INSULATION
   b. STC rating for wall (rated for no windows or doors): 37
   c. Description of Windows: WOOD DOUBLE HUNG, INSULATING GLASS
   d. STC rating for window type 22
   e. Description of doors WOOD, FLUSH, SOLID CORE
   f. STC rating for doors 30
   g. Percentage of wall (per wall, per dwelling unit) composed of windows 10% and doors 5%
   h. Combined STC rating for wall component 30dB

2. For walls perpendicular to noise source(s):
   a. Description of wall construction* SAME AS ABOVE
   b. STC rating for wall (rated for no windows or doors) 37
   c. Description of windows SAME AS ABOVE
   d. STC rating for windows 22
   e. Description of doors NO DOORS

SAMPLE

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f. STC rating for doors ___

g. Percentage of wall (per wall, per dwelling unit) composed of windows 10% and doors 0

h. Combined STC rating for wall component 30

3. Roofing component (if overhead attenuation is required due to aircraft noise):
   a. Description of roof construction N/A

   b. STC rating (rated as if no skylights or other openings) ___

   c. Description of skylights or overhead windows ___

   d. STC rating for skylights or overhead windows ___

   e. Percentage of roof composed of skylights or windows (per dwelling unit) ___

   f. Percentage of roof composed of large uncapped openings such as chimneys ___

   g. Combined STC rating for roof component ___

4. Description of type of mechanical ventilation provided Central Air Conditioning

Prepared by ___

Date: ___

*If walls contain vents or similar openings, attach a description of duct arrangement and insulation and a statement of how much the wall STC is reduced by the presence of the vent.

SAMPLE

Quiz on Noise Attenuation

Questions

1. What are the three basic ways to provide noise attenuation?
2. What are the responsibilities of HUD personnel regarding noise attenuation?
3. When a barrier is introduced between a source and a receiver the sound energy is redistributed along 3 indirect paths. What are these three paths?
4. What is "Path Length Difference" and how does it affect the attenuation level provided by a barrier?
5. What are "Transmission Loss Values?"
6. How does the transmission loss value of barrier material affect the attenuation capability of the barrier?
7. As a general rule, what transmission loss values should you look for?
8. If you have more than one barrier between the source and the receiver is the amount of attenuation increased substantially?
9. What are the four things to check when reviewing a proposed barrier?
10. List 3 ways to make a barrier more effective without increasing its overall height.
11. List 3 ways to make a barrier more effective without increasing its overall length.
12. What is the maximum percentage of the total area of a barrier that can be made up of openings without a significant loss in barrier effectiveness?
13. List 3 site planning techniques that are used to shield residential developments.
14. When are parks and playgrounds not noise compatible uses that can be employed as buffers?
15. What are the two main things to look for when reviewing site plan changes?
16. What are some of the building orientations which can aggravate noise problems?
17. What is the Sound Transmission Class (STC) rating?
18. Which is better a high STC or a low STC rating?
19. What kinds of conditions were STC ratings originally developed for?
20. What should you do when using STC ratings in a transportation noise situation?
21. List 5 ways to improve the attenuation capability of a wall.
22. Windows are one of the acoustically weakest components in a wall. List 3 ways to reduce the negative effects of windows.
23. What is the best way to reduce the effect of doors?

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Quiz on Noise Attenuation

Answers

1. a. barriers or berms
   b. site design
   c. acoustical construction
2. a. to make sure the project sponsor/developer is aware of the attenuation requirements
   b. provide sponsor/developer with an overview of available options
   c. review attenuation proposals to make sure they are adequate
3. a. A diffracted path over the top of the barrier
   b. A transmitted path through the barrier
   c. A reflected path away from the receiver
4. "Path Length Difference" is the difference in distance that sound must travel diffracting over the barrier rather than passing directly through it. Since sound energy decreases over distance, the greater the path length distance the greater the attenuation.
5. "Transmission Loss Values" represent the amount noise levels will be reduced when the sound waves pass through a barrier.
6. Since the attenuation provided by a barrier is a function of both the sound energy that goes over the top and the energy that goes through the barrier, if the transmission loss value is low then the effectiveness of the barrier will be greatly reduced.
7. If the transmission loss value of the barrier material is at least 10dB greater than the attenuation level provided by diffraction (i.e. barrier height) there shouldn't be any problem.
8. No. The combined effect of multiple barriers does not normally provide significantly greater attenuation than a single barrier. For design purposes, the general procedure is to assume the attenuation of the most effective barrier.
9. a. Is it high enough?
   b. Is it long enough?
   c. Is it made of the right material?
   d. Is it properly constructed?
10. a. move the barrier closer to the source
    b. bend the top of the barrier towards the source
    c. do both
11. a. move it closer to the receiver
    b. bend the ends toward the receiver
    c. do both
12. 1 percent
13. Any 3 of the below:
    a. increasing the distance between the source and the receiver
    b. placing noise compatible land uses between the source and the receiver
    c. locating barrier type buildings parallel to the source
    d. orienting residences away from the noise
14. when they are the only ones associated with the project
15. a. is the separation between the source and receiver great enough
    b. if a noise compatible building is being used as a barrier is it tall and long enough?
16. Building orientations which trap noise and cause it to reverberate off building walls. This would include shapes where a court is open to the source or where a series of buildings are arranged perpendicular to the source.
17. The STC rating is equal to the number of decibels a sound is reduced as it passes through a material.
18. A high STC rating is better.
19. The STC ratings were originally intended primarily for use with interior partitions and for noise such as speech, radios, television.
20. Recognize that the STC rating may overstate the effectiveness of the materials by 2-3db.
21. Any of the 9 below:
    a. increase the mass and stiffness of the wall
    b. use cavity partitions
    c. increase the width of the airspace
    d. increase the spacing between studs
    e. use staggered studs
    f. use resilient materials to hold the studs and finish materials together
    g. use of dissimilar layers (leaves)
    h. add acoustical blankets
    i. seal cracks and edges
22. Any of the 4 below:
    a. close the windows and provide mechanical ventilation
    b. reduce window size
    c. increase glass thickness
    d. install double glazed windows
23. Eliminate them from severely impacted walls

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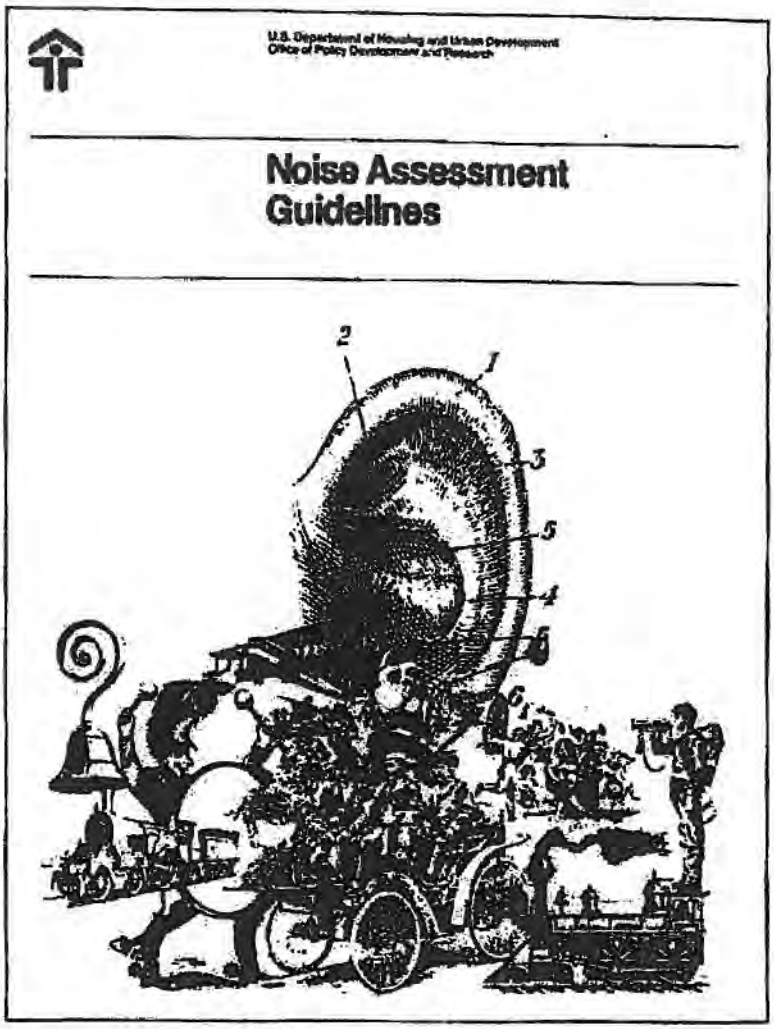
Chapter 5

Noise Assessment Guidelines



Noise Assessment Guidelines

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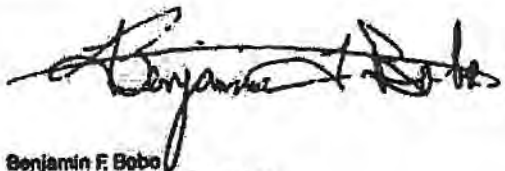
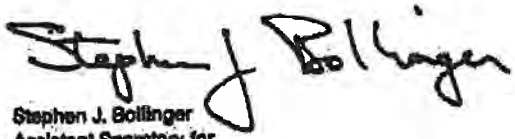
Foreword

In choosing among alternative sites for housing, potential noise problems are prominent among the issues that must be examined. These Noise Assessment Guidelines were developed to provide HUD field staff, interested builders, developers, and local officials with an easy-to-use method of evaluating noise problems with a minimum of time and effort.

We believe that this set of tools will simplify the process of balancing the goal of environmental protection with those of efficiency and reduced housing costs. We hope you will find them useful, and invite your comments.



Benjamin F. Bobo
Acting Assistant Secretary for
Policy Development and Research



Stephen J. Bollinger
Assistant Secretary for
Community Planning and
Development

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Preface

The Department of Housing and Urban Development, in its efforts to provide decent housing and a suitable living environment, is concerned with noise as a major source of environmental pollution and has issued Subpart B on Noise Abatement and Control to Part 51 of Title 24 of the Code of Federal Regulations.

The policy established by Subpart B embodies HUD objectives to make the assessment of the suitability of the noise environment at a site: (1) easy to perform; (2) uniformly applicable to different noise sources; and (3) as consistent as possible with the assessment policies of other Federal departments and agencies. In furtherance of these objectives, the Office of Policy Development and Research has sponsored research to provide site analysis techniques. These *Noise Assessment Guidelines* do not constitute established policy of the Department but do provide a methodology whose use is encouraged by HUD as being consistent with its objectives. The *Guidelines* provide a means for assessing separately the noise produced by airport, highway, and railroad operations, as well as the means for aggregating their combined effect on the overall noise environment at a site.

This booklet has been prepared by Bolt Beranek and Newman Inc., under Contract No. H-2243R for the U.S. Department of Housing and Urban Development. It is a revision of an earlier edition published in August 1971. With the exception of changes made by the Department, the contractor is solely responsible for the accuracy and completeness of the data and information contained herein.

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Introduction

These guidelines are presented as part of a continuing effort by the Department of Housing and Urban Development to provide decent housing and a suitable living environment for all Americans.

The procedures described here have been developed so that people without technical training will be able to assess the exposure of a housing site to present and future noise conditions. In this context, the site may hold only one small building, in which case the noise assessment is straightforward. Larger sites may hold larger buildings, or many buildings, and the noise level may be different at different parts of the site (or building). Assessments of the noise exposure should be made at representative locations around the site where significant noise is expected. These are designated as "Noise Assessment Locations," abbreviated NAL in the following text.

The only materials required are a map of the area, a ruler (straight edge), a protractor and a pencil. Worksheets and working figures are provided separately.

All of the information you need can be easily obtained – usually by telephone. For convenience, this information is listed at the beginning of each section under headings that indicate the most likely source. While you are obtaining this information, be sure to ask about any approved plans for future changes that may affect noise levels at the site - for example: land-use changes, changes in airport runway traffic, widening of roads, and so forth. In all evaluations, you should assess the condition that will have the most severe or most lasting effect on the use of the site.

Wherever possible, you should try to assess noise environments expected at least ten years in the future.

The degree of acceptability of the noise environment at a site is determined by the outdoor day-night average sound level (DNL) in decibels (dB). The assessment of site acceptability is presented first as an evaluation of the site's exposure to three major sources of noise – aircraft, roadways, and railways. These are then combined to assess the total noise at a site. Worksheets are provided at the back of these Guidelines to use in summarizing your evaluations.

The noise environment at a site will come under one of three categories:

Acceptable (DNL not exceeding 65 decibels) The noise exposure may be of some concern but common building constructions will make the indoor environment acceptable and the outdoor environment will be reasonably pleasant for recreation and play.

Normally Unacceptable (DNL above 65 but not exceeding 75 decibels) The noise exposure is significantly more severe; barriers may be necessary between the site and prominent noise sources to make the outdoor environment acceptable; special building constructions may be necessary to ensure that people indoors are sufficiently protected from outdoor noise.

Unacceptable (DNL above 75 decibels) The noise exposure at the site is so severe that the construction cost to make the indoor noise environment acceptable may be prohibitive and the outdoor environment would still be unacceptable.

When measuring the distance from the site to any noise source, measure from the source to the nearest points on the site where buildings having noise-sensitive uses are located. These points define the Noise Assessment Locations for the site. The relevant measurement location for buildings is a point 2 meters (6.5 feet) from the facade.

If at any point during the assessment the site's exposure to noise is found to be Unacceptable or Normally Unacceptable, every effort should be made to improve the condition, e.g., the location of the proposed dwellings can be changed or some shielding can be provided to block the noise from that source.

Where quiet outdoor space is desired at a site, distances should be measured from the important noise sources to the outdoor area in question and the combined noise exposure should be assessed.

Frequently, the locations of dwellings have not yet been specified at the time the noise assessment of a site is made. In these instances, distances used in the noise assessment should be measured as 2 meters less than the distance from the building setback line to the major sources of noise.

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Combining Sound Levels in Decibels

The noise environment at a site is determined by combining the contributions of different noise sources. In these Guidelines, Workcharts are provided to estimate the contribution of aircraft, automobile, truck, and train noise to the total day-night average sound level (DNL) at a site. The DNL contributions from each source are expressed in decibels and entered on Worksheet A. The combined DNL from all the sources is the DNL for the site and is the value used to determine the acceptability of the noise environment.

Sound levels in decibels *are not combined by simple addition!* The following table shows how to combine sound levels:

Table

Difference in Sound Level	Add to Larger Level
0	3.0
1	2.5
2	2.1
3	1.8
4	1.5
5	1.2
6	1.0
7	0.8
8	0.6
9	0.5
10	0.4
12	0.3
14	0.2
16	0.1
greater than 16	0

Use the table by first finding the numerical difference in sound level between two levels being combined. Entering the table with this value, find the value to be added to the larger of the two levels, add this value to the larger level to determine the total. Where more than two levels are to be combined, use the same procedure to combine any two levels; then use this subtotal and combine it with any other level, and so on. Fractional numerical values may be interpolated from the table; however, the final result should be rounded to the nearest whole number.

Example 1: In performing a site evaluation, the separate DNL values for airports, road traffic, and railroads have been listed on Worksheet A as 56, 63, and 61 decibels. In order to complete the final evaluation of the site, these separate DNL values must be combined. The difference between 63 and 56 is 7; from the table you find that 0.6 should be added to 63, for a subtotal of 63.6. The difference between 63.6 and 61 is 2.6; from the table you interpolate that approximately 1.9 should be added to 63.6 for a total of 65.7 or 66 dB when rounded to whole numbers. This example shows how noise from different sources may be Acceptable, individually, at a site, but when combined, the total noise environment may exceed the Acceptable DNL limit of 65 decibels.

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Aircraft

Necessary Information

To evaluate a site's exposure to aircraft noise, you will need to consider all airports (civil and military) within 15 miles of the site. The information required for this evaluation is listed below under headings that indicate the most likely source. Before beginning the evaluation, you should record the following information on Worksheet B:

From the FAA Area Office or the Military Agency in charge of the airport:

- Are current DNL or NEF (Noise Exposure Forecast) contours available? Noise contours are available for almost all military airports. These contours have been developed and published as part of the Air Installation Compatible Use Zone (AICUZ) program of the Department of Defense. The contours are published normally as part of an AICUZ report. Noise contours are also available for many civil airports. When available, they are superimposed on a map with an appropriately marked scale (see Figure 1, page 4).
- Any available information about approved plans for runway changes (extensions or new runways).

From the FAA Control Tower or Airport Operations (if DNL or NEF contours are *not* available):

- The number of nighttime jet operations (10 p.m. - 7 a.m.)
- The number of daytime jet operations (7 a.m. - 10 p.m.)
- The flight paths of the major runways.
- Any available information about expected changes in airport traffic, e.g., will the number of operations increase or decrease in the next 10 or 15 years.

In making your evaluation, use the data for the heaviest air traffic condition, whether present or future.

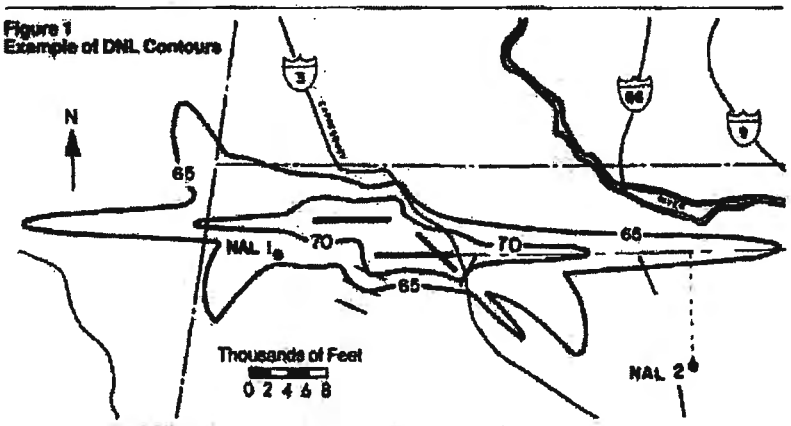
Evaluation of Site Exposure to Aircraft Noise

If current DNL (or NEF) contours are available (as in Figure 1 page 4), locate the site on the map by referring to the marked distance scale. If there are no other noise sources in the area, you do not need to do anything else. If there are other noise sources affecting the site, you will need to find the precise DNL value so you can combine it with the other sources. Obtain the DNL at the appropriate NAL on the site by interpolation between the contours on either side of the NAL. If NEF contours are used, estimate DNL by adding 35 decibels to the NEF values. Note that contours are usually provided in 5 decibel increments. (See Example 2 on page 4.) When supersonic aircraft operations are present, DNL contours are *required* for the assessment.

If DNL or NEF contours are *not* available, the DNL at a site may be estimated in several different ways:

- An FAA Handbook (Reference 1) can be used to estimate DNL contours for sites in general aviation airport vicinities. General aviation airports exclude commercial jet transports but may include business jets.
- A handbook available from EPA (Reference 2 at the back of this Guide) can be used to calculate DNL at individual points.
- A procedure for constructing approximate DNL contours for sites near commercial jet

Figure 1
Example of DNL Contours



Example 2: The illustration in Figure 1 at the top of page 4 shows the NAL's on a map that has DNL contours. We find that NAL number 1 lies between the 65 and 70 dB contours and that NAL number 2 lies outside the 65 dB contour.

We find the DNL at NAL number 1 by interpolation from the distances between the NAL and the 65 and 70 dB contours.

By scaling off the map, we find that the distance from the NAL, measured perpendicularly to the contours, is 800 feet to the 65 dB contour and 2400 feet to the 70 dB contour. The distance between the 65 and 70 dB contours is 2400 + 800 =3200 feet. We find the DNL at the NAL number 1 to be 65 decibels plus 800/3200 x 5 decibels = 66.3 decibels.

Example 3: The illustration in Figure 2 at the bottom of page 5 shows an airport for which DNL or NEF contours are not available. The airport has 10 nighttime and 125 daytime jet operations.

To construct the approximate contours, we determine the effective number of operations as follows:

10 (nighttime) x 10 = 100

Add to this the actual number of daytime operations:

100 + 125 (daytime) = 225

To determine the distances A and B in relation to the runway (see Figure 3, page 5), enter the effective number of operations on the horizontal scales of the charts in Figure 3;

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airports without supersonic aircraft is as follows:

Determine the "effective" number of jet operations at the airport by first multiplying the number of nighttime jet operations by 10.

Then add the number of daytime jet operations to obtain an effective total (see Example 3, page 4).

On a map of the area showing the principal runways, mark the location of the site and, using the diagram and charts of Figure 3 on page 5, construct approximate DNL contours of 65, 70, and 75 dB for the major runways and flight paths most likely to affect the site. (see Figure 2, page 5.)

Although a site may be Acceptable for exposure to aircraft noise, exposure to other sources of noise, when combined with the aircraft noise, may make the site Unacceptable. Therefore, if necessary, values of aircraft noise exposure less than 65 dB can be estimated from Table 2. Scale the shortest distance D^2 from the NAL to the flight path, as in Figure 2. Scale the distance D^1 from the 65 dB contour to the flight path. Divide D^2 by D^1 and enter this value into the following table to find the approximate DNL at the NAL.

Table 2

$\frac{D2}{D1}$	DNL dB
1.00	65
1.12	64
1.26	63
1.41	62
1.58	61
1.78	60
2.00	59
2.24	58
2.51	57
2.82	56
3.16	55

Figure 2
Example of Approximate DNL Contours for an Airport with 225 Effective Number of Operations

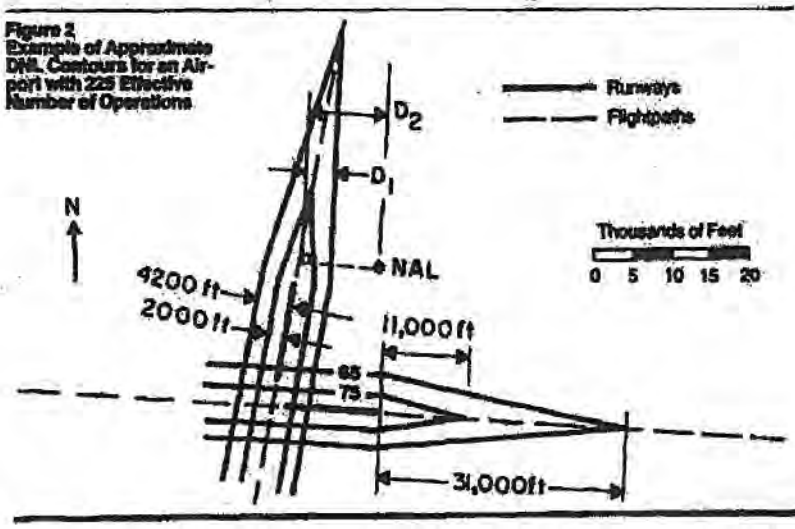
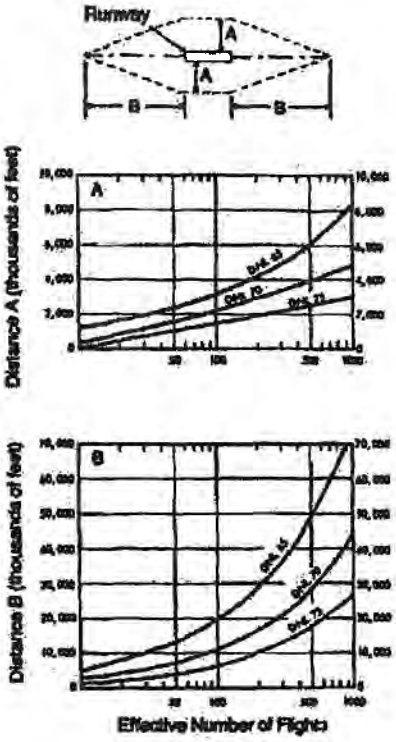


Figure 3
Charts for Estimating DNL for Aircraft Operations



read up to the DNL curves; read across the chart to the left to obtain distances A and B from the vertical scales on the charts.

We find from Figure 3, for example, that for 225 effective operations, distance A is 4200 feet for the 65 dB contour and 2000 feet for the 75 dB contour. Distance B is 31,000 feet for the 65 dB contour and 11,000 feet for the 75 dB contour.

Example 4a: The NAL shown in Figure 2 is outside the 65 dB contour. The distance D^2 from the NAL to the flight path is 9700 feet. The distance D^1 from the 65 dB contour to the flight path, measured perpendicularly from the contour, is 3700 feet. The ratio D^2/D^1 is 9700/3700 = 2.62. From Table 2 we find the DNL from the airport to be 56.6 dB. We do not know whether the site is Acceptable or not, however, since we must also assess the contribution of roadway and train noise to the total DNL at the site.

Example 4b: We observe that the perpendicular distance (D^2) from NAL number 2 (Figure 1) to the flight path is more than 3 times the distance (D^1) from the 65 dB contour to the flight path. From Table 2 we find that the contribution of the airport to the DNL at NAL number 2 is less than 55 decibels. We need not consider the airport further in accessing the noise environment at this site.

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Necessary Information

To evaluate a site's exposure to roadway noise, you will need to consider all roads that might contribute to the site's noise environment; roads farther away than 1000 feet normally may be ignored.

Before beginning the evaluation, determine if roadway noise predictions already exist for roads near the site. Also try to obtain all available information about approved plans for roadway changes (e.g., widening existing roads or building new roads) and about expected changes in road traffic (e.g., will the traffic on this road increase or decrease in the next 10 to 15 years).

If noise predictions have been made, they should be available from the City (County) Highway or Transportation Department. If not, record the following information on page 1 of Worksheet C:

- The distances from the NAL's for the site to the near edge of the nearest lane and the far edge of the farthest lane for each road.
- Distance to stop signs.
- Road gradient, if 2 percent or greater.
- Average speed.
- The total number of automobiles for both directions during an average 24-hour day. Traffic engineers refer to this as ADT, Average Daily Traffic (or sometimes AADT, meaning Annual Average Daily Traffic).
- The number of trucks during an average 24-hour day in each direction.

If possible, separate trucks into "heavy trucks" – those weighing more than 26,000 pounds with three or more axles – and "medium trucks" – those between 10,000 and 26,000 pounds. (Each medium truck is counted as equal to 10 automobiles.) Trucks under 10,000 pounds are counted as automobiles. Count buses capable of carrying more than 15 seated passengers as "heavy" trucks – others, as "medium" trucks. If it is not possible to separate the trucks into those that are heavy and those that are not, treat all trucks as though they are "heavy."

Note: If the road has a gradient of 2 percent or more, record the numbers for uphill and downhill traffic separately since these figures will be needed later; otherwise, simply record the total number of trucks. Most often you will have to assume that the uphill and downhill traffic are equally split.

- The fraction of ADT that occurs during nighttime (10 p.m. to 7 a.m.). If this is unknown, assume 0.15 for both trucks and autos.

Evaluation of Site Exposure to Roadway Noise

Traffic surveys show that the amount of roadway noise depends on the percentage of trucks in the total traffic volume. To account for this effect, you must evaluate automobile and truck traffic separately and then combine the results.

The noise environment at each site due to traffic noise is determined by utilizing a series of Worksheets to define the contribution of automobiles and trucks from one or more roads at that site. Each noise source yields a separate DNL value.

Worksheet 1 provides a graph for assessing a site with respect to the noise from automobiles, light and medium trucks; Worksheet 2 provides a similar graph for assessment of heavy truck noise. These values are combined for each road affecting the noise environment at the site to obtain the total contribution of roadway noise. Remember, the noise from aircraft and railways must also be considered before determining the suitability of this site's noise environment.

Effective Distance

Before proceeding with these separate evaluations, however, determine the "effective distance" to each road from the dwelling or outdoor residential activity (the NAL's for the site) by averaging the distances to the nearest edge of the nearest lane and to the farthest edge of the farthest lane of traffic. (See Example 5, page 6, and Figure 4, page 7.)

Note: For roads with the same number of lanes in both directions, the effective distance is the distance to the center of the roadway (or median strip, if present).

Automobile Traffic

Worksheet 1 was derived with the following assumptions:

- There is line-of-sight exposure from the site to the road; i.e., there is no barrier which effectively shields the site from the noise of the road.
- There is no stop sign within 600 feet of the site; traffic lights do not count because there is usually traffic moving on one street or the other.
- The average automobile traffic speed is 55 mph.
- The nighttime portion of ADT is 0.15.

If each road meets these four conditions, proceed to Worksheet 1 for the evaluation. Enter the horizontal axis with the effective distance from the roadway to the NAL; draw a vertical line upward from this point. Enter the vertical axis with the effective automobile ADT; draw a horizontal line across from this point. (The "effective" automobile ADT is the sum of automobiles, light trucks, and 10 times the number of medium trucks in a 24-hour day.) Read the DNL value from Worksheet 1 where the vertical and horizontal lines intersect. Record this value in column 1B, Worksheet C.

But:

If any of the four conditions is different, make

Example 5: The site shown in Figure 4 is exposed to noise from three major roads: Road No. 1 has four lanes, each 12 feet wide, and a 30-foot wide median strip which accommodates a railroad track. Road No. 2 has four lanes, each 12 feet wide. Road No. 3 has six lanes, each 15 feet wide, and a median strip 30 feet wide.

The distance from NAL No. 1 to the near edge of Road No. 1 is 300 feet. The distance to the far edge of Road No. 1 is 300 feet, plus the number of lanes times the lane width, plus the width of the median strip. Thus, the distance to the farthest edge of the road is:

$$300 + (4 \times 12) = 378 \text{ ft}$$

The effective distance is

$$\frac{378 + 300}{2} = 339 \text{ ft}$$

This is the value to be entered on line 1c of Worksheet C. The effective distances from the appropriate NAL's to Road No. 2 and Road No. 3 are found by the same method.

The distances shown in Figure 4 will be used for all roadway examples in this booklet.

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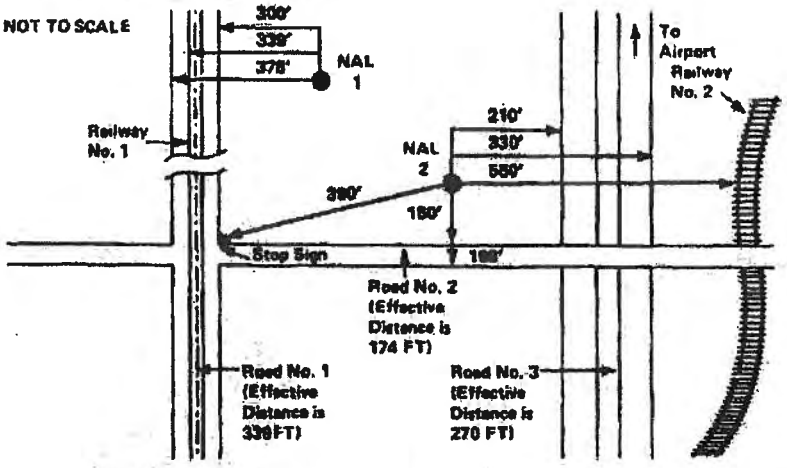
Figure 4
Plan View of Site showing How Distance Should Be Measured from the Noise Assessment Location (NAL) of the Dwelling Nearest to the Source

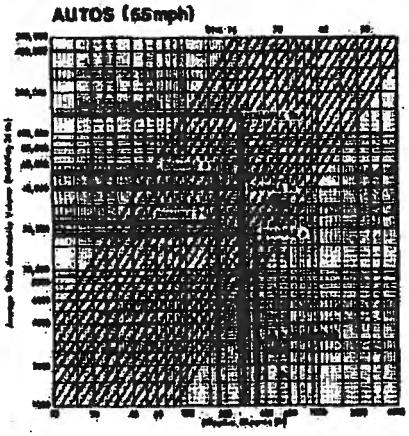


the necessary adjustments (on page 2, Worksheet C) listed below and *then* use Workchart 1 for the final evaluation.

First, a few general words about adjustments as they are applied in these Guidelines. Each Workchart has been derived for a baseline condition which is often found in practical cases. Where conditions differ from the baseline, they are accounted for by a series of one or more adjustment factors.

The adjustment factors are used as multipliers times the average number of vehicles operating during a 24-hour day. If more than one adjustment is required, it is not necessary that each be multiplied times the basic traffic flow separately; all adjustment factors are multiplied together, and them multiplied times the original traffic flow data. This will become clearer as you examine the Worksheets at the back of these Guidelines and work through the examples. After you have become familiar with the Guidelines, you will be able to work examples directly from the worksheets without referring back to the text. To simplify your work, all the adjustment factors are summarized at the back of these Guidelines.

Figure 5
Use of Workchart 1 To Evaluate Automobile Traffic Noise



Adjustments for Automobile Traffic

Stop-and-Go Traffic:
If there is a stop sign (not a traffic signal) within 600 feet of the NAL so that the flow of traffic is completely interrupted on the road under consideration, find the stop-and-go adjustment factor for automobiles from Table 3. Enter this value in column 9 on Worksheet C.

Table 3

Distance from NAL to Stop Sign In Feet	Automobile Stop-and-Go Adjustment Factor
0	0.10
100	0.25
200	0.40
300	0.55
400	0.70
500	0.85
600	1.00

Average Traffic Speed:
If the average automobile speed is other than 55 mph, enter the appropriate adjustment from Table 4 in column 10 of Worksheet C.

Table 4

Average Traffic Speed	Auto Speed Adjustment Factor
20 (mph)	0.13
25	0.21
30	0.30
35	0.40
40	0.53
45	0.67
50	0.83
55	1.00
60	1.19
65	1.40
70	1.62

Example 6: Road No. 1 meets the four conditions that allow for an immediate evaluation. In obtaining the information necessary for this evaluation, it was found that the automobile ADT is 18,000 vehicles (Line 5c of Worksheet C). On Workchart 1 we locate on the vertical scale the point representing 18,000 and on the horizontal scale the point representing 339 feet (see Figure 5). (Note that we must estimate the location of this point.) Using a straight-edge we draw lines to connect these two values and find that the NAL exposure to automobile noise from this road is a DNL of 58 dB, as read from the scale at the top of the graph.

Example 7: Road No. 2 has a stop sign at 390 feet from NAL No. 2. The automobile ADT is reported as being 32,500 vehicles (line 5c of Worksheet C). From Table 3 we interpolate between 300 and 400 feet to find the adjustment factor for stop-and-go traffic to be 0.69. The adjusted traffic ADT is

0.69 × 32,500 = 22,425 vehicles per day

and with an effective distance of 174 feet from NAL No. 2, we find from Workchart 1 that the approximate value of DNL is 64 dB.

Example 8: Suppose that the stop sign on Road No. 2 were replaced by a traffic signal for which no stop-and-go adjustment is made and that the ADT increases to 75,000 vehicles. In addition, assume that the average speed is 45 mph instead of 55 mph. You adjust the new automobile ADT of 75,000 vehicles by the Auto Speed Adjustment Factor from Table 4

0.67 × 75,000 = 50,250 vehicles

and at an effective distance of 174 feet find from Workchart 1 that the approximate value of DNL is 67 dB.

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Nighttime Adjustment.

DNL values are affected by the proportion of traffic volume that occurs during "daytime" (7 a.m. to 10 p.m.) and "nighttime" (10 p.m. to 7 a.m.). The graph on Workchart 1 assumes that 15 percent of the total ADT occurs during nighttime. If a different proportion of the traffic occurs at night, find the appropriate nighttime adjustment factor from Table 5. Record your answer in column 11 of Worksheet C.

Table 5

Nighttime Fraction of ADT	Nighttime Adjustment Factor
0	0.43
0.01	0.46
0.02	0.50
0.05	0.62
0.10	0.81
0.15	1.00
0.20	1.19
0.25	1.38
0.30	1.57
0.35	1.77
0.40	1.96
0.45	2.15
0.50	2.34

Once you have selected all the appropriate adjustment factors and entered them on page 2 of Worksheet C, multiply all the factors together, then multiply by the automobile ADT (column 12) for 24 hours, found on page 1 of Worksheet C. The resulting adjusted ADT should be entered in column 13. This is the ADT value to be used, in conjunction with the effective distance from the NAL to the road, to find the DNL value from Workchart 1. Enter this DNL value in column 14 of Worksheet C. Remember this is the DNL from automobile (as well as light and medium truck) noise; you must still find the DNL contribution from heavy truck noise in order to obtain the total DNL produced by the roadway you are assessing.

Attenuation of Noise by Barriers:

This adjustment reduces the noise produced by automobiles and trucks on the same road. Instructions for this adjustment appear after the noise assessment for truck traffic below.

Truck Traffic

Wherever possible, separate the average daily volume of trucks into heavy trucks (more than 26,000 pounds vehicle weight and three or more axles); medium trucks (less than 26,000 pounds but greater than 10,000 pounds), light trucks (counted as if they are automobiles). You should already have accounted for medium and light trucks in your automobile evaluation. Do not forget that buses that can carry more than 15 seated passengers are counted as heavy trucks. Heavy trucks (including buses) must be analyzed separately because they have quite different noise characteristics. If it is not possible to separate the trucks into those that are heavy and those that are not, treat all trucks as though they are "heavy."

Workchart 2, which is used to evaluate the site's exposure to heavy truck noise, was derived with the following assumptions:

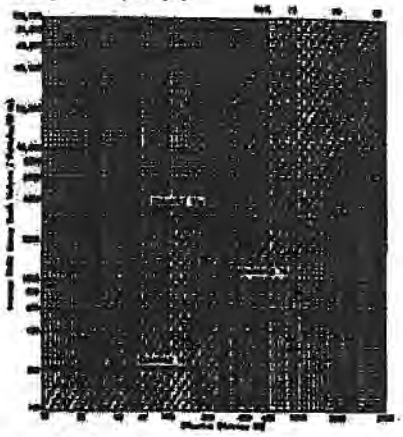
- There is line-of-sight exposure from the site to the road; i.e., there is no barrier which effectively shields the site from the road noise.
- The road gradient is less than 2 percent.
- There is no stop sign (traffic signals are permissible) within 800 feet of the site.
- The average truck traffic speed is 55 mph.
- The nighttime fraction of ADT is 0.15.

If the road meets these five conditions, proceed to Workchart 2 for an immediate evaluation of the site's exposure to heavy truck noise from that road.

But:

If any of the conditions is different, make the necessary adjustment(s) listed below and *then* use Workchart 2 for the evaluation.

Figure 6.
Use of Workchart 2 to Evaluate Heavy Truck Noise



Adjustments for Heavy Trucks

Road Gradient:

If there is a gradient of 2 percent or more, find the appropriate adjustment factor, for heavy trucks going uphill only, as shown in Table 6. List this factor in column 17 of Worksheet C.

Table 6

Percent of Gradient	Adjustment Factor
2	1.4
3	1.7
4	2.0
5	2.3
6 or more	2.5

Example 9a: Road No. 3 is a limited access highway with no stop signs and the average speed is 55 mph. Current traffic data indicate an automobile ADT of 40,000 vehicles of which 15 percent occurs during nighttime hours (10 p.m. to 7 a.m.). With an effective distance of 270 feet to NAL No. 2, Workchart 1 is used to show that the DNL for existing automobile traffic is between 63 and 64 dB. Round off to 64 dB.

Example 9b: However, traffic projections estimate that in 10 years the ADT will increase to 100,000 vehicles at an average speed of 55 mph and nighttime usage will increase to 25 percent. For future traffic, you must adjust the future ADT of 100,000 for the effect of increased nighttime use. From Table 5, you find an adjustment factor of 1.38. The adjusted ADT is

$1.38 \times 100{,}000 = 138{,}000$

and at an effective distance of 270 feet you find from Workchart 1 that the DNL will increase to 69 dB; therefore, provision for extra noise control measures should be explored. We will examine in Example 13 the effect of terrain as a shielding barrier that provides sound attenuation.

Example 10: Road No. 1 on Figure 4 meets the four conditions that allow for an immediate evaluation. The ADT for heavy truck flow is 1200 vehicles. Workchart 2 shows that the exposure to truck noise from this road at an effective distance of 339 feet is a DNL of 63 dB at NAL No. 1.

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Average Traffic Speed:

Make this adjustment if the average speed differs from 55 mph. If the average truck speed differs with direction, treat the uphill and downhill traffic separately. Select the appropriate adjustment factors from Table 7 below, entering them in column 18 of Worksheet C.

Table 7

Average Traffic Speed MPH	Heavy Truck Speed Adjustment Factor
50 or less	0.81
55	1.00
60	1.17
65	1.38

Once you have found the speed adjustment factor, you can combine the uphill and downhill traffic. For uphill traffic, multiply the gradient factor times the speed adjustment factor times uphill traffic volume (truck ADT column 19) (assuming one half the total 24-hour average number of trucks unless specific information to the contrary exists), entering the product in column 20. Multiply the speed adjustment factor for downhill traffic times the downhill traffic volume (truck ADT/2 column 19). Add the values for uphill and downhill traffic, entering this sum in column 21. You may now complete the assessment of heavy truck noise without regard to uphill and downhill traffic separation.

Stop-and-Go Traffic:

If there is a stop sign (remember, not a traffic signal) within 600 feet of an NAL for the site on the road being assessed, find the adjustment factor determined according to Table 8. Enter it in Column 22 of Worksheet C.

Table 8

Heavy Truck Traffic Volume per Day	Heavy Truck Stop-and-Go Adjustment Factor
Less than 1200	1.8
1201 to 2400	2.0
2401 to 4800	2.3
4801 to 9600	2.8
9601 to 19,200	3.8
More than 19,200	4.5

Nighttime Adjustment

After all the above adjustments are made, do not forget to adjust for nighttime operations if they are not 15 percent of the total ADT, using the factors obtained from Table 5 just as for automobiles. Enter this value in column 23 of Worksheet C.

At this point, multiply the adjustment factors for nighttime and stop-and-go traffic times the heavy truck traffic volume in column 21 to find the adjusted heavy truck ADT, entering the product in column 24. Use this value and the effective distance from the NAL to the road to find the truck DNL from Workchart 2, entering your answer in column 25 of Worksheet C. If no shielding barriers are to be considered, combine the DNL from heavy trucks with the DNL from automobiles (column 14). The result is the DNL from the road being assessed and should be entered on Worksheet C.

But:

If a shielding barrier is to be considered for the site, make the analysis described below separately for automobiles and then for heavy trucks *before* combining the DNL values. This step is necessary since barriers are far more effective for automobiles than for heavy trucks. Once you have found the amount of attenuation provided by the barrier for automobiles, enter it in column 15. Find the value of barrier attenuation for heavy trucks and enter it in column 25. Subtract these attenuation values from the DNL values obtained previously (columns 14 and 24), entering the reduced DNL values in columns 16 and 27. Combine the automobile and heavy truck DNL values, reduced by the attenuation provided by the barrier, to find the final DNL produced by the roadway at the site.

Remember to combine the contributions to DNL of *all* roads that affect the noise environment at each NAL for the site to obtain the total DNL from all roadways. Enter this DNL on both Worksheet C and the summary Worksheet A.

Attenuation of Noise by Barriers

Noise barriers are useful for shielding sensitive locations from ground level noise sources. For example, a barrier may be the best way to deal with housing sites at which the noise exposure is not acceptable because of nearby roadway traffic.

A barrier may be formed by the road profile, by a solid wall or embankment, by a continuous row of noise-compatible buildings, or by the terrain itself. To be an effective shield, however, the barrier must block all residential levels from line of sight to the road; it must not have any gaps that would allow noise to leak through.

Some Preliminary Matters:

In evaluating noise barrier performance, you will be working with different kinds of "distances" between the sound source, the observer, and the barrier.

Actual Distance – the existing distance that would be measured using a tape measure with no corrections or adjustments. This may mean one of two things, *depending on the application*; either the:

- *slant distance* – the actual distance,

Example 11: Road No. 2 has a stop sign at 390 feet from NAL No. 2. There is also a road gradient of 4 percent. No heavy trucks are allowed on this road, but a schedule shows an average of 12 large buses pass along the road per hour between 7 a.m. and 10 p.m., although no buses are scheduled during the remaining nighttime period. The buses are equally divided in each direction along the road. (Remember large buses, those that carry over 15 seated passengers, count as heavy trucks.)

We find the ADT for the "heavy trucks" (the buses in this case) by multiplying the average number of vehicles per hour by the number of hours between 7 a.m. and 10 p.m. That is, 12 x 15 = 180, or 90 vehicles in each direction. We find from Table 6 that the gradient adjustment factor for uphill traffic is 2.0. We find the truck volume adjusted for gradient is

uphill: $90 \times 2.0 = 180$
downhill: $= 90$
total (column 21) $= 270$ *vehicles*

From Table 8, we find the adjustment factor for stop-and-go traffic to be 1.8.

We also remember that we have no buses in the nighttime period and find the factor in Table 5 on page 8 for zero nighttime operations to be 0.43.

Our final adjusted ADT is (column 24)

$1.8 \times 0.43 \times 270 = 209$ *Vehicles*

From Workchart 2, with an effective distance of 174 feet, we find a DNL of 59 dB.

Example 12a: Road No. 3 is a depressed highway and the profile shields all residential levels of the housing from line of sight to the traffic. The average truck speed is 50 mph. The ADT for heavy trucks is 4400 vehicles. We adjust for average speed (from Table 7)

$4400 \times 0.81 = 3564$

and find from Workchart 2 that, with an effective distance of 270 feet, the DNL from truck noise would be 69 dB if no barrier existed. We proceed to analyze the barrier attenuation.

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measured along the line of sight between two points; or the

- *map distance* – the actual distance, measured on a horizontal plane, between the two points, as on a map or on the project plan.

For an observer high in an apartment tower, the *slant* distance to the road may be much longer than the *map* distance.

Barrier effectiveness is expressed in terms of noise attenuation in decibels (dB), determined with the aid of Worksheet 6. This numerical value is subtracted from the previously calculated DNL in order to find the resultant DNL at the Noise Assessment Location.

Note: A noise barrier can be considered as a means of protecting a site from noise even if it cannot wrap around the site to shield from view practically all of the source of noise at every sensitive location on the site. It must be recognized, however, that such a barrier is much less effective than an ideal barrier. (See Worksheet 7 and Step 6 below.)

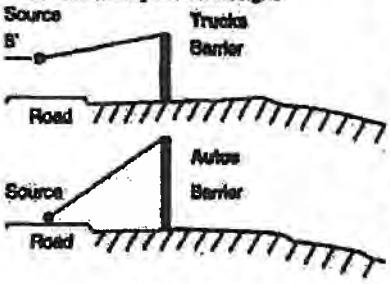
Barriers of reasonable height cannot be expected to protect housing more than a few stories above ground level. Barriers will generally protect the ground and the first two or three floors, but not the higher floors. If there are to be frequently occupied balconies on the upper levels, one solution is to move the building farther from the noise source and face the sensitive areas away from the noise.

Steps to Evaluate a Barrier

1. For the observer's position, use the mid-height of the highest residential level. For the source position, use the following heights (see Figure 7):

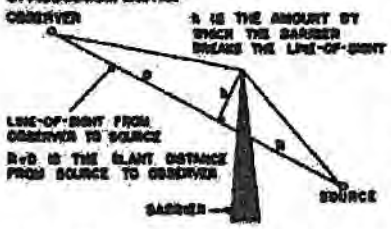
- autos, medium trucks, railway cars – the road or railway surface height.
- heavy trucks – 8 feet above the road surface
- diesel locomotives or trains using horns or whistles at grade crossings – 15 feet above the rails.

Figure 7.
Source Heights to Be Used in Roadway Barrier Designs



Get accurate values for the following quantities: h, the shortest distance from the barrier top to the line of sight from source to observer; R and D, the slant distances along the line of sight from the barrier to the source and observer, respectively (see Figure 8).

Figure 8.
Generalized Geometry of Acoustical Barrier



Specifically, R and D are the two segments into which h breaks the line of sight. Note that h is *not* the height of the barrier above the ground but the distance from the barrier top to the line of sight.

2. Enter at the top of Worksheet 6 with the value of h on the left-hand scale; move right to intersect the curve corresponding to R (or D, whichever is *smaller*).

3. Move down to intersect the curve corresponding to the value of D/R (or R/D, whichever is *smaller*).

4. Move right to intersect the vertical scale in order to find the barrier shielding value A in decibels.

5. Interruption of the line of sight with a barrier between the noise source and an observer reduces the amount of sound attenuation provided by the ground. Find the amount of this loss B from the table on Worksheet 6 by entering the table with the value of D/R. Find the barrier attenuation value S corresponding to an ideal barrier that completely hides the noise source from view by subtracting B from the value of A obtained in Step 4.

6. If the barrier exists along only a part of the road so that unshielded sections of the road would be visible from the site, the barrier is less effective than an ideal barrier. On a plan view of the site, locate the two ends of the barrier and draw lines from these points to the Noise Assessment Location. Use a protractor to measure the angle formed at the NAL by the two lines. Enter the horizontal scale of Worksheet 7 with the values of this angle; read up to the curve having the value of S determined from Step 5 (interpolating if necessary); read left across to the vertical scale labeled "actual barrier performance" to find the value of FS to use for the actual barrier in question.

7. Subtract the barrier attenuation value S (or FS if adjusted for finite barrier length according to Worksheet 7) from the value of DNL previously determined to reevaluate the site with the noise barrier in place.

Example 12b: (Refer to Figure 9.) Six stories are planned for the housing where the site has an elevation of 130 feet. The effective elevation for the highest story is found by multiplying the number of stories by 10 feet, adding the site elevation, and subtracting 5 feet.

(6 × 10) + 130 - 5 = 185 feet

The barrier, which in this case is formed by the road profile, has no "height" other than the elevation of the natural terrain above the noise sources traveling on the roadway. The important dimensions are indicated in *Figure 9.*

Some people with a technical background will be able to fit the geometric diagram to the site situation readily, working from the project drawings and a scratch sheet.

But if you are *not* confident of your geometry, Worksheet 5 gets you the values of R, D, and h from the map distances and elevations of the site. We illustrate that procedure in this example.

First, enter the elevations of the source (S), the observer (O), and the top of the barrier (H), as well as the map distances from the barrier to the source (R') and observer (D'), at the top right of Worksheet 5. Then, follow the steps on that Worksheet to derive the values of h, R, and D that are needed in using Worksheet 6.

Entering Worksheet 6 at the upper left with the value of h (5.5 feet), we move horizontally

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Figure 9.
Detail of Site Showing Measurements Necessary for a Barrier Adjustment

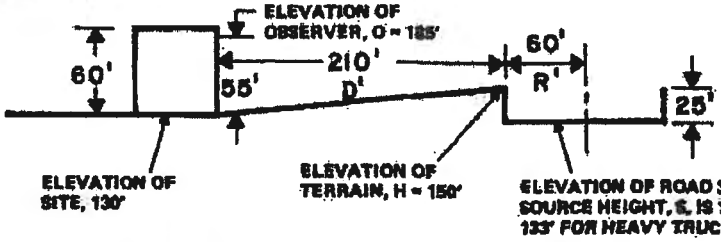
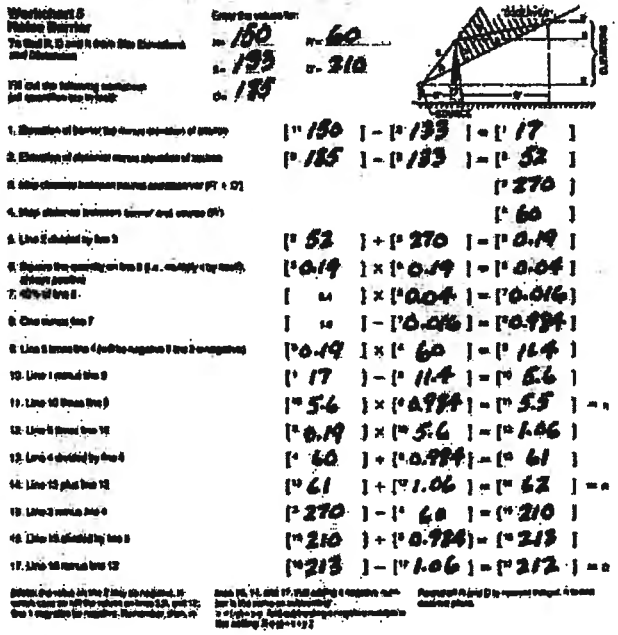


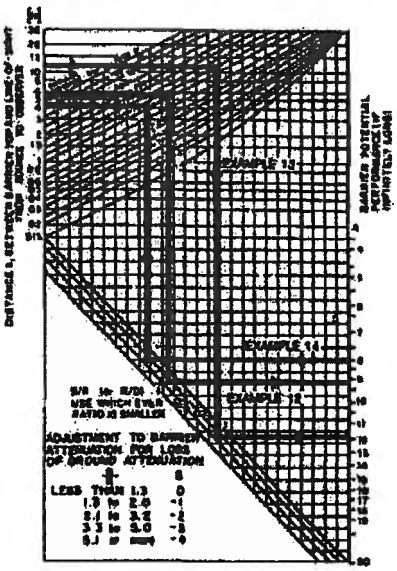
Figure 10.
Use of Worksheet 5 to Determine Barrier Dimensions in Example 12b



Worksheet 5 Noise Barrier	Enter the values for:	h= 150	R= 62	
		S= 133	D= 210	
		O= 125		
1. Elevation of barrier top minus elevation of observer	[150	] − [133	] = [17	]
2. Elevation of observer minus elevation of source	[125	] − [133	] = [52	]
3. Slope distance between source and observer (Pt 1 to Pt 2)			[270	]
4. Slope distance between barrier and source (Pt 1 to Pt 3)			[60	]
5. Line 2 divided by line 3	[52	] ÷ [270	] = [0.19	]
6. Square the quantity on line 5 (i.e., multiply it by itself); always positive	[0.19	] × [0.19	] = [0.04	]
7. 40 times line 6	[40	] × [0.04	] = [0.016	]
8. One minus line 7	[1.0	] − [0.016	] = [0.984	]
9. Line 5 times line 4 (use the negative if line 2 is negative)	[0.19	] × [60	] = [11.4	]
10. Line 1 minus line 9	[17	] − [11.4	] = [5.6	]
11. Line 10 times line 8	[5.6	] × [0.984	] = [5.5	] = a
12. Line 5 times line 10	[0.19	] × [5.6	] = [1.06	]
13. Line 4 divided by line 8	[60	] ÷ [0.984	] = [61	]
14. Line 13 plus line 12	[61	] + [1.06	] = [62	] = a
15. Line 3 minus line 4	[270	] − [60	] = [210	]
16. Line 15 divided by line 3	[210	] ÷ [0.984	] = [213	]
17. Line 15 minus line 12	[213	] − [1.06	] = [212	] = a

Figure 11.
Use of Worksheet 6 to Evaluate Barrier in Examples 12b, 13 and 14

Noise Barrier Worksheet 6



to the right until we meet the value of R or D, whichever is smaller: in this example, R = 62 feet. From that point we drop vertically downward until we meet the value of R/D or D/R, whichever is smaller: in this case, R/D = 0.29. From that point, move horizontally to the right to find the value for A = 9 dB. Entering the table for determining loss of ground attenuation effect due to the barrier with a value for D/R of 3.5, the reduction in attenuation (B) is found to be 3 dB. Substracting 3 dB from 9 dB provides a net attenuation of 6 dB. With 6 dB of attenuation, the original DNL of 69 dB (Example 12a) is reduced to 63 dB.

Example 13: An alternative approach, which is somewhat more direct, is illustrated here for the noise of automobiles on Road No. 3.

A preliminary step is to make an accurately scaled sketch of the general geometry introduced on page 8. It must include the positions of the source (this time at the road surface), the observer, and the top of the barrier; and will show the distances h, R, and D. Such a sketch is shown superimposed on the profile of the road and its neighborhood in Figure 12.

If we carefully scale the dimensions directly from this sketch, we find the following values for h, R, and D:

R=63 feet

R/D=0.3

D=214 feet

h=11 feet

The barrier attenuation is found, by entering Worksheet 6 with these values, to be A=12 dB. It is larger than that found for trucks because the noise source is lower and is, therefore, better shielded by the barrier. The loss from ground attenuation is again B=3 dB for a net attenuation of 12 - 3 = 9 dB. In Example 9b, we found that the DNL

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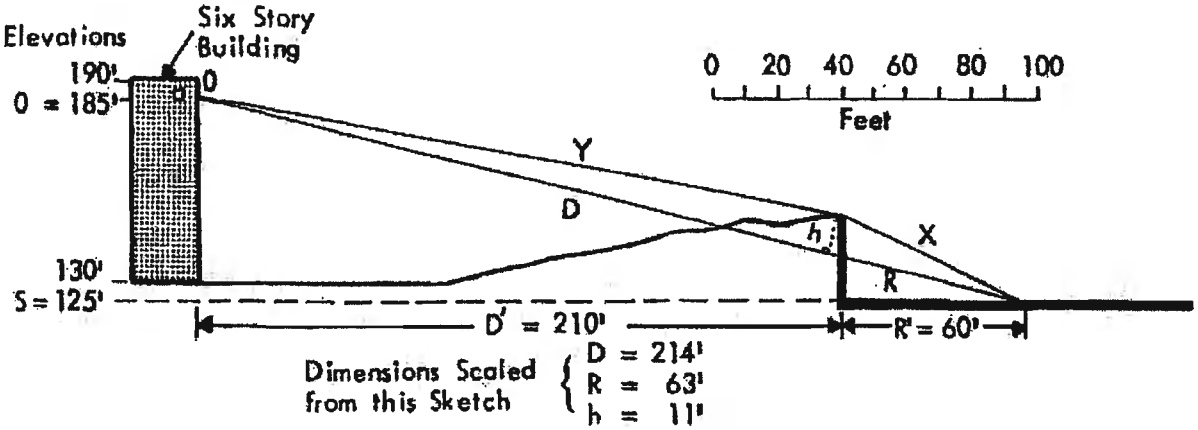
Figure 12.
Sketch Showing Dimensions for Example 13



for the projected traffic volume of 100,000 vehicles per day was 69 dB if no consideration was given the shielding provided by the terrain. Subtracting the 9 dB attenuation from 69, we find the partial DNL for automobiles is 60 dB.

In order to find the combined truck and automobile noise for Road No. 3, we combine the 63 dB of truck noise with the 60 dB of automobile noise using Table 1. We find that 1.8 should be added to 63 dB, for a combined DNL of 64.8 dB, or 65 dB when rounded to the nearest whole number.

Example 14: Where no natural barrier exists, Workchart 6 can be used in reverse to estimate the height of a barrier needed to obtain a required attenuation. In example 9b we found that, without any attenuation from terrain or a barrier, the automobile traffic produced a DNL of 69 dB, and in Example 12a the heavy truck traffic produced a DNL of 69 dB. When combined, the total DNL is 72 dB. Suppose the terrain were not rising between NAL and Road No. 3, as shown in Figure 12, but instead was level between the NAL and the edge of the road, as shown in Figure 13. We want to find out how high a wall, infinite in length, would be required at the edge of the road to reduce the combined truck and automobile noise to less than 65 dB. We have found in the previous examples that a barrier of a given height will provide more attenuation for automobiles than it will for trucks. As a first step in our analysis, we will find the height of a wall that will reduce the truck noise to just below 65 dB, say 64 dB, and then find out whether the additional attenuation it provides for automobile noise will be sufficient to reduce the combined truck and automobile noise to less than 65 dB. We begin by finding the height of wall that will provide 5 dB attenuation for truck noise.

We estimate that the ratio of R/D is about the same as R'/D', the ratio of horizontal distance in Figure 13, which is equal to 0.29. Before entering Workchart 6, we find from the loss of ground attenuation table that for D/R = 3.4 we will lose 3 dB attenuation from an ideal barrier. In order to have a net attenua-

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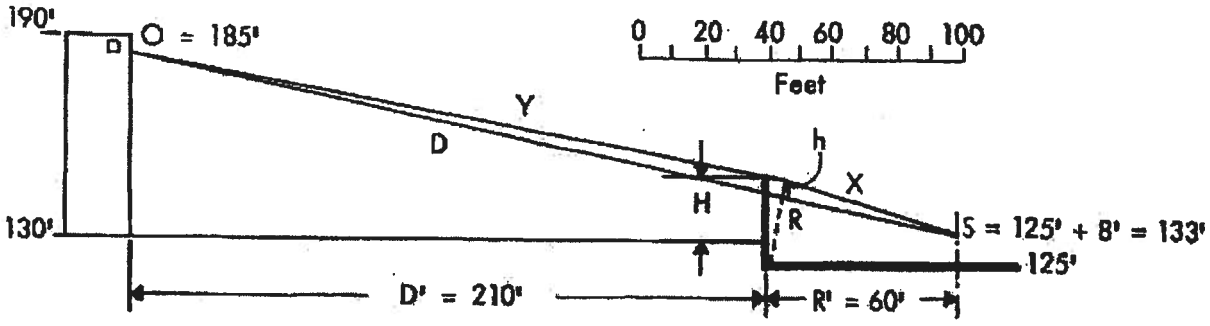
Figure 13.
Sketch Showing Dimensions for Example 14



lion of 5 dB, we must have an ideal barrier that provides 5 + 3 = 8 dB attenuation.

Entering Workchart 6 on the right side scale A at 8 decibels, we move across to the diagonal lines, finding 0.29 by interpolating between the lines marked at 0.2 and 0.5. Moving directly up to a point midway between the R lines of 50 and 70, we find our estimated R of approximately 60. Moving across to the left we find that the line of sight between the observer and the truck source height must be broken by a value of h equal to 4.5 feet.

We can determine the height of the wall H in several ways. By drawing h=4.5 feet to scale on Figure 13, we can scale the total wall height H to be approximately 20 feet. Those who feel comfortable with geometry can calculate H by using the similar triangle relationships in Figure 13 to determine that H is 19.1 feet.

Now we must find how much a wall 19 feet high will attenuate automobile noise, remembering that the source height for automobiles is at the road surface elevation of 125 feet. By scaling the drawing, or by geometry, we determine that the line of sight between the observer position and the automobile source is broken by a value of h that is approximately 13 feet. Entering Workchart 6 at 13 feet we find, for R=60 feet and R/D=0.29, that the potential barrier attenuation is 12dB. We must reduce this by 3 dB for loss of ground attenuation to find the actual shielding of automobile noise to be 9 dB. The original 69 dB of automobile noise is reduced to 69 - 9 = 60 dB.

Finally, we combine the heavy truck noise, attenuated by the wall to 69 - 5 = 64 dB, with the automobile noise reduced to 60 dB, to find a combined DNL of 65.5 dB, or 66 dB when rounded upward. Remember, however, that this is for an infinite wall. Further adjustments would have to be made once the actual length was known.

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Railways

Necessary Information

To evaluate a site's exposure to railway noise, you will need to consider all rapid transit lines and railroads within 3000 feet of the site (except totally covered subways). The information required for this evaluation is listed below under headings that indicate the most likely source.

Before beginning the evaluation, you should record the following information on Worksheet D:

From the area map and/or the (County) Engineer:

- The distance from the appropriate NAL on the site to the center of the railway track carrying most of the traffic.

From the Supervisor of Customer Relations for the railway:

- The number of diesel trains and the number of electrified trains in both directions during an average 24-hour day.
- The fraction of trains that operate during nighttime (10 p.m. - 7 a.m.) If this is unknown, assume 0.15.
- The average number of diesel locomotives per train. If this is unknown, assume 2.
- The average number of railway cars per diesel train and per electrified train. If this is unknown, assume 50 for diesel trains and 8 for electrified trains.
- The average train speed. If this is unknown, assume 30 mph.
- Is the track made from welded or bolted rails?

From the Engineering Department of the railway:

- Is the site near a grade crossing that requires prolonged use of the train's horn or whistle? If so, where are the whistle posts located? (Whistle posts are signposts which tell the engineer to start blowing the horn or whistle. Every grade crossing has whistle posts and they are listed on the railroad's "track charts." If traffic on the track is one-way, there will be only one whistle post. The grade crossing itself is the other "whistle post."

Electrified rapid transit and commuter trains that do not use diesel engines should be treated the same as railway cars.

Note: Buildings closer than 100 feet to a railroad track are often subject to excessive vibration transmitted through the ground. Construction at such sites is discouraged.

Evaluation of Site Exposure to Railway Noise

Railway noise is produced by the combination of diesel engine noise and railway car noise. These Guidelines provide for the separate evaluation of diesel locomotives and railroad cars, and then the combination of the two, in order to obtain the DNL from trains. When rapid transit or electrified trains that do *not* use diesel engines are the only trains passing near a site go directly to the second part of the evaluation since these trains are treated in the same manner as railway cars.

Diesel Locomotives

Workchart 3 was derived with the following assumptions:

- A clear line of sight exists between the railway track and the Noise Assessment Location.
- There are two diesel locomotives per train.
- The average train speed is 30 mph.
- Nighttime operations are 0.15 of the 24-hour total.
- The site is not near a grade crossing requiring prolonged use of the train's horn or whistle.

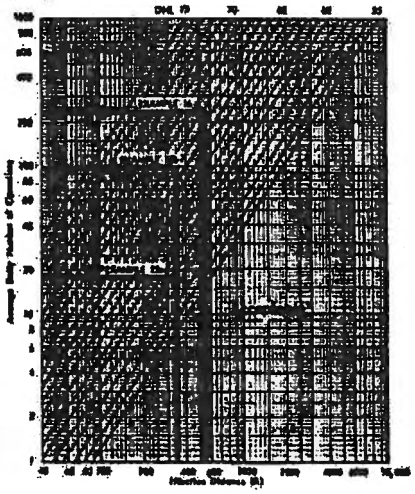
If the situation meets these conditions, proceed to Workchart 3 for an immediate evaluation of diesel locomotive noise.

But:

If any of the conditions is different, make the necessary adjustments listed below and *then* use Workchart 3 for the evaluation.

Figure 14.
Use of Workchart 3 to Evaluate Diesel Locomotive Noise

Railroads – Diesel Locomotives



Adjustments for Diesel Locomotives

Number of Locomotives:

If the average number of diesel locomotives per train is not 2, divide the average number by 2. Enter this value in column 9 of Worksheet D.

Example 15a: The distance from NAL number 1 to Railway Number 1 is 339 feet. Two percent of the 35 daily operations occur at night; there is clear line of sight between the tracks and the NAL, and no horns or whistles are used. No information is available on train size or speed, therefore we will assume 2 engines per train and a speed of 30 mph.

Since the percentage of nighttime operations is different from 15 percent, we must adjust the actual number of daily operations, multiplying by 0.50 according to Table 5.

0.50 x 35 = 17.5 = 18

Entering Workchart 3 with 18 daily operations and a distance of 339 feet, we find that the contribution of diesel engine noise is a DNL of 59 dB (see Figure 14).

In order to find the total contribution of the trains to the total DNL, we must also find the noise level produced by the train's cars. Entering Workchart 4 (see Figure 15) with 18 daily operations and a distance of 339 feet, we find the DNL is below 50 on the chart, or more than 10 decibels lower than the noise level produced by the engines. Based on the chart for decibel addition, the combination of the noise from the engines and the cars adds less than 0.5 decibels to the DNL value for the engines alone, 59 dB.

Example 15b: Suppose that a forecast of train operations for Railway 1 indicates that there will still be 35 trains per day, but now 50 percent of the operations will occur at night, the average train will have 4 engines and 75 cars, and the average speed will be 50 mph.

We first find the contribution to DNL made by diesel locomotives by using the following adjustment factors:

- number of engines adjustment: 2
- speed adjustment: 0.60
- day/night adjustment: 2.34

We multiply these adjustments together with the number of trains:

2 X 0.60 X 2.34 X 35 = 98

Entering Workchart 3 (see Figure 14) with 98 daily operations and a distance of 339

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Average Train Speed:

If the average train speed is different from 30 mph, find the appropriate adjustment factor from Table 9 and list in column 10 of Worksheet D.

Table 9

Average Speed (mph)	Speed Adjustment Factor
10	3.00
20	1.50
30	1.00
40	0.75
50	0.60
60	0.50
70	0.43

Horns or Whistles:

If the NAL is perpendicular to any point on the track between the whistle posts for the grade crossing, enter the number 10 in column 11, Worksheet D.

Nighttime Adjustment:

Remember to adjust for nighttime operations, if different from 0.15 of the total, by selecting the appropriate adjustment factor from Table 5 on page 8. Enter in column 12, Worksheet D.

Multiply the adjustment factors together, times the number of diesel trains per day (you have listed this number previously on line 2a, page 1, of Worksheet D, and should enter this number again in column 13) to obtain the adjusted number of trains per day. Enter the adjusted number of diesel trains per day in column 14. Use this value, in conjunction with the distance from the NAL to the track (line 1, page 1, of Worksheet D), to find from Workchart 3 the DNL produced by diesel locomotives. List in column 15 of Worksheet D.

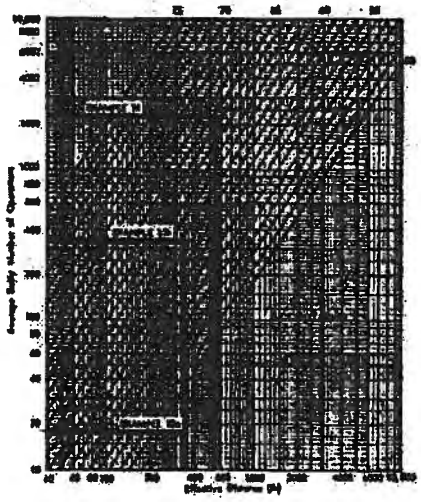
Railway Cars and Rapid Transit Systems

Workchart 4 was derived with the following assumptions:

- A clear line of sight exists between the railway and the NAL.
- There are 50 cars per train.
- The average train speed is 30 mph.
- Nighttime operations are 0.15 of the 24-hour total.
- Rails are welded together.

If the situation meets these conditions, proceed to Workchart 4 for an immediate evaluation of railway car noise. Again, if any of the conditions is different, make the necessary adjustments listed below and then use Workchart 4 for the evaluation.

Figure 15.
Use of Workchart 4 to Evaluate Railway Car Noise



Adjustments for Railway Cars and Rapid Transit Trains

Number of Cars:

Divide the average number of cars by 50 and enter this number in column 18 of Workchart D.

Average Speed:

Make this adjustment, if the average speed is not 30 mph, by selecting the appropriate value from Table 10, entering it in column 19 of Worksheet D.

Table 10

Average Speed (mph)	Speed Adjustment Factor
10	0.11
20	0.44
30	1.00
40	1.78
50	2.78
60	4.00
70	5.44
80	7.11
90	9.00
100	11.11

Bolted Rails:

Enter the number 4 in column 20 of Worksheet D.

Nighttime Adjustment:

Enter the appropriate adjustment factor from Table 5 in column 21 of Worksheet D.

---

feet, we find that the site has an engine noise contribution to DNL of 66 dB.

We next obtain the adjustment factors for the noise produced by the cars:

- number of cars adjustment: 1.50
- speed adjustment: 2.78
- day/night adjustment: 2.34

Multiplying the adjustment factors times the average daily number of trains:

1.5 X 2.78 X 2.34 X 35 = 342

Entering Workchart 4 (see Figure 15) with 342 operations and a distance of 339 feet, we find the contribution of the cars to the DNL is 60 dB. Using Table 1 for combining levels, we find that the 6 dB difference between engine noise at 66 and car noise at 60 gives a combined DNL of 67 dB for these trains.

Example 16: The distance from NAL number 2 to Railroad Number 2 is 550 feet; there are 100 operations per day, of which 30 percent occur at night. A clear line of sight exists between the site and the railroad, and no horns or whistles are used nearby. An average train on this track uses 4 engines, has 100 cars, the average speed is 40 miles per hour, and the track has bolted, not welded, rails.

We first find the adjustment factors for the diesel engines:

- number of engines adjustment: 2
- speed adjustment: 0.75
- day/night adjustment: 1.57

Multiplying the adjustments together, times the number of trains:

2 X 0.75 X 1.57 X 100 = 236

Entering Workchart 3 (see Figure 14) with 236 operations at a distance of 550 feet, we find the DNL contribution from engine noise to be 67 dB.

Next we find the adjustment factors for the railroad cars:

- number of cars adjustment: 2
- speed adjustment: 1.78
- bolted track adjustment: 4
- day/night adjustment: 1.57

Multiplying the adjustments together, times the number of trains:

2 X 1.78 X 4 X 1.57 X 100 = 2236

Entering Workchart 4 (see Figure 15) with

(Continued next page)

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Figure 16.
Sketch Showing Dimensions for Example 16

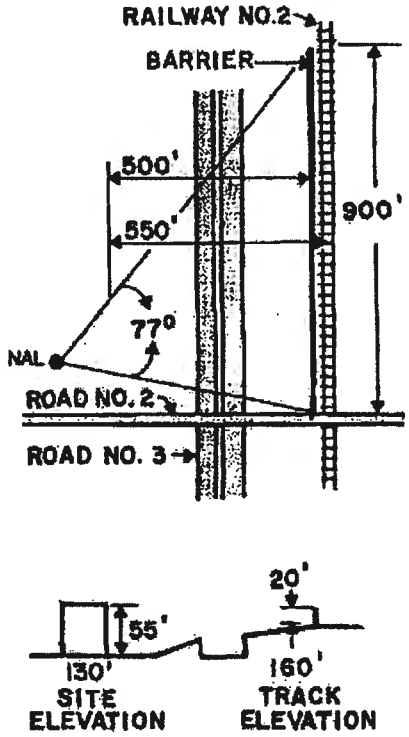


Figure 17.
Use of Workchart 6 in Example 16

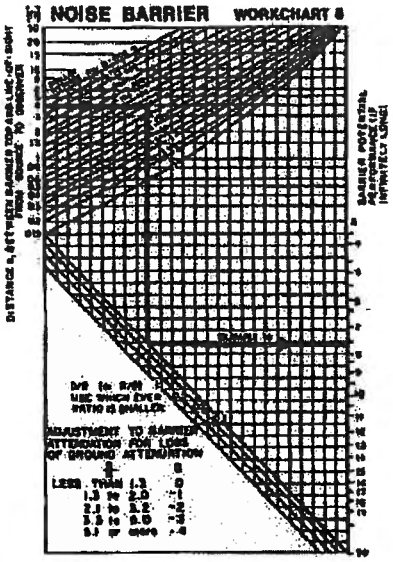
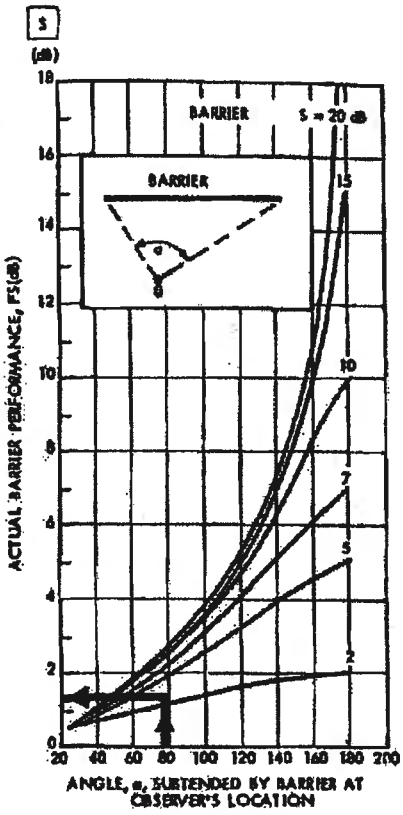


Figure 18.
Use of Workchart 7 in Example 16



2236 operations at a distance of 550 feet, we find the DNL contribution from the railroad cars to be 65 dB. Combining the engine sound levels with the car sound levels we find the total DNL from the trains to be 69 dB.

It would be possible to erect a 20-foot noise barrier, running parallel to the track at a distance of 50 feet; it could start at Road Number 2 and run 900 feet north toward the airport, as shown in Figure 16. Both the railroad track and the ground level at the barrier location are at an elevation of 160 feet. Thus, we have the following values with which to calculate the potential reduction in engine noise (using Workchart 5). (Because the distances involved are so unequal, this situation does not lend itself to direct scaling of the distances.)

H = 180 feet (20' above the ground)

S = 175 feet (15' above the track, see page 19)

D = 285 feet (from Example 11 in the section on roadway noise)

R' = 50 feet

D' = 500 feet

We find from Worksheet 5 that the values of R and D are no different (within the accuracy of the calculation) from R' and D', a situation that will always occur when the differences in elevation are so much smaller than the distances from the site to the noise source. The value of h is 4 feet; R/D = 0.1

We can now use these numbers to enter Workchart 6 to find the *potential* barrier performance (that is, the barrier adjustment factor that would apply in the case of an infinitely long barrier). Entering Workchart 6 at h = 4 feet, with R/D = 0.1, we find the basic attenuation of the barrier to be 7.5 dB. However, with D/R = 10, we find from the table of loss-of-ground-effect attenuation that we must subtract 4 dB from the 7.5, or a net effect of 3.5 dB. However, the situation is even worse, since the barrier is finite in length.

To find the actual attenuation for this finite barrier, we must first find the angle subtended by the barrier to the NAL. Referring to Figure 16, we draw lines from the NAL each end of the barrier. With

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References

1. D.E. Bishop, A.P. Hays, "Handbook for Developing Noise Exposure Contours for General Aviation Airports," FAA-AS-75-1, December 1975 (NTIS No. AD-A023429).

2. D.E. Bishop, et al., "Calculation of Day-Night Levels Resulting From Civil Aircraft Operations," BBN Report 3157 for Environmental Protection Agency, March 1976 (NTIS No. PB 266 165).

3. B.A. Kugler, D.E. Commins, W.J. Galloway, "Highway Noise – A Design Guide for Prediction and Control," NCHRP Report 174, Transportation Research Board, National Research Council, 1976.

4. T.J. Schultz, W.J. Galloway, "Noise Assessment Guidelines – Technical Background," Office of Policy Development and Research, U.S. Department of Housing and Urban Development," 1980.

5. M.A. Simpson, "Noise Barrier Design Handbook," FHWA-RD-76-58, Federal Highway Administration, February 1976 (NTIS No. PB 266 378).

a protractor we measure the angle between the two lines to be 77 degrees. Locate the curve on Workchart 7 corresponding to the potential barrier attenuation of 3.5 dB; it lies midway between the two lowest curves (see Figure 16). The point on this curve corresponding to a subtended angle of 77 degrees indicates that the actual barrier performance would be only 1.5 dB. With only 1.5 dB of attenuation, the barrier is clearly not cost-effective. In order to achieve a usable attenuation from the barrier, it would have to be extended beyond the other side of Road Number 2 to obtain a larger subtended angle. This extension, however, would still not be cost-effective unless the height of the barrier were increased substantially.

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Summary of Adjustment Factors

Combination of Sound Levels

Table 1

Difference in Sound Level	Add to Larger Level
0	3.0
1	2.5
2	2.1
3	1.8
4	1.5
5	1.2
6	1.0
7	0.8
8	0.6
9	0.5
10	0.4
12	0.3
14	0.2
16	0.1
greater than 16	0.

Aircraft

Table 2 DNL Outside 65 dB Contour

D^1=distance from 65 dB contour to flight path
D^2=distance from site to flight path

D2 D1	DNL dB
1.0	65
1.12	64
1.26	63
1.41	62
1.58	61
1.78	60
2.00	59
2.24	58
2.51	57
2.82	56
3.16	55

Automobile Traffic

Table 3 Stop-and-go

Distance from Site to Stop Sign feet	Automobile Stop-and-go Adjustment Factor
0	0.10
100	0.25
200	0.40
300	0.55
400	0.70
500	0.85
600	1.00

Table 4 Average Traffic Speed

Average Traffic Speed	Adjustment Factor
20 (mph)	0.13
25	0.21
30	0.30
35	0.40
40	0.53
45	0.67
50	0.83
55	1.00
60	1.19
65	1.40
70	1.62

Table 5 Nighttime (applies to all sources)

Nighttime Fraction of ADT	Nighttime Adjustment Factor
0	0.43
0.01	0.46
0.02	0.50
0.05	0.62
0.10	0.81
0.15	1.00
0.20	1.19
0.25	1.38
0.30	1.57
0.35	1.78
0.40	1.96
0.45	2.15
0.50	2.34

Medium Trucks

(less than 26,000 pounds, greater than 10,000 pounds)

Multiply adjusted automobile traffic by 10.

Heavy Trucks

Table 6 Road Gradient

Percent of Gradient	Adjustment Factor
2	1.4
3	1.7
4	2.0
5	2.2
6 or more	2.5

Table 7 Average Speed

Average Traffic Speed (mph)	Truck Speed Adjustment Factor
50 or less	0.81
55	1.00
60	1.17
65	1.38

Table 8 Stop-and-go

Heavy Truck Traffic Volume per Day	Heavy Truck Stop-and-Go Adjustment Factor
Less than 1200	1.8
1201 to 2400	2.0
2401 to 4800	2.3
4801 to 9600	2.8
9601 to 19,200	3.8
More than 19,200	4.5

Railroads - Diesel Engines

Number of Engines per Train
The number of engines divided by 2.

Table 9 Average Train Speed

Average Speed (mph)	Speed Adjustment Factor
10	3.00
20	1.50
30	1.00
40	0.75
50	0.60
60	0.50
70	0.43

Whistles or horns
Multiply number of trains by 10.

Railroads - Cars and Rapid Transit

Numbers of cars.
Number of cars per train divided by 50.

Table 10 Average Train Speed

Average Speed (mph)	Speed Adjustment Factor
10	0.11
20	0.44
30	1.00
40	1.78
50	2.78
60	4.00
70	5.44
80	7.11
90	9.00
100	11.11

Bolted Rails
Multiply number of trains by 4.

Whistles or Horns
Multiply number of trains by 100.

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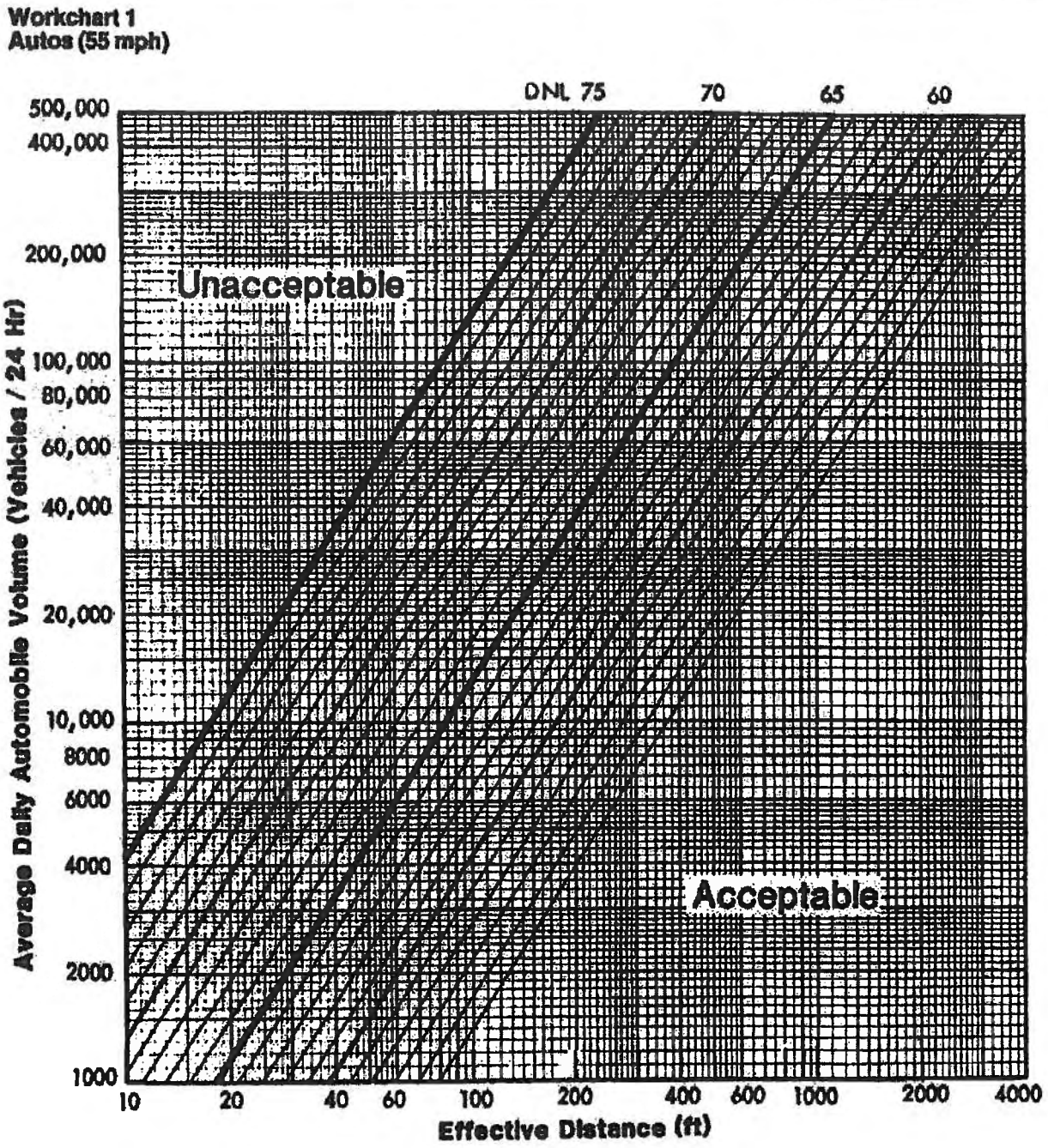
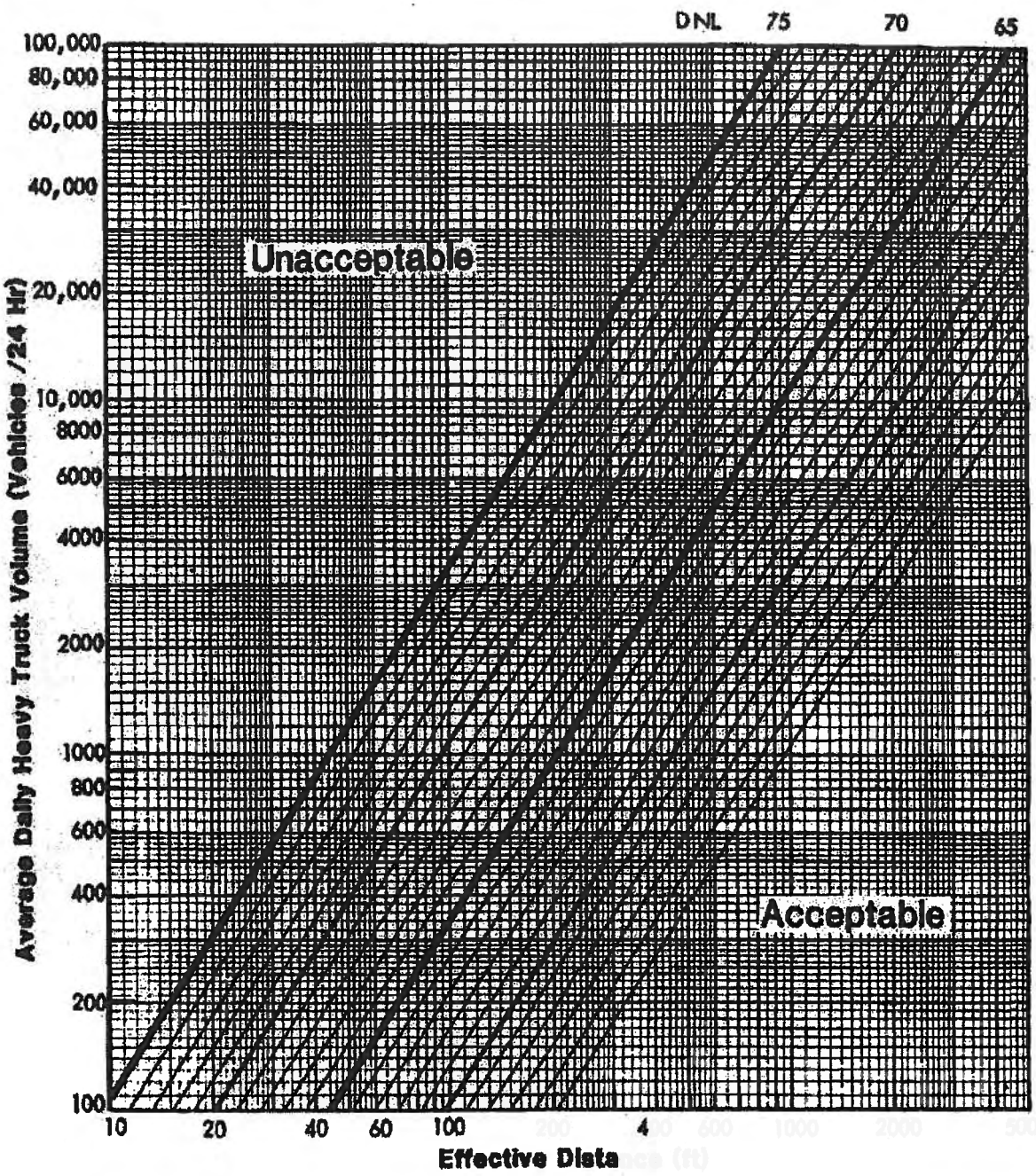

Workchart 1
Autos (55 mph)
DNL 75
70
65
60
500,000
400,000
200,000
100,000
80,000
60,000
40,000
20,000
10,000
8000
6000
4000
2000
1000
Unacceptable
Acceptable
Average Daily Automobile Volume (Vehicles / 24 Hr)
10
20
40
60
100
200
400
600
1000
2000
4000
Effective Distance (ft)

Workchart 2
Heavy Trucks (55 mph)



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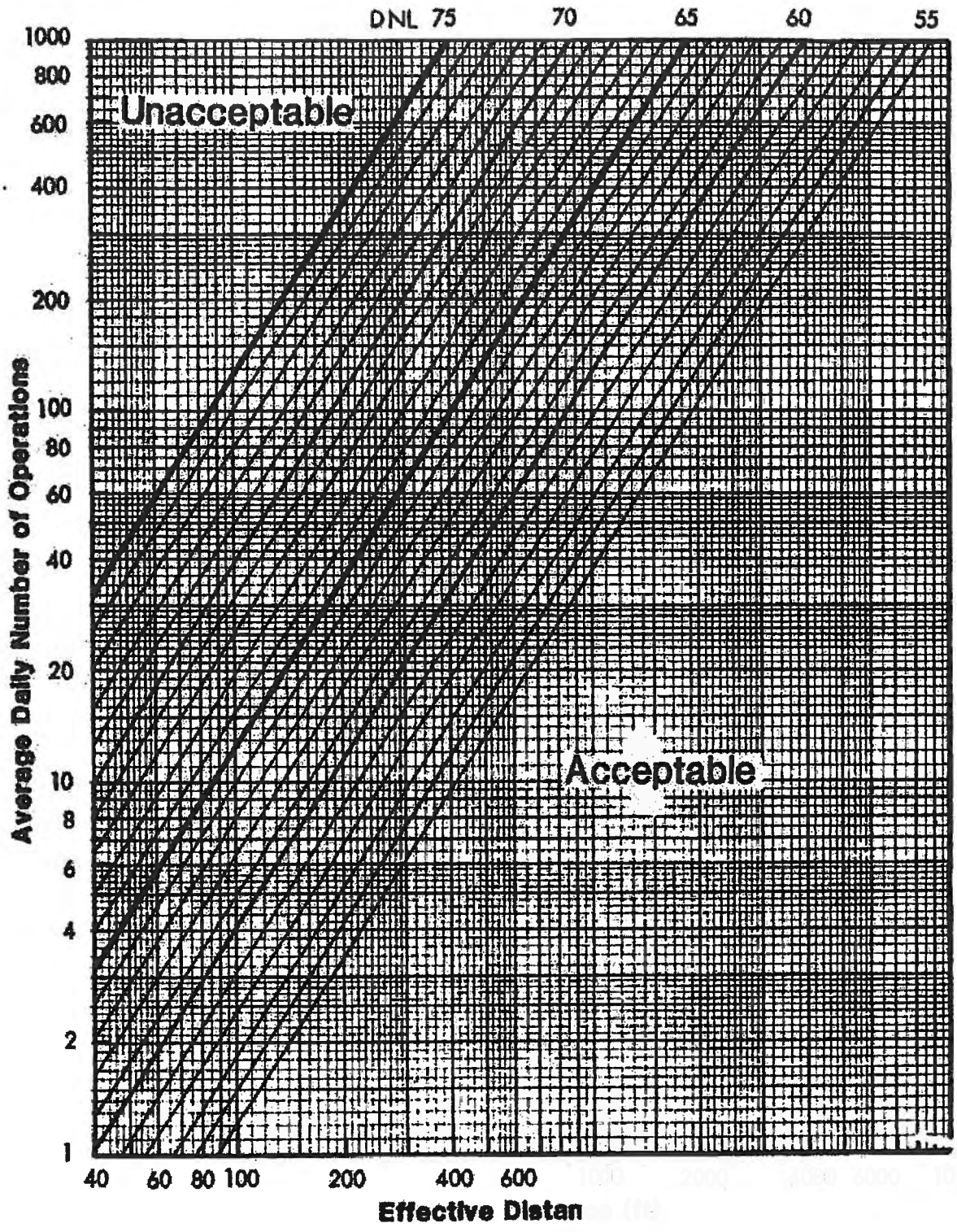
Workchart 3
Railroads - Diesel Locomotives



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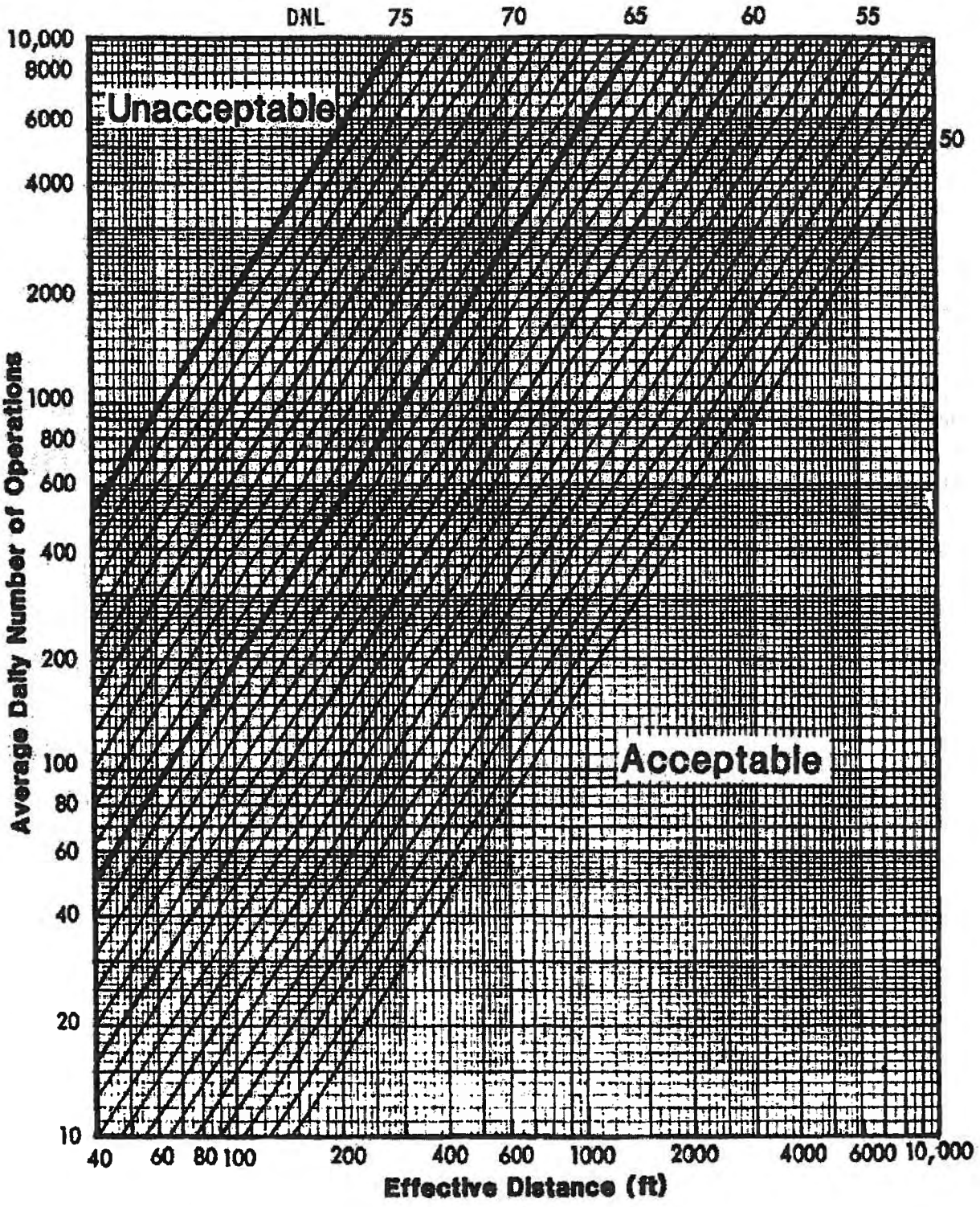
Workchart 4
Railroads - Cars and Rapid Transit



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Workchart 5
Noise Barrier

To find R, D and h from Site Elevations and Distances

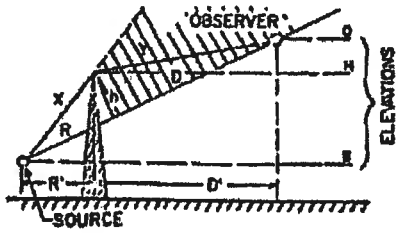
Enter the values for:

H= _____ R'= _____

S= _____ D'= _____

Fill out the following worksheet (all quantities are in feet):

O= _____



1. Elevation of barrier top minus elevation of source	[H		] − [S		] = [1		]	
2. Elevation of observer minus elevation of source	[O		] − [S		] = [2		]	
3. Map distance between source and observer (R' + D')						[3	]	
4. Map distance between barrier and source (R')						[4	]	
5. Line 2 divided by line 3	[2		] ÷ [3		] = [5		]	
6. Square the quantity on line 5 (i.e., multiply it by itself): always positive	[5		] × [5		] = [6		]	
7. 40% of line 6	[	0.4	] × [6		] = [7		]	
8. One minus line 7	[	1.0	] − [7		] = [8		]	
9. Line 5 times line 4 (will be negative if line 2 is negative)	[5		] × [4		] = [9		]	
10. Line 1 minus line 9	[1		] − [9		] = [10		]	
11. Line 10 times line 8	[10		] × [8		] = [11		]	= h
12. Line 5 times line 10	[5		] × [10		] = [12		]	
13. Line 4 divided by line 8	[4		] ÷ [8		] = [13		]	
14. Line 13 plus line 12	[13		] + [12		] = [14		]	= R
15. Line 3 minus line 4	[3		] − [4		] = [15		]	
16. Line 15 divided by line 8	[15		] ÷ [8		] = [16		]	
17. Line 16 minus line 12	[16		] − [12		] = [17		]	= D

[Note: the value on line 2 may be negative, in which case so will the values on lines 5,9, and 12; line 1 may also be negative. Remember, then, in lines 10, 14, and 17, that adding a negative number is the same as subtracting: x+(-y)=x-y. And subtracting a negative number is like adding: x-(-y)=x+y.

Round off R and D to nearest integer, h to one decimal place.

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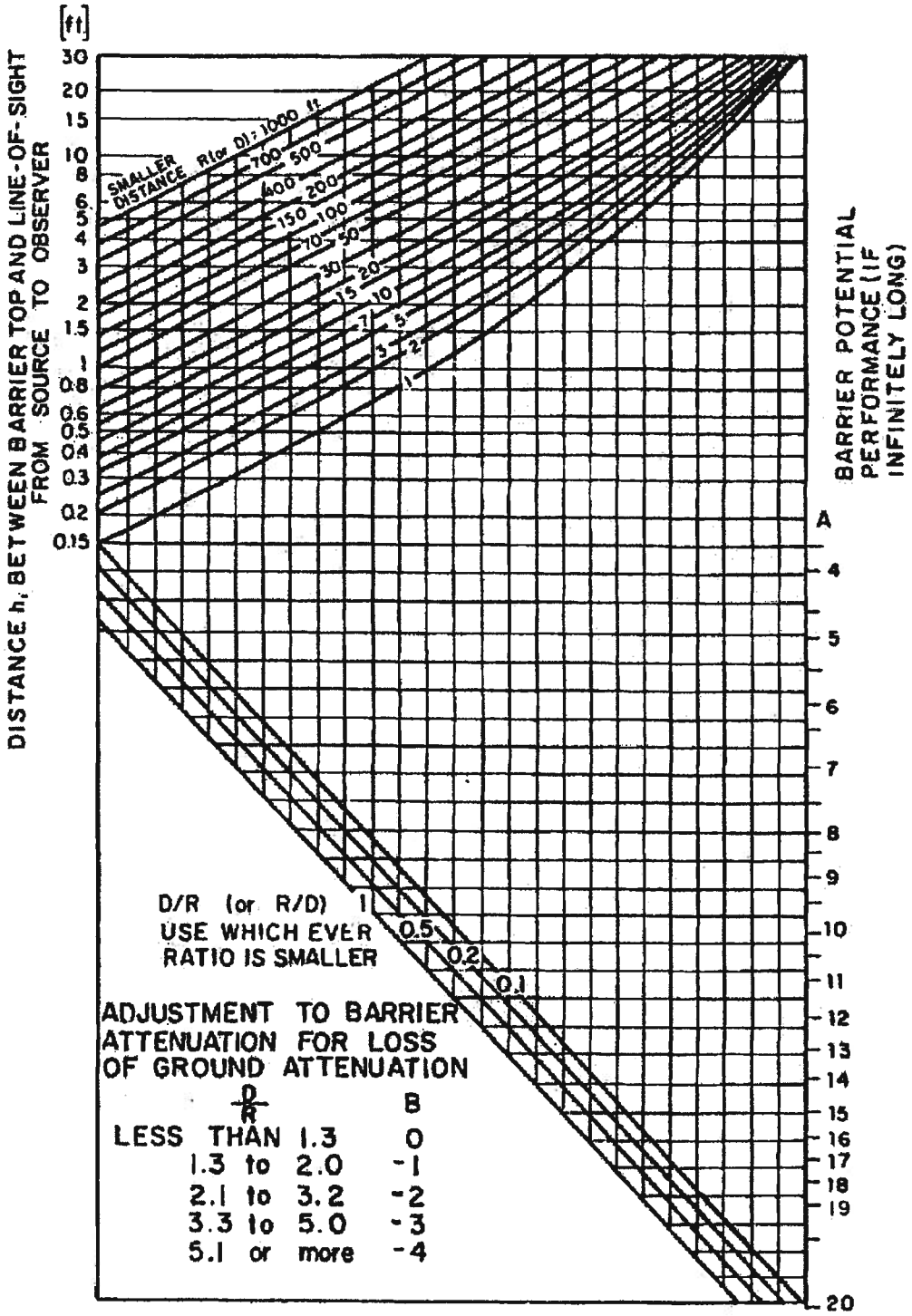
Workchart 6
Noise Barrier



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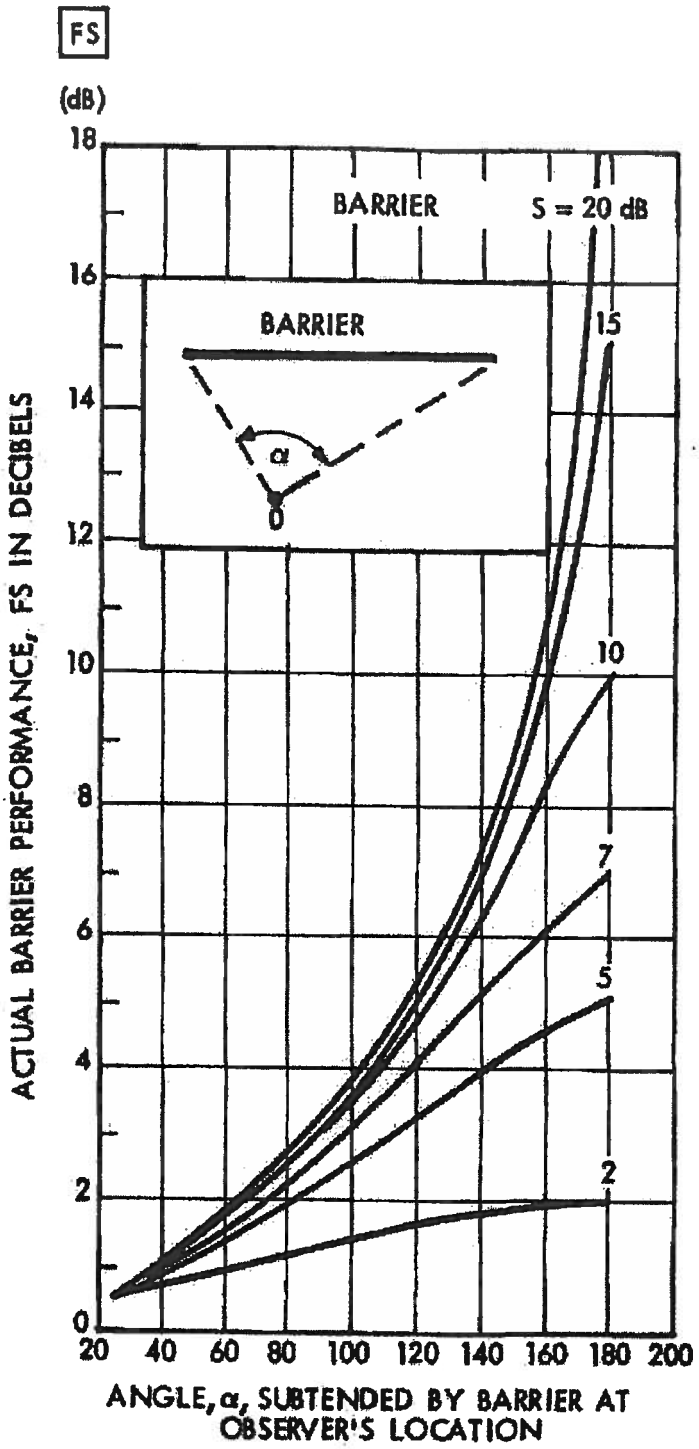
Workchart 7



Correction to be applied to barrier potential in order to find the actual performance of the barrier of the same construction but of finite length.

Worksheet A
Site Evaluation

Noise Assessment Guidelines

Site Location

Program

Project Name

Locality

File Number

Sponsor's Name

Phone

Street Address

City, State

	Acceptability Category	DNL	Predicted for Operations in Year
1. Roadway Noise			
2. Aircraft Noise			
3. Railway Noise			
Value of DNL for all noise sources: (see page 3 for combination procedure)			

Final Site Evaluation (circle one)

Acceptable

Normally Unacceptable

Unacceptable

Signature _____ Date _____

Clip this worksheet to the top of a package containing Worksheets B-E and Worksharts 1-7 that are used in the site evaluations

P11-0050/P12-0220, Exhibit 16
Public Comments

Worksheet B
Aircraft Noise

List all airports within 15 miles of the site:

1. _____

2. _____

3. _____

Necessary Information:	Airport 1	Airport 2	Airport 3
1. Are DNL, NEF or CNR contours available? (yes/no)			
2. Any supersonic aircraft operations? (yes/no)			
3. Estimating approximate contours from Figure 3:			
a. number of nighttime jet operations			
b. number of daytime jet operations			
c. effective number of operations (10 times a + b)			
d. distance A for 65 dB			
70dB			
75 dB			
e. distance B for 65 dB			
70 dB			
75 dB			
4. Estimating DNL from Table 2:			
a. distance from 65 dB contour to flight path, D^1			
b. distance from NAL to flight path, D^2			
c. D^2 divided by D^1			
d. DNL			
5. Operations projected for what year?			
6. Total DNL from all airports			

Signed _____ Date _____

P11-0050/P12-0220, Exhibit 16
Public Comments

List all major roads within 1000 feet of the site:

1. _____
2. _____
3. _____
4. _____

Necessary Information	Road 1	Road 2	Road 3	Road 4
1. Distance in feet from the NAL to the edge of the road				
a. nearest lane				
b. farthest lane				
c. average (effective distance)				
2. Distance to stop sign				
3. Road gradient in percent				
4. Average speed in mph				
a. Automobiles				
b. heavy trucks - uphill				
c. heavy trucks - downhill				
5. 24 hour average number of automobiles and medium trucks in both directions (ADT)				
a. automobiles				
b. medium trucks				
c. effective ADT (a + (10xb))				
6. 24 hour average number of heavy trucks				
a. uphill				
b. downhill				
c. total				
7. Fraction of nighttime traffic (10 p.m. to 7 a.m.)				
8. Traffic projected for what year?				

Worksheet C
Roadway Noise

Adjustments for Automobile Traffic

	9 Stop and-go Table 3		10 Average Speed Table 4		11 Night-Time Table 5		12 Auto ADT (line 5c)		13 Adjusted Auto ADT		14 DNL (Worksheet 1)		15 Barrier Attenuation		16 Partial DNL
Road No. 1	_____	X	_____	X	_____	X	_____	=	_____	_____	–	_____	=	_____	
Road No. 2	_____	X	_____	X	_____	X	_____	=	_____	_____	–	_____	=	_____	
Road No. 3	_____	X	_____	X	_____	X	_____	=	_____	_____	–	_____	=	_____	
Road No. 4	_____	X	_____	X	_____	X	_____	=	_____	_____	–	_____	=	_____	

Adjustments for Heavy Truck Traffic

	17 Gradient Table 6		18 Average Speed Table 7		19 Truck ADT 2		20	21	22 Stop and-go Table 8		23 Night-Time Table 5		24 Adjusted Truck ADT		25 DNL (Work-chart 2)		26 Barrier Attn.		27 Partial DNL
Uphill	_____	X	_____	X	_____	=													
Road No. 1								Add _____	X	_____	X	_____	=	_____	_____	–	_____	=	_____
Downhill			_____	X	_____	=													
Uphill	_____	X	_____	X	_____	=													
Road No. 2								Add _____	X	_____	X	_____	=	_____	_____	–	_____	=	_____
Downhill			_____	X	_____	=													
Uphill	_____	X	_____	X	_____	=													
Road No. 3								Add _____	X	_____	X	_____	=	_____	_____	–	_____	=	_____
Downhill			_____	X	_____	=													
Uphill	_____	X	_____	X	_____	=													
Road No. 4								Add _____	X	_____	X	_____	=	_____	_____	–	_____	=	_____
Downhill			_____	X	_____	=													

Combined Automobile & Heavy Truck DNL

Road No. 1 _____ Road No. 2 _____ Road No. 3 _____ Road No. 4 _____ Total DNL for All Roads _____

Signature _____ Date _____

P11-0050/P12-0220, Exhibit 16
Public Comments

List All Railways within 3000 feet of the site:

1. _____

2. _____

3. _____

Necessary Information:	Railway No. 1	Railway No. 2	Railway No. 3
1. Distance in feet from the NAL to the railway track:			
2. Number of trains in 24 hours:			
a. diesel			
b. electrified			
3. Fraction of operations occuring at night (10 p.m. – 7 a.m.):			
4. Number of diesel locomotives per train			
5. Number of rail cars per train:			
a. diesel trains			
b. electrified trains			
6. Average train speed:			
7. Is track welded or bolted?			
8. Are whistles or horns required for grade crossings?			

Adjustments for Diesel Locomotives

	9 No. of Locomotives / 2	10 Average Speed Table 9	11 Horns (enter 10)	12 Night-time Table 5	13 No. of Trains (line 2a)	14 Adj. No. of Opns.	15 DNL Workchart 3	16 Barrier Attn.	17 Partial DNL
Railway No. 1	____ X	____ X	____ X	____ X	____ =	____	____ –	____ =	____
Railway No. 2	____ X	____ X	____ X	____ X	____ =	____	____ –	____ =	____
Railway No. 3	____ X	____ X	____ X	____ X	____ =	____	____ –	____ =	____

Adjustments for Railway Cars or Rapid Transit Trains

	18 Number of cars / 50	19 Average Speed Table 10	20 Bolted Rails (enter 4)	21 Night-time Table 5	22 No. of Trains (Line 2a or 2b)	23 Adj. No. of Opns.	24 DNL Work-chart 4	25 Barrier Attn.	26 Partial DNL
Railway No. 1	____ X	____ X	____ X	____ X	____ =	____	____ –	____ =	____
Railway No. 2	____ X	____ X	____ X	____ X	____ =	____	____ –	____ =	____
Railway No. 3	____ X	____ X	____ X	____ X	____ =	____	____ –	____ =	____

Combined Locomotive and Railway Car DNL

Railway No. 1 _____ Railway No. 2 _____ Railway No. 3 _____ Total DNL for all Railways _____

Signature _____ Date _____

Chapter 6

A Workbook for the Noise Assessment Guidelines

Introduction

The following problems were prepared to give you the opportunity to practice the calculations and procedures described in the *Noise Assessment Guidelines*. Because it is so rarely used, we have not included any problems dealing with the aircraft noise procedure.

We have not reproduced the charts or tables from the *Guidelines* so you will need to have it at hand to do the problems.

Noise Assessment Guidelines Workbook

Problems

Problems 1 Through 7: Combining Sound Levels in Decibels

Calculate the Combined Sound Level for the Following Sets of Individual Levels:

1. 67 LDN
   61 LDN
   _____ Combined Level

2. 63 LDN
   63 LDN
   _____ Combined Level

3. 51 LDN
   68 LDN
   _____ Combined Level

4. 62 LDN
   65 LDN
   _____ Combined Level

5. 67 LDN
   72 LDN
   _____ Combined Level

6. 59 LDN
   63 LDN
   71 LDN
   _____ Combined Level

7. 73 LDN
   72 LDN
   61 LDN
   67 LDN
   _____ Combined Level

Problems 8 and 9: Calculating Effective Distance

Calculate the Effective Distances for the Following Roads:

8. Distance in Feet from NAL to:
   Near Edge of Nearest Lane — 22 Feet
   Far Edge of Farthest Lane — 76 Feet
   Effective Distance — _____

9. Distance in Feet from NAL to:
   Near Edge of Nearest Lane — 60 Feet
   Far Edge of Farthest Lane — 84 Feet
   Effective Distance — _____

Problems 10 Through 15: Adjustment Factors

List The Adjustment Factors Necessary for Each of the Following Situations and the Numerical Value for Each Adjustment Factor.

10. A Roadway Where the Road Gradient is 1%, the Average Speed for Both Autos and Trucks is 30 MPH and the Fraction of Nighttime Traffic is 10%.

    Adjustment Factors Needed: _____

    _____

    _____

    Value of Adjustment Factors: _____

    _____

    _____

11. A Roadway Where There is A Stop Sign 400 Feet from the NAL. The Gradient is 1%, the Average Speed for Autos is 45 MPH (There Are No Trucks) and the Fraction of Nighttime Traffic is 15%.

    Adjustment Factors Needed: _____

    _____

    _____

    Value of Adjustment Factors: _____

    _____

    _____

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Public Comments

12. A Roadway Where the Road Gradient is 2%, the Average Speed for Autos is 50 MPH and for Trucks (Both Uphill and Downhill) is 50 MPH and the Fraction of Nighttime Traffic is 10%.

Adjustment Factors Needed: _____

Value of Adjustment Factors: _____

13. A Railroad Where the Fraction of Operations Occurring at Night is 30%, the Average Train Speed is 40 MPH, the Track is Bolted and There Are No Whistle Or Horns Required for Grade Crossings.

Adjustment Factors Needed: _____

Value of Adjustment Factors: _____

14. A Railroad Where the Fraction of Operations Occurring at Night is 5%, the Average Train Speed is 10 MPH, the Tracks Are Welded and There Are No Whistles Or Horns Required for Grade Crossing.

Adjustment Factors Needed: _____

Value of Adjustment Factors: _____

15. A Railroad Where the Fraction of Operations Occurring at Night is 20%, the Average Train Speed is 30 MPH, the Track is Bolted and No Whistles or Horns Are Required for Grade Crossings.

Adjustment Factors Needed: _____

Value of Adjustment Factors: _____

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Public Comments

Problems 16 Through 21: Some Basic Problems

Calculate the Combined Noise Levels for Each of the Following Situations:

16. A Roadway Where the distance in Feet from the NAL to the Near Edge of the Nearest Lane is 310 Feet, the Distance to the Far Edge of the Farthest Lane is 358 Feet. There is A Stop Sign 400 Feet from the NAL. The Gradient is 1%. The Average Number of Automobiles is 17,000, the 24 Hour Average Number of Medium Trucks is 1,500, the 24 Hour Average Number of Heavy Trucks is 400 Total. The Fraction of Nighttime Traffic is 20%.

    The Combined Noise Level for This Roadway is _____

17. A Site Exposed to Noise from Two Roads. For Roadway Number 1 the Distance in Feet from the NAL to the Near Edge of the Nearest Lane is 125 Feet, the Distance to the Far Edge of the Farthest Lane is 233 Feet. There is A Stop Sign 250 Feet from the NAL. The Gradient is 3%. The Average Speed for Both Autos and Trucks is 30 MPH.

    The 24 Hour Average Number of Autos is 22,000, the 24 Hour Average Number of Medium Trucks is 2,000. The 24 Hour Average Number of Heavy Trucks is 950 Total. The Fraction of Nighttime Traffic is 10%.

    For Roadway Number 2, the Distance to the Near Edge of the Nearest Lane is 45 Feet, the Distance to the Far Edge of the Farthest Lane is 93 Feet. There is A Stop Sign 100 Feet from the NAL and the Gradient is 1%. The Average Speed for Both Autos and Heavy Trucks is 30 MPH. The 24 Hour Average Number of Automobiles is 14,000, for Medium Trucks 700, and for Heavy Trucks 600 Total. The Fraction of Nighttime Traffic is 20%.

    The Combined Noise Level for This Site is _____

18. A Site Exposed to Noise from Two Railroads. For Railroad 1, the Distance in Feet from the NAL to the Railway Track is 150 Feet. There Are 35 Diesel Trains Every 24 Hours, No Electrified Trains. The Fraction of Operations Occurring at Night is 25%. There Are 3 Diesel Locomotives Per Train and 70 Cars Per Train. The Average Speed is 30 MPH and the Track is Bolted. No Whistles Or Horns Are Used.

    For Railroad 2, the Distance in Feet from the NAL to the Railway Track is 310 Feet. There Are 20 Diesel and 2 Electrified Trains Each 24 Hours. The Fraction of Operations Occurring at Night is 15%. There Are 2 Locomotives Per Diesel Train and 45 Cars for Each Diesel Train and 15 Cars Per Electrified Train. The Average Train Speed is 40 MPH and the Track is Bolted. No Horns Or Whistles Are Used.

    The Combined Noise Level for This Site is _____

19. A Site Exposed to Noise from Two Railroads. For Railroad 1, the Distance in Feet from the NAL to the Railway Track is 75 Feet. There Are 34 Diesel Trains Every 24 Hours, No Electrified Trains. Twenty Percent of the Operations Occur at Night. There Are 5 Locomotives Per Train and 75 Cars Per Train. The Average Train Speed is 35 MPH and the Track is Welded. No Horns Or Whistles.

    For Railway 2, the Distance in Feet from the NAL to the Railway Track is 120 Feet. There Are 12 Diesel Trains in 24 Hours, No Electrified Trains. Twenty-Five Percent of the Operations Occur at Night. There Are 4 Locomotives Per Train and 40 Cars Per Train. The Average Train Speed is 20 MPH and the Track is Bolted. No Horns Or Whistles Are Used.

    The Combined Noise Level for This Site is _____

20. A Site Exposed to Noise from Three Roads. For Road 1, the Distance in Feet from the NAL to the Near Edge of the Nearest Lane is 100 Feet, to the Far Edge of the Farthest Lane, 208 Feet. There is No Stop Sign and the Gradient is 1%. The Average Speed for Autos is 55 MPH. (There Are No Trucks Allowed On This Road.) The 24 Hour Average Number of Autos is 40,000. The Fraction of Nighttime Traffic is 15%.

    For Road 2, the Distance from the NAL to the Near Edge of the Nearest Lane is 45 Feet, to the Far Edge of the Farthest Lane 75 Feet. There is A Stop Sign 175 Feet from the NAL and the Road Gradient is 4%. The average Speed for Both Autos and Trucks is 40 MPH. The 24 Hour Average Number of Autos is 15,000, for Medium Trucks 900 and for Heavy Trucks 320 Total. The Fraction of Nighttime Traffic is 20%.

    For Road 3, the Distance from the NAL to the Near Edge of the Nearest Lane is 52 Feet, to the Far Edge of the Farthest Lane 92 Feet. There is A Stop Sign 400 Feet from the NAL and the Gradient is 1%. The Average Speed for Both Autos and Trucks is 25 MPH. The 24 Hour Average Number of Autos is 6,000, for Medium Trucks 1,050 and for Heavy Trucks 175 Total. The Fraction of Nighttime Traffic is 20%.

    The Combined Noise Level for This Site is _____

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Public Comments

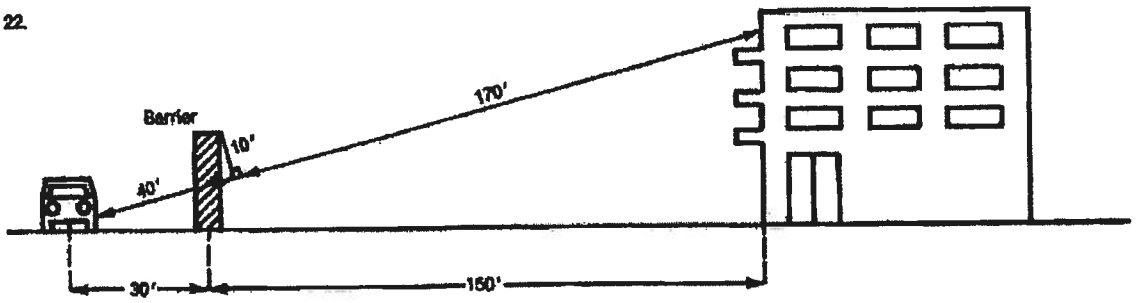
21. A Site Exposed to Noise from A Railroad. The Distance from the NAL to the Railroad Is 110 Feet. There Are 30 Diesel Trains Every 24 Hours, No Electrified Trains. Twenty Percent of the Operations Occur at Night. There Are 3 Locomotives Per Train and 50 Cars Per Train. The Average Train Speed Is 30 MPH, the Track Is Bolted and There Is A Grade Crossing Where Horns and Whistles Are Used 100 Feet from the NAL.

The Combined Noise Level at This Site Is _____.

Problems 22 Through 24: Barriers - Identifying the Values for H, R, R', D and D'

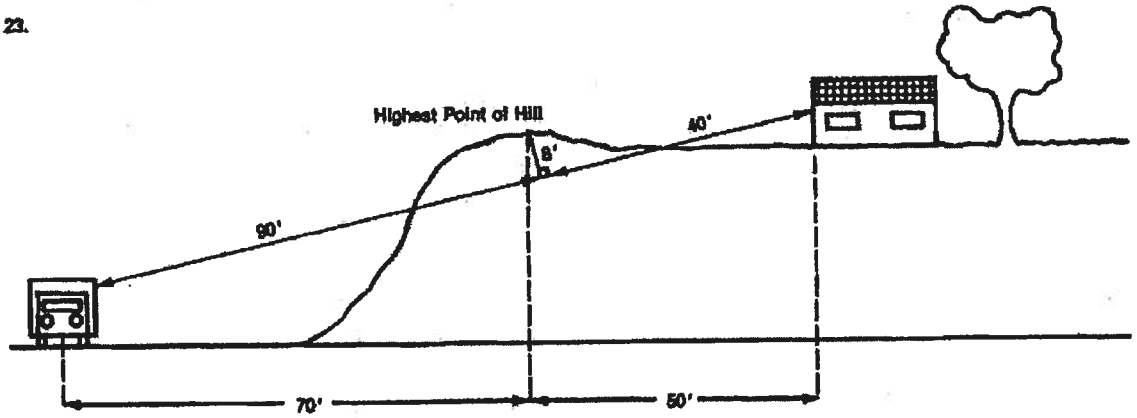
Identify the Values for H, R, R', D and D' for Each of the Following Barriers:

22.



H = _____, R = _____, R' = _____ D = _____ and D' = _____

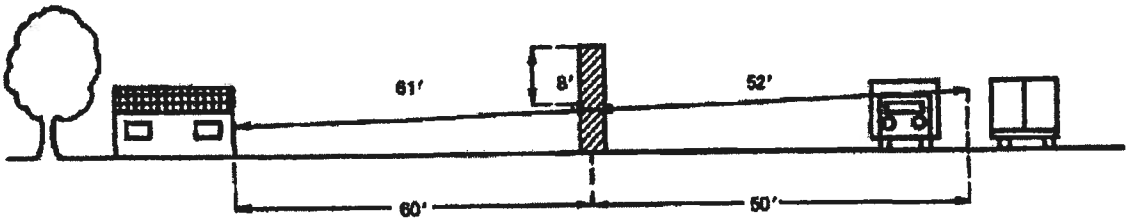
23.



H = _____, R = _____, R' = _____, D = _____ and D' = _____

Barrier	40'	10'	170'	90'	70'
Highest Point of Hill	30'	150'		8'	50'
				40'	

24.



H = _____, R = _____, R' _____, D = _____ and D' _____

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Public Comments

Problems 25 Through 27: Barrier Calculations Using Workcharts 6 and 7.

Using Workcharts 6 and 7 Only, Calculate the Noise Attenuation Provided by the Barriers Illustrated in Problems 22 Through 24. Additional Data on the Angles Subtended by the Ends of the Barriers and the NAL for Each Location is Provided.

25. Calculate the Noise Attenuation Provided by the Barrier Described in Problem 22. The Angle Subtended by the Ends of the Barrier and the NAL is 150 Degrees.

The Noise Attenuation Provided is _____ Decibels.

26. Calculate the Noise Attenuation Provided by the Barrier Described in Problem 23. The Angle Subtended by the Ends of the Barrier and the NAL is 90 Degrees.

The Noise Attenuation Provided is _____ Decibels.

27. Calculate the Noise Attenuation Provided by the Barrier Described in Problem 24. The Angle Subtended by the Ends of the Barrier and the NAL is 130 Degrees.

The Noise Attenuation Provided is _____ Decibels.

Problems 28 Through 30: Barrier Calculations Using Workcharts 5, 6 and 7

Calculate the Attenuation Provided By the Barriers in the Following Situations. Use Workcharts 5, 6 and 7.

28. A Two Story Building is Exposed to Noise Levels of 68 LDN from Automobiles. The Barrier is 15 Feet High and is Located 40 Feet from the Source and 20 Feet from the Building. The Source, Barrier, and Building Are All On Level Ground. The Angle Subtended by the Ends of the Barrier and the Noise Assessment Location is 110 Degrees.

The Noise Attenuation Provided by This Barrier is _____ Decibels.

Is This Sufficient? _____

29. A Three Story Building is Exposed to A Noise Level of 72 LDN from Diesel Locomotives and 60 LDN from Railroad Cars. The Barrier is 12 Feet High and is Located 40 Feet from the Source and 85 Feet from the Building. The Barrier and the Building Are on the Same Level, But the Track is Depressed 25 Feet. The Angle Subtended by the Ends Of the Barrier and the NAL is 120 Degrees.

The Noise Attenuation Provided by This Barrier is _____ Decibels.

Is This Sufficient? _____

30. A Three Story Building is Exposed to Noise Levels of 67 LDN from Automobiles and 71 LDN from Trucks. The Barrier is 16 Feet High and is Located 36 Feet from the Source and 58 Feet from the Building. The Source, the Barrier and the Building Are All At the Same Level. The Angle Subtended by the Barrier Ends and the NAL is 130 Degrees.

The Noise Attenuation Provided by This Barrier is _____ Decibels.

Is This Sufficient? _____

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Public Comments

Noise Assessment Guidelines Workbook
Answers

Problem

1. 66 LDN (67–61 = 6, Add 1dB (From Table) to 67 = 68 LDN)
2. 66 LDN (63–63 = 0, Add 3dB (From Table) to 63 = 66 LDN)
3. 69 LDN (69–51 = 0, Add 0dB to 69 = 69 LDN)
4. 67 LDN (65–62 = 3, Add 1.8dB to 65, Round Off to Nearest Whole Number, 66.8 = 67 LDN)
5. 73 LDN (72–65 = 5, Add 1.2 = 73.2 = 73 LDN)
6. 72 LDN (63–59 = 4, Add 1.5 = 64.5, 71–64.5 = 6.5
Interpolate From Table: 6 = 1.0, 7 = .8
6.5 = .9) 71 + .9 = 71.9 = 72 LDN)

7. 76 LDN (67–61 = 6, Add 1.0 = 68, 72–68 = 4, Add 1.5 = 73.5, 73.5–73 = .5, Interpolate From Table, Add 2.75 = 76.25 = 76 LDN)

8. 49 Feet (76 + 22 = 98 – 2 = 49)
9. 72 Feet (84 + 60 = 144 – 2 = 72)

10. Adjustment Factors Needed: Speed and Night-Time Percentage

    Value of Factors: Speed = Autos .30
    Trucks .81
    Nighttime
    Percentage .81

    Note—You Must Have Different Speed Adjustments for Autos and Trucks.

11. Adjustment Factors Needed: Speed and Stop and Go Traffic
    Value of Factors: Speed .67
    Stop and Go .70

12. Adjustment Factors Needed: Gradient, Speed and Nighttime Percentage

    Value of Factors: Gradient 1.4
    Speed = Autos .30
    Trucks .81
    Nighttime
    Percentage .81

13. Adjustment Factors Needed: Nighttime Percentage, Speed, Bolted Track

    Value of Factors: Nighttime
    Percentage 1.57
    Speed = Engines .75
    Cars 1.78
    Bolted Track 4

    Note—You Must Have Different Speed Adjustments for Engines and Cars.

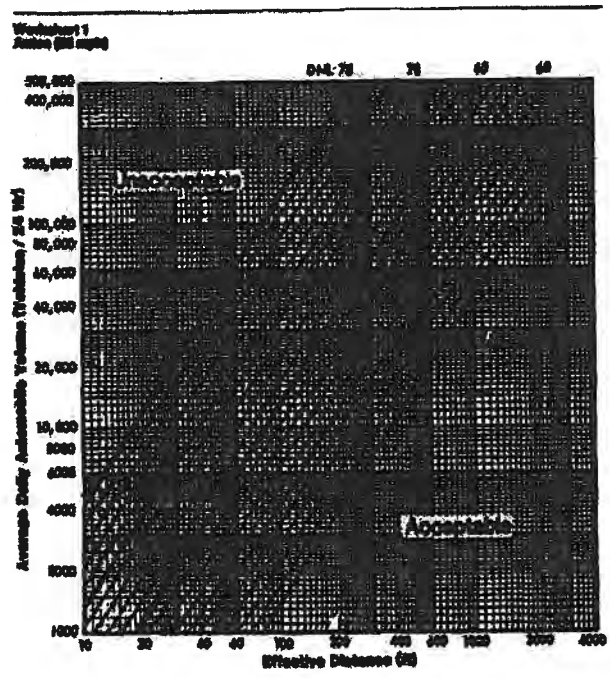
14. Adjustment Factors Needed: Nighttime Percentage and Speed

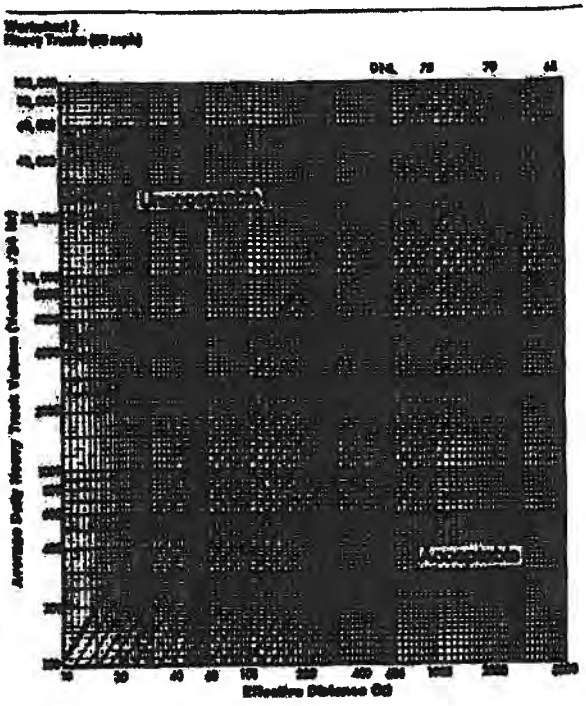
    Value of Factors: Nighttime
    Percentage .62
    Speed = Engines 3.0
    Cars .11

15. Adjustment Factors Needed: Nighttime Percentage and Bolted Track

    Value of Factors: Nighttime
    Percentage 1.19
    Bolted Track 4

16. Combined Noise Level = 62 LDN (If Your Answer Is Plus or Minus 1dB Its OK – Between Rounding Off and the Large Scale on the Nomographs, That's Close Enough)





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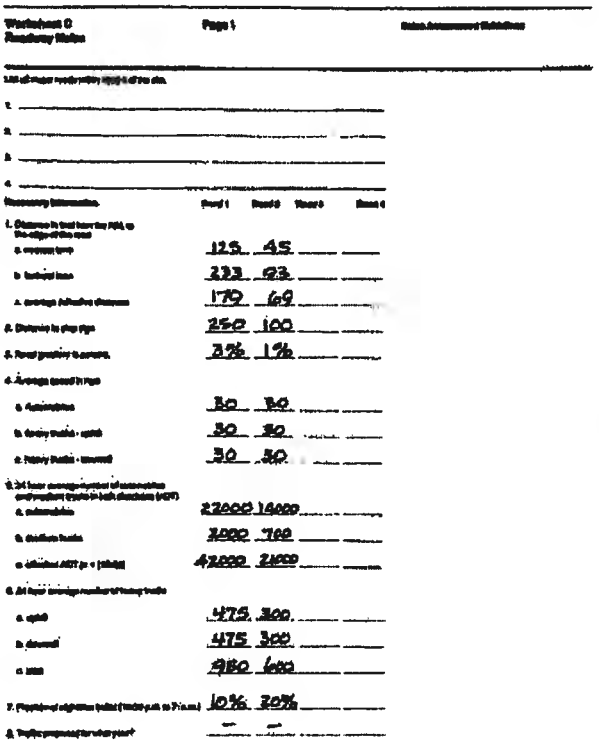
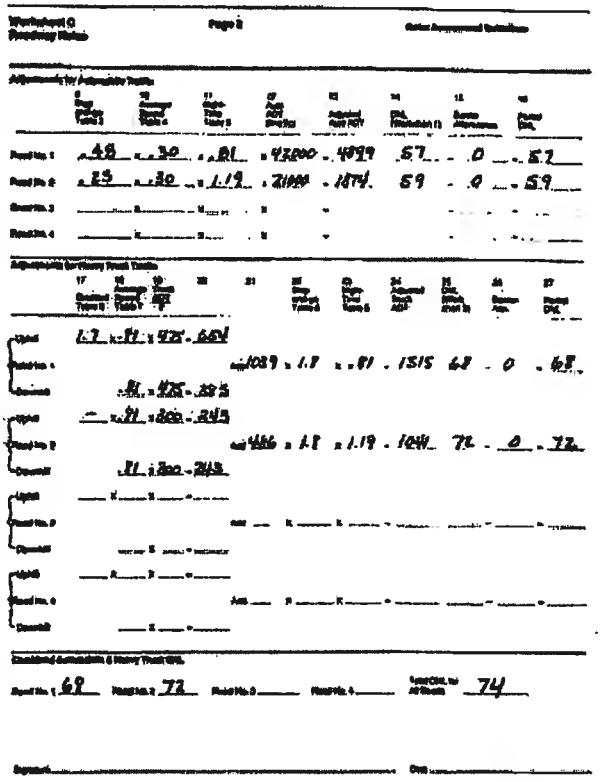
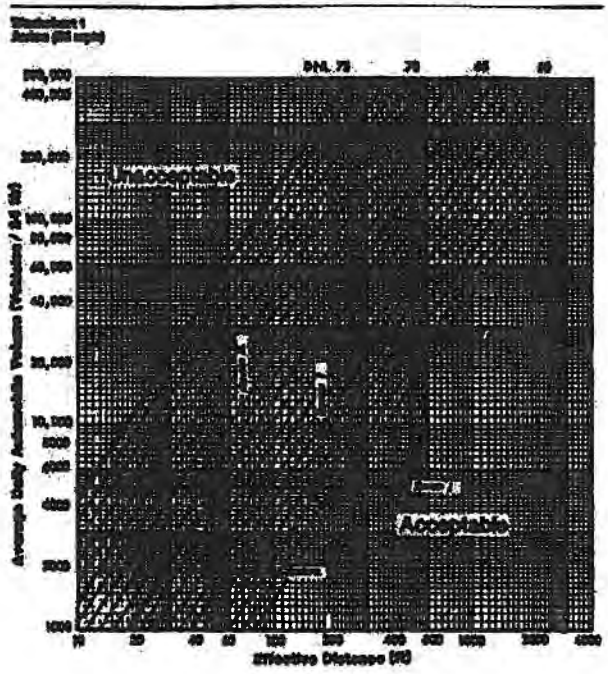
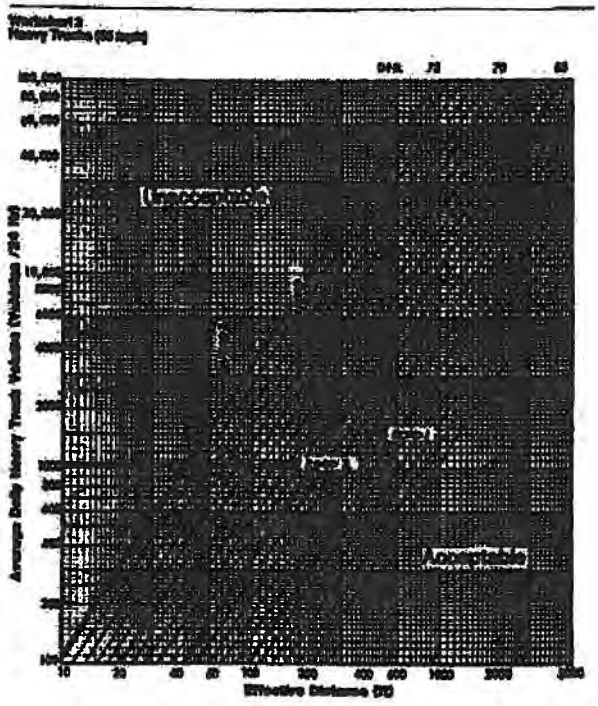
Public Comments

17. Combined Noise Level = 74 LDN (+ OR – 1 dB)









18. Combined Noise Level = 71 LDN

Note—In Order to Complete Column 18 for Railway #2 You Must Find the Average Number of Cars Per Train. Multiply the Number of Diesel Trains Times the Number of Cars Per Train (20 x 45 = 900), Multiply the Number of Electrified Trains Times the Number of Cars Per Train (2 x 15 = 30). Add the Two Totals Together and Divide By the Total Number of Trains (900 + 30 = 930 – 22 = 42).

Worksheet D
Railway Noise

Page 2

Noise Assessment Guidelines

Railway No. 1	1.5	1.0	—	1.38	35	72	70	0	72
Railway No. 2	1	.75	—	1.0	20	15	58	0	58
Railway No. 3									

Railway No. 1	14	1.0	4	1.38	35	270	64	0	64
Railway No. 2	.94	1.78	4	1.38	22	112	57	0	57
Railway No. 3									

Railway No. 1 71 Railway No. 2 61 Railway No. 3 71

Signature _____ Date _____

19. Combined Noise Level = 76 LDN

Worksheet D
Railway Noise

Page 2

Noise Assessment Guidelines

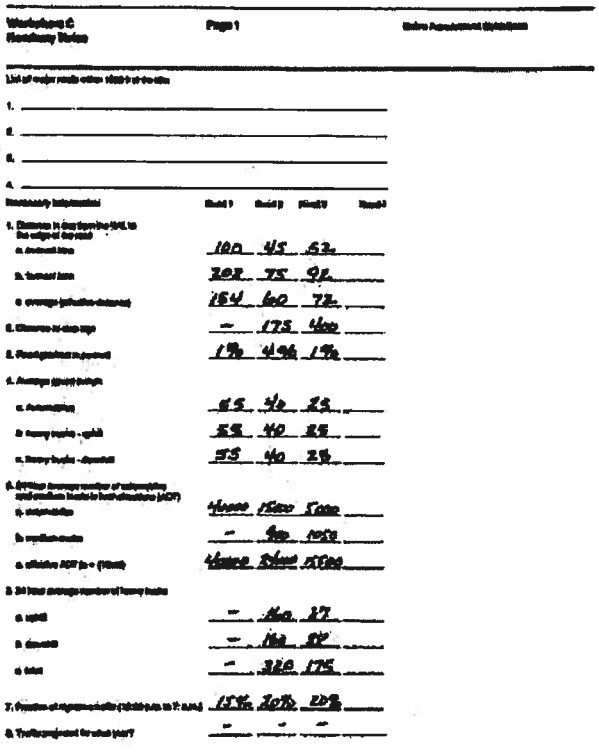
Railway No. 1	2.5	1.0	—	1.19	34	89	75	0	75
Railway No. 2	1	1.50	—	1.38	12	50	70	0	70
Railway No. 3									

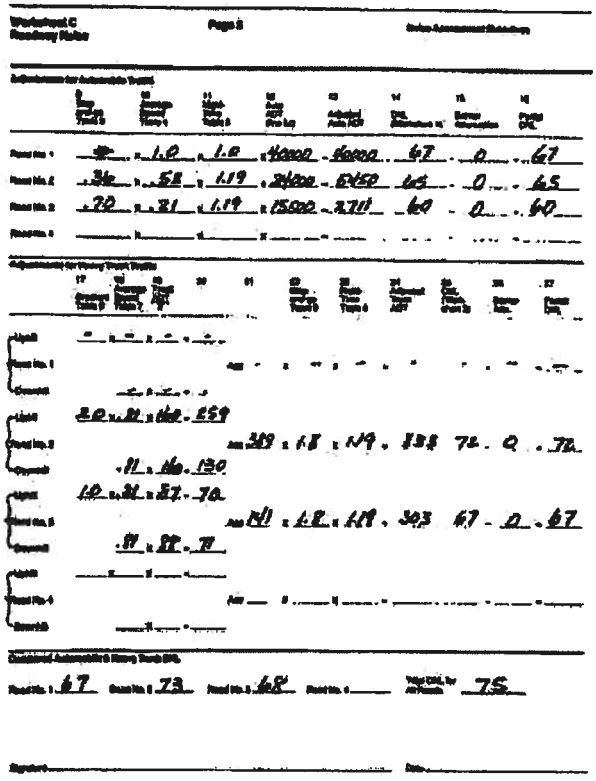
Railway No. 1	15	1.19	—	1.19	34	84	63	0	63
Railway No. 2	.90	.94	4	1.38	12	23	55	0	55
Railway No. 3									

Railway No. 1 75 Railway No. 2 70 Railway No. 3 _____ Total Daily Level of Railways 76

Signature _____ Date _____

20. Combined Noise Level = 75 LDN





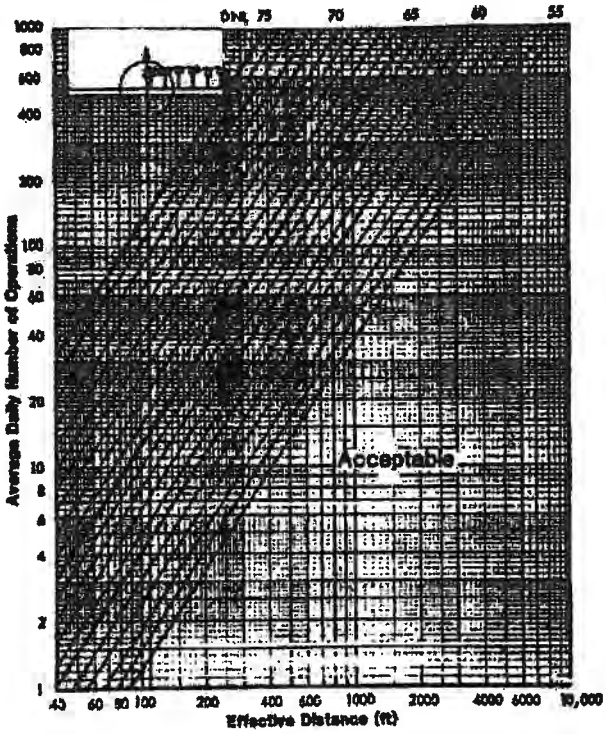
21. Combined Noise Level = 81 LDN

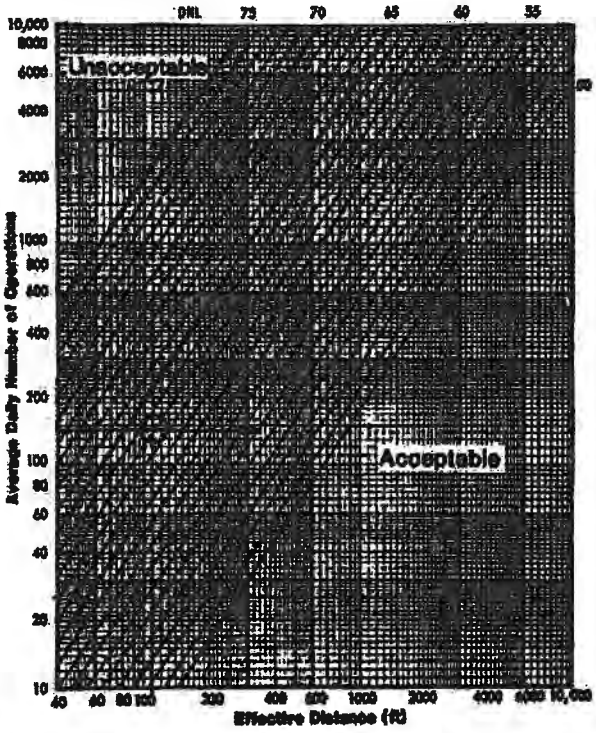
To Solve This Problem You Must Add Some More Lines to the Workchart for Engines Because the Workchart as Set up Does Not Go High Enough. There Are A Variety of Ways to Do This But One of the Easiest is to Take A Piece of Blank Paper (A 3 x 5 Card Does Very Well) Place the Edge of the Paper Along Either the Top Or Bottom Edge of the Workchart and Mark Where the LDN Lines Fall Along the Edge of the Blank Paper. Then Once You Have Drawn Your Distance and Operations Lines on the Work Chart, You Take Your Paper with the Line Markings and Lay it along the Line for Adjusted Operations with the Mark Farthest to the Right Lined up with the 75 LDN Line. Now Just Count over until You Reach the Intersection of the Operations and Distance Lines.

	1.5	1.0	10	1.19	30	635	81	0	81

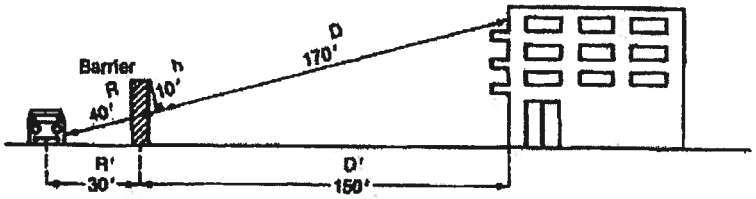
	10	1.0	4	1.19	50	143	63	0	63

81

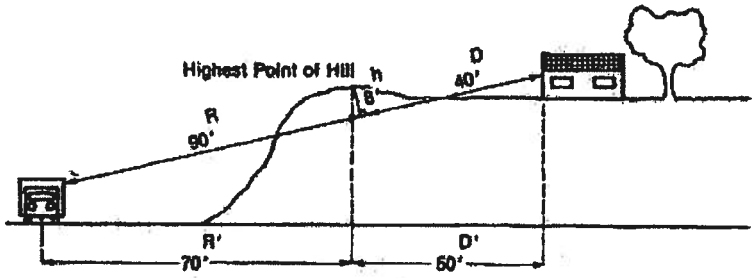




22. H = 10 Feet, R = 40 Feet, R′ = 30 Feet, D = 170 Feet, D′ = 150 Feet

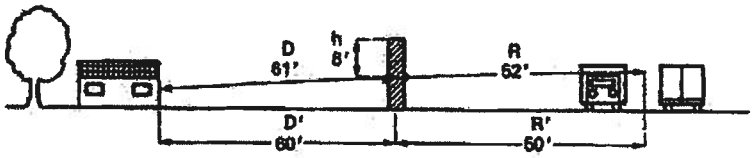


23. H = 8 Feet, R = 90 Feet, R′ = 70 Feet, D = 40 Feet, D′ = 50 Feet



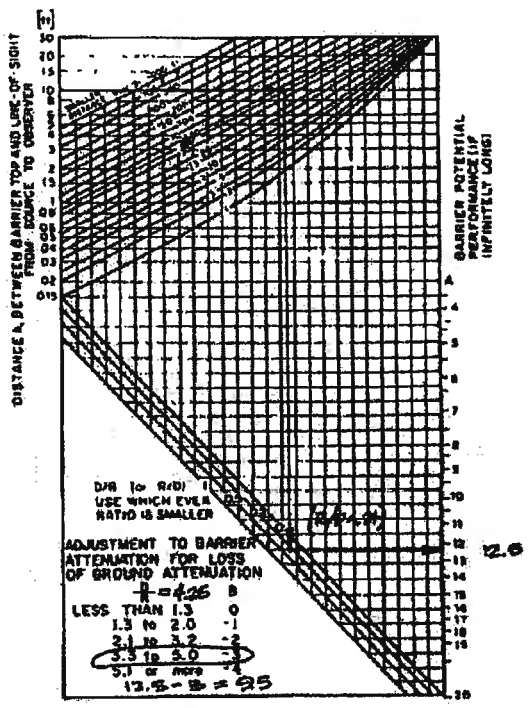
Note—The Line of Sight Line Starts Above the Road Level Because of the Trucks.

24. H = 8 Feet, R = 52 Feet, R′ = 50 Feet, D = 61 Feet, D′ = 60 Feet

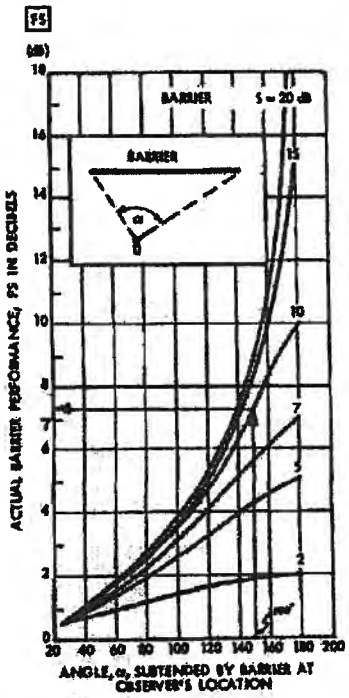


25. The Noise Attenuation Provided is 7 Decibels

Worksheet 6
Noise Barrier

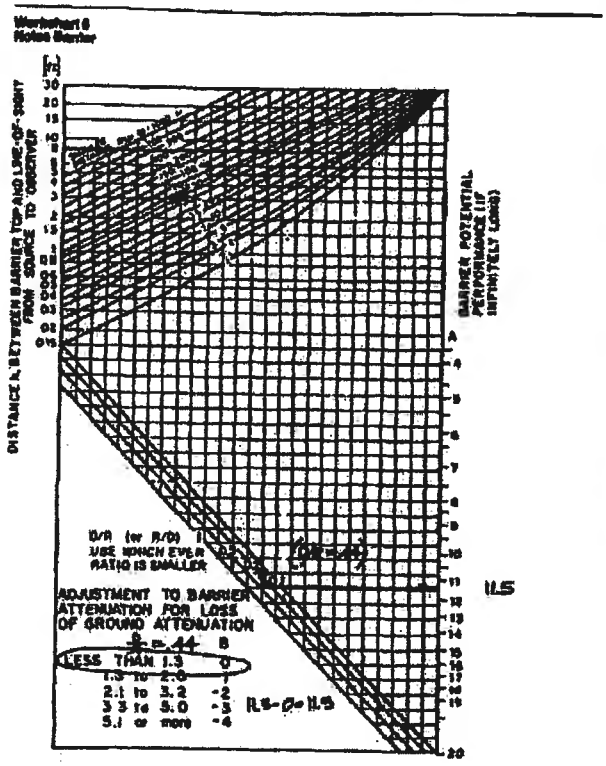


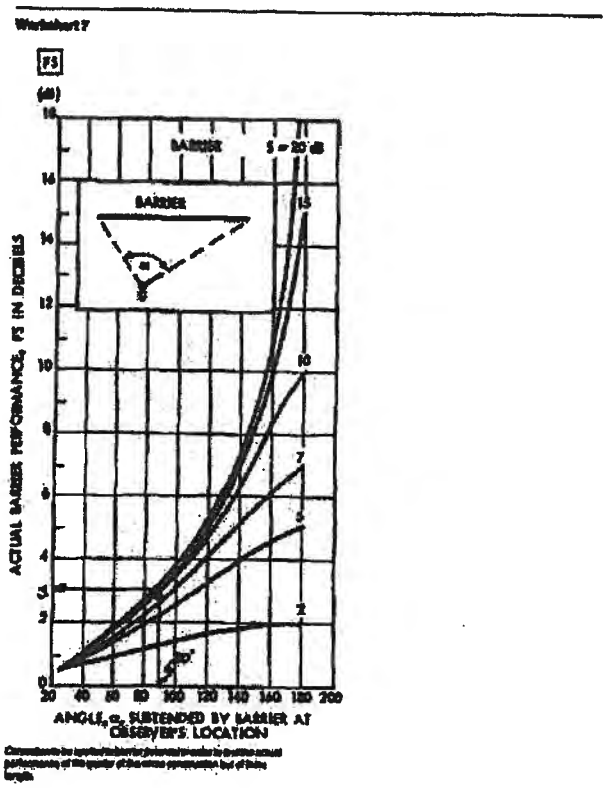
Worksheet 7



26. The Noise Attenuation Provided Is 3 Decibels

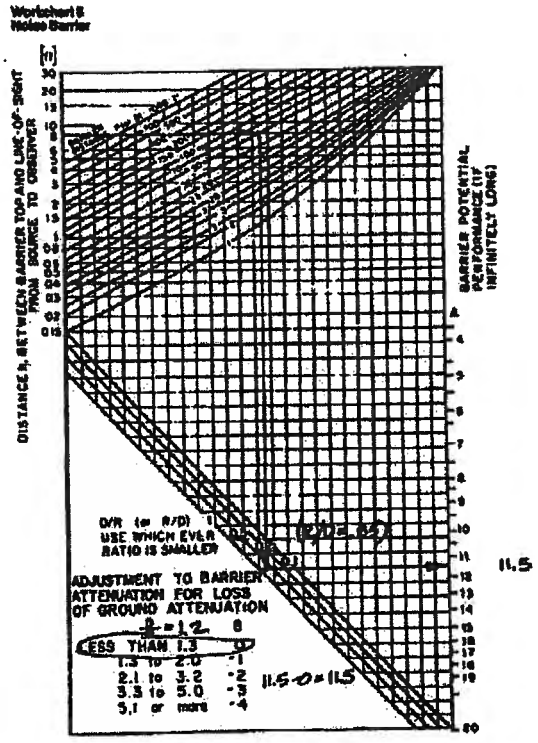
Note—When the Curves ARe So Close Together Don't Worry About Extrapolating. In This Case You Couldn't Anyway, the 15 dB and 10 dB Curves Have Merged.

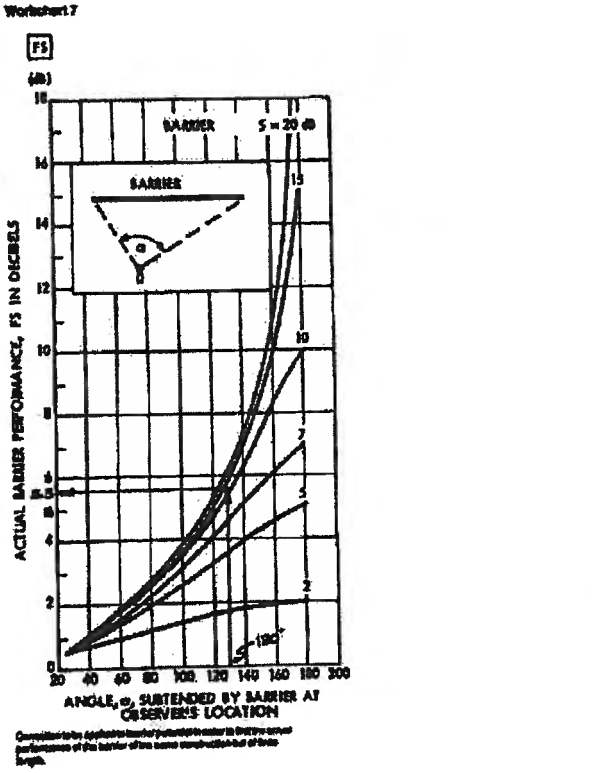




27. The Noise Attenuation Provided is 6 Decibels (5.5 Rounded Up)

Note—Again You Have Problems With Extrapolating—Don't Worry About Being Too Precise.



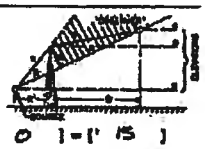


28. The Noise Attenuation Provided by This Barrier is 4 dB. This is Sufficient

Note—Don't Forget That the Height of the observor is 5' Less Than the Total Height of the Building and the Height of the Building is 10 Feet Times the Number of Stories. And Did You Remember to Make the Adjustment for Ground Attenuation Loss.

Worksheet 6
Noise Barrier

Enter the values for:
h_s = 15 h_r = 40
g_s = 0 g_r = 20
d_p = 15

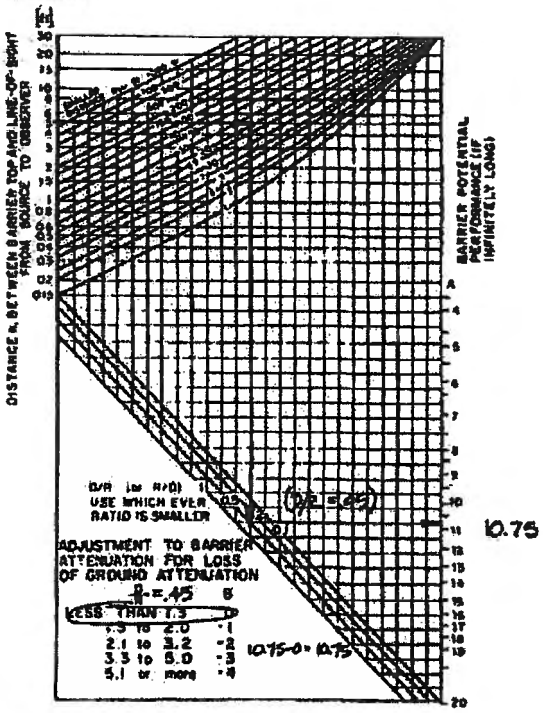


1.	[15]	− [0]	= [15]	
2.	[15]	− [0]	= [15]	
3.			[60]	
4.			[40]	
5.	[15]	÷ [60]	= [.25]	
6.	[.25]	× [.25]	= [.0625]	
7.	[40]	× [.0625]	= [2.5]	
8.	[40]	− [2.5]	= [37.5]	
9.	[.25]	× [40]	= [10]	
10.	[15]	− [10]	= [5]	
11.	[5]	× [37.5]	= [187.5]	−0
12.	[.25]	× [5]	= [1.25]	
13.	[40]	÷ [37.5]	= [1.07]	
14.	[1.07]	+ [1.25]	= [2.32]	−0
15.	[60]	− [40]	= [20]	
16.	[20]	÷ [37.5]	= [.533]	
17.	[.533]	− [1.25]	= [−.717]	−0

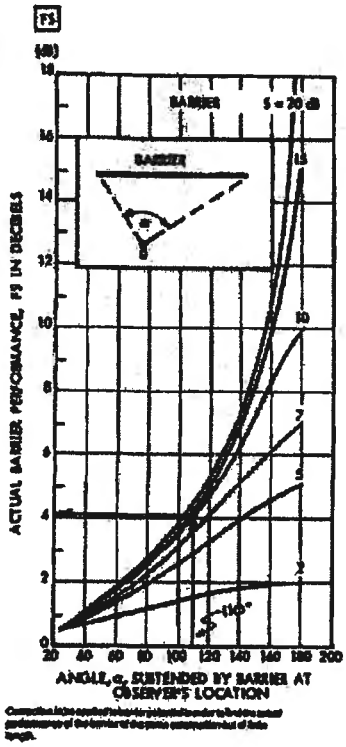
Enter 16, 14, and 17, then adding a negative number to the same or subtracting a negative number, from it.

Round off to two decimal places.

Worksheet 8
Noise Barrier



Worksheet 7

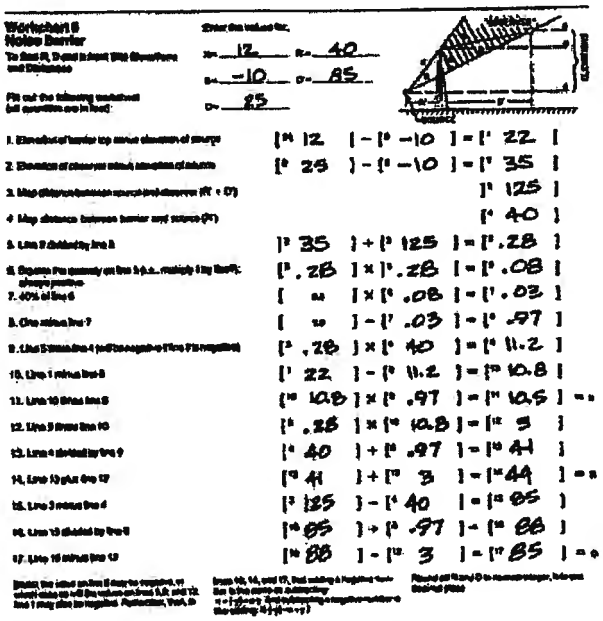


Correction for a specific barrier to be used under other than standard conditions of the number of the same construction of finite length.

29. The Noise Attenuation Provided by This Barrier is Approximately 5 dB for Both the Engines and the Railroad Cars.

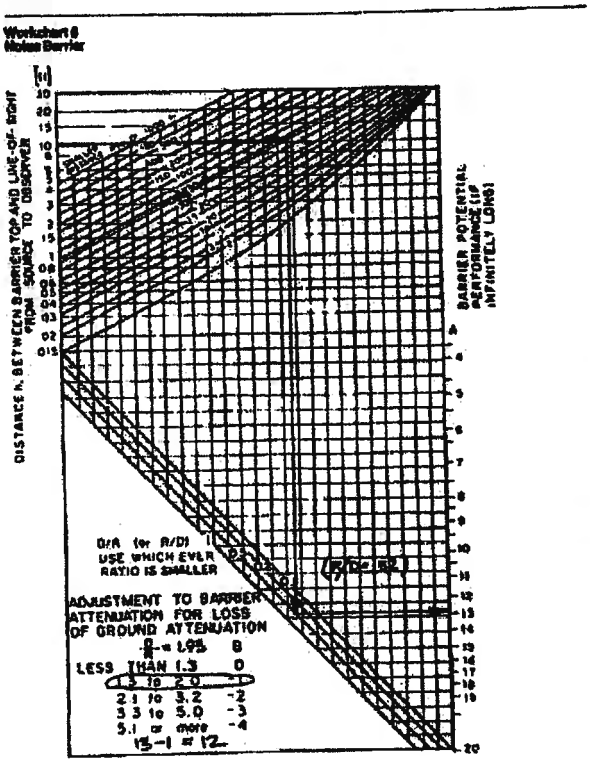
    This is Not Sufficient.

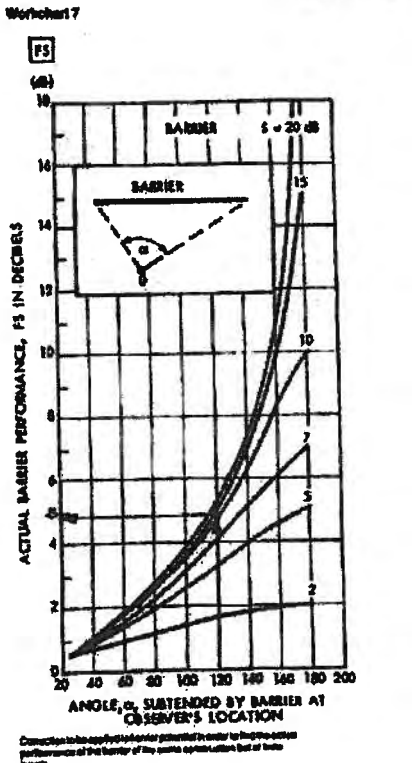
    Note—You Were Supposed to Calculate Attenuation for Diesel Engines and Cars Separately Because the Source Heights Are Different. The Value of S for the Engines Should Have Been −10 and the Value of S for the Railroad Cars Should Have Been − 25.



Worksheet 8
Noise Barrier

1.	[12	− [−10	] = [22]
2.	[25	− [−10	] = [35]
3.			[125]
4.			[40]
5.	[35	+ [125	] = [.28]
6.	[.28	× [.28	] = [.08]
7.	[40%	× [.08	] = [.03]
8.	[100	− [.03	] = [.97]
9.	[.28	× [40	] = [11.2]
10.	[22	− [11.2	] = [10.8
11.	[10.8	× [.97	] = [10.5] = s
12.	[.28	× [10.8	] = [3]
13.	[40	+ [.97	] = [41]
14.	[41	+ [3	] = [44] = s
15.	[125	− [40	] = [85]
16.	[85	+ [.97	] = [88]
17.	[88	− [3	] = [85] = s





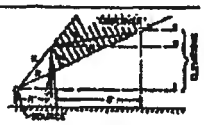
Worksheet 8
Noise Barrier

Enter the values for:

a = 12 c = 40

b = -25 d = 85

f = 25



1. Elevation of barrier top minus elevation of source	[a 12]	− [c -25]	= [1 37]	
2. Elevation of observer minus elevation of source	[b 25]	− [c -25]	= [2 50]	
3. Map distance between source and observer (R' + D')			[3 125]	
4. Map distance between barrier and source (R')			[4 40]	
5. Line 2 divided by line 3	[5 .50]	+ [3 125]	= [5 .4]	
6. Square the quantity on line 5 (i.e., multiply it by itself); always positive	[5 .4]	× [5 .4]	= [6 .16]	
7. 40% of line 6	[40]	× [6 .16]	= [7 .06]	
8. One minus line 7	[1]	− [7 .06]	= [8 .94]	
9. Line 5 times line 4 (with the negative sign if line 5 is negative)	[9 .4]	× [4 40]	= [9 16]	
10. Line 1 minus line 9	[1 37]	− [9 16]	= [10 21]	
11. Line 10 times line 8	[10 21]	× [8 .94]	= [11 19.7]	= 1
12. Line 5 times line 10	[5 .4]	× [10 21]	= [12 8.4]	
13. Line 4 divided by line 8	[4 40]	+ [8 .94]	= [13 42.6]	
14. (Line 13 plus line 12	[13 42.6]	+ [12 8.4]	= [14 51]	= 2
15. Line 3 minus line 4	[3 125]	− [4 40]	= [15 85]	
16. Line 15 divided by line 8	[15 85]	+ [8 .94]	= [16 90.4]	
17. Line 16 minus line 12	[16 90.4]	− [12 8.4]	= [17 82]	= 3

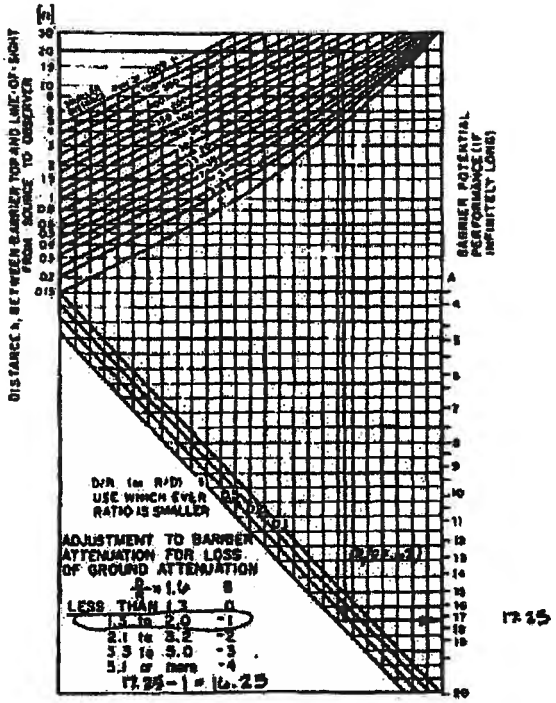
Select the value on line 1 or line 11, or the smaller of the two, and enter it here. If line 1 was chosen, enter 0 here; if line 11 was chosen, enter 1 here.

Select the value on line 2 or line 14, or the smaller of the two, and enter it here. If line 2 was chosen, enter 0 here; if line 14 was chosen, enter 2 here.

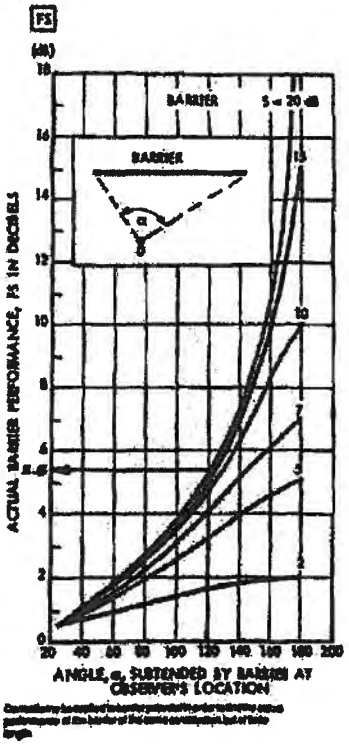
Select the value on line 3 or line 17, or the smaller of the two, and enter it here. If line 3 was chosen, enter 0 here; if line 17 was chosen, enter 3 here.

Record all three of the numbers you entered above.

Worksheet 8
Noise Barrier



Worksheet 7



30. The Noise Attenuation Provided by This Barrier Is 3 dB for Trucks and 5 dB for Autos. The Combined Level Resulting Is 69 LDN.

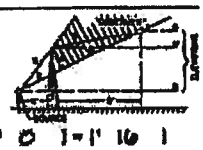
This Is Not Sufficient

Note—You Must Calculate the Barrier Effect Separately for Autos and Trucks Because the Source Height Is Different. Then Recombine levels.

Worksheet 5
Noise Barrier

Enter the values for:

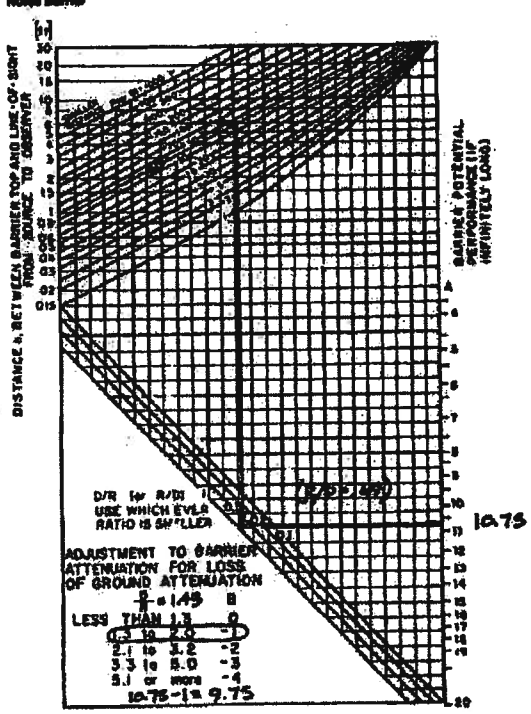
H = 16	H' = 36
S = 0	D = 56
Q = 25	



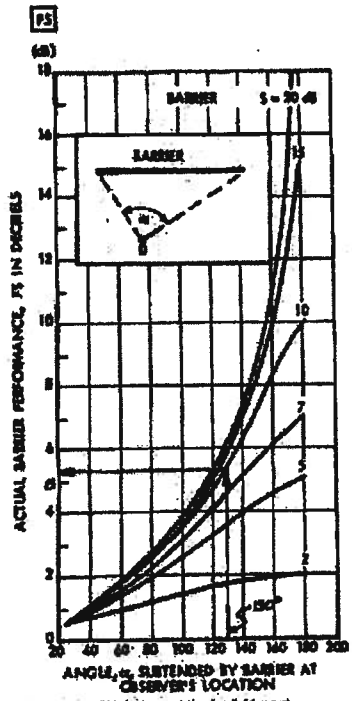
1. Elevation of barrier top minus elevation of source	[16]	− [0]	= [16]	
2. Elevation of observer minus elevation of source	[25]	− [0]	= [25]	
3. Map distance between source and observer (H' + D')			[92]	
4. Map distance between barrier and source (H')			[36]	
5. Line 2 divided by line 3	[25]	+ [92]	= [.27]	
6. Square the quantity on line 5 (i.e., multiply any fourth-charge positive)	[.27]	× [.27]	= [.07]	
7. 40% of line 6	[4%]	× [.07]	= [.03]	
8. One minus line 7	[1.0]	− [.03]	= [.97]	
9. Line 5 (minus line 4 in the negative if line 2 is negative)	[.27]	× [36]	= [9.7]	
10. Line 1 minus line 9	[16]	− [9.7]	= [6.3]	
11. Line 10 times line 8	[6.3]	× [.97]	= [6.1]	= a
12. Line 5 times line 10	[.27]	× [6.1]	= [1.7]	
13. Line 4 divided by line 8	[36]	+ [.97]	= [37]	
14. Line 13 plus line 12	[37]	+ [1.7]	= [39]	= b
15. Line 2 minus line 4	[92]	− [36]	= [56]	
16. Line 15 divided by line 8	[56]	+ [.97]	= [58]	
17. Line 16 minus line 12	[58]	− [1.7]	= [56]	= c

[illegible]

Worksheet 6
Noise Barrier



Worksheet 7



[illegible]

Worksheet 8
Noise Barrier

Given the values for:

h = 16 h' = 36

a = 8 a' = 56

d = 15

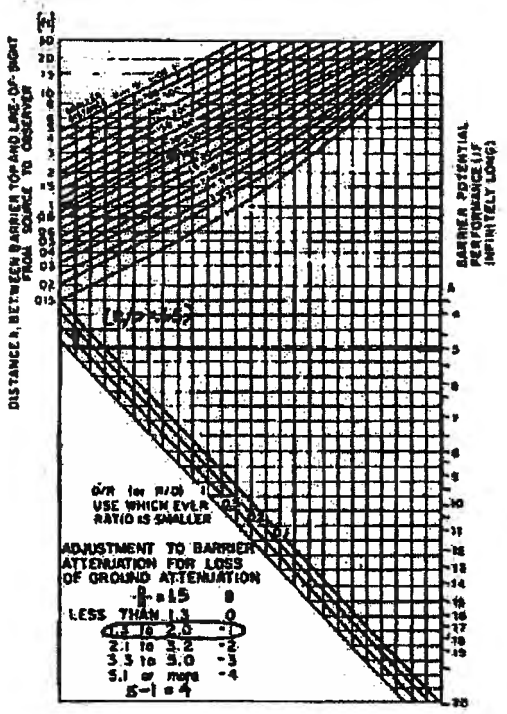
Fill out the following worksheet (all quantities are in feet)

1. Elevation of barrier top minus elevation of source	[H 16]	− [S 8]	= [' 8]	
2. Elevation of observer minus elevation of source	[O 25]	− [S 8]	= [' 17]	
3. Slope distance between source and observer (R' = b)			[' 92]	
4. Slope distance between barrier and observer (R')			[' 36]	
5. Line 2 divided by line 3	[' 17]	÷ [' 92]	= [' .2]	
6. Square the quantity on line 5 (i.e. multiply it by itself; straight number)	[' .2]	× [' .2]	= [' .04]	
7. 40% of line 6	[.04]	× [' .04]	= [' .02]	
8. One minus line 7	[.02]	− [' .02]	= [' .98]	
9. Line 5 minus line 1 (or line 1 minus line 5 if negative)	[' .2]	× [' 36]	= [' 7]	
10. Line 1 minus line 9	[' 8]	− [' 7]	= [' 1]	
11. Line 10 times line 8	[' 1]	× [' .98]	= [' .98]	= a
12. Line 5 times line 10	[' .2]	× [' 1]	= [' .2]	
13. Line 4 divided by line 8	[' 36]	÷ [' .98]	= [' 37]	
14. Line 13 plus line 12	[' 37]	+ [' .2]	= [' 37]	= a
15. Line 3 minus line 4	[' 92]	− [' 36]	= [' 56]	
16. Line 15 divided by line 5	[' 56]	÷ [' .98]	= [' 57]	
17. Line 16 minus line 12	[' 57]	− [' .2]	= [' 57]	= b

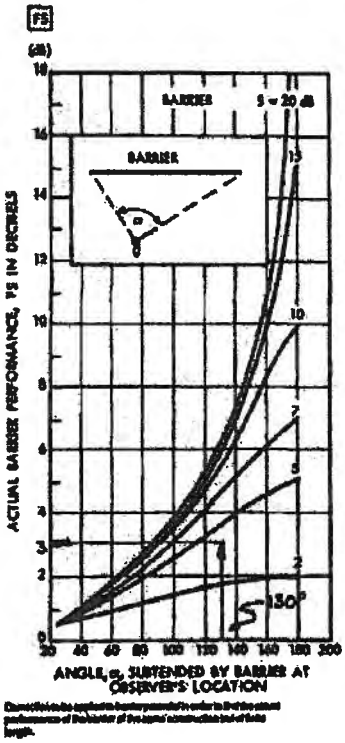
When the values on line 9 are to be negative, in which case add the values on lines 5,8, and 10; line 1 may also be negative. Nevertheless, lines 10, 11, and 12, that setting a negative value typically the same as subtracting a negative line, and summarizing, a negative value of the setting, 5-(-2)=+7.

Round off 11 and 13 to nearest integer, 1 decimal place.

Worksheet 8
Noise Barrier



Worksheet 7



Correction to the approximate barrier potential in order to find the actual performance of the barrier of the same construction but of finite length.

Chapter 7

The Use of Noise Measurements

Noise Calculations Are Best For HUD Use

There are two ways to determine noise levels for a site under review: the noise can be calculated or it can be measured. While one's first reaction might well be that it would obviously be better to go out and actually measure the noise levels at the site, calculated noise levels are really much better for implementing HUD's noise policy.

Calculated noise levels are developed using mathematical models that contain a variety of assumptions about the process of noise propagation as well as data on sound levels generated by typical sources (i.e. aircraft engines, automobile tires etc.). The model can be a complex computer model or it can be a simple desktop model such as the procedures in the *Noise Assessment Guidelines*. The models can also employ a variety of noise descriptors. (See chapter 1 for a discussion of noise descriptors.) Most noise studies done for the Federal Highway Administration, for example, use either the L_{10} or the L_{eq} noise descriptor. Many aircraft noise studies use the NEF or CNEL descriptor. All of these descriptors are compatible with the L_{dn} noise descriptor system that is preferred by HUD and the HUD noise regulation contains instructions for converting all of them into L_{dn}. (sections 51.106(a)(1) and (2))

Whether produced by a sophisticated computer model or by the desktop *Noise Assessment Guidelines*, calculated noise levels are more useful for HUD needs than measured levels for two significant reasons: The first is that with noise measurements you have no good way to take into account future changes in the future noise environment. The houses we help build today are going to be around for a long time and it is very important that we determine, to the extent we can, the noise environment that will exist throughout the life of the buildings.

While there are clearly limitations on how far into the future we can reasonably project traffic levels for roads, railroads and airports, we can at least look 5 to 10 years ahead. The HUD noise regulation (24 CFR 51B) requires that "to the extent possible, noise exposure shall be projected to be representative of conditions that are expected to exist at a time at least 10 years beyond the date of the project or action under review." It is very easy to make these projections if you use the *Noise Assessment Guidelines* or a computer model to determine noise levels.

The second reason why we prefer that you calculate noise levels is that through the calculation process you can use monthly or yearly data to determine traffic levels. Thus you come up with a more typical picture of conditions. With noise measurements there is always the possibility that the day or even days chosen for measurements will not be typical and that the measurements may over or understate the problem. While the conscientious measurer will try to account for any unusual conditions, it isn't always possible. So long as cost considerations limit the number of days that measurements can be taken there will always be the problem of unrepresentative data. With calculations this isn't a problem. The computer model that generates contours for airports, for example, uses an entire years data to develop the average day. Certainly the results are more likely to be representative than the results that would be derived from just a few days measurements.

When Noise Measurements Are Useful

While it is the preferred procedure to calculate noise levels, there are a few situations where the noise models might not be accurate and it might be better to rely on measurements. One instance would be when there is insufficient or inadequate traffic data. Another case might be where you have a unique physical situation that is not accounted for in whatever mathematical model is available.

Obtaining good traffic data can be difficult. You may only be able to get gross data that simply lists total vehicles without making any distinctions between trucks and automobiles. Or you may not be able to get any reliable data on the percentage of traffic between 10 pm and 7 am. While the *Noise Assessment Guidelines* do contain some assumptions that you can use when you don't have all the data you need, there may be instances when you just don't think those assumptions would accurately portray the problem.

By the same token, there are certain physical situations that mathematical models such as the *Noise Assessment Guidelines* couldn't anticipate and therefore do not reflect in their formulas. For example, the *Guidelines* say that you don't have to calculate the noise levels for underground transit lines. Well what if the line is underground but there are large air vents that reach from the belowground tunnels to the surface? A great deal of noise can reach the surface through these vents but the *Noise Assessment Guidelines* don't have any way to take it into account. You couldn't treat it as if the subway line were aboveground because it isn't really and at least some of the noise is blocked. This would be a case where a noise measurement would probably be the best way to determine the noise levels. By the same token, the guidelines do not really take into account the sometimes significant amounts of reflected noise that can occur at urban sites surrounded by tall buildings, i.e. the canyon effect.

When Not to Use Measurements

One thing noise measurements should not be used for is to confirm or refute calculated noise levels, especially computer generated aircraft contours. Our experience with both the *Noise Assessment Guidelines* and with computer noise models is that both are quite accurate if done properly. If you are convinced that the calculations were done correctly, and if you believe that the data used were good, you should strongly discourage anyone who wants to take measurements because they think that measurements are inherently more accurate than calculations. Comparing measured noise levels to calculated levels is like comparing apples and oranges. The

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Public Comments

calculated noise levels should include projected traffic levels, the measured ones will not. The calculated levels will be based on daily traffic counts derived by averaging months of data, the measured levels will, at best, reflect just a few days. (This is particularly true for aircraft noise contours. The day-to-day operations of an airport can vary significantly depending upon weather conditions and any one or two days worth of measurements are very likely to show different levels from those generated by a computer model employing a year of data to derive an average day.)

If you have determined that noise measurements are appropriate, you must make sure that they are done properly, otherwise the data will be useless. There are four elements to proper measurements: 1) where the measurements are taken; 2) when they are taken; 3) the type of equipment used; and 4) the actual measurement procedure.

Where measurements should be taken: The locations for noise measurements should be selected using the same criteria you would use to select a Noise Assessment Location for a *Noise Assessment Guidelines* calculation. The *Noise Assessment Guidelines* recommend that "assessments of the noise exposure should be made at representative locations around the site where significant noise is expected." Further, the *Guidelines* state that when selecting these locations you should consider those buildings containing noise sensitive uses which are closest to the predominant noise sources. Where quiet outdoor space is desired at a site, you should also select points in the outdoor area in question. Specifically, the "relevant measurement location for buildings is a point 2 meters (6.5 feet) from the facade." If there are no buildings yet the measurement point should be 2 meters from the closest point setback requirements would allow a building facade.

When measurements should be taken: Because measurements are only going to be taken for a few days at best, special care should be taken to make sure that the days selected are representative of average traffic levels. For highways, avoid both Monday and Friday, particularly before or after a holiday. In fact holiday periods, such as the Christmas/New Years season, should be avoided entirely. Highway traffic, or rather more importantly, truck traffic is likely to be down during these periods and noise levels may be significantly lower than normal. On the other hand, holiday periods are often peak travel periods for airlines and measurements taken around airports then would show unusually high noise levels.

Whoever is taking the measurements should also check to make sure that there aren't any special circumstances that might affect traffic levels. For example road construction or repair work might divert additional traffic onto the road being measured, or divert traffic away. In both cases the noise levels measured would not be representative.

And finally, noise measurements should not be taken during extreme weather conditions both because of the possible effects on traffic levels but also because the weather conditions can exaggerate the actual noise levels.

Ideally, noise measurements should be taken over several days spread over at least a few months. But given that time and money will normally preclude this, at least make sure the one or two days you can get are as close to typical as possible.

What equipment to use: There are many sound level meters on the market which are suitable for taking noise measurements for transportation sources. They need only to meet the requirements of American National Standard Specification for Type 1 Sound Level Meters: S1.4–1971. Type 1 sound level meters are "precision" meters and provide the most accurate measurements. They are also, of course, the most expensive. Fast time-averaging and A frequency weighting are to be used. The sound level meter with the A-weighting is progressively less sensitive to sound with frequencies below 1,000 hertz, somewhat as is the ear. With fast time averaging the sound level meter responds particularly to recent sounds almost as quickly as does the ear in judging the loudness of a sound. Fast time averaging has a time constant of about 1/8 second.

While a sound level measuring system that averages decibel readouts on a short term basis such as for every minute or every hour is acceptable, it would be far better if a system that actually provides a 24 hour integrated L_{dn} readout were used. Such a system eliminates the need for calculating the L_{dn} value, an area where many inexperienced consultants go astray. These systems are more expensive however, and the consultant who doesn't do much noise work is unlikely to have one.

Measurement procedures: Detailed procedures for making sound level measurements are spelled out in the American National Standards Institute's Standard Methods ANSI S1.2-1962(R1976) *American National Standard Method for the Physical Measurement of Sound* and ANSI S1.13-1971(R1976) *American National Standard Methods for the Measurement of Sound Pressure Levels.*

Some of the basic procedures that should be followed are:

1. Measurements should normally be made over a continuous 24 hour period. If this is not possible, measurements may be made over a period of days but still must cover the entire 24 hour period. The selection of the days becomes even more critical so that they are as similar as possible. Sampling is not acceptable.
2. The sound level meter must be calibrated before each use.
3. The sound level meter should be provided with a wind screen.
4. Care should be taken to insure that there are no temporary obstructions, such as parked trucks, between the meter and the source.

The Noise Study

The noise study prepared to describe the measurement results should contain at least the following:

1. A map showing where the measurements were taken
2. A vicinity map showing the site and the major noise sources
3. A chart indicating the date, the time, and weather conditions when measurements were taken at each measurement location
4. The type of microphone used
5. Any variations from ANSI procedures
6. The results of the measurements in L_{dn} for each measurement location
7. Any unusual conditions that existed during the measurement period—i.e. construction activity, major traffic tieup, etc.
8. If an integrating sound level meter was not used, the calculations used to derive the L_{dn} value.

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Public Comments

U.S. Department of Housing and Urban Development
Office of Community Planning and Development

Noise Notebook

Chapter 4
Supplement

Sound Transmission Class Guidance

P11-0050/P12-0220, Exhibit 16
Public Comments

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Sound Transmission Class Guidance

Introduction

The Noise Guidebook, pages 33-37, provides an elementary discussion of STC, provides some STC ratings for common building materials and limited exterior and interior wall construction configurations, and describes a method to determine composite STC value of a wall containing a window or door. This update provides for an understanding of STC and provides an expanded material and construction classification for both internal and external building materials and typical construction patterns.

The intent of this chapter is not to endorse anyone building manufacturer or product over another but to keep HUD Environmental staff and other interested persons advised on the STC values of current building materials and practices which can be applied to HUD supported housing activities. Additional subsections on specific types of building materials, construction techniques and STC values will be periodically added.

As stated in the Noise Guidebook, "STC is used as a measure of a material's ability to reduce sound," and effectively mitigate any adverse noise levels that could impede a person's use of a residential or commercial structure. The higher the STC value, the greater the sound attenuation and presumably the quieter the structure's interior. In addition to STC, another interior building measuring technique to evaluate sound impact or absorption between floors is the Impact Isolation Class (IIC). Both techniques will be fully discussed after a brief explanation of the following basic principals related to sound.

What Is Sound

Sound is indicated in two ways: frequency and intensity. Frequency, the high or low pitch of sound, is expressed as the number of vibrations or cycles per second. One vibration or cycle per second is a hertz (Hz). For example on a piano the middle C note has a frequency of 262 Hz and the total range of a piano has a frequency of 27 Hz to 4186 Hz, well within the 16 to 20,000 Hz range of the human ear. The sound created by the piano is heard by the human ear by air pressure created by vibration. The greater the pressure, the greater the loudness or intensity of the sound heard by the human ear. Loudness is expressed in decibels (dB). The decibel is one-tenth of a "Bel," a unit named for Alexander Graham Bell. Since the ear is more sensitive to sound in the middle range of frequencies, loudness (intensity) is determined at a frequency of 1,000 Hz. On the decibel scale, 0 dB indicates a level of sound at 1,000 Hz, a sound just barely audible to person with normal unimpaired hearing.

The A-weighted scale of a sound meter is designed to adjust the sensitivity of a sound meter to sounds of different frequencies that closely approximate how the human ear might respond to moderate sound levels in the 1,000 to 4,000 Hz range. The A-weighted sound level is used extensively for measuring community and transportation noises.

The Sound Transmission Class (STC), measured in decibels, is used to measure building material's ability to absorb sound. The STC can be used to measure sound absorption for both external building walls and internal walls in single and multifamily structures. The STC is measured by positioning a representative sample of the building material midway in an acoustical chamber, dividing the chamber in half or into two rooms. One section of the chamber contains the sound source and the other section the sound receiving equipment. The test procedure calls for a steady sound in the source room and measuring the sound level in both the source and receiving rooms. Differences in sound levels in the rooms determines the transmission loss characteristics of the material tested. For example, if a generated sound level of 80 dB is measured in the source room and 30 dB is measured in the adjacent receiving room, the tested material has a sound reduction intensity (STC) of 5OdB.

The Impact Isolation Class (IIC), measured in decibels, is the classification system used to determine sound *impact* from floor to ceiling in a structure. The IIC is not to be used to measure airborne sound penetration or absorption in walls. The IIC numerical rating efficiency increases with improved impact isolation performance of the floor and its component sub flooring and materials. The rating scale values are generally equivalent to the airborne sound transmission loss. The impact of steps or vibrations on a floor and the reverberation of that noise in the room below is dependent upon the type, density and thickness of the floor and ceiling material, its absorption material, and quality of construction. A separate section on common floor materials and construction patterns to illustrate both the STC and IIC ratings is included.

Sound Reduction In Structures

Four general techniques for controlling noise in single-family and multifamily structures are:

1. Elimination of the cause or source of the noise,
2. Employ materials which absorb sound rather than reflect noise,

3. Use sound barriers in building layout to prevent sound from being transmitted from one adjoining area into another, and
4. Use design considerations to mask or absorb the noise.

A description of each technique and its applicability follows.

1. ELIMINATION:
The elimination of a noise source may be impractical or impossible to achieve, whether emanating from within or outside the structure. Examples include the operation of mechanical equipment within the dwelling unit, excessive corridor noise, air conditioning/heating system, elevators, exhaust fans, and outdoor transportation sounds such as automotive traffic, aircraft overflights, and commercial or industrial activities. Some noise reduction could be achieved through sound reduction or absorption techniques, but total elimination of these sounds may be impossible.

2. ABSORPTION:
Sound absorption control is the reduction of sound emanating from a source within a room. The extent of control depends upon the efficiency of the room's surfaces in absorbing rather than reflecting sound waves. A surface, which could theoretically absorb 100% of the sound would have a sound absorption coefficient of 1.0. A surface absorbing 35% of the sound would have a coefficient of 0.35. The effectiveness of wall construction as a means of sound absorption is tested in a similar manner as that of STC. If a generated sound level of 80 dB is observed in one room and 30 dB is measured in an adjacent room, the reduction in sound absorption for the intervening wall is 50 dB. In choosing the type of construction material for interior walls to absorb sound transmission, porosity and density of the material should be considered. Resistance to sound transmission increases with unit weight and decreases with porosity. For example, unpainted, open textured concrete block exhibits improved resistance to sound passage after sealing the surface with plaster or paint. The sealing of the pores result in a reduction in the sound absorption of the block. In multifamily structures using concrete block partitions to separate public areas such as stairwells and corridors from adjacent living areas, sound transmission reduction is achieved through plastering or painting the surface of the residential unit or living area on the opposite side of the partition. The sound is absorbed by the concrete masonry's unpainted side and its transmission is prevented into the residential unit or living area by the plaster or paint on the other side.

However, all of the design elements that are employed to control sound can be nullified through poor or improper construction practices. Sound leakage will occur through any opening in a wall. An improperly fitted door or window is a prime source of sound leakage, as well as openings around ducts, pipes and electrical outlets which are improperly fitted or sealed.

3. SOUND BARRIERS:
Prudent building layout can be effective in controlling noise in single-family and multifamily housing. Sound waves can be prevented from being transmitted from one adjoining area to another. Closets, stairways and corridors can be used as buffers against airborne sound transmission between apartments or bedrooms. Concrete blocks or solid partitions can be employed to separate boiler rooms, air conditioning units, work areas or noisy public areas such as stairwells, corridors or lobbies from adjacent living areas. Partitions designed to absorb sound on one side and to retain sound absorption on the other can effectively block or reduce sound transmission into living areas intended for quiet use. The barrier should have a high sound absorption coefficient on one side and an equally high sound retention coefficient on the reverse side to effective. For example, unpainted porous concrete block would have a high sound absorption coefficient and a high noise retention coefficient on the reverse side if the porous surface in the living unit was effectively sealed by plaster or paint. Similarly, noise originators such as cloths washing machines, central heaters, and other noisy major appliances can be placed in a basement or utility rooms that are physically isolated from other living areas by walls or floors to absorb or block the emitted sounds.

4. DESIGN:
Design factors is the last major element to consider in controlling noise in single-family and multifamily structures. Design considerations offer the most infinite prospects for controlling noise due to the numerous types of building designs. For example, adjacent apartments can be arranged to have quiet areas (bedrooms or living rooms) abut and have noisy areas (kitchens and bathrooms) next to similar noisy areas. Apartment door openings into the same hallway can be staggered to reduce sound penetration into the unit directly across the hall. Since sound travels in a straight line, some of the sound from one doorway would be absorbed or diffused into the wall building material of the unit directly across the hall.

Windows should be placed as far away as possible from common walls. The closer the windows are to each other, the more sound will pass from one apartment to another. Medicine cabinets in opposite bathroom partitions should be offset. Cabinets placed back-to-back will transmit almost as much noise as an opening. Heating/cooling ducts are like speaking tubes, carrying noise from one room to another. Techniques should be employed to trap or splinter

sound or have turns in the ducts to reduce noise transference.

Noise producing equipment should be kept as far as possible from living areas and especially the bedrooms. Flexible connectors should be used to couple mechanical equipment to pipes and ducts. Pipes and ducts should not be firmly connected to parts of a building that could serve as sounding boards but be supported by resilient connections to solid supports. Where pipes and ducts pass through walls and floors, they should be isolated by gaskets. The acoustical integrity of a building or a building section with an otherwise adequate STC rating can be significantly reduced by a small hole or crack in the exterior wall or any other path that allows sound to bypass the exterior or interior walls and flow into other areas of the structure.

Weather and Sound

Air will attenuate noise at high frequencies usually from 1,000 Hz upwards. Sound absorption by air changes with wind speed, temperature and humidity. For example, wind blowing at slower speeds near the ground surface than at higher elevations will produce a bending of the sound upwards, resulting in less noise at ground level. Temperature gradients have a similar effect because the velocity of sound increases with the higher temperatures. If the temperature is higher near the ground than in the upper layers (usually the case during the day), the sound waves higher above the ground will travel slower and the sound will be bent upwards resulting in quieter conditions at ground level. The reverse is true at night, the temperature is lower near the ground, sound will bend towards the ground, increasing noise at the ground level. Wind and temperature- gradient effects can also account for the occasional freak reception of sounds over long distances, especially train whistles. The sound has been bent upwards by a temperature or wind gradient and after travelling some way at high level is bent down again by a reverse gradient.

Weather conditions can produce substantial variations of as much as +- 10 dB. For example, fog causes an increase in the absorption in the air. A moderately dense fog, visibility 150 feet, gives extra attenuation of 1 to 3 dB per 300 feet, depending on frequency. Similarly, snow forms an absorbent layer on the ground, which affects ground reflection, thereby reducing the sound level.

Weather can also be a significant source of noise in a structure. Common irritants are wind and rain. Wind whistling around a building, into ventilation grilles, screens or past other external architectural or artistic features can result in disturbing noise. Similarly, the impact of rain on lightweight roofing, gutters or skylights can produce high internal noise levels.

STC Ratings for Wall, Floor and Window Materials and Assemblies

Appendix A illustrates sound transmission class ratings for wall, floor, window and door assemblies. The data used in this section is compiled from laboratory reports and various technical and trade literature publications received by this Office. Each item has an assigned STC rating, an accompanying sketch and a brief description of its composition or assembly. In addition, where possible, an Impact Isolation Class (IIC) rating has been assigned to floors to determine sound impact from floor to ceiling. Appendix A is a guide designed to aid HUD Housing and Environmental personal in determining STC values for most common housing construction practices and materials used in residential construction. The STC information can be used to supplement acoustical measurements by providing approximate interior noise levels for existing or proposed dwellings located in high noise areas by deducting the STC value from the exterior noise level. The data could also be used to advise HUD clients in determining and achieving compliance with the noise criteria stated in 24 CFR Part 51 B through the use of common construction materials and techniques to achieve noise attenuation for new construction and rehabilitation.

The appendix is divided into the following subsections:

1. WALLS
    - Exterior
    - Interior
2. FLOORS
    - Wood
    - Concrete
3. WINDOWS
4. DOORS
    - Exterior
    - Interior

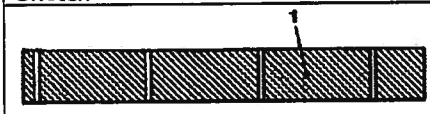
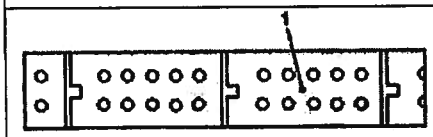
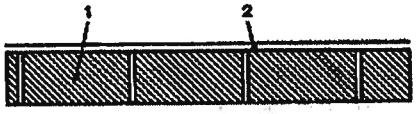
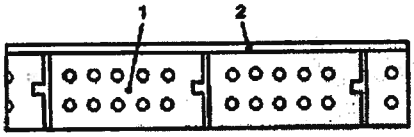
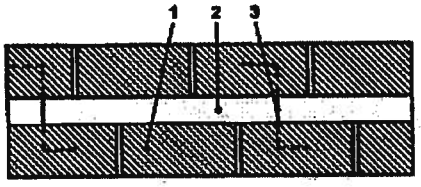
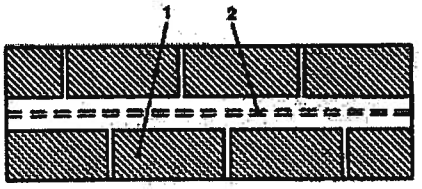
A bibliography of the reports, manufacturer's catalogs, technical papers, testing laboratories and other publications used in compiling this data is listed in the Appendix B.

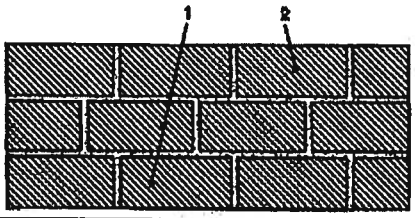
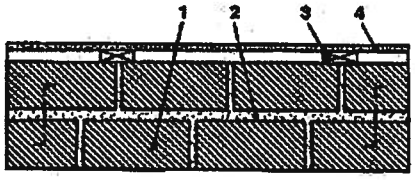
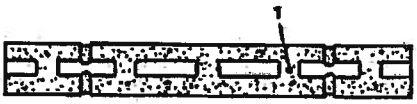
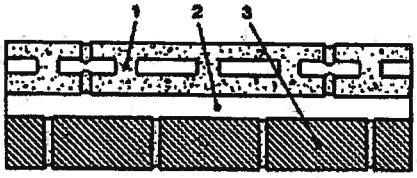
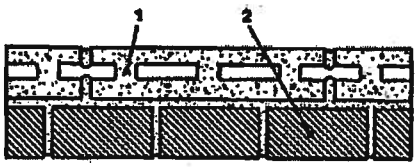
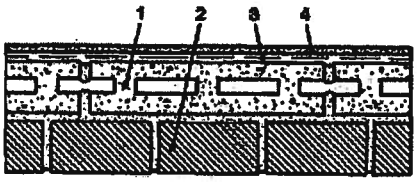
Appendix A STC Ratings

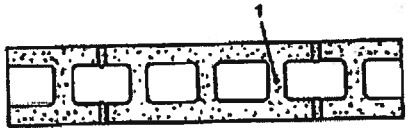
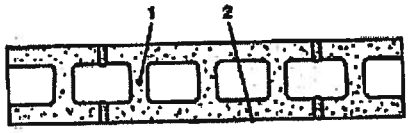
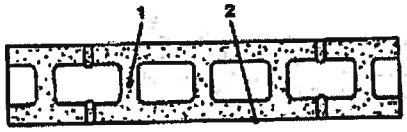
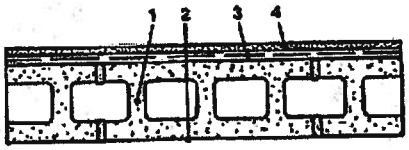
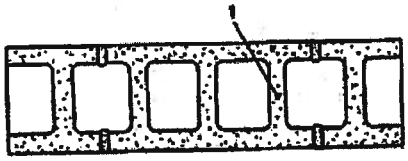
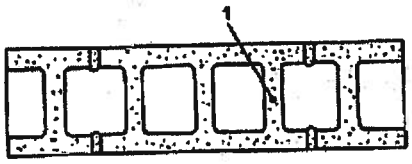
Appendix A

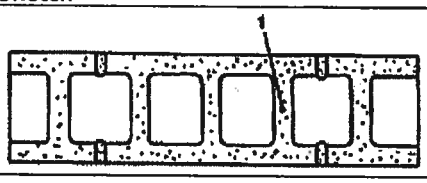
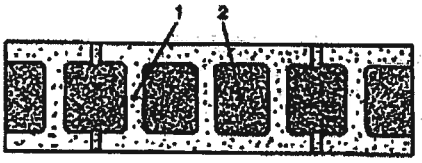
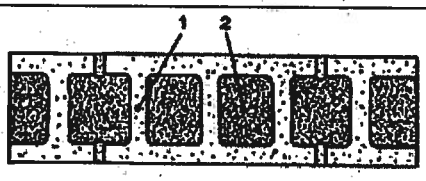
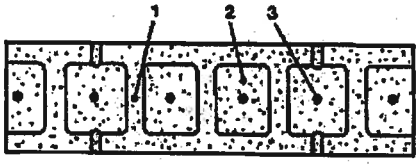
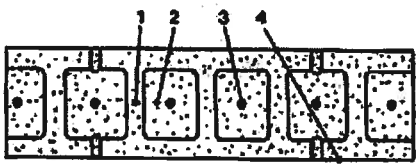
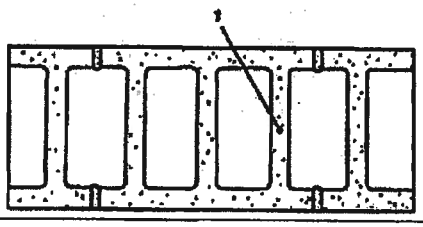
Walls: Exterior

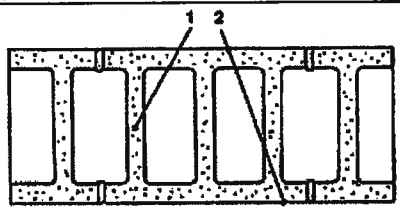
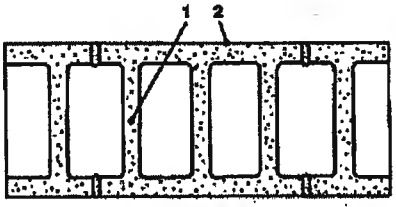
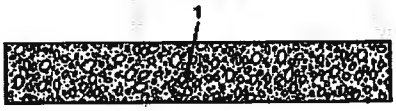
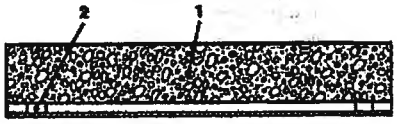
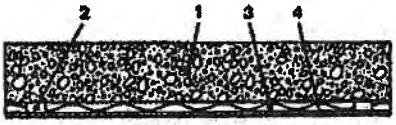
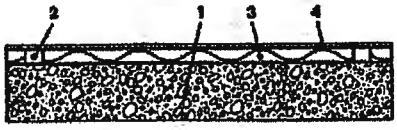
STC Ratings

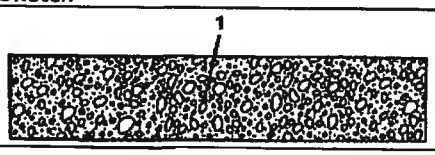
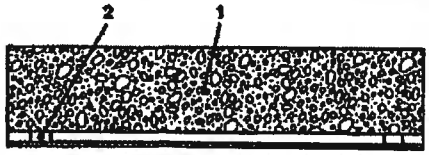
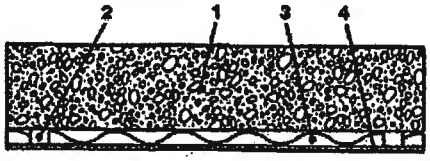
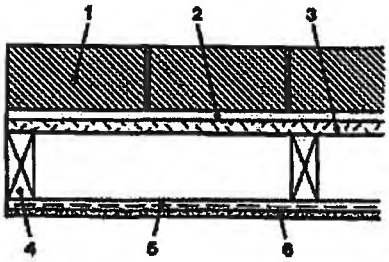
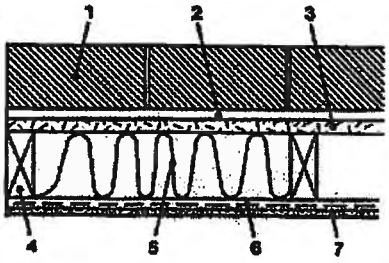
Sketch	Brief Description	STC
	1. 4" face brick, mortared together.	45
	1. Hollow core brick, mortared together.	51
	1. Common brick, mortared together. 2. ½" gypsum/sand plaster.	50
	1. Hollow core brick, mortared together. 2. ½" gypsum/sand plaster.	53
	1. Face brick, mortared together. 2. 2" air space. 3. Metal ties.	50
	1. Brick, mortared together. 2. 2 ¼" cavity filled with concrete grout and #6 bars vertically 48"o.c. and #5 bars horizontally 30"o.c.	59

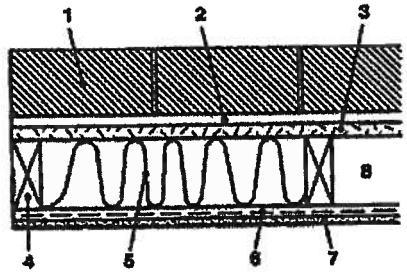
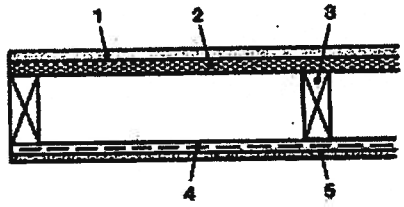
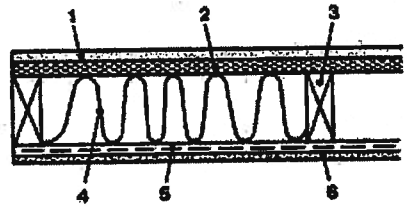
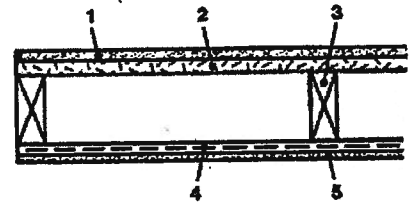
Sketch	Brief Description	STC
	1. Common brick, mortared together. 2. Face brick, mortared together.	59
	1. Common brick, mortared together. 2. ¾" mortar-filled cavity with metal Z ties 24"o.c. in both directions. 3. 1x3" furring strips 16"o.c. and nailed vertically into mortar joints 12"o.c. 4. ½" gypsum board nailed 8"o.c. along edges and 12"o.c. in field.	53
	1. 4x8x16" 3-cell lightweight concrete masonry units (17 lbs./block).	40
	1. 4x8x18" 3-cell lightweight concrete masonry units (19 lbs./block). 2. 2" air cavity. 3. Common brick, mortared together.	54
	1. 4x8x18" 3-cell lightweight concrete masonry units (19 lbs./block). 2. Common brick, mortared together. (brick headers after every second course of block to tie the withes together).	51
	1. 4x8x18" 3-cell lightweight concrete masonry units (19 lbs./block). 2. Common brick, mortared together. 3. Resilient channels. 4. ½" gypsum board screwed to channels.	56

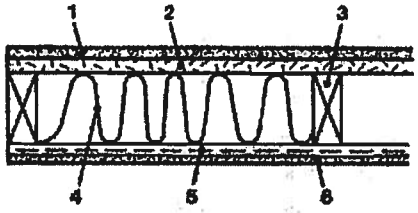
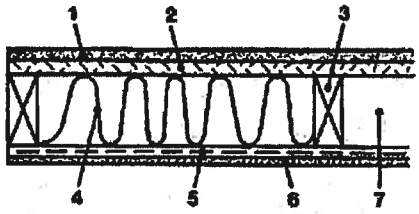
Sketch	Brief Description	STC
	1. 6x8x16" 3-cell lightweight concrete masonry units (21 lbs./block).	44
	1. 6x8x16" 3-cell lightweight concrete masonry units (21 lbs./block). 2. Paint both sides with primer-sealer coat and finish coat of latex.	46
	1. 6x8x18" 3-cell dense concrete masonry units (36 lbs./block). 2. Paint both sides with primer-sealer coat and finish coat of latex.	48
	1. 6x8x16" 3-cell lightweight concrete masonry units (21 lbs./block). 2. Paint, primer-sealer coat and finish coat of latex. 3. Resilient channels, 24"o.c. 4. ½" gypsum board screwed to channels.	53
	1. 8x8x16" 3-cell lightweight concrete masonry units (28 lbs./block).	45
	1. 8x8x18" 3-cell lightweight concrete masonry units (34 lbs./block).	49

Sketch	Brief Description	STC
	1. 8x8x18" 3-cell lightweight concrete masonry units (38 lbs./block).	49
	1. 8x8x18" 3-cell lightweight concrete masonry units (34 lbs./block). 2. Expanded mineral loose-fill insulation.	51
	1. 8x8x18" 3-cell lightweight concrete masonry units (38 lbs./block). 2. Expanded mineral loose-fill insulation.	51
	1. 8x8x18" 3-cell lightweight concrete masonry units (33 lbs./block). 2. Grout in cells. 3. #5 bar in each cell.	48
	1. 8x8x18" 3-cell lightweight concrete masonry units (33 lbs./block). 2. Grout in cells. 3. #5 bar each cell. 4. Paint two coats flat latex each side.	55
	1. 12x8x16" 3-cell lightweight concrete masonry units (43 lbs./block).	39

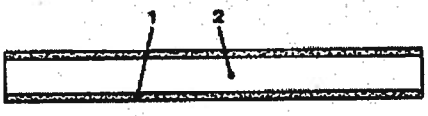
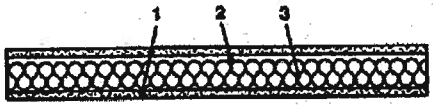
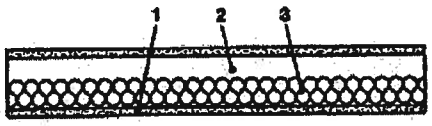
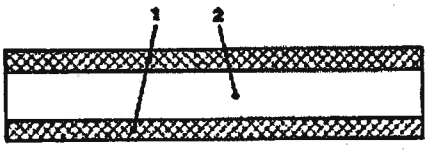
Sketch	Brief Description	STC
	1. 12x8x16. 3-cell lightweight concrete masonry units (43 lbs./block). 2. Paint both sides with 3 coats of latex block filler.	50
	1. 12x8x16" 3-cell lightweight concrete masonry units (43 lbs./block). 2. Paint one side only with 3 coats latex block filler.	51
	1. 6" cast concrete wall (71 psf).	57
	1. 6" cast concrete wall. 2. "Z" furring channels. 3. ½" gypsum board.	59
	1. 6" cast concrete wall. 2. "Z" furring channels. 3. 1", 8-pcf rockwool. 4. ½" gypsum board.	62
	1. 6" cast concrete wall. 2. 2x2" wood furring. 3. 1 ½" 4-pcf rockwool. 4. ½" gypsum board.	63

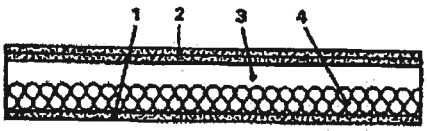
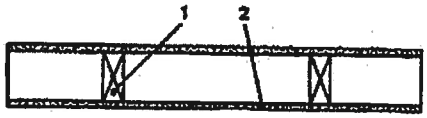
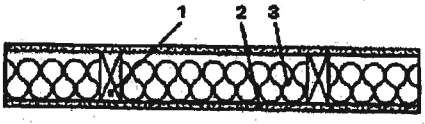
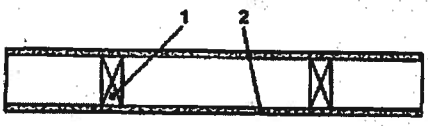
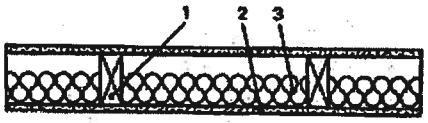
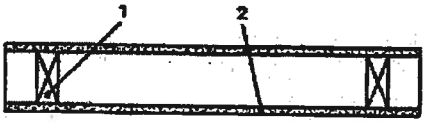
Sketch	Brief Description	STC
	1. 8" cast concrete wall (96.6 psf).	58
	1. 8" cast concrete wall. 2. 2x2" wood furring. 3. ½" gypsum board.	59
	1. 8" cast concrete wall. 2. 2x2" wood furring. 3. 1 ½", 4 psf rockwall. 4. ½" gypsum board.	63
	1. Face brick. 2. ½" air space, with metal ties. 3. ¾" insulation board sheathing. 4. 2x4" studs 16"o.c. 5. Resilient channel. 6. ½" gypsum board.	54
	1. Face brick. 2. ½" air space, with metal ties. 3. ¾" insulation board sheathing. 4. 2x4" studs 16"o.c. 5. Fiberglas building insulation (3 ½"). 6. Resilient channel. 7. ½" gypsum board.	56

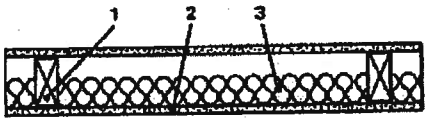
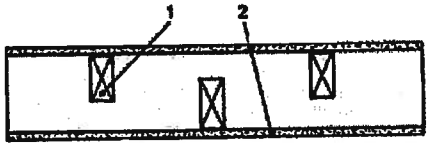
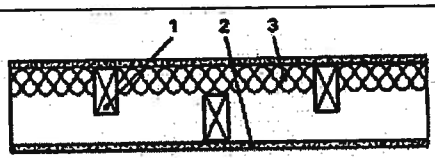
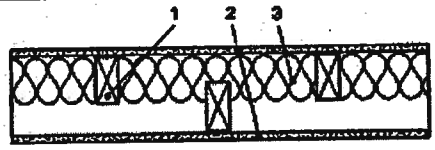
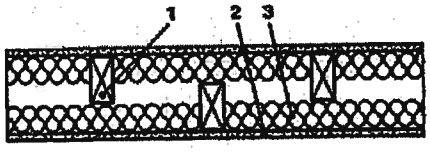
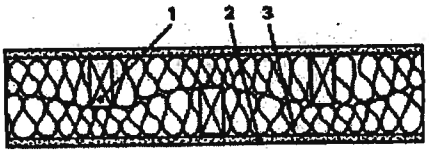
Sketch	Brief Description	STC
	1. Face brick (9x14' wall). 2. ½" air space, with metal ties. 3. ¾" insulation board sheathing. 4. 2x4" studs 16"o.c. 5. Fiberglas building insulation (3 ½"). 6. Resilient channel. 7. ½" gypsum board. 8. Wall penetrated by 6x5' picture window 1" glazed insulating glass.	39
	1. 7/8" stucco. 2. No.15 felt building paper and 1" wire mesh. 3. 2x4" studs 16"o.c. 4. Resilient channel. 5. ½" gypsum board screwed to channel.	49
	1. 7/8" stucco. 2. No.15 felt building paper and 1" wire mesh. 3. 2x4" studs 16"o.c. 4. Fiberglas building insulation (3 ½"). 5. Resilient channel. 6. ½" gypsum board screwed to channel.	57
	1. 5/8 x 10" redwood siding. 2. ½" insulation board sheathing. 3. 2x4" wood studs 16"o.c. 4. Resilient channel. 5. ½" gypsum board screwed to channel.	43

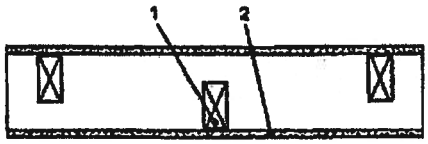
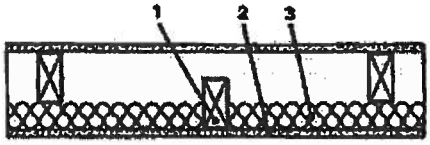
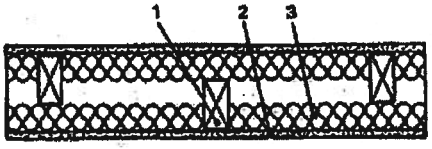
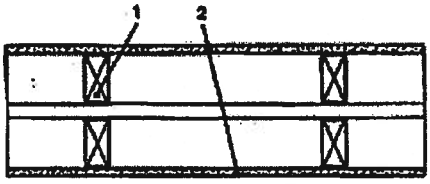
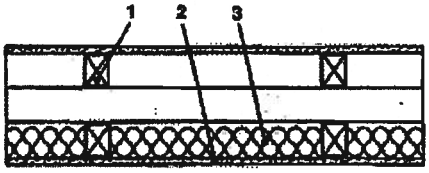
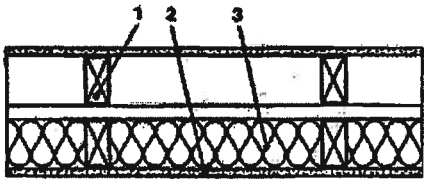
Sketch	Brief Description	STC
	1. 5/8x10" redwood siding. 2. ½" insulation board sheathing. 3. 2x4" wood studs 16"o.c. 4. Fiberglas building insulation (3 ½"). 5. Resilient channel. 6. ½" gypsum board screwed to channel.	47
	1. 5/8x10" redwood siding (9x14' wall). 2. ½" insulation board sheathing. 3. 2x4" wood studs 16.o.c. 4. Fiberglas building insulation (3 ½"). 5. Resilient channel. 6. ½" gypsum board screwed to channel. 7. a. Wall penetrated by a 6x5' picture window, 1" glazed insulating glass. b. Wall penetrated by a 6x5' 16 panel window, glazed single strength.	(a.38) (b.35)

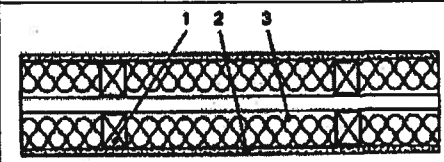
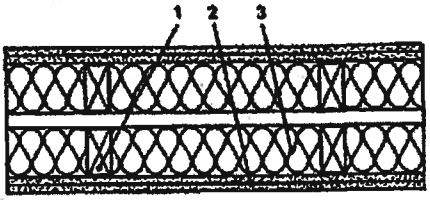
WALLS: Interior: Wooden Studs

Sketch	Brief Description	STC
	1. ½" gypsum board. 2. 3/16" plywood laminated with contact cement.	28
	1. ½" gypsum board. 2. ½" wood-fiber board laminated with gypsum joint compound.	30
	1. 2x4" studs, 16"o.c. 2. 5/8" gypsum board screwed to studs.	28
	1. ½" gypsum board, no studs. 2. 2 ½" air space.	30
	1. ½" gypsum board, no studs. 2. 2 ½" air space. 3. 2" thick sound attenuation blanket.	44
	1. ½" gypsum board, no studs. 2. 3 5/8" air space. 3. 2" thick sound attenuation blanket.	45
	1. 1 3/8" thick wood-fiber board nailed to 2x4" plates top and bottom and painted both sides. 2. 3 ½" air cavity.	44

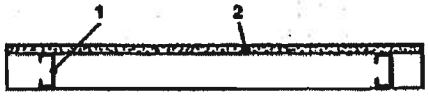
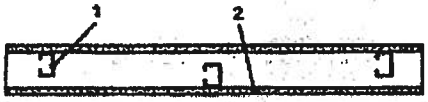
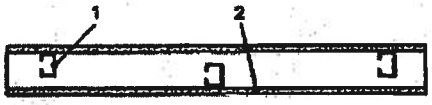
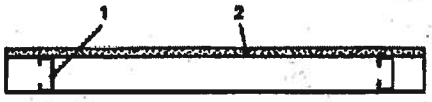
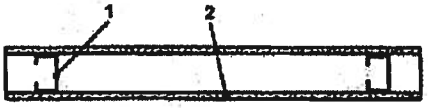
Sketch	Brief Description	STC
	1. ½" gypsum board, no studs. 2. ½" gypsum board laminated to base layer with gypsum joint compound. 3. 3 5/8" air cavity. 4. 2" thick sound attenuation blanket.	48
	1. 2x4" studs, 16"o.c. 2. 3/8" gypsum board nailed to studs.	35
	1. 2x4" studs, 16"o.c. 2. 3/8" gypsum board nailed to studs. 3. 3" thick sound attenuation blanket.	41
	1. 2x4" studs, 16"o.c. 2. ½" gypsum board screwed to studs.	34
	1. 2x4" studs, 16"o.c. 2. ½" gypsum board screwed to studs. 3. 2" thick sound attenuation blanket.	37
	1. 2x4" studs, 24"o.c. 2. ½" gypsum board screwed to studs.	36

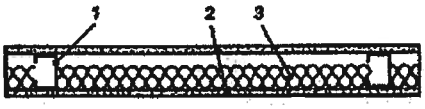
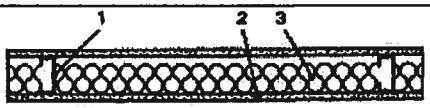
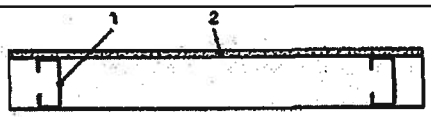
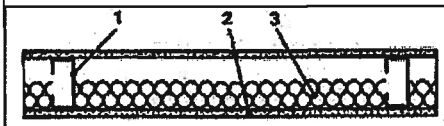
Sketch	Brief Description	STC
	1. 2x4"studs, 24"o.c. 2. ½" gypsum board screwed to studs. 3. 2" thick sound attenuation blanket.	40
	1. 2x4" studs spaced 16"o.c. and staggered 8"o.c. on 2x6" plates. 2. ½" gypsum board screwed 12"o.c.	39
	1. 2x4" studs spaced 16"o.c. and staggered 8"o.c. on 2x6" plates. 2. ½" gypsum board screwed 12"o.c. 3. 2 ¼" thick sound attenuation blanket.	48
	1. 2x4" studs spaced 16"o.c. and staggered 8"o.c. on 2x6" plates. 2. ½" gypsum board screwed 12"o.c. 3. 3 ½" thick sound attenuation blanket.	49
	1. 2x4" studs spaced 16"o.c. and staggered 8"o.c. on 2x6" plates. 2. ½" gypsum board screwed 12"o.c. 3. 2 ¼" thick sound attenuation blankets in both stud cavities.	49
	1. 2x4" studs spaced 16"o.c. and staggered 8"o.c. on 2x6" plates. 2. ½" gypsum board screwed 12"o.c. 3. 3 ½" thick sound attenuation blankets in both stud cavities.	51

Sketch	Brief Description	STC
	1. 2x4" studs spaced 24"o.c. and staggered 12"o.c. on 2x6" plates. 2. ½" type X gypsum board screwed 12"o.c.	42
	1. 2x4" studs spaced 24"o.c. and staggered 12"o.c. on 2x6" plates. 2. ½" gypsum board screwed to studs. 3. 2" thick sound attenuation blanket.	46
	1. 2x4" studs spaced 24"o.c. and staggered 12"o.c. on 2x6" plates. 2. ½" type X gypsum board screwed 12"o.c. 3. 2" thick sound attenuation blankets in both stud cavities.	48
	1. Double row of 2x4" studs 16"o.c. on separate plates spaced 1" apart. 2. ½" type X gypsum board screwed 12"o.c.	47
	1. Double row of 2x3" studs 16"o.c. on 2x3" plates spaced 2 ½" apart. 2. ½" gypsum board screwed 16"o.c. 3. 2 ¼" thick sound attenuation blanket.	55
	1. Double row of 2x4" studs 16"o.c. on separate plates spaced 1" apart. 2. ½" type X gypsum board screwed 12"o.c. 3. 3 ½" thick sound attenuation blanket.	56

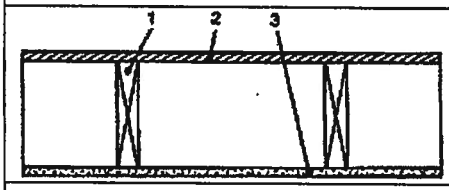
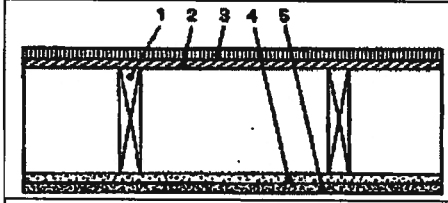
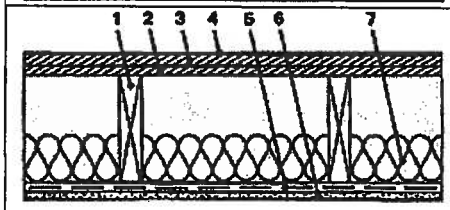
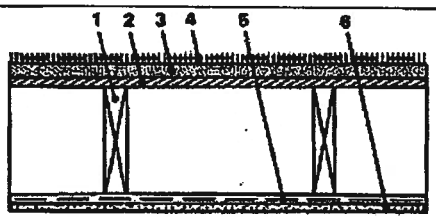
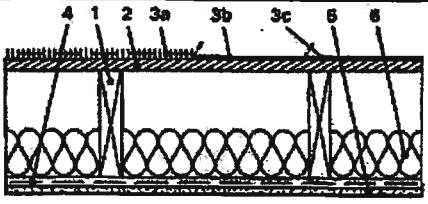
Sketch	Brief Description	STC
	1. Double row of 2x4" studs 16"o.c. on separate plates spaced 1" apart. 2. ½" gypsum board screwed 12"o.c. 3. 2 ¼" thick sound attenuation blankets in both stud cavities.	56
	1. Double row of 2x4" studs 16.o.c. on separate plates spaced 1" apart. 2. Double row of 5/8" type X gypsum board screwed 16.o.c. 3. 3 ½" thick sound attenuation blankets in both stud cavities.	63

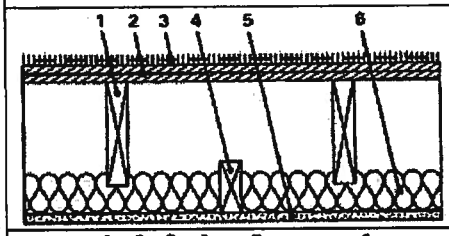
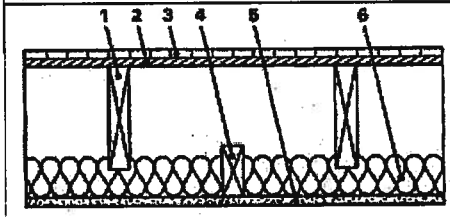
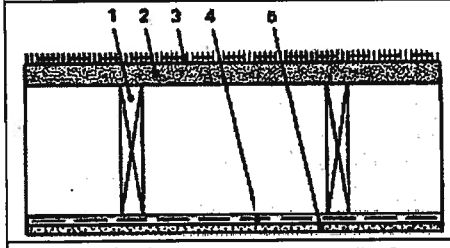
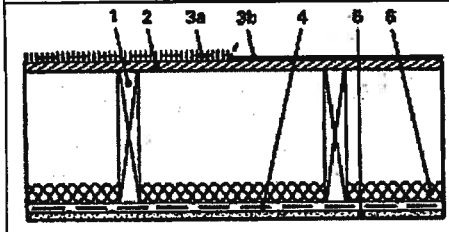
WALLS: Interior: Metal Studs

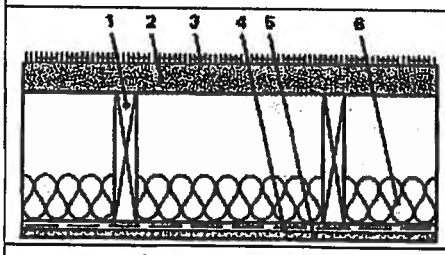
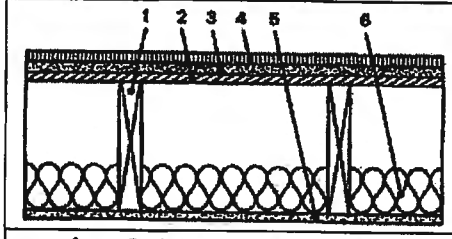
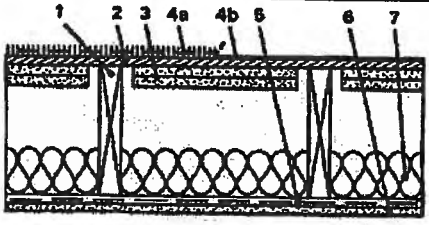
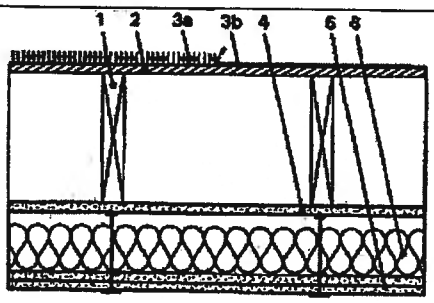
Sketch	Brief Description	STC
	1. 1 5/8" metal studs, 24"o.c. 2. 1/2. vinyl-faced gypsum board screwed to studs.	27
	1. 1 5/8" metal studs spaced 24"o.c. and staggered 12"o.c. on 2 ½" metal tracks. 2. 1/2" gypsum board screwed to studs.	34
	1. 1 5/8" metal studs, 24"o.c. 2. 5/8" gypsum board screwed 12"o.c. at edges and 24"o.c. in field.	37
	1. 1 5/8" metal studs spaced 24"o.c. and staggered 12"o.c. on 21/2" metal channels. 2. 5/8" gypsum board screwed to studs.	38
	1. 2 ½" metal studs, 24"o.c. 2. 1/2" vinyl-faced gypsum board screwed to studs.	27
	1. 2 1/2" metal studs, 24"o.c. 2. 5/8" gypsum board screwed to studs.	37

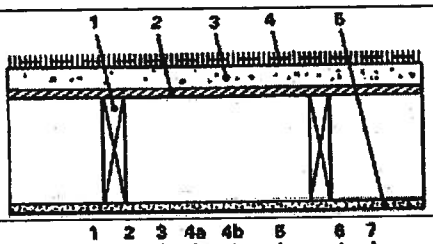
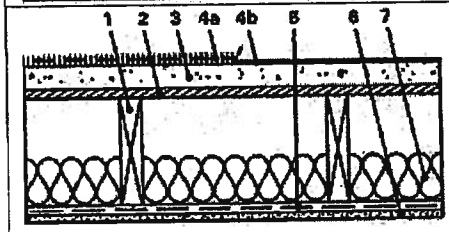
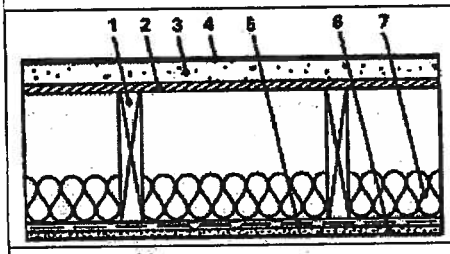
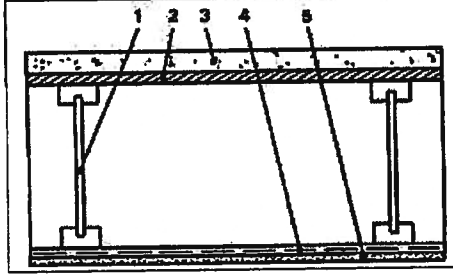
Sketch	Brief Description	STC
	1. 2 ½" metal studs, 24"o.c. 2. 5/8" gypsum board screwed 12"o.c. at edges and 24"o.c. in field. 3. 1 ½" thick sound attenuation blanket.	42
	1. 2 ½" metal studs, 24"o.c. 2. ½" gypsum board screwed to studs. 3. 2" thick sound attenuation blanket.	44
	1. 3 5/8" metal studs, 24"o.c. 2. 1/2. gypsum board screwed to studs.	27
	1. 3 5/8" metal studs, 24"o.c. 2. ½" gypsum board screwed to studs.	36
	1. 3 5/8" metal studs, 24"o.c. 2. ½" gypsum board screwed to studs. 3. 2" thick sound attenuation blanket.	44

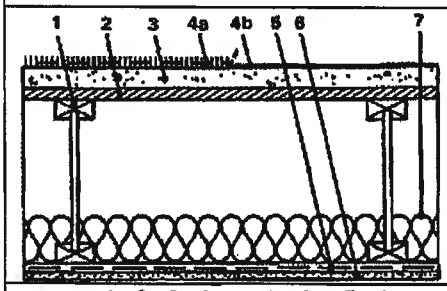
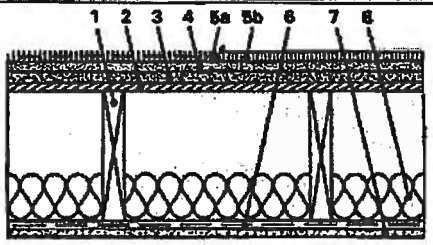
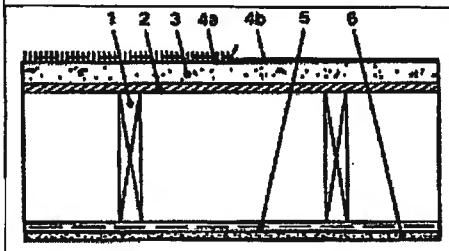
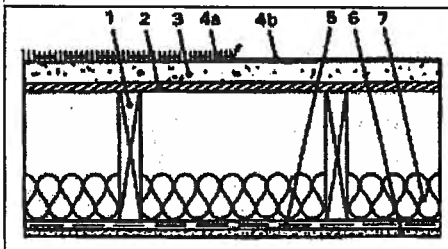
Floors: Wood

Sketch	Brief Description	STC (IIC)
	1. 2x8" wooden joists, 16"o.c. 2. 7/8" tongue and groove nailed to joints. 3. 3/8" gypsum nailed to joints.	NA (32)
	1. 2x8" wooden joists, 16"o.c. 2. ½" plywood nailed. 3. 25/32" hardwood flooring. 4. 1/2" gypsum nailed to joists. 5. Ceiling tire.	NA (37)
	1. 2x8" wooden joists, 16"o.c. 2. 5/8" tongue and groove plywood nailed with 8d nails 6"o.c. 3. 3/8" plywood stapled 3"o.c. at edges and 6"o.c. in field. 4. .075" sheet vinyl. 5. Resilient channels, 24"o.c. 6. 5/8" gypsum board screwed 12"o.c. 7. 3" thick sound attenuation blanket.	46 (44)
	1. 2x8" wooden joists, 16"o.c. 2. 5/8" plywood nailed with 8d nails. 3. ½" nominal wood-fiber board glued to plywood. 4. 44 oz. carpet on 50 oz. pad. 5. Resilient channels, 24"o.c. 6. 5/8" gypsum board screwed 12"o.c.	48 (65)
	1. 2x8" wooden joists, 16"o.c. 2. 19/32" tongue and groove plywood nailed with 8d nails 6"o.c. at edges and 10"o.c. in field. 3. a. 44 oz. carpet on 40 oz. hair pad. b. .075" sheet vinyl. c. 1/16" sheet vinyl. 4. Resilient channels, 24"o.c. 5. 5/8" gypsum board screwed 12"o.c. 6. 3" thick sound attenuation blanket.	48 (a. 69) (b. 45) (c.43)

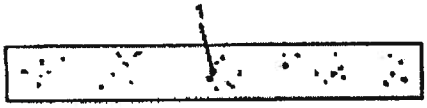
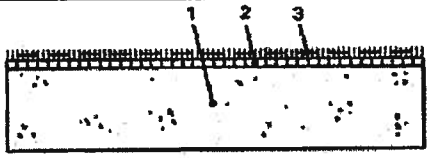
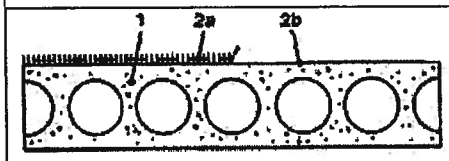
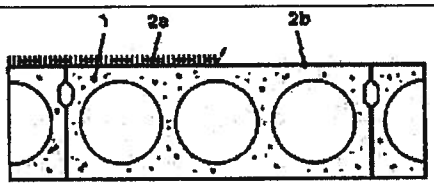
Sketch	Brief Description	STC (IIC)
	1. 2x8" wooden joists, 16"o.c. 2. 1 1/8" tongue and groove plywood nailed 6"o.c. at edges and 16"o.c. in field. 3. 44 oz. wool carpet on 40 oz. hair pad. 4. 2x4" ceiling joists, 16"o.c. and staggered between floor joists. 5. 5/8" gypsum board nailed to 2x4" joists. 6. 3" thick sound attenuation blanket.	53 (80)
	1. 2x8" wooden joists, 16"o.c. 2. 1/2" plywood nailed with 8d nails 6"o.c. at edges and 16"o.c. in field. 3. 25/32" wood strip flooring nailed to sub floor. 4. 2x4" wooden ceiling joists, 16"o.c. and staggered between floor joists. 5. 5/8" gypsum board nailed to 2x4" joists. 6. 3" thick sound attenuation blanket.	54 (45)
	1. 2x10" wooden joists, 16"o.c. 2. 1 11/32" tongue and groove wood-fiber board. 3. 44 oz. wool carpet on 40 oz. hair pad. 4. Resilient channels, 24"o.c. 5. 5/8" gypsum screwed 12"o.c.	49 (68)
	1. 2x10" wooden joists, 16"o.c. 2. 19/32" tongue and groove plywood. 3. a. Carpet and pad. b. Vinyl tile. 4. Resilient channels, 24"o.c. 5. 5/8" gypsum screwed 12"o.c. 6. 1" thick sound attenuation blanket.	51 (a. 74) (b.51)

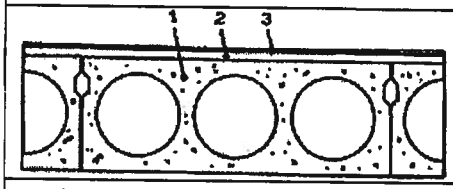
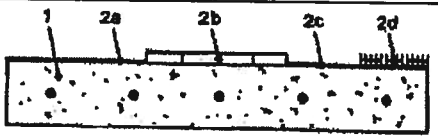
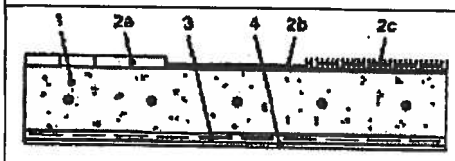
Sketch	Brief Description	STC (IIC)
	1. 2x10" wooden joists, 16"o.c. 2. 1 11/32" tongue and groove wood-fiber board. 3. 40 oz. wool carpet on 80 oz. sponge rubber pad. 4. Resilient channels, 24"o.c. 5. 1/2" gypsum board screwed 12"o.c. 6. 3" thick sound attenuation blanket.	50 (72)
	1. 2x10" wooden joists, 16"o.c. 2. 5/8" plywood sub floor glued to joists, nailed with 8d nails 12"o.c. 3. ¼" particleboard glued to plywood. 4. ½" parquet wood flooring glued to particleboard. 5. ½" type-X gypsum board screwed 12"o.c. 6. 3" thick sound attenuation blanket.	43 (NA)
	1. 2x10" wooden joists, 16"o.c. 2. 5/8" tongue and groove plywood nailed with 8d nails 6"o.c. along edges and 10"o.c. in field. 3. Two layers of 5/8" gypsum board attached with screws 12"o.c. to underside of sub floor. 4. a. 44 oz. carpet on 40 oz. hair pad. b. 1/16" vinyl asbestos tile. 5. Resilient channels, 24"o.c. 6. 5/8" gypsum board screwed 12"o.c. 7. 3 ½" thick sound attenuation blanket.	56 (a. 74) (b.50)
	1. 2x10" wooden joists, 16"o.c. 2. 5/8" tongue and groove plywood nailed with 8d nails 6"o.c. along edges and 10"o.c. in field. 3. a. 44 oz. carpet on 40 oz. hair pad. b. 1/16" vinyl asbestos tile. 4. 5/8" gypsum board nailed 7"o.c. 5. Two layers of 5/8" gypsum board suspended by wire hangers 5" long in a 2x4' heavy-duty T grid ceiling system. 6. 3 ½" thick sound attenuation blanket.	49 (a. 68) (b.47)

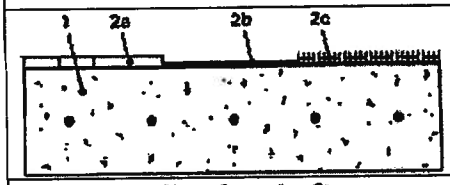
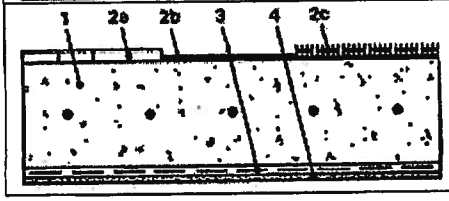
Sketch	Brief Description	STC (IIC)
	1. 2x8" wooden joists, 16"o.c. 2. 5/8" tongue and groove plywood nailed to joists with 8d nails 6"o.c. at edges and 10"o.c. in field. 3. 1 5/8" lightweight concrete over 4 mil. polyethylene film. 4. 44 oz. carpet on 40 oz. hair pad. 5. 5/8" gypsum board nailed to joists.	47 (66)
	1. 2x8" wooden joists, 16"o.c. 2. 5/8" tongue and groove plywood nailed to joists with 8d nails 6"o.c. at edges and 10"o.c. in field. 3. 1 5/8" thick lightweight concrete over 4 mil. polyethylene film. 4. a. 44 oz. carpet on 40 oz. hair pad. b. .075" sheet vinyl. 5. Resilient channels, 24"o.c. 6. 5/8" gypsum board screwed 12"o.c. 7. 3" thick sound attenuation blanket.	53 (a. 74) (b. 47)
	1. 2x10" wooden joists. 16"o.c. 2. 5/8" plywood nailed to joists. 3. 3. 1 ½" thick lightweight concrete, 13 psf. 4. Cushioned vinyl. 5. Resilient channels, 24"o.c. 6. 5/8" gypsum board screwed to channels. 7. 3 ½" thick sound attenuation blanket.	NA (51)
	1. Plywood web I-beams 12" deep and 24"o.c. 2. 3/4" plywood sub floor nailed with 6d nails 6"o.c. at edges and 10"o.c. in field. 3. 1 ½" thick lightweight concrete, 15 psf. 4. Resilient channels, 24"o.c. 5. 5/8" gypsum board screwed 12"o.c.	57 (NA)

Sketch	Brief Description	STC (IIC)
	1. Plywood web I-beams 12" deep and 24"o.c. 2. 3/4" plywood sub floor nailed with 6d nails 6"o.c. at edges and 10"o.c. in field. 3. 1 1/2" thick lightweight concrete, 15 psf. 4. a. 44 oz. carpet on 40 oz. hair pad. b. .07" vinyl tile. 5. Resilient channels, 24.o.c. 6. 5/8" gypsum board screwed 12"o.c. 7. 3" thick sound attenuation blanket.	58 (a. 77) (b. 50)
	1. 2x10" wooden joists, 16"o.c. 2. 5/8" plywood glued to joists, nailed with 8d nails 12"o.c. 3. ¼" particleboard glued to plywood. 4. ½" fiberboard glued to particleboard. 5. a. 76 oz. carpet on 50 oz. hair pad. b. 1/2" parquet wood flooring. 6. Resilient channels, 24"o.c. 7. ½" type-X gypsum board screwed 12"o.c. 8. 3" thick sound attenuation blanket.	51 (NA)
	1. 2x10" wooden joists, 16"o.c. 2. 5/8" plywood sub floor nailed with 8d nails 6"o.c. along edges, 10"o.c. in field. 3. 1 1/2" thick lightweight concrete over 15 lb. asphalt felt. 4. a. 20 oz. carpet on 40 oz. hair pad. b. 1/16" thick vinyl-asbestos tile. 5. Resilient channels, 24"o.c. 6. ½" type-X gypsum board screwed 12"o.c.	56 (NA)
	1. 2x10" wooden joists, 16"o.c. 2. 5/8" plywood sub floor nailed with 8d nails 6"o.c. along edges, 10"o.c. in field. 3. 1 ½" thick lightweight concrete over 15 lb. asphalt felt. 4. a. 20 oz. carpet on 40 oz. hair pad. b. 1/16" thick vinyl-asbestos tile. 5. Resilient channels, 24"o.c. 6. 5/8" type-X gypsum board screwed 12"o.c. 7. 3 ½" thick sound attenuation blanket.	61 (NA)

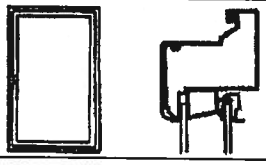
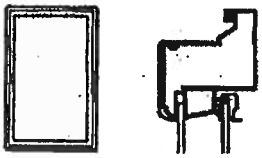
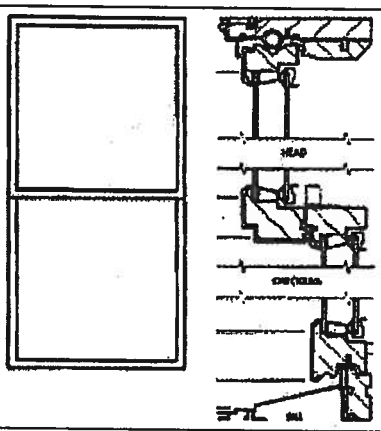
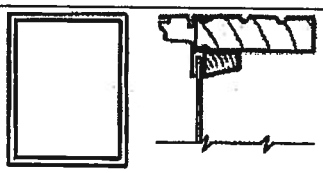
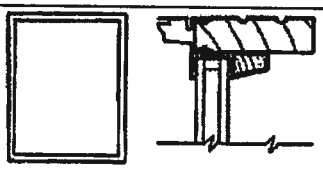
FLOORS: Concrete

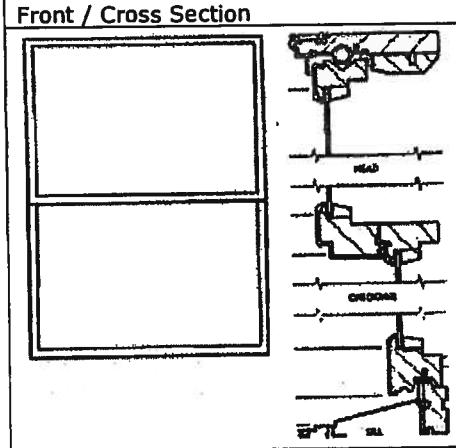
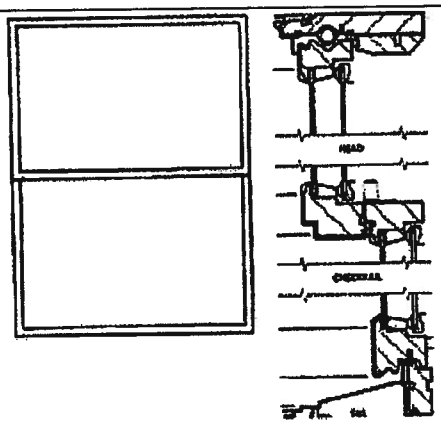
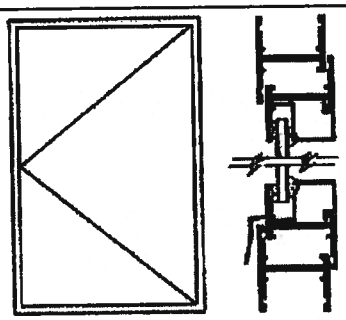
Sketch	Brief Description	STC (IIC)
	1. 4" thick concrete slab, 54 psf.	44 (25)
	1. 6" thick concrete slab, 75 psf.	55 (34)
	1. 6" thick concrete slab. 2. ½" wood-fiber board glued to concrete. 3. 44 oz. carpet on 40 oz. hair pad.	NA (81)
	1. 6" thick hollow-core concrete panel, 45 psf. 2. a. Carpet and pad. b. No floor covering.	48 (a. 69) (b. 23)
	1. 8" thick hollow-core concrete panel, 57 psf. 2. a. 66 oz. carpet on 50 oz. hair pad. b. No floor covering.	50 (a. 74) (b. 28)

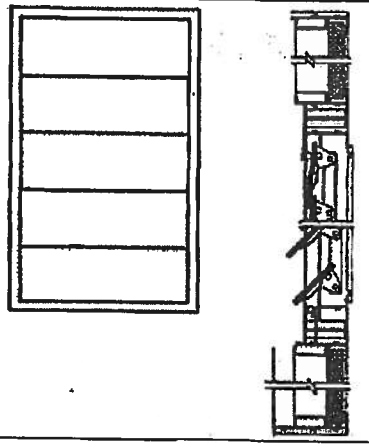
Sketch	Brief Description	STC (IIC)
	1. 8" thick hollow-core concrete panels, 57 psf. 2. 1/4" inorganic felt-supported underlayment board, .6 psf. 3. 3/32" vinyl-asbestos tile.	50 (51)
	1. 3" thick reinforced concrete slab, 35 psf, ceiling bare. 2. a. Vinyl asbestos, 0.08" thick. b. Wood parquet 1/2" thick. c. Soft vinyl tile with foam plastic backing. d. Carpet over soft padding, at least ¼" thick.	45 (a. 42) (b.45) (c. 49) (d. 70)
	1. 3" thick reinforced concrete slab, 35 psf. 2. a. Wood parquet ½" thick. b. Soft vinyl tile with foam plastic backing. c. Carpet over soft padding, at least ¼" thick. 3. Resilient furring channels on ½" fiberglass blanket. 4. ½" gypsum board.	56 (a.51) (b. 55) (c. 70)

Sketch	Brief Description	STC (IIC)
	1. 5" thick reinforced concrete slab, 55 psf. ceiling bare. 2. a. Wood parquet ½" thick. b. Soft vinyl tile with foam plastic backing. c. Carpet over soft padding, at least ¼" thick.	51 (a. 46) (b. 50) (c. 70)
	1. 5" thick reinforced concrete slab, 55 psf. 2. a. Wood parquet ½" thick. b. Soft vinyl tile with foam plastic backing c. Carpet over soft padding, at least ¼" thick. 3. Resilient furring channels on ½" fiberglass blankets. 4. ½" gypsum board.	56 (a. 51) (b. 55) (c. 75)

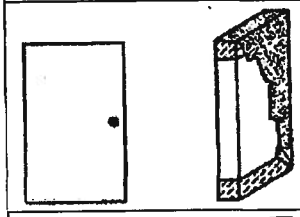
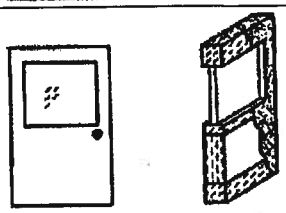
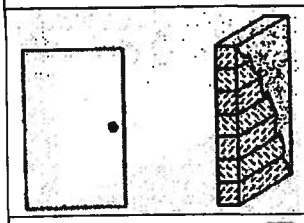
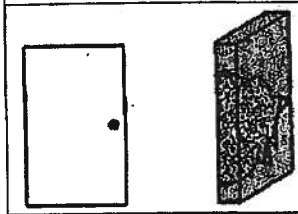
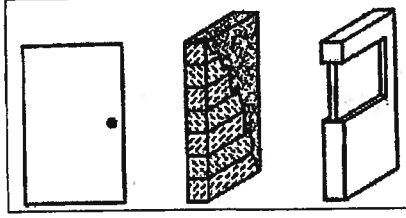
WINDOWS

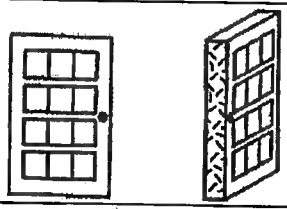
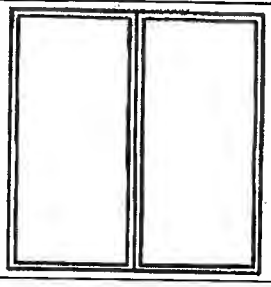
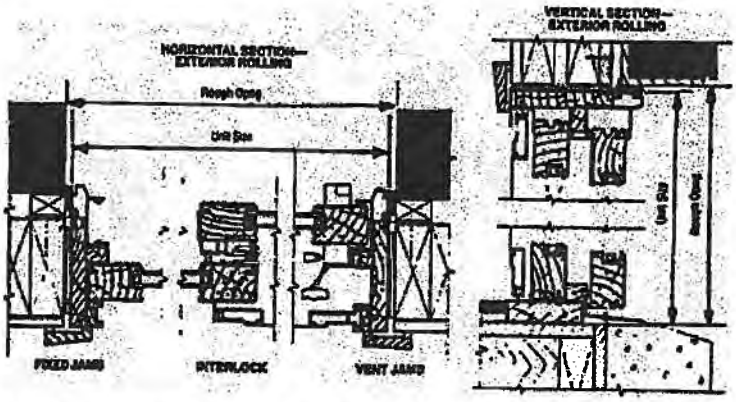
Sketch Front / Cross Section	Brief Description	STC
	30x48" aluminum clad casement, two 1/8" panels of glass, 13/16" apart in a wood frame.	29
	30x48" aluminum clad casement, one 3/32" panel and one 1/8" panel, 13/16" apart in a wood frame.	31
	32x24x24" aluminum double-hung windows (32" wide with 24" high upper sash and a 24" high lower sash), each sash has one 3/32" panel and one 1/8" panel, 13/16" apart in a wood frame.	29
	6x5' picture window glazed double strength, single panel.	29
	6x5' picture window plus storm sash, glazed double strength single panel, 3 ¾" separation between panels.	38

Sketch Front / Cross Section	Brief Description	STC
	3x5' double hung window, 7/16" glazed insulating glass, single panel.	26
	3x5' double hung window, 7/16" glazed insulating glass, single panel plus storm sash, glazed single strength, single sealed separation between panels: upper 1 ½", lower 2 13/16".	35
	3x4' awning window, glazed double strength, cranked shut.	24

Sketch Front / Cross Section	Brief Description	STC
	3x4' jalousie window, glazed ¼" glass, 4 ½" wide louvers with ½" in overlap, cranked tight shut.	20

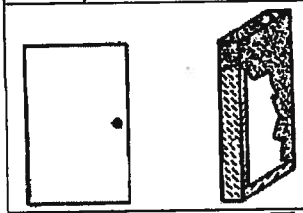
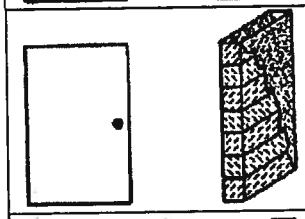
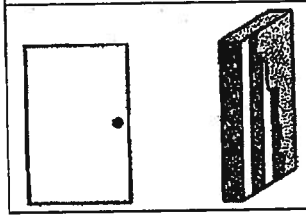
DOORS: Exterior

Sketch Front / Cross Section	Brief Description	STC
	3x7' hollow-core wood door, 1 ¾" thick.	20
	3x7' hollow-core door, 1 3/4" thick, 30% of area glazed with 1/8" glass.	19
	3x7' solid-core wood door, 1 ¾" thick.	27
	3x7' steel-faced door, 1 ¾" thick, rigid polyurethane core.	26
	3x7' solid-core wood door, 1 ¾" thick plus an aluminum storm door, glazed single strength.	34

Sketch Front / Cross Section	Brief Description	STC
	3x7' wood French door, 12 lights glazed single strength, mounted in frame, brass weather strip.	26
	6x6' sliding glass doors, ¾" insulating glass (2 pieces 1/8" tempered glass), one door opens, other is permanent in place.	28
		

*All exterior doors are sealed with a weathering strip around the frame. Interior doors do not have a weather strip and are not flush to the floor to permit the installation of a carpet.

DOORS: Interior

Sketch Front / Cross Section	Brief Description	STC
	3x7' solid-core wood door, 1 ¾" thick, weight 1.5 lb/ft².	17
	3x7' solid-core wood door, 1 ¾" thick, weight 4.0 lb/ft².	20
	3x7' hollow-core steel door, 1 ¾" thick, weight 5.0 lb/ft².	17

Appendix B References

Appendix B
General References

Books:
Acoustical and Thermal Performance of Exterior Residential Walls. Doors and Windows; NBS Building Science Series 77, U.S. Department of Commerce/National Bureau of Standards, 1975.

Acoustics Noise and Buildings; Parkin, Humphreys and Cowell; Faber and Faber; London; 1979.

Airborne Sound Transmission Loss, Characteristics of Wood Frame Construction; Fred F. Rudder, Jr.; USDA, Forest Service; General Technical Report FPL-43.

Handbook of Architectural Acoustics and Noise Control; Michael Retting; Tab Book; Blue Ridge Summit, Pa.; 1979.

Quieting: A Practical Guide to Noise Controls; U.S. Department of Commerce/National Bureau of Standards; NBS Handbook 119; 1976.

Institutions and Organizations:

Amerada Architectural Glass.
DeSco Windows.
Georgia-Pacific.
Industrial Acoustics Company.
National Concrete Masonry Association.
Office of Noise Control; California Department of Health Services.
Overly Manufacturing Company.
Paella Products.
Portland Cement Association.
U.S. Gypsum Company.

Testing Laboratories:

Cedar Knolls Acoustical Laboratories.
Geiger and Hamme.
Kaiser Gypsum.
Kodaras Acoustical.
National Institute of Standards and Technology.
National Research Council of Canada.
Riberbank Acoustical Laboratories.

P11-0050/P12-0220, Exhibit 16
Public Comments

ERRATA SHEET

The Noise Guidebook
Railway Noise Guidance and Calculation Corrections

February 2009

The following should replace the paragraph entitled "Horns and Whistles" on page 63 (also marked 15) in the Noise Assessment Guidelines, Chapter 5, of *The Noise Guidebook* (September 1991).

> If the Noise Assessment Location (NAL) is perpendicular to any point on along a railroad track between the whistle posts for a road crossing, a factor to account for the noise of warning horns or whistles must be included in the calculation. There are 2 factors to be used based on the type of locomotive. If the locomotive is diesel-powered, enter the number 10 in column 11 of Worksheet D. If the locomotive is electric-powered, enter the number 100 in column 18 of Worksheet D. If the NAL is not between the whistle posts for a road crossing, enter the number 1 in each column.
>
> *Note: Whichever horn factor is appropriate, it must only be applied once. If a factor is applied for diesel locomotives in the first section of the worksheet, it must not be applied to the railcar noise calculation in the second part. In that instance, enter the number 10 in column 11 and the number 1 in column 18.*

A revised Worksheet D also accompanies this correction. It is easily distinguished from the original. The new Worksheet D has an additional column in the second section of page 2 for a total of 27 columns. The original version, with 26 columns, is hereby void.

Railway Noise Data Sheet

Noise Assessment Guidelines

List All Railways within 3000 feet of the site:

1. _____

2. _____

3. _____

Necessary Information	Railway No. 1	Railway No. 2	Railway No. 3	Notes
1. Effective distance:				Measured in feet from NAL to center of track
2. Number of Trains in 24 hours:				
a. diesel				
b. electrified				
3. Fraction of operations occuring at night:				10 p.m. - 7a.m.
4. Number of diesel locomotives per train:				
5. Number of rail cars per train:				
a. diesel trains				
b. electrified trains				Include locomotive for electrified trains
6. Average train speed:				
7. Is track welded or bolted?				
8. Is the site opposite a section of tracks between whistle stops?				

Adjustments for Diesel Locomotives

	9 No. of Locomotives 2	10 Average Speed (Table 9)	11 Horns (Enter 10)	12 Night-time (Table 5)	13 No. of Trains (Line 2a)	14 Adj. No of Opns.	15 DNL (Workchart 3)	16 Barrier Attn.	17 Partial DNL
Railway No. 1	____ x	____ x	____ x	____ x	____ =	____	____ -	____ =	____
Railway No. 2	____ x	____ x	____ x	____ x	____ =	____	____ -	____ =	____
Railway No. 3	____ x	____ x	____ x	____ x	____ =	____	____ -	____ =	____

Adjustments for Railway Cars or Rapid Transit Trains and Electric Locomotives

	18 Horns on Electric Trains only (Enter 100)	19 Number of cars 50	20 Average Speed (Table 10)	21 Bolted Rails (Enter 4) Welded (Enter 1)	22 Night-time (Table 5)	23 No. of Trains (Lines 2a and 2b)	24 Adj. No. of Opns.	25 DNL (Workchart 4)	26 Barrier Attn.	27 Partial DNL
Railway No. 1	____ x	____ x	____ x	____ x	____ x	____ x	____ =	____	____ -	____ =	____
Railway No. 2	____ x	____ x	____ x	____ x	____ x	____ x	____ =	____	____ -	____ =	____
Railway No. 3	____ x	____ x	____ x	____ x	____ x	____ x	____ =	____	____ -	____ =	____

Combined Locomotive and Railway Car DNL (See combining noise levels table for procedures)

Partial DNL Railway No. 1	Partial DNL Railway No. 2	Partial DNL Railway No. 3	Partial DNL Total DNL for all Railways
____	____	____	____

Signed _____ Date _____

Noise and Its Effects

By Dr. Alice H. Suter, Conference Consultant, Administrative Conference of the United States, November 1991

This report was prepared for the consideration of the Administrative Conference of the United States. The views expressed are those of the author and do not necessarily reflect those of the members of the Conference or its committees except where formal recommendations of the Conference are cited.

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I. Introduction

This report presents an overview of noise and its effects on people. Special emphasis is placed on developments over the past decade, both in terms of noise conditions and noise effects research. By doing so, this report should illustrate some of the reasons for concern about noise problems, which persist after the closing of EPA's Office of Noise Abatement and Control (ONAC).

Noise has a significant impact on the quality of life, and in that sense, it is a health problem in accordance with the World Health Organization's (WHO) definition of health. WHO's definition of health includes total physical and mental well-being, as well as the absence of disease. Along these lines, a 1971 WHO working group stated: "Noise must be recognized as a major threat to human well-being." (Suess, 1973)

The effects of noise are seldom catastrophic, and are often only transitory, but adverse effects can be cumulative with prolonged or repeated exposure. Although it often causes discomfort and sometimes pain, noise does not cause ears to bleed and noise-induced hearing loss usually takes years to

develop. Noise-induced hearing loss can indeed impair the quality of life, through a reduction in the ability to hear important sounds and to communicate with family and friends. Some of the other effects of noise, such as sleep disruption, the masking of speech and television, and the inability to enjoy one's property or leisure time also impair the quality of life. In addition, noise can interfere with the teaching and learning process, disrupt the performance of certain tasks, and increase the incidence of antisocial behavior. There is also some evidence that it can adversely affect general health and well-being in the same manner as chronic stress. These effects will be discussed in more detail in the paragraphs below.

II. ONAC'S Activities in Noise Effects Research and Criteria

In response to the mandates of Section 5 of the Noise Control Act of 1972, ONAC published Public Health and welfare Criteria for Noise (EPA, 1973a) and Information on Levels of Environmental Noise Requisite to Protect Public Health and welfare with an Adequate Margin of Safety (EPA, 1974a), popularly known as the "Levels Document" for obvious reasons). Also in 1973,ONAC sponsored an international conference in Yugoslavia on the effects of noise, from which voluminous proceedings there published (EPA, 1973b). All of these documents there widely distributed and, although somewhat dated, are still read and referenced today. Because a considerable amount of research in this area has been conducted over the past 2 decades, these documents would benefit from revision.

In these documents ONAC established dose-response relationships for noise and its effects, and identified safe levels of noise to prevent hearing loss and activity interference. The agency also established the day-night average noise level as a universal descriptor to be used in assessing the impact of community noise.

Section 14 of the Act directs ONAC to conduct or finance research on noise effects, including investigations of the psychological and physiological effects of noise on humans and the effects of noise on animals. Approximately 35 technical reports resulted from these efforts, as well as contractor reports and numerous articles in scientific journals.

Some of the more noteworthy examples of EPA's research program there:

- Projects involving the cardiovascular effects of noise at the University of Miami, Johns Hopkins University and the Massachusetts Institute of Technology (Peterson, et al., 1978, 1981, 1983; Hattis and Richardson,1980; Turkkan et al, 1983).
- A longitudinal study of noise exposure and hearing threshold levels in children conducted by the Fels Institute (Roche et al., 1977).
- An interagency agreement with the U.S. Air Force to study the effects of noise on hearing (e.g., Guignard, 1973; Johnson, 1973; Schori and McGatha, 1978; Suter, 1978).
- A study identifying the sound levels of speech communication in various environments (Pearsons, et al., 1977).
- Two studies at Northeastern University comparing methods for predicting the loudness and acceptability of noise (Scharf et al., 1977; Scharf and Hellman, 1979).

Although much useful information was derived from these programs, some of them there irreparably damaged by the abrupt termination of funding from ONAC that occurred in 1981 and 1982. For one example, the Johns Hopkins study of cardiovascular effects of noise on primates was terminated after testing on only one subject had been completed. For another, the longitudinal data from the Fels Institute is now of little value after a hiatus of more than a decade.

III. Physical Properties and Measurement of Sound

A. Physical Properties

Noise is often defined as unwanted sound. To gain a satisfactory understanding of the effects of noise, it would be useful to look briefly at the physical properties of sound.

Sound is the result of pressure changes in a medium (usually air), caused by vibration or turbulence. The amplitude of these pressure changes is stated in terms of sound level, and the rapidity with which these changes occur is the sound's frequency. Sound level is measured in decibels (abbreviated dB), and sound frequency is stated in terms of cycles per second, or nowadays, Hertz (abbreviated Hz). Sound level in decibels is a logarithmic rather than a linear measure of the change in pressure with respect to a reference pressure level. A small increase in decibels can represent a large increase in sound energy. Technically, an increase of 3 dB represents a doubling of sound energy, and an increase of 10 dB represents a tenfold increase. The ear, however, perceives a 10-dB increase as doubling of loudness.

Another important aspect is the duration of the sound, and the way it is distributed in time. Continuous sounds have little or no variation in time, varying sounds have differing maximum levels over a period of time, intermittent sounds are interspersed with quiet periods, and impulsive sounds are characterized by relatively high sound levels and very short durations.

The effects of noise are determined mainly by the duration and level of the noise, but they are also influenced by the frequency. Long-lasting, high-level sounds are the most damaging to hearing and generally the most annoying. High-frequency sounds tend to be more hazardous to hearing and more annoying than low-frequency sounds. The way sounds are distributed in time is also important, in that intermittent sounds appear to be somewhat less damaging to hearing than continuous sounds because of the ear's ability to regenerate during the intervening quiet periods. However, intermittent and impulsive sounds tend to be more annoying because of their unpredictability.

B. Instrumentation

The instrument for measuring noise is the basic sound level meter or a number of its derivatives, including noise dose meters (usually called dosimeters), integrating sound level meters, graphic level recorders, and community noise analyzers. Improvements in all of these instruments have taken place during the last decade. This is especially true of the computerized dosimeters and integrating meters, which can measure, compute, store, and display comprehensive data on the noise field (Earshen, 1986). These instruments are now able to measure over very wide dynamic ranges and to measure impulsive sounds with a high degree of accuracy.

C. Measurement and Descriptors

Most sound level meters and dosimeters use built-in frequency filters or "weighting networks " in the measurement process. By far the most frequently used filter is the A weighting network, which discriminates against low-frequency and very high-frequency sounds. A weighting approximates the equal-loudness response of the ear at moderate sound levels, and correlates well with both hearing damage and annoyance from noise. A weighting will be assumed throughout this report unless otherwise specified.

Composite measures of noise, such as the equivalent continuous sound level (Leq) and the day-night average sound level (DNL) incorporate A weighting, (The mathematical notation for DNL is Ldn.) these levels constitute sound energy averages over given periods of time, the DNL incorporates a 10-dB nighttime penalty from 10:00 pm to 7:00 am, meaning that events occurring during

that time are counted as 10 dB higher than they really are. A variant of the DNL that is used in California (and Europe) is the community noise equivalent level (CNEL), which incorporates a 5-dB penalty for evening noise events, as well as the 10-dB nighttime penalty (California Code of Regulations, 1990).

For more than a decade, both the DNL and the simple Leq have been used extensively for assessing the impact of aircraft/airport noise. Recently, however, communities have expressed dissatisfaction with these metrics when used to regulate noise (Wesler, 1990). Metrics that employ averaging fail to describe the disturbance arising from single events, especially low-flying aircraft, unexpected or newly occurring flights, or flights occurring in areas where solitude is at a premium. The sound exposure level (SEL), an event's sound level normalized to one second, is gaining popularity as a supplement to the DNL and the Leq for characterizing single events.

IV. Noise in America

A. Population Trends

The U.S. population has increased an average of 25 million with each census since 1950. According to the World Almanac (1991), the population in 1980 was 226 million and approximately 250 millio in 1990. This reflects an increase of nearly 11 percent over the decade, or slightly more than 1 percent per year. Presently, 77 percent of the U.S. population lives in the nation's 283 designated metropolitan areas, and the rate of growth in these areas is twice that of nonmetropolitan areas (Bryant, 1991).

Not surprisingly, EPA research indicates that noise levels in communities is directly related to the population density (EPA, 1974b).[1] Because the noise in urban areas generally exceeds that of suburban and rural areas, it is not unreasonable to assume that noise in the U.S. is increasing at least in proportion to the increase in urbanization and more rapidly than the growth of the general population. In addition, noise sources appear to be multiplying at a faster pace than the population.

B. Noise Sources

Figure 1, from EPA's simplified version of the Levels Document, Protective Noise Levels, shows the range of sound levels for some common noise sources (EPA, 1978). Most leading noise sources will fall into the following categories: road traffic, aircraft, railroads, construction, industry, noise in buildings, and consumer products.

1. Road traffic noise

In its Levels Document (1974), EPA estimated that road traffic noise was the leading source of community noise. EPA's contractors found that to be true in 1981 (EPA, 1981), and there is little reason to believe otherwise today.

Truck transportation, as a convenient and economical means of moving raw materials and consumer goods from place to place, is growing at a faster pace than the general population. For example, a total[2] of 33.6 million trucks there registered in the U.S. in 1980. That number grew to 45.5 million in 1989, an increase of about 35 percent (American Trucking Assoc., 1991).

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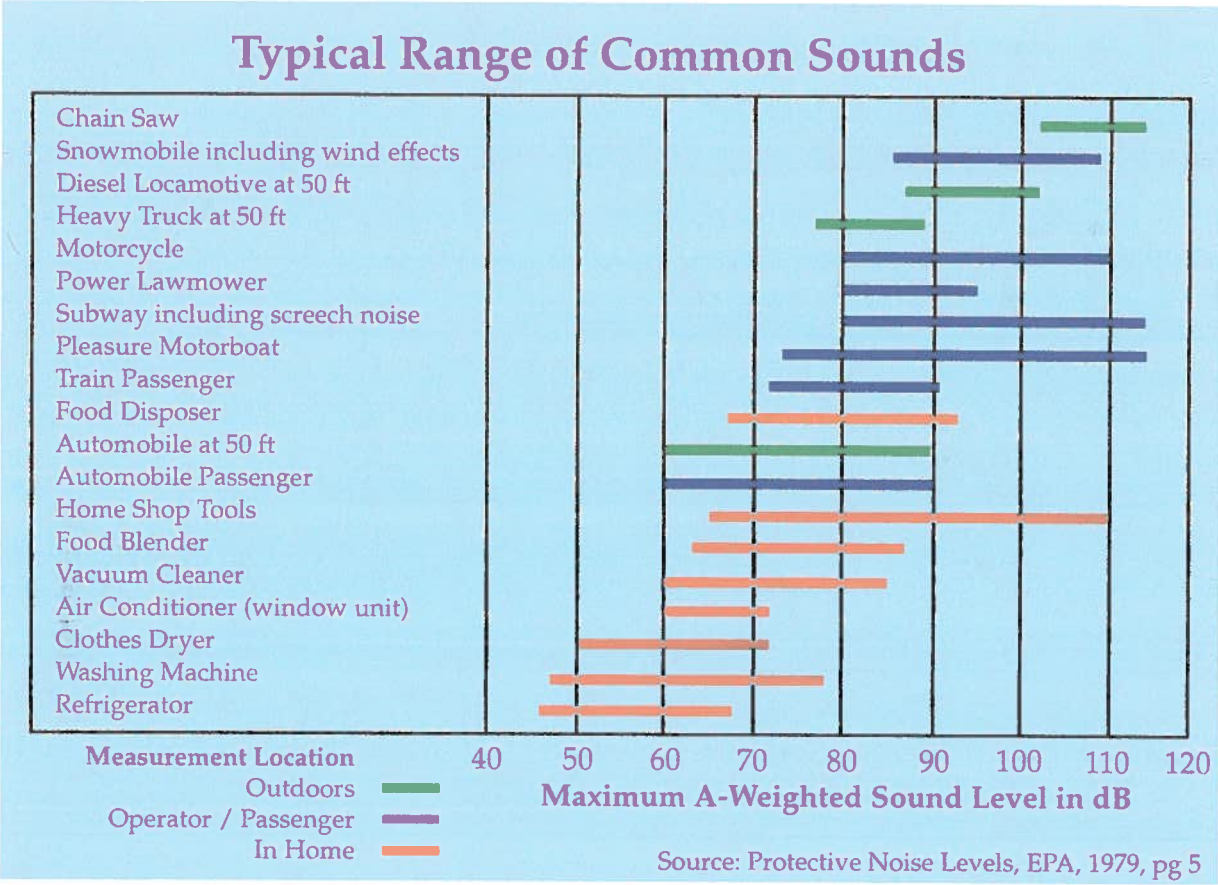
[1] The day-night average sound level appears to be proportional to the log of population density in people per square mile (EPA.1974b).

[2] The total number of trucks registered includes personal-use as well as commercial trucks of all weight classes.

Noise from the motors and exhaust systems of large trucks provides the major portion of highway noise impact, and provides a potential noise hazard to the driver as well.[3] In addition, noise from the interaction of tires with the roadway is generated by trucks, buses, and private autos.

In the city, the main sources of traffic noise are the motors and exhaust systems of autos, smaller trucks, buses, and motorcycles. This type of noise can be augmented by narrow streets and tall buildings, which produce a "canyon" in which traffic noise reverberates.

Typical Range of Common Sounds



2. Aircraft noise

Air traffic also appears to be increasing more rapidly than the U.S. population. In 1980, U.S. scheduled airlines flew approximately 255.2 billion passenger miles and 5.7 billion cargo (ton) miles. By 1990, these figures there 457.9 billion and 10.6 billion, respectively (Air Transport Assoc., 1991a). This represents an increase of 79 percent in passenger mileage, and 86 percent in air height mileage. Air cargo traffic has grown particularly rapidly in the last five years, and will probably continue that trend over the next decade.

By 1989, the quieter "Stage III" airplanes comprised nearly 40 percent of the domestic fleet (Air Transport Assoc, 1991b). By the year 2004, all of the noisier Stage II aircraft must be phased out

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[3] According to Reinhart (1991) the most common complaint about truck noise is related to problems caused by tampering with the mufflers of trucks using compression brakes. About 5 percent of the heavy trucks surveyed by Reinhart and his colleagues had no functioning muffler, despite the existence of antitampering laws.

(Airport Noise and Capacity Act, 1990). This requirement should promote a quieter environment around airports, but the growth of air transportation and the pressing need for airport expansion threatens to offset the benefits of the quieter aircraft.

Nowadays, the problem of low-flying military aircraft has added a new dimension to community annoyance, as the nation seeks to improve its "nap-of-the-earth" warfare capabilities. In addition, the issue of aircraft operations over national parks, wilderness areas, and other areas previously unaffected by aircraft noise has claimed national attention over recent years (Fidell, 1990; Cantoni, 1991; Weiner, 1990; Mouat, 1990).

3. Noise from railroads

The noise from locomotive engines, horns and whistles, and switching and shunting operations in rail yards can impact neighboring communities and railroad workers. For example, rail car retarders can produce a high-frequency, high-level screech that can reach peak levels of 120 dB at a distance of 100 feet (EPA, 1974), which translates to levels as high as 138 or 140 dB at the railroad worker's ear.

Unlike truck and air transportation, however, rail transportation does not appear to be increasing. According to the Association of American Railroads, the railroad industry loaded 22.1 million freight cars in 1988, down slightly from 22.6 million in 1980 (AAR, 1991).

4. Construction noise

The noise from construction of highways, city streets, and buildings is a major contributor to the urban scene. Construction noise sources include pneumatic hammers, air compressors, bull dozers, loaders, dump trucks (and their back-up signals), and pavement breakers. The construction industry has done very well over recent years with a value-added GNP of $97.9 billion in 1977, increasing to $247.7 billion in 1989 (Dept. of Commerce, 1991), an increase of about 153 percent. The number of workers employed in construction grew from 4.3 million in 1980 to about 5.2 million in 1990, an increase of nearly 21 percent (BLS, 1991a).

5. Noise in industry

Although industrial noise is one of the less prevalent community noise problems, neighbors of noisy manufacturing plants can be disturbed by sources such as fans, motors, and compressors mounted on the outside of buildings. Interior noise can also be transmitted to the community through open windows and doors, and even through building walls. These interior noise sources have significant impacts on industrial workers, among whom noise-induced hearing loss is unfortunately common.

The size of the U.S. manufacturing industry has not grown significantly over the last decade. Although the industrial. GNP increased from $673.9 billion in 1980 to $969.6 billion in 1990 (in terms of constant dollars) (BLS, 1991b), the workforce has declined from slightly more than 20 million to about 19 million during that period (BLS, 1991c). Consequently, industrially-generated community noise is probably no greater than it was in 1980.

From the worker's perspective the industrial noise problem is still very serious. The Occupational Safety and Health Administration has cut back on the enforcement of occupational noise standards and has allowed the substitution of hearing protection devices in lieu of engineering controls in many cases (OSHA, 1986). However, it is difficult to know whether noise levels in industry are increasing or decreasing because no comprehensive survey has been performed since the 1976 survey performed by Bolt Beranek and Newman Inc. (BBN, 1976).

6. Noise in buildings

Apartment dwellers are often annoyed by noise in their homes, especially when the building is not well designed and constructed. In this case, internal building noise from plumbing, boilers, generators, air conditioners, and fans, can be audible and annoying. Improperly insulated walls and ceilings can reveal the sound of amplified music, voices, footfalls, and noisy activities from neighboring units. External noise from emergency vehicles, traffic, refuse collection, and other city noises can be a problem for urban residents, especially when windows are open or insufficiently glazed.

Wetherill (1987) reports that although the lack of soundproofing is the most frequent environmental complaint of apartment dwellers, the knowledge to solve these problems is not being applied. In fact, the quality of construction is steadily declining, and the noise problems are getting worse (Wetherill, 1991).

7. Noise from consumer products

Certain household equipment, such as vacuum cleaners and some kitchen appliances, have been and continue to be noisemakers, although their contribution to the daily noise dose is usually not very large. Added to this list would be yard maintenance equipment, such as lawn mowers and snow blowers, which can, at least, cause disharmony with one's neighbors, and pother shop tools, which can be hazardous to hearing if used for sufficient periods of time.

One example of a fairly new product is the gasoline-pothered leaf blower, with average A-weighted sound levels at the operator's position of 103.6 dB, and maximum levels of 110-112 dB (Clark, 1991). In an extensive review of nonoccupational noise exposures, Davis et al. (1985) report that the manufacturers of household devices have been reluctant to release sound level information. Consequently, it could be difficult to assess the magnitude of the problem and the extent to which noise levels are increasing or decreasing.

Residents of suburban and rural areas are sometimes disturbed by recreational noise sources, such as off-road vehicles, high-pothered motor boats, and snowmobiles. Some of these sources, such as snowmobiles, are not as noisy as they there more than a decade ago, due to attention to the problem by the manufacturers and their trade associations. Others are no less noisy, and possibly more so because noise seems to be generic to the sport. Example would be motorcycle and car racing, and events like "tractor pulls."

In fact, the allure of noisy recreational activities seems to be considerably greater now than it was a decade or so ago. The technology of sound reproduction has advancer to the point where loudspeakers can faithfully reproduce music and other sounds at levels well above 120 dB. Sporting events use giant digital "applause meters" to measure and display enthusiasm for the more popular team. The extreme in car stereo technology is now the "boom car", with sound levels exceeding 140 dB.[4] Activities like aerobic exercising and ice skating, as well as disco dancing, are accompanied by amplified music played at high sound levels. After summarizing the results of 16 studies of discotheques and rock concerts Clark (1991) reported the geometric mean of the measured sound levels as 103.4 dB. The trend in noise levels for these kinds of activities is definitely upward.

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[4] The International Auto Sound Challenge Association sponsors contests and gives the most points to contestants whom speakers produce the highest sound pressure levels, up to 140 dB. However, levels above that merit no more than 140 points.

One of the most serious sources of recreational noise is sport shooting, where peak sound pressure levels at the ear can range from about 144 dB up to more than 170 dB[5] (Odess, 1972). In his analysis of this literature, Clark (1991) cites estimates of the number of people responding positively to questions about hunting or target shooting. These estimates range from 14 percent of the general population in Scandinavia and the U.K. (Axelsson et al., 1981; Davis et al., 1985) to nearly 50 percent in the Canadian workforce (Chung et al., 1981), which Clark found to be consistent with estimates from U.S. industry. In a population of rural schoolchildren, 45 out of 47 boys and 2 out of 21 girls reported having used guns (Kramer and Wood, 1982).

A subcategory of consumer product noise that deserves mention is noisy toys. A few toys, such as firecrackers, snappers, and cap pistols have been part of the adventurous child's experience for generations. The general assumption is that these toys do not pose a hazard when used occasionally and located at a sufficient distance from the ear[6]. Nowadays, there is a large variety of noisy toys, thanks to the availability of improved technology. Many of them mimic adult noisemakers, such as amplified toy guitars, child-shed vacuum cleaners, and miniature pother saws. Some of these toys generate quite high levels of sound. For example, a baby's squeeze toy (Fay, 1991) and the battery operated siren of a toy police car have both been measured at 110 dB[7].

In a recent report on noisy toys, Leroux and Laroche (1991) cite studies showing A-weighted noise levels for a toy motor at 107 dB and a child's rattle at 99-100 dB (LNE, 1973). Current Canadian legislation limits the sound output of toys to "one hundred decibels measured at the distance that the product ordinarily would be from the ear of the child using it..." (Act, 1969), but Leroux and Laroche propose that this limit be lowered to an A-weighted level of 75 dB.

C. Numbers of People Exposed to Noise

The fact that people are variously exposed to noise is not surprising. Considering that decibels are measured on a logarithmic scale, however, the magnitude of these variations can be enormous. For example, the average noise level outside an urban apartment can be 1,000 times more intense than in a rural residential neighborhood. Fortunately, this difference will be perceived more like an eightfold rather than a thousand-fold increase. Figure 2, from EPA's document Protective Noise Levels, shows examples of outdoor day-night average sound levels measured at various locations (EPA, 1978).

In 1974, EPA estimated that nearly 100 million Americans lived in areas where the daily average noise levels exceeded its identified safe DNL of 55 dB (EPA, 1974a). Figure 3, from EPA's Levels

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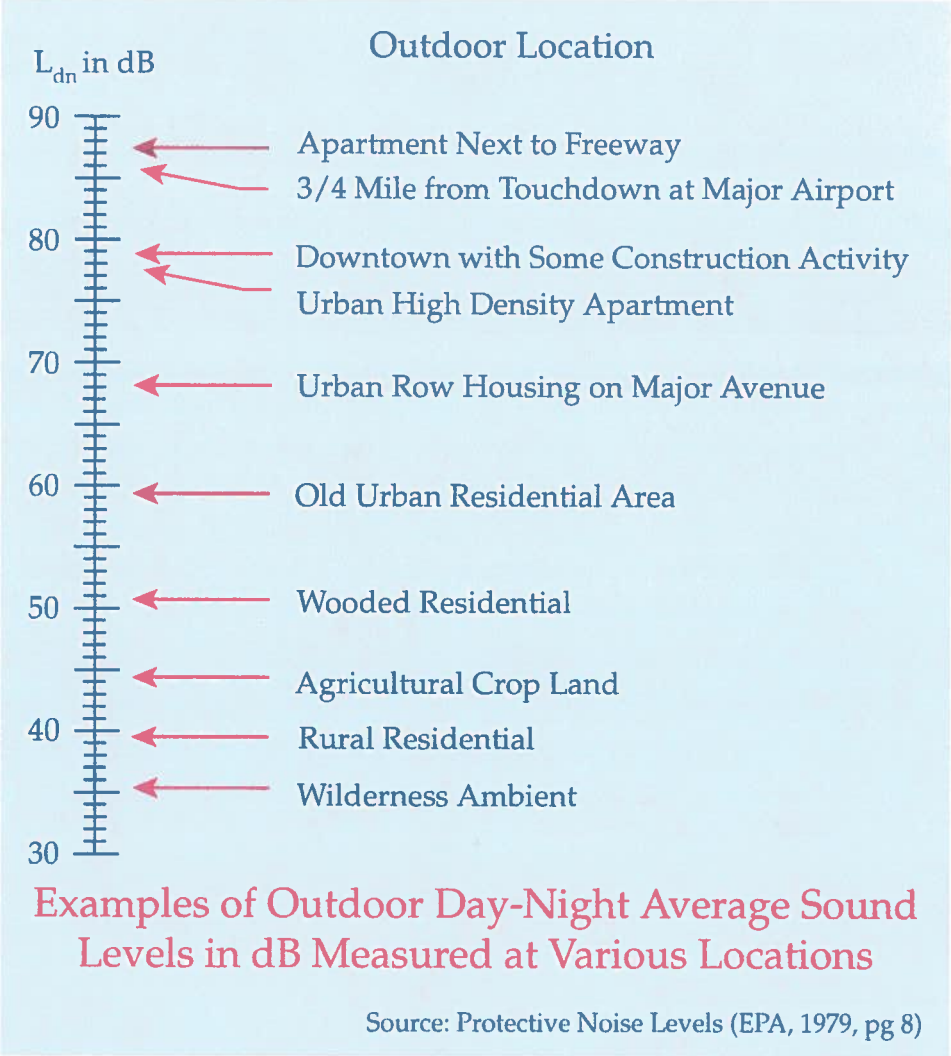
[5] A-weighted level. of these weapons would measure somewhat lower, with levels for .22 caliber rifles at about 132-139 dB and shotguns at 150-165 dB. (See Clark, 1991)

[6] Certain European studies, however, have reported as many as 1 percent to 3.7 percent of teenage children suffer hearing losses caused by impulsive noise from toys (Gjaevenes, 1967; Moe, 1966). Noise from cap guns, for example, can exceed peak sound pressure levels of 140 dB (Gjaevenes, 1966; Hodge and McCommons, 1966; Marshall and Brandt, 1973; all as cited by Leroux and Laroche,
1991).

[7] New York audiologist Thomas Fay has measured the noise levels of a variety of children's toys. In doing so he places the sound level meter's microphone quite close to the noise source (from 2 inches to 1/2 inch away), based on his observations of the children at play. (Personal communication, April 1991).

Document, shows the residential noise environment of the U.S. population as a function of the exterior DNL, with separate curves for the freeway and aircraft increments.

Examples of Outdoor Day-Night Average Sound Levels in dB Measured at Various Locations



A few years later EPA contracted with the consulting firm Bolt Beranek and Newman (BBN) to develop more detailed estimates. The resulting report, Noise in America, includes a breakdown according to noise exposure source (EPA, 1981). Table I gives the estimated number of Americans exposed to traffic; aircraft, construction, rail, and industrial noise for various DNLs from 55 dB to 80 dB. The authors note that there will be some overlap among populations exposed to different sources, so the numbers across categories are not additive. The far right column represents the total estimated number of people exposed to the combined sources. Although the authors do not give an estimate for the number of people exposed above Ldn 55 dB, another authority puts it at 138 million at that time (Eldred, 1990).

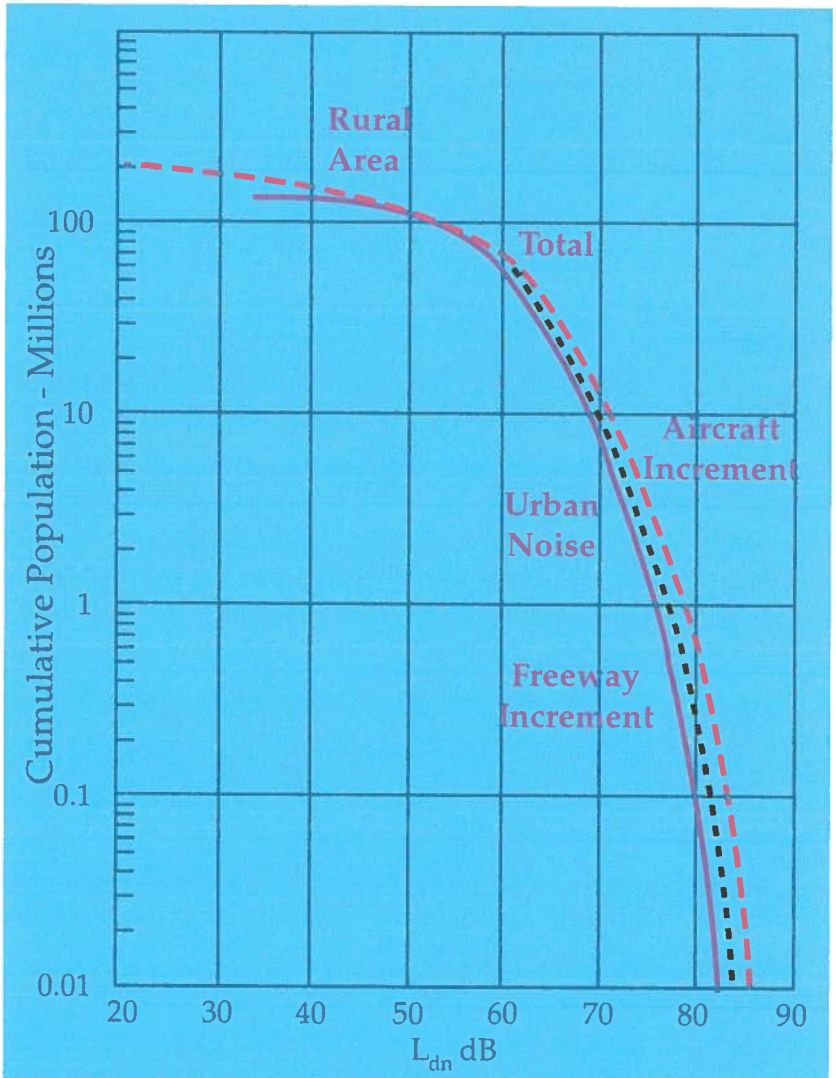
These estimates do not represent the results of a national survey. Instead, the authors used data and models available to EPA and BBN at the time. Because of this, some categories of noise exposure are likely to be more accurate than others. They did, however, represent the best available esti-

mates at the time, and because no efforts have been made to update them, they are the best estimates available today.

D. Summary: Noise in America

It is safe to assume that noise in communities is increasing. Noise levels are directly related to population density, and the urban population is increasing at twice the pace of the nonurban population. In addition, the last decade has seen rapid growth in air transportation, trucking, and the construction industries, indicating that noise levels from these sources has most likely increased. The fact that some of these sources have been and continue to be quieted (especially new generations of trucks and aircraft) should mitigate this increase, but the extent of this mitigation will remain unknown until some sort of national survey is performed. Noise from construction continues to be a problem, and it appears that noise inside buildings as well as noise from recreational activities and consumer products is on the rise. Estimates of the number of people exposed to noise at various levels are now somewhat outdated.

Residential Noise Environment of the National Population As a Function of Exterior Day-Night Average Sound Level



Residential Noise Environment of National Population as Function of Exterior Day-Night Average Sound Level

Source: Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety (EPA, 1974a, pg 16)

Table 1: Summary of U.S. Population Exposed to Various Day-Night Average Sound Levels (or higher) From Noise Sources in the Community. (1) From Noise in America (EPA, 1981, pp. 10 and 15)

Estimated Number (in Millions) of People in Each Noise Category

DNL (dB)	Traffic	Aircraft	Construction	Rail	Industrial	Total
>80	0.1	0.1	—	—	—	0.2
>75	1.1	0.3	0.1	—	—	1.5
>70	5.7	1.3	0.6	0.8	—	8.1
>65	19.3	4.7	2.1	2.5	0.3	27.8
>60	46.6	11.5	7.7	3.5	1.9	63.6
>55	96.8	24.5	27.5	6.0	6.9	92.4*

(1) DNL values are yearly averages, outdoors
(2) Note that there is some overlap among populations exposed to different noise sources. For example, some of the 96.8 million people exposed to Ldn 55 dB and above from traffic noise are also exposed to aircraft noise.
(3) Construction estimates include both residential and nonresidential exposure.

*Distribution of total exposed to all sources starts at Ldn 58 dB since the analysis involves combining distributions exposed to 55 dB and above.

V. Effects of Noise

A. Noise-Induced Hearing Loss

Hearing loss is one of the most obvious and easily quantified effects of excessive exposure to noise. Its progression, however, is insidious, in that it usually develops slowly over a long period of time, and the impairment can reach the handicapping stage before an individual is aware of what has happened. While the losses are temporary at first, they become permanent after continued exposure, and there is no medical treatment to counteract the effect. When combined with presbycusis, hearing loss naturally occurring with the aging process, the result is a premature impairment that grows inexorably with age.

According to the U.S. Public Health Service (PHS, 1991), some 10 million of the estimated 21 million Americans with hearing impairments owe their losses to noise exposure (as cited in Carney, 1991). The study goes on to say that it is unclear whether the incidence of hearing impairment has risen in recent years because the necessary studies have not been conducted.

1. Extent of noise-induced hearing loss from environmental sources

Although the major cause of noise-induced hearing loss is occupational, substantial damage can be caused by nonoccupational sources. In addition to the frequently-blamed sources of loud music and shooting, noise-induced hearing loss has been noted in the children of farm families, presumably from the frequent use of tractors (e.g., Broste et al., 1979); general aviation pilots because of the high noise levels emitted by piston aircraft (Anon., 1982); and users of earlier generations of cordless telephones because of the placement of the ring mechanism in the earpiece (Orchik et al., 1985 and 1987).

The prevailing notion among parents is that the hearing threshold levels of children are worse than they used to be because of exposure to loud music. Actually, a recent national survey of 38,000 school children found better hearing threshold levels than 30 years ago, but blames the discrepancies on the sampling methods used in the earlier study and the conversion from an older to a nether zero reference level (Lundeen, 1991). There is, however, evidence that the hearing of some young people is being affected by noisy leisure time activities (Axelsson et al., 1987).

Loud music in particular appears to be the cause of hearing impairment and tinnitus in rock musicians. Such luminaries as Pete Townshend and Ted Nugent[8] have acquired substantial hearing losses and are now campaigning for hearing conservation (Murphy, 1989). Some studies point to a hearing hazard for attendees as well (see in Clark, 1991; Clark and Bohne, 1986; Danenberg et al.,1987).

As mentioned above, probably the greatest nonoccupational hazard to hearing comes from sport shooting. Clark (1991) cites studies of industrial workers by Chung et al. (1981), Johnson and Riffle (1982), and Prosser et al. (1988), showing significantly greater hearing losses among sport-shooters than among their nonshooting counterparts. These losses are almost always characterized by worse hearing in the left ear than the right.

The contribution from nonoccupational sources is called "sociocusis" (a contraction of "socio-acusis"). Evidence from primitive societies suggests that the absence of sociocusis explains the large differences in hearing threshold level between these populations and those of the "civilized" nations (Rosen, 1962). Sociocusis, occupational hearing loss, and presbycusis contribute in various

2. The handicap of noise-induced hearing loss

Vowel sounds tend to be low in frequency and high in sound energy, while the consonants are much higher in frequency and have considerably less amplitude. It also happens that consonants provide the primary intelligibility to speech. Because noise damages the ear's ability to perceive high-frequency sounds much earlier and more severely than the low-frequency sounds, individuals with noise-induced hearing loss are at a particular disadvantage in understanding speech.

Individuals with early noise-induced hearing loss often think that other people no longer speak dearly. They soon begin to notice that they have difficulty understanding speech when there is noise in the background, and in groups of people, and that it is hard to identify which person is talking. As the hearing loss progresses, these individuals avoid social occasions and situations where they must listen at a distance, like church and theater. The eventual result can be loneliness and isolation.

3. The study of noise-induced hearing loss

Noise damages the delicate sensory cells of the inner ear, the cochlea. This process can be studied in the laboratory by inducing temporary shifts in hearing threshold level in humans. Over recent years the preferred method of investigation is to produce temporary and permanent threshold shifts in animals, and to study the resulting physiological and anatomical changes in the cochlea, as well as shifts in hearing threshold level. The laboratory allows for strict control of noise level and

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[8] According to Nugent, who has worn an earplug in his right ear since 1967: "My left ear is there just to balance my face, because it doesn't work at all." (Murphy 1989) proportion to an individual's total hearing impairment. While the contribution of each source may be less than significant, the combination of all three can be enough to produce a handicapping condition. As longevity in the U.S. population increases, the toll of noise-induced hearing loss will become increasingly evident (Carney, 1991).

duration, but the durations are usually relatively short because of the time and expense involved. Also there is some controversy over the extent to which the results can be generalized to humans.

Much of the recent laboratory effort in noise research has focused on the structural and functional basis of noise-induced hearing loss, which has been greatly aided by the electron microscope. Investigators have identified the sensory cell's stereocilia and the rootlets which anchor them as the auditory system's most vulnerable components with respect to noise exposure (Libermnan, 1990).

Field studies of noise-exposed workers avoid the problems of species generalization, and the exposure durations can be over many decades. They are usually cross-sectional studies, however, meaning that the current hearing threshold levels are related to noise exposures that have been experienced over many years. Although the current noise measurements may be valid, their validity over prior years usually has to be assumed without benefit of precise data.

4. Risk of hearing impairment from continuous noise

The methods and results of the major field studies of continuous noise exposure conducted in the late 1960s and early 1970s remain unchallenged. Examples are the studies of Burns and Robinson (1970), Baughn (1973), Passchier-Vermeer (1968), and the U.S. National Institute for Occupational Safety and Health (NIOSH, 1973). Data from these studies have been used by various organizations to estimate the risk of hearing impairment over a working lifetime of exposure to noise. These types of studies have also been used by the EPA to estimate the hazard of nonoccupational noise (Guignard, 1973; Johnson, 1973; EPA, 1973a). The data cited above of Burns and Robinson, Baughn, and Passchier-Vermeer went into EPA's identification of a yearly average exposure level of 70 dB as the safe level, which could be experienced over a lifetime (EPA, 1974a)[9].

A new international standard (ISO, 1989), which is based mainly on the data of Passchier-Vermeer and Burns and Robinson, contains formulas for assessing the risk of noise-induced hearing impairment and handicap: using either a highly screened (for non-occupational hearing loss) or an unscreened population as a control group. The data and analyses found in these major studies have not been seriously challenged, and remain in use today.

5. Varying and intermittent noise

There has been some debate over the best rule for combining noise level and duration to assess the damaging effects of noise, especially varying and intermittent noise. This relationship is often called the doubling rate, or nowadays, the exchange rate. The EPA, as well as most other federal agencies (and most European countries, the United Kingdom, some Canadian provinces) use the equal-energy rule, which incorporates a 3-dB exchange rate. OSHA uses the 5-dB exchange rate, and the U.S. Air Force, uses 4 dB. None of these rules makes any provisions for the temporal order of sounds, although the 5-dB exchange rate supposedly represents a simplification of criteria that take a certain number of intermittencies into account.[10]

Investigations of the relationship between noise level and duration have been conducted over recent years using laboratory animals. The results have confirmed the validity of the equal energy (3-dB) rule for single exposures to continuous noise (Bohne and Pearse, 1982; Ward and Turner, 1982),

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[9] The 70-dB 24-hour average sound level can be interpreted as a 75-dB 8-hour average sound level plus an average sound level during the other 16 hours of less than 60 dB (see EPA's Levels Document, p.29, footnote d).

[10] The 5-dB rule does not necessarily provide for intermittencies because it allows uninterrupted exposures to continuous noise at high levels. See Suter 1983.

or when the exposures are broken up into 8-hour, or even 1-hour "workdays", 5 days per week, so long as the sound energy is equivalent (Ward, 1983). There is, however, some benefit to intermittent quiet periods (Ward and Turner, 1982), during which the ear can recover from small, temporary hearing losses. For this reason EPA has adjusted its identified safe level upward by 5 dB[11] since most environmental noise exposures are intermittent in nature. EPA's use of the equal-energy rule and the 5-dB adjustment have not been seriously challenged.

6. Impulse noise

The effects of impulse noise have been studied extensively over recent years, but there is less agreement on this topic than there is for continuous and intermittent noise. Although there was consensus favoring the 3-dB rule at a 1981 international meeting in England (von Gierke et al., 1981), actual dose-response relationships are still elusive. The effects of impulse noise do not always follow the 3-dB rule, in that temporal pattern, waveform, and rise time can affect the growth of hearing loss, despite constancy of sound energy (Henderson and Hamernik, 1986).

Frequency also has some bearing on the damage caused by impulse noise, in that low-frequency impulses produce significantly less damage than sounds in the mid-to-high-frequency range (Price, 1983). The ear appears to be most susceptible to impulses with peaks around 4,000 Hz (Price, 1989). Also, there may be a critical level, above which the ear is considerably more at risk because of a change in the response mechanism. On the basis of his research, Price (1981) has suggested a critical level of 145 dB, with a standard deviation of 8 dB.

7. Susceptibility

Evidence from field studies indicates that men incur more hearing loss than women from comparable noise exposures (Burns and Robinson, 1970; Berger et al., 1978; Royster et al., 1980), and that Caucasians appear to be more susceptible than Blacks to noise-induced hearing loss (Royster et al., 1980). Other factors, such as age, preexposure hearing threshold level, general health, and use of alcohol, have not yet proved to be reliable predictors of susceptibility (Ward, 1986), although

8. Interactions with other agents

Noise can interact with drugs and industrial agents to produce additive or even synergistic effects on hearing. As expected, the higher the levels of noise and the greater the dose of the other agent, the greater will be the resulting hearing loss. The ototoxic properties of certain drugs, most notably the aminoglycoside antibiotics (the "mycin" drugs), are heightened by exposure to noise. Numerous studies of kanamycin plus noise exposure have revealed additive and some synergistic results (Humes, 1984). High doses of salicylates (aspirin) accompanied by noise exposure can produce temporary hearing losses (McFadden and Plattsmier, 1983), but permanent losses do not seem to occur. Cisplatin, used in cancer chemotherapy, is known to be toxic to the auditory system, and has been shown to interact significantly with none exposure (Boettcher et al., 1989).

A variety of industrial agents, which can be potent neurotoxins, have been shown to be capable of producing hearing loss (Fechter, 1989). These agents include heavy melds, such as lead and mercury, organic solvents, such as toluene, xylene, and carbon disulfide, and an asphyxiant, carbon monoxide.

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[11] The identified safe level of 70 dB reflects the incorporation of the 5-dB adjustment there is some indication that the use of tobacco may increase susceptibility to noise-induced hearing loss (Barone, et al., 1987; Stark, et al., 1988)

9. Hearing protectors

As its first (and only) labeling regulation, EPA promulgated a regulation for labeling the attenuation of hearing protection devices (EPA, 1979). The standard required manufacturers to subject their hearing protectors to specific laboratory tests, and to publish a "Noise Reduction Rating" (NRA) on the product's package. The NRA was subsequently adopted by OSHA in its hearing conservation amendment, which required employers to use it in assessing the adequacy of hearing protectors for given noise environments (OSHA, 1981 and 1983). Recent research shows that the NRA greatly overestimates the noise reduction to be achieved by these devices in actual field use.[12] These kinds of findings have led to the formation of a new ANSI working group to investigate alternatives to the current NRA (Berger et al. 1990), and the recommendation that EPA revise its existing labeling regulation (Berger, 1991; Stewart, 1991).

10. Summary: Noise-induced hearing loss

Noise-induced hearing loss is probably the most well-defined of the effects of noise. Predictions of hearing loss from various levels of continuous and varying noise have been extensively researched and are no longer controversial. Some discussion still remains on the extent to which intermittencies ameliorate the adverse effects on hearing and the exact nature of dose-response relationships from impulse noise. It appears that some members of the population are somewhat more susceptible to noise-induced hearing loss than others, and there is a growing body of evidence that certain drugs and chemicals can enhance the auditory hazard from noise.

Although the incidence of noise-induced hearing loss from industrial populations is more extensively documented, there is growing evidence of hearing loss from leisure time activities, especially from sport shooting, but also from loud music, noisy toys, and other manifestations of our "civilized" society. Because of the increase in exposure to recreational noise, the hazard from these sources needs to be more thoroughly evaluated. Finally, the recent evidence that hearing protective devices do not perform in actual use the way laboratory tests would imply, lends support to the need for reevaluating current methods of assessing hearing protector attenuation.

B. Interference With Communication

Noise can mask important sounds and disrupt communication between individuals in a variety of settings. This process can cause anything from a slight irritation to a serious safety hazard involving an accident or even a fatality because of the failure to hear the warning sounds of imminent danger. Such warning sounds can include the approach of a rapidly moving motor vehicle, or the sound of malfunctioning machinery. For example, Aviation Safety (Anon., 1982), states that hundreds of accident reports have many "say again" exchanges between pilots and controllers, although neither side reports anything wrong with the radios.

Noise can disrupt face-to-face and telephone conversation, and the enjoyment of radio and television in the home. It can also disrupt effective communication between teachers and pupils in schools, and can cause fatigue and vocal strain in those who need to communicate in spite of the noise. Interference with communication has proved to be one of the most important components of noise-related annoyance (EPA, 1974a).

In its Levels Document, EPA determined that a yearly average day-night sound level of 45 dB would permit adequate speech communication in the home, and a DNL of 55 dB would permit

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[12] In a summary of 10 studies, Berger (1983) shows that most hearing protectors in the field provide only one-third to one-half the attenuation that they do in the laboratory.

normal communication outdoors at a distance of about 3 meters.[13] These levels also apply to hospitals and educational facilities. Higher average noise levels would be satisfactory for certain nonresidential spaces, such as commercial and industrial facilities, and inside transportation, depending on the degree to which speech communication is critical. Research over the last 20 years has expanded and refined EPA's criteria development in this area, but has not generated any major changes.

1. Prediction of speech interference

Methods of predicting the amount of speech that can be communicated in various noise backgrounds have been available for decades. Probably the most popular and respected method is the articulation index (AI) (French and Steinberg, 1947), which requires the measurement or estimation of the spectrum level of both speech and noise in 20 contiguous bands. Over the past 2 decades investigators have suggested adjustments to the AI for 1/3-octave bands, reverberation time, various vocal efforts, etc., and more recently for various degrees of hearing impairment (Humes, et al., 1986 and 1987).

The speech interference level (SIL) (Beranek, 1954) provides a quick method for estimating the distance at which communication can occur for different levels of vocal effort. The current method involves measuring octave-band sound pressure levels at 500, 1,000, 2,000, and 4,000 Hz and referring to a chart to determine the die potential communication distance. The basic chart has been expanded to include such parameters as a broader range of voice levels and provisions for room reverberation (Webster, 1983). Additions to both the AI and the SIL have been proposed by Lazarus (1990), who offers modifications and extensions to account for strain on the part of both talker and listener, and the wearing of hearing protectors.

Another popular method to predict speech communication in a variety of conditions, the speech transmission index (STI), has been developed by a Netherlands research group (Houtgast, 1980; Houtgast and Steeneken, 1983). The STI takes into account room volume and reverberation time, in addition to speech and none levels, and distance between talker and listener. A more recent outgrowth, the rapid speech transmission index (RASTI), represents a simplified version of the STI intended for field use, and is available in an instrument conforming to an international standard (IEC, 1987).

Finally the sound level meter's A-weighting network can be successfully used to predict speech interference levels. It is easy to use, available on virtually all sound level meters, and effective when the noise spectra are not complex.

2. Criteria for speech and warning signals

In addition to the classic work of Beranek and his colleagues (Beranek et al., 1971), Beranek has recently refined the traditional curves to account for the annoyance due to low-frequency "rumble" (Beranek, 1989). New criteria for determining acceptable background levels of noise in rooms are also offered by Lazarus (1986a, 1986b, 1987, and 1990). Lazarus includes in his criteria a variety of parameters such as: type of room, type of communication, communication distance, vocal effort, quality of speech intelligibility, AI, communication strain, listener's hearing sensitivity, and the use of hearing protectors.

Guidelines for audible warning signals have been developed by Patterson (1982). These guidelines, which there originally created for civil aircraft, there later adapted to helicopters and even station-

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[13] These levels represent EPA's identification of safe levels of environmental noise to protect the public health and welfare against all adverse effects of noise with the exception of hearing loss.

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ary workplaces like hospitals (Patterson, 1985; Rood et al., 1985). Another set of guidelines for acoustic warning signals has been developed by Lazarus and Hoge (1986), and are based on the compatibility of signal type with various desired or undesired situations.

Although criteria have not yet been developed for speech recognition involving nonnative listeners, experiments by Florentine (1985) and Nabelek (1983) indicate that these individuals need more favorable listening conditions (less background noise and reverberation) than their native- language counterparts. These findings have implications for air traffic control systems.

3. The effect of hearing protectors on speech and warning signal perception

Hearing protectors attenuate both noise and the desired signal by equal amounts in a given frequency band, reducing both to levels where the ear is less likely to distort. This process often improves speech recognition when the level of background noise exceeds 80 to 90 dB. However, because hearing protectors usually provide considerably more attenuation in the high frequencies than in the low frequencies, listeners who have high-frequency hearing losses are at a disadvantage. Many speech sounds and some warning signals will be attenuated beyond the range of audibility. This is especially true of individuals whose losses exceed an average of 30 dB at the audiometric frequencies 2000, 3000, and 4000 Hz (Lindeman, 1976). A potential solution for this problem lies in some newly developed hearing protectors with flat attenuation across the frequency spectrum (Allen and Berger, 1990; Killion et. al., 1988). One type of these protectors has already become popular with orchestral musicians (Killion et al., 1988) and even some rock musicians (Cohen, 1990).

Individuals tend to speak more softly when they wear hearing protectors, and consequently, speech communication is degraded when both talker and listener wear these devices (Hoermann et al,, 1984), Hearing protectors also interfere with the localization of sounds in space, and this is especially true of the ability to localize sounds in the vertical plane while wearing ear muffs (Noble, 1981). Both ear plugs and ear muffs cause these types of problems, but it appears that they are more pronounced with ear muffs (Howell and Martin, 1975; Abel et al., 1982). These findings can have serious implications for safety in some circumstances.

4. Scholastic performance

Noise can disrupt communication in the classroom to the extent that the instructional method used in schools close to airports is sometimes nicknamed " jet pause" teaching. Cohen and Weinstein (1981) have reviewed several studies, which, after controlling for socioeconomic factors, indicate that the academic performance of children in quiet schools is better than that of children in noisy schools.

For example, elementary school children on the side of a school facing train tracks. performed more poorly on a reading achievement test than children in classrooms on the quiet side of the school (Bronzaft and McCarthy,:1975).[14] Cohen and Weinstein also discuss research showing that skills, such as auditory discrimination and reading achievement can be adversely affected when children live in noisy circumstances, even though their schools may be no noisier than average. These latter studies indicate that interference with communication in the classroom is not the only

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[14] Bronzaft reported that in 1978 the city of New York reduced the noise of the elevated train and installed acoustical insulation in the affected classrooms, providing a total reduction in the A-weighted noise level of 6 to 8 dB (Bronzaft, 1981). By 1981, there was essentially no difference. in reading achievement between students on the two sides of the school for the classroom studied.

process at work here. Possible additional explanations include adverse effects on children's information processing strategies and their feelings of personal control[15] (Cohen and Weinstein, 1981).

5. Summary: Interference with communication

Interference with speech communication and other sounds is one of the most salient components of noise-induced annoyance. The resulting disruption can constitute anything from an annoyance to a serious safety hazard, depending on the circumstance.

Research over the past 2 decades has expanded and refined methods for predicting communication interference, but has not produced any major changes. Numerous adjustments have been suggested for the AI, the SIL has been modified and refined, and a new predictive method, the STI has been added. Criteria for determining acceptable background levels in rooms have also been expanded and refined, and progress has been made on the development of effective acoustic warning signals.

It is now clear that hearing protection devices can interfere with the perception of speech and warning signals, especially when the listener is hearing impaired, both talker and listener wear the devices, and when wearers attempt to locate a signal's source.

Noise can interfere with the educational process, and the result has been dubbed "jet-pause teaching" around some of the nation's noisier airports, but railroad and traffic noise can also produce scholastic decrements.

C. Effects of Noise on Sleep

Noise is one of the most common forms of sleep disturbance, and sleep disturbance is a critical component of noise-related annoyance. A study used by EPA in preparing the Levels Document showed that sleep interference was the most frequently cited activity disrupted by surface vehicle noise (BBN, 1971). Aircraft none can also cause sleep disruption, especially in recent years with the escalation of nighttime operations by the air cargo industry. When sleep disruption becomes chronic, its adverse effects on health and well-being are well-known.

1. Assessing sleep disturbance

Noise can cause the sleeper to awaken repeatedly and to report poor sleep quality the next day, but noise can also produce reactions of which the individual is unaware. These reactions include changes from heavier to lighter stages of sleep, reductions in "rapid eye movement" (REM) sleep, increases in body movements during the night, changes in cardiovascular responses, and mood changes and performance decrements the next day. The accuracy and efficiency with which these effects are measured has been greatly assisted by the use of contemporary computers. The most popular measurement tool nowadays is electro-encephalography, but other methods, such as electrocardiography, electromyography, and electrooculography are also used, as well as clinical observation, self-assessment surveys, and accelerometry to measure the motion of the bed frame.

As a result of many years of research on the effects of noise on sleep, it is clear that intermittent and impulsive noise is more disturbing than continuous noise of equivalent energy, and that meaningful sounds are more likely to produce sleep disruption than sounds with neutral content. Also, older people are more likely to have their sleep disturbed by noise than younger people. In fact, children appear to be about 10 dB less sensitive to noise-induced sleep disruption than adults (Eberhardt, 1990). Sleep disturbance from noise tends to be greater in the early hours of the morn-

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[15] See also the discussion of noise, performance, and behavior in sections D.4, and D.5, below.

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ing, when individuals spend more time in lighter sleep stages, and this is particularly true of the elderly.

2. Criteria for sleep interference

In the Levels Document EPA identified an indoor DNL of 45 dB, which translates to a nighttime average sound level of 35 dB, as necessary to protect against sleep interference. However, consensus on the levels of noise that can be tolerated without sleep disruption is incomplete at this time. In an attempt to develop a quantitative model for predicting noise-induced sleep interference, Pearsons et al., (1989) reviewed and analyzed 21 studies. However, the authors there unable to derive dose-response relationships from these studies because of large discrepancies between studies conducted in the laboratory and those conducted in the field.

In a recent review of the noise and sleep research, Griefahn (1990) recommends that the nighttime average sound level be kept below 45 dB in the sleeper's quarters. She cites research by Eberhardt (1987 and 1990; Eberhardt et al., 1987;) and Vallet et al., (1976 and 1990) showing self- reported adverse effects from continual road traffic when the average sound level is 40 dB and physiological responses at an average level of 37 dB. For intermittent road traffic noise, maximum recommended levels for single events (as opposed to average levels) range from 45 to 68 dB, depending on the investigation (Griefahn, 1990). Vallet et al. (1990), recommend maximum outside levels of 65 dB, which, of course, relies on some attenuation by the residence. Griefahn also points out that higher maximum levels can be tolerated if the ambient noise level is not very low, and that the difference between single events and the ambient level should not exceed 8 to 10 dB.

3. After-effects and habituation

Numerous recent investigations have revealed after-effects due to noisy nights. Ohrstrom (1983) found mood changes on the day following nights when the average sound level was as low as 35 dB. Adverse effects on performance, such as increased reaction time, have also been measured (Jurriens et al., 1983), and it appears that older peoples' next day performance is more adversely affected by noise than that of younger people (Griefahn and Gros, 1983).

Although people often believe they get used to nighttime noise, physiological tests point to the contrary. Studies have shown that while the subjective response improves with time, cardiovascular responses remain unchanged (Muzet, 1983). Vallet et al. (1990) conclude that habituation is not complete, even after 5 years of exposure to noise.

4. Summary: Effects of noise on sleep

Noise-induced sleep interference is one of the critical components of community annoyance. It can produce short-term adverse effects, such as mood changes and decrements in task performance the next day, with the possibility of more serious effects on health and well-being if it continues over long periods.

EPA's identified indoor DNL of 45 dB has not been seriously challenged over the past decade, but consensus in this area is lacking. One problem is that different experimenters tend to use a variety of descriptors (DNL, Leq, and maximum single-event levels) and a variety of methods for evaluating the effects (EEG, EKG, self-report, etc.). Perhaps one reason for the lack of clear-cut criteria is that this a complex area to research, requiring considerable time and expense. Another is, of course, a need for more field studies in this area.

D. Effects on Performance and Behavior

EPA did not use the literature on the effects of noise on performance and behavior in the identification of its levels of noise to protect against activity interference. One reason may have been that much of the information at that time related to the occupational setting rather than the general environment. Another may have been the complexity of the topic and the difficulty involved in identifying a single noise level that could apply to a great variety of tasks and conditions. Although these difficulties still pertain, much research has been generated in this area over recent years.[16]

Noise can cause adverse effects on task performance and behavior at work, and in nonoccupational and social settings. These effects are the subject of some controversy, however, since they do not always occur as predicted. Sometimes noise actually improves performance, and sometimes there are no measurable differences between performance in noisy and quiet conditions. The presence and degree of effects depends on a variety of intervening variables.

1. Sensory and motor effects

Experiments on the effects of noise on vision have produced conflicting results, with the suggestio of some effects on visual discrimination (Cohen, 1977). There is evidence, however, that high levels of noise can produce shifts in visual field (Parker, et al., 1976, 1978). High levels of noise can affect vestibular function, especially when the presentation to the two ears is asymmetrical, (or the level of attenuation is greater in one ear) (Harris, 1968). Impulsive or other sudden loud sounds can produce a startle response that does not completely habituate with repeated, predictable exposures (May and Rice, 1971).

2. Noise variables

Sound level is one of the most important parameters when predicting performance effects. The level of noise necessary to produce adverse effects is greatly dependent upon the type of task. Simple tasks remain unaffected at noise levels as high as 115 dB or above, while more complex tasks are disrupted at much lower levels. Until fairly recently, the level of beginning effects was thought to be around 95 dB for most conditions, but a summary of recent research (Jones, 1990) points to effects at much lower levels. Effects on serial reaction tasks have been noted for continuous noise with C-weighted noise levels of 90 dB (Jones, 1983) and for intermittent noise with C-weighted levels of around 80 dB (Lahtela et al., 1986).

Frequency and temporal characteristics also play a part. High-frequency sound is more disruptive titan low-frequency sound, and intermittent noise can affect performance more adversely titan continuous noise of equivalent energy. Aperiodic intermittencies are more likely to produce adverse effects than regular ones, and impulse noise may be even more disruptive. Again the effects are variable, depending upon task complexity and other factors.

Much of the important research in the effects of noise on performance conducted over the last decade has focused on the effects of irrelevant speech.[17] The adverse effects of irrelevant speech appear to be fairly independent of sound level, at least in the 55-95 dB range, and therefore, are not mitigated simply by attenuating them by 10 dB or so (Jones, 1990). It also appears that irrelevant speech affects processes involving memory (e.g., reasoning, mental arithmetic, and problem solving)

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[16] For a comprehensive review of the effects of noise on job performance, see Suter, 1989.

[17] The initial work was performed by Salame and Baddeley (1982, 1983, and 1987), and has been summarized by Jones (1990) at a recent conference in Stockholm.

rather than attention. With respect to reading tasks, however, meaningful speech is more disruptive than meaningless speech (Jones, 1990). These findings have significance for many modern work and school environments, where information processing and exchange is so important, especially those of the "open plan" variety.

3. Task variables

Task complexity has been identified in numerous experiments as a crucial determinant of the effects of noise on performance. Noise exposure usually leaves simple routine tasks unaffected, and can even improve performance of monotonous tasks, presumably by elevating one's level of arousal (Broadbent, 1971). Some tasks, such as tracking and jobs requiring intellectual function, can be momentarily disrupted without decrements in overall performance (Broadbent, 1979). But if the noise level is sufficiently high or if the task becomes more complex, noise will have an adverse effect. When two or more tasks must be performed simultaneously in a noisy environment, performance on the primary task usually remains unaffected, while performance on the subsidiary task deteriorates (Hockey and Hamilton, 1970; Davies and Jones, 1975; Finkleman and Glass, 1970).

4. After-effects

It seems that noise can have even greater effects after than during exposure. The most common after-effect appearing in the experimental literature is a reduced tolerance for frustration, manifested in a series of experiments as a reduction in willingness to persist in trying to solve insoluble puzzles (Glass and Singer, 1972; Percival and Loeb, 1980). This research also indicates that predictability of the noise signal greatly reduces its adverse after-effects (Glass and Singer, 1972). One study found that the type of noise also influenced the after-effect. Aircraft noise modified to produce sudden onsets and offsets resulted in a lower tolerance for frustration after the exposure than white noise that ad been similarly modified (Percival and Loeb, 1980).

5. Effects of noise on social behavior

There is an extensive literature concerning the effect of noise on social behavior, and just a few examples of this research will be discussed here. Singer et al. (1990) point out that noise has been used as a noxious stimulus in a variety of investigations because it produces the same biological and psychological effects as other stressors. In fact, they observe that the effects of noise combined with perceived control have been frequently demonstrated, and these investigations have also been extended to many other situations where the presence of control reliably moderates the effects of stress.[18]

In a frequently-cited laboratory study, Matthews and Cannon (1975) found that fewer subjects there willing to help someone who had "accidentally" dropped materials when background noise levels there 85 dB than when they there 65 dB. In a subsequent field study, the same results there demonstrated in a background of lawn mother noise, and this time the addition of a cast on the "victim's" arm enhanced helping behavior under quiet conditions, but failed to do so during the noise episodes (Matthews and Cannon, 1975). In another such experiment, Sauser et al. (1978) found that subjects recommended lower salaries for fictitious employees when exposed to A-weighted levels of office noise at 70 to 80 dB than in quiet. Broadbent (1979 and 1983) cites additional evidence suggesting that subjects will give each other increased amounts of shock and noise when they themselves are exposed to noise, and also cites evidence that noise increases anxiety levels (Broadbent, 1983).

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[18] Singer et al. (1990) cite the research of Langer and Rodin on the effects of patient control in a nursing home situation.

As mentioned above, the presence of control, or even perceived control, is one of the most important predictors of adverse behavioral effects. Subjects who perceive that they have control over the noise show significantly greater tolerance for frustration than subjects without control, even if the control is never exercised (Glass and Singer, 1972). In a recent experiment, Singer and his colleagues found that subjects who there told that they had control of an A-weighted, 103-dB noise stimulus showed significantly greater persistence on a difficult task than subjects who had no control or subjects that had control for only part of the experiment (Singer et al., 1990). This finding occurred despite the fact that the subjects with only partial control reported feelings of control no different from those with full control. To the extent that these findings can be generalized to populations living in noisy areas, this kind of research may have significant sociological implications.

6. Summary: Effects on performance and behavior

Noise can adversely affect task performance in a variety of circumstances. In the past, research in this area has focused mainly on the occupational setting, where noise levels must be sufficiently high and the task sufficiently complex for performance decrements to occur. Recent research implicates more moderate noise levels, especially when speech is the disruptive noise stimulus. Some research indicates that noise can also produce disruptive after-effects, commonly manifested as a reduced tolerance for frustration, and it appears that the presence and timing of control over the noise are critical to the prediction of after-effects. Even moderate noise levels can increase anxiety, decrease the incidence of helping behavior, and increase the risk of hostile behavior in experimental subjects. These effects may, to some extent, help explain the "dehumanization" of today's urban environment.

E. Extra-Auditory Health Effects

Noise has been implicated in the development or exacerbation of a variety of health problems, ranging from hypertension to psychosis. Some of these findings are based on carefully controlled laboratory or field research, but many others are the products of studies that have been severely criticized by the research community. In either case, obtaining valid data can be very difficult because of the myriad of intervening variables that must be controlled, such as age, selection bias, preexisting health conditions, diet, smoking habits, alcohol consumption, socioeconomic status, exposure to other agents, and environmental and social stressors. Additional difficulties lie in the interpretation of the findings, especially those involving acute effects. For example, if noise raises blood pressure on a temporary basis, will prolonged exposure produce permanent changes? In cases where these effects are permanent but slight, what are the long-term implications? These types of questions and problems have caused this particular area of noise research and criteria development to be very controversial.

1. Theoretical basis

Noise is considered a nonspecific biological stressor, eliciting a response that prepares the body for action, sometimes referred to as the "fight or flight" response. The physiological mechanism thought to be responsible for this reaction is the stimulation by noise (via the auditory system) of the brain's reticular activating system (Cohen, 1977). Neural impulses spread from the reticular system to the higher cortex and throughout the central nervous system. Noise can, therefore, influence perceptual, motor, and cognitive behavior, and also trigger glandular, cardiovascular, and gastrointestinal changes by means of the autonomic nervous system. Evidence of these effects, however, is not easy to. come by. Despite decades of research and probably hundreds of studies, relatively little can be said with much confidence.

2. Effects on blood pressure

Probably the most attention has been directed toward cardiovascular effects, especially potential elevations in blood pressure. Many studies of the stressful effects of noise have been conducted on rodents and other laboratory animals. the advantage of these studies is that they offer a greater degree of control and it is possible to have longer exposures than with human subjects. The disadvantages are that there is difficulty generalizing to humans, especially with the smaller animals, the expense involved when larger animals are used, and the prevailing public sentiment against animal experimentation.

EPA sponsored one of the most notable animal studies of noise exposure, in which Peterson and his colleagues performed five sets of experiments on the cardiovascular effects of noise on monkeys (Peterson et al., 1978, 1981, and 1983). The stimulus consisted of A-weighted levels of workplace noise at 85 to 90 dB, and the exposures there as long as 9 months. The results showed significant elevations of both systolic and diastolic blood pressure the fact that these changes persisted long after exposure cessation argues for a chronic effect, at least in this case. Unfortunately, an attempt to replicate this experiment with another primate model was discontinued for lack of funding after only two subjects had been exposed (Turkkan, et al., 1983). Relatively few animal experiments have been conducted in this area over recent years.

With respect to laboratory investigations involving human subjects, Rehm (1983) cites six studies showing increases in blood pressure, but questions whether these effects would be permanent. In an attempt to identify more susceptible populations, Michalak et al. (1990) investigated the effects of low-flying aircraft on elderly subjects. Using recorded aircraft sounds, they found significant increases in both systolic and diastolic blood pressure after exposure to the two types of noise, with significantly greater response to the rapid-onset flyover noise. Whether or not these increases would become permanent with protracted exposure is not known.

Field studies of noise and blood pressure among workers or community residents are becoming increasingly popular, but the results are not always consistent. Rehm (1983) has reviewed 14 field studies, mostly of occupational noise exposure, and reports that the majority showed significant increases in either systolic or diastolic blood pressure, or both. Van Dijk et al. (1983), however, reports that six other studies of exposure to occupational noise found no significant differences between exposed and nonexposed groups.

Knipschild and Oudshoom (1977) avoided some of the pitfalls characteristic of epidemiological studies by examining a population near the Amsterdam airport before and after an increase in exposure to aircraft noise, and comparing it to a nonexposed population nearby. The dependent variable was the purchase of certain prescription drugs: tranquilizers, sleeping pills, antacids, and cardiovascular drugs. The investigators found that the use of these drugs in the nonnoise area was essentially stable, whereas the use of most types of these drugs in the area newly impacted by noise increased steadily over the years investigated. This increase was especially noticeable for antihypertensive drugs.

In a more recent review, van Dijk (1990) analyzed 12 cross-sectional studies, with half of them showing a positive relation between noise exposure and blood pressure, and the others no significant effects. Van Dijk criticizes these kinds of investigations for the following kinds of weaknesses: inadequate description of noise and blood pressure measurements; absence or inadequate control of intervening variables; use of hearing loss as a determinant of exposure magnitude; use of hearing. protectors; and questionable interpretation of the results. Part of the problem may be that the investigators often come from only one discipline, when, in fact, a multi-disciplinary team is needed.

Thompson and Fidell (1990) recommend the use of prospective or case-control models, rather than the more convenient cross-sectioned study, and they stress the importance of adequate sample size. They maintain that because any changes in blood pressure resulting from community noise are likely to be small, careful controls, large sample sizes, and at least 5 years of exposure to noise would be nerved to identify significant effects.

3. Effects on blood chemistry

Blood chemistry is also of interest in studies of wire exposure and the cardiovascular system. In the review cited above, Rehm (1983) reports on a series of experiments, both laboratory and field, which show increased levels of the catecholamines epinephrine and norepinephrine. Among them are the series of experiments by Ising and his colleagues (1981a, 1981b, 1981c), showing a connection between noise exposure and magnesium metabolism and humans and animals. According to Rehm, this finding suggests a possible mechanism for cardiovascular effects in that a chronic magnesium imbalance can lead to increased intracellular levels of calcium (in the heart, for instance), which, in turn, can cause vasoconstriction and increases the sensitization for catecholamines.

A large epidemiological study, the Caerphilly and Speedwell Heart Disease Study in England, holds some promise for investigating the effects of road traffic noise (Babisch and Gallacher, 1990). This study of heart disease and a variety of environmental factors uses both the cross-sectional and prospective approaches, and should continue for more than 10 years. The investigators have performed detailed noise exposure measurements. Sample sizes of more than 2000 men have been drawn from both the Caerphilly and Speedwell communities, and controls for age, socio-economic factors, family history, body weight, smoking habits, alcohol, and physical activity have been instituted. Initial results (from the cross-sectional study) indicate significant noise related elevations of serum cholesterol and glucose levels, and plasma viscosity, with an absence of significance for blood pressure or any of the other cardiovascular risk factors. The authors point out that all of the effects there slight, but even small increases, should they prove to be real, would be relevant to the public health.

4. Interactions

Several investigators have suggested that aversion to noise may be more highly correlated with health problems than the noise itself. For example, a study by Rehm (1983) found a significant correlation between noise annoyance and cardiovascular disorders. Her data also suggest that those with existing health problems are more annoyed by environmental factors, such as noise. Similarly, Rovekamp (1983) found that subjects who described themselves as sensitive to noise showed significantly greater noise-induced increases in peripheral vasoconstriction than their "normal" counterparts. Finally, a recent study . of road traffic and aircraft noise failed to show a significant increase in blood pressure resulting from noise, but did show a correlation between the presence of noise and subjective health complaints (Pulles et al.,1990). Differences in effects between noise and non-noise groups there dependent upon the subjects' perceived control over the noise, but independent of noise level.

5. Other adverse effects

Adverse health effects from noise exposure other than cardiovascular effects are even more difficult to isolate. Several studies have investigated the effects of noise on fetal development, with inconclusive results. Some have shown an indication of reduced birth weight or an increase in premature births, but the effects are usually slight, and (except in one case, McDonald et al., 1988), not statistically significant (Rehm and Jansen, 1978; Knipschild et al.., 1981).

The effects of noise on documented mental health disorders are likewise inconclusive. Rehm (1990) cites a series of studies showing increased numbers of psychoneurotic and psychosomatic complaints due to noise exposure, but whether or not these complaints lead to chronic disfunction or illness is not obvious.

6. Summary: Extra-auditory effects

As a biological stressor, noise can influence the entire physiological system. Most effects appear to be transitory, but with continued exposure some effects have been shown to be chronic in laboratory animals. Probably the strongest evidence lies in the cardiovascular effects. However, many studies show adverse effects, while many others show no significant differences between experimental and control populations.

Undoubtedly because of the lack of consistent evidence in thin area, EPA could not use data on extra-auditory health effects in its identification of safe levels of environmental noise. Instead, this subject was relegated to a brief discussion in an appendix in the Levels Document. Although considerable attention was devoted to this topic at the international conference in Yugoslavia, and some coverage was given in the 1973 Criteria Document, the evidence was far from sufficient and much too complex to enable the formulation of dose-response relationships. Later, EPA did fund some promising research in this area (Hattis and Richardson, 1980; Peterson et al., 1978, 1981, 1983; Turkkan, 1983), some of which has clearly demonstrated adverse cardiovascular effects at noise levels typical of occupational settings.

In the interim, there has been considerable European research activity in this area, but nearly 20 years later, criteria are still lacking. What is available, however, should give public policymakers as well as noise producers some reason for concern, especially in situations where those impacted by the noise have no control over or perceive they have no control over their exposures.

F. Annoyance

Annoyance is the measured outcome of a community's response to survey questions on various environmental and other factors, such as noise exposure. Although annoyance in individuals is sometimes measured in the laboratory, field evaluations of community annoyance are most useful for predicting the consequences of planned actions involving highways, airports, road traffic, railroads, or other noise sources. Factors directly affecting annoyance from noise include interference with communication and sleep disturbance, which have been discussed in earlier sections. Other less direct effects are disruption of one's peace of mind, the enjoyment of one's property, and the enjoyment of solitude. The consequences of noise-induced annoyance are privately felt dissatisfaction, publicly expressed complaints to authorities, and potential adverse health effects, as suggested above.

"Annoyance" has been the term used to describe the community's collective feelings about noise ever since the early noise surveys in the 1950s and 1960s, although some have suggested that this term tends to minimize the impact. While "aversion" or "distress" might be more appropriate descriptors, their use would make comparisons to previous research difficult. It should be clear, however, that annoyance can connote more than a slight irritation; it can mean a significant degradation in the quality of life. This represents a degradation of health in accordance with the WHO's definition of health, meaning total physical and mental well-being, as well as the absence of disease.

1. Predicting annoyance for public policy purposes

To facilitate the development of criteria and public policy, Schultz (1978) summarized and analyzed a large number of studies of community annoyance from aircraft, road traffic, and railroad noise. As

part of this effort, Schultz made several simplifying assumptions, among them that the percentage of the population determined to be "highly annoyed" would be the only parameter plotted as a function of day-night average sound level. The resulting curve portrays annoyance as independent of noise source, and it has been dubbed the Schultz curve.

Recently, Fidell et al. (1991) reanalyzed the original data used by Schultz, adding new data from it community noise surveys. The resulting function shows slightly greater annoyance in the range between DNLS of 51 dB and 72 dB, and slightly less annoyance above about a DNL of 76 dB than the original curve. In general, the two curves are fairly close, indicating that the new studies have not drastically altered the prediction of community annoyance, at least when reactions to various noise sources are plotted together. When annoyance from various noise sources is analyzed separately, however, the new data are quite revealing, as will be discussed below.

Although it has been used internationally in the formation of noise policy, the Schultz curve has been the subject of much debate (Kryter, 1982a, 1982b; Griffiths, 1983). For example, Griffiths (1983) criticizes Schultz for treating attitudinal data categorically (highly annoyed or otherwise) rather than scaling it, for failing to analyze the distribution of annoyance, for assuming a fixed threshold for noise-related annoyance, and for choosing such an extreme criterion as highly annoyed. Perhaps because of these reasons, as well as a number of others, researchers and policymakers are beginning to examine alternatives to the Schultz curve for predicting community annoyance from noise.

2. Metrics

The metrics most commonly used to describe the relationship between noise and community annoyance are the equivalent continuous sound level, and the day-night average sound level (DNL), composite ratings based on the A-weighted sound level. The DNL is used almost exclusively for airport planning in the U.S., but this practice has recently been called into question. For example, the importance of communication and relaxation in the evening hours has been recognized (in California and occasionally in Europe) by the use of the community noise equivalent level (CNEL), a metric that includes a 5-dB penalty for noises occurring between 7:00 and 10:00 pm as well as the 10-dB nighttime penalty (California Code of Regulations, 1990). In a study of the communities surrounding two French airports, residents expressed the greatest annoyance during the hours between 7:00 and 11:00 pm (Francois, 1977).

Some authorities are considering the use of the sound exposure level (SEL) for evaluating the effects of single events, such as aircraft flyovers (EPA/FAA, 1990). The importance of other parameters are also being considered, such as rise time (or onset time) as an indicator of the annoyance from low-flying military aircraft (Harris, 1989). Officials from the U.S. Forest Service report that their agency has begun to use an aircraft detectability criterion to site recreational facilities (Harrison et al., 1990).

3. Criteria

Community annoyance resulting from noise-induced activity interference was one of the most important considerations in EPA's identification of an outdoor DNL of 55 dB as the "safe" level of environmental noise (EPA, 1974a). Some years later, a Federal Inter-Agency Committee on Urban

Noise (FICUN) developed guidelines for considering noise in land-use planning and control (DOT, 1980).[19]

In its noise zone classification table, "minimal" exposures to noise there defined as DNLS below 55 dB, and between DNLS of 55 and 65 dB, the exposures there labeled "moderate." However, all of these exposures there considered "acceptable" according to land-use planning standards specified by the Department of Housing and Urban Development (HUD). No research was cited to support these conclusions. In a footnote, FICUN stated the following:

HUD, DOT and EPA recognize Ldn = 55 dB as a goal for outdoors in residential areas in protecting the public health and welfare with an adequate margin of safety (Reference: EPA "Levels" Document.) However, it is not a regulatory goal. It is a level defined by a negotiated scientific consensus without concern for economic and technological feasibility or the needs and desires of any particular community.

The Department of Transportation's Federal Aviation Administration (FAA) has adopted a DNL of 65 as the point above which residential land-use becomes "normally unacceptable." Below this level, the FAA does not require airport authorities to draw noise contours or discuss the impact of airport noise on the surrounding communities for purposes of compatibility planning or to receive grants under the Part 150 program.[20] Thus, public policy decisions, at least on the federal level, have not considered the annoyance of individuals living in the DNL 55-65 dB range.

Recent research confirms the findings of earlier investigations relied upon by the EPA, that annoyance is often generated at day-night average sound levels well below 65 dB (Fidell et al., 1985; Fidell et al., 1991; Hall et al., 1981). Figures 4 and 5 from Fidell et al. (1991) portray the responses from surveys of two mid-sized airports in California: Burbank Airport and the Orange County Airport. The percentage of respondents highly annoyed is depicted as a function of DNL, and compared to the Schultz curve. Both studies show significantly greater numbers of people highly annoyed than would have been predicted by the Schultz curve. For example, at 60 dB, as many as 70 percent of the Burbank population described themselves as highly annoyed and some 40 percent near the Orange County Airport.

Presumably because of this kind of evidence, another interagency task force has convened to discuss the extent to which day-night average sound levels below 65 dB should be taken into account in assessing the impact of aircraft/airport noise, and to examine the possible need for a single-event metric to supplement the DNL (EPA/FAA, 1990).[21]

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[19] FICUN was an ad-hoc interagency panel composed of representatives from EPA, FAA, HUD, the Department of Defense, and the Veterans Administration. In 1990 another such group, the Federal Interagency Committee on Noise (FICON) has been activated (focussing mainly on aircraft noise), but a report has not been published to date.

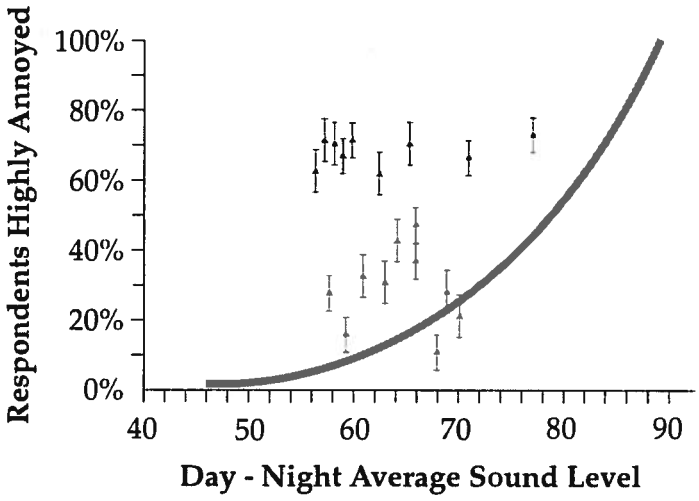
[20] Part 150 studies are conducted at airports where the noise generated by airport construction or expansion is potentially incompatible with the surrounding community. These studies must follow the procedure set out by Federal Aviation Regulations (FAR) Part 150.

[21] The U.S. EPA and FAA put together an intragency agreement to examine the extent to which single event analyses and information beyond the Ldn = 65 contour provide useful additions to current methods of evaluating potential airport noise impacts. Under this agreement, a contractor would identify eight existing airports and perform a quantitative analysis using existing data. No new annoyance data would be developed.

4. Sources

The sources of noise producing community annoyance are primarily aircraft, road traffic, and railroad noise, although noise from industry, construction, and within buildings can also be problematical. The leading offenders are usually aircraft and road traffic noise, although the hierarchy depends upon many factors, such as urbanization, numbers of noise events, and proximity to the sources. Recent research indicates that, despite equivalent noise levels, some sources of community noise are more annoying than others, providing further indication that the Schultz curve cannot be valid for all circumstances.

Treating annoyance from all sources with one predictive curve provokes the hoards of oversimplification. De Jong (1990a) reports that an analysis of Dutch studies carried out over the previous 15 years showed that aircraft and highway noise produced considerably more annoyance than equivalent levels of train, tramway, and urban road noise (Miedema, 1988). The divergence was particularly pronounced at high noise levels. The fact that aircraft generate more annoyance than surface transportation is portrayed dramatically in the analysis described above by Fidell et al. (1991), where annoyance related to mid-sized airports appears substantially greater than that predicted by the Schultz curve, while annoyance from urban sources, such as trains, trams, and street traffic, is considerably less than that predicted by the Schultz curve.[22] Figures 6 and 7, also from Fidell et al. (1991), depict data from British and Swedish railroad studies, showing somewhat less annoyance from these sources in relation to the Schultz curve.



Relationship of data from Burbank Airport Study to 1978 synthesis (Schultz) curve, showing percentage of respondents highly annoyed as a function of day-night average sound level. (After Fidell et al. 1991)

[22] See also Fidell et al. (1985), Hall et al. (1981), and de Jong (1990).

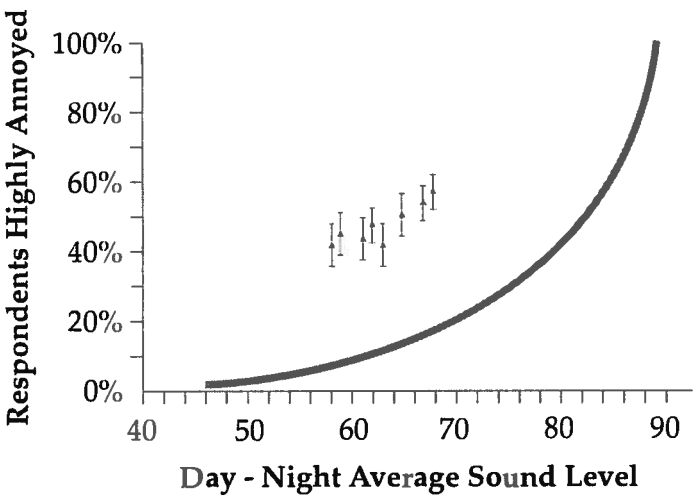


Figure 5
Relationship of data from Orange Country Airport Study to 1978 synthesis (Schultz) curve, showing percentage of respondents highly annoyed as a function of day-night average sound level. (After Fidell et al., 1991).

The explanation for these source-related differences is not necessarily that aircraft noise is inherently more annoying than surface transportation noise. It may be related to differences in people's criteria for responding to various noise sources (de Jong, 1990b; Green and Fidell, 1991). Or it may be caused by differences in sensitivity which are actually biologically based.[23] Green and Fidell (1991) point out that this evidence does not discredit the predictive validity of the DNL, but suggest that communities adopt a more sensitive criterion when evaluating the impact of aircraft noise.[24]

Impulse noise also appears to be more annoying than continuous noise of equivalent energy, and various penalties have been proposed ranging from 0 dB at relatively high ambient noise levels of about 67 dB, to 10 dB at ambient levels as low as 35 dB (Rice, 1983). Vos and Smoorenburg (1983) have recommended a formula for computing the impulse noise penalty, taking into account the type of noise source, the signal level, and the ambient noise level.

As de Jong points out (1990b), most people are exposed to some combination of noise sources, posing a very complex predictive problem. Several models for predicting noise annoyance from complex sources have been proposed, but most fail to solve the difficult theoretical problems involved (de Jong cites Berglund et al., 1981, and Miedema, 1985). Among the groups working on these models are the Institute for Sound and Vibration Research in England, and the Netherlands' Organization for Applied Scientific Research, TNO.

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[23] De Jong (1990b) cites the work of Di Nisi et al. (1987) and Ising, et al.(1981b) to support this theory.

[24] Green and Fidell found a difference of 5.2 dB bettheen the noise levels at which the same percentage of people are highly annoyed by aircraft noise versus noise from surface transportation.

5. Nonacoustics variables

Although it is dear that community annoyance is positively correlated with noise exposure level, other variables also appear to be important, such as ambient noise level, time of day and year, location, and socioeconomic status. None of these other variables, however, is as powerful as the attitude of the residents surveyed. This is a good example of the fact that the human being is not a black box, where the effect is a simple consequence of the input. In a recent analysis of 280 social surveys, Fields (1990) examined 17 hypotheses as they relate to community annoyance from noise. Besides noise exposure level, the only variables Fields identified as strongly correlated with noise annoyance there the attitudinal hypotheses: (1) fear that the noise source might be a danger to the neighborhood, (2) belief that the noise is preventable, (3) awareness that non-noise problems are associated with the noise source, (4) stated sensitivity to noise, and (5) belief that the economic activity represented by the source is not important for the community.

6. Habituation

The evidence is fairly dear that so long as the stimulus remains the same, noise annoyance does not subside over time (e.g., Fields, 1990). Griffiths (1983) cites studies showing no habituation for highway noise 4 months to 2 years after the opening of new routes. De long (1990) found that annoyance in a previously surveyed community increased by 10 percent with no change in noise levels. He suggests that this increase could represent a shift of internal criteria due to increased publicity and other factors, or perhaps an increase in physiological sensitization.

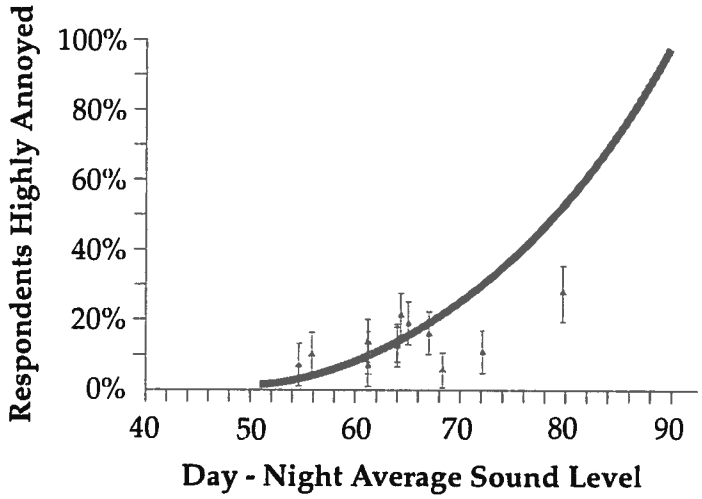

Figure 7 - Relationship of data from Swedish Railroad Study to 1978 synthesis (Schulz) curve, showing percentage of respondents highly annoyed as a function of day-night average sound level. After Fidell et al, 1991).

There has been very little study of the effects of noise-related annoyance on general health, although this would appear to be a fertile field. The study mentioned in section E.4, above by Rehm (1983) suggests a relationship between annoyance and cardiovascular disorders. Likewise, another study indicates a connection between noise and subjective health complaints (Pulles, et al., 1990). De Jong (1990a) refers to the recent use in Germany of the concept of "substantial annoyance" as a

predictor of possible health damage.[25] He recommends the development of an integrated theory of noise effects "to uncover the relationships among medical, physiological, behavioral, and ecological effects of environmental noise. " (de Jong, 1990a, p.520)

8. Summary: Annoyance

Annoyance can be viewed as the expression of negative feelings resulting from interference with activities, as well as disruption of one's peace of mind and the enjoyment of one's environment. Although this reaction can run the gamut of mild irritation to extreme distress, only responses categorized as "highly annoyed" (and greater) have been used to measure the impact of noise on communities. The most respected and widely used criterion to assess community annoyance in the U.S. has been the Schultz curve, although this criterion has been the subject of heated debate. Several recent studies indicate that the Schultz curve underestimates annoyance due to aircraft noise and overestimates annoyance from the noise of urban traffic and trains, leading to the conclusion that annoyance from these categories should be assessed separately. In addition, there has been growing interest in supplementing the traditional DNL with a descriptor for single events.

EPA's Levels Document identified the outdoor level to protect against activity interference as a day-night average sound level of 55 dB. This identification was not to be construed as a standard or regulation,[26] but as information to aid states, localities, and the general public. Later, an interagency task force identified average levels between 55 and 65 dB as "acceptable" for purposes of land-use planning. The DNL 65-dB criterion, which has been applied particularly to airport noise assessments, is now being reconsidered by another interagency task force.

There is evidence that impulse noise is more annoying than continuous noise of equivalent energy, and various correction factors have been proposed to account for the difference. In addition, most people are exposed to a combination of noise sources, and models for predicting the resulting annoyance are in the formative stages.

The most important variables other than noise exposure level relate to people's attitudes about the noise, such as fear of possible danger, stated sensitivity, and the belief that the noise is preventable. Finally, it appears that noise-related annoyance does not subside over time.

VI. Conclusions

Noise has a significant impact on the quality of American life. There is no evidence that the impact has diminished in the years since ONAC was abolished. Rather, it appears that the impact is at least as great, and most probably greater, than it was 10 years ago, due to population growth, especially in urban areas, and the proliferation of certain noise sources.

A considerable amount of noise effects research has been conducted over the last decade, much of it taking place in the European nations where governmental concern about noise is greater than it is in the U.S. at this time. These studies have expanded the knowledge base and filled certain gaps. Many of them suggest important interrelationships between the various noise effects that remain largely unexplored. For example, perceived control over noise appears to decrease its adverse effects on the subsequent performance of certain tasks. The concept of control also has a bearing on annoyance from noise, as do several other nonacoustic factors. Annoyance appears to be related to

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[25] De Jong cites Jansen (1986).

[26] See Foreword, Levels Document (EPA, 1974a).

extra-auditory health effects, and chronic sleep interference, which is a component of annoyance, can have adverse effects on health and well-being.

All of these effects are, to a varying degree, stress related. Nowadays there is increasing evidence in the medical literature on the relationship between stress and illness, one which is often exacerbated by lack of control.

Cumulatively, this evidence suggests the potential for a unifying hypothesis that may well explain some of the health effects that have been observed in connection to noise exposure, but have usually been dismissed because of the absence or insufficiency of direct cause and effect relationships. Such a hypothesis, however, can only be validated by a new interdisciplinary approach, one which takes a broader and somewhat different perspective than is currently employed. This approach could very well provide the key to understanding a great deal more about the general impact of noise on society, and the extra-auditory effects in particular.