City of Riverside

WASTEWATER COLLECTION AND TREATMENT FACILITIES INTEGRATED MASTER PLAN

VOLUME 4: WASTEWATER TREATMENT SYSTEM
CHAPTER 10: RECYCLE STREAM MANAGEMENT

FINAL
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City of Riverside

WASTEWATER COLLECTION AND TREATMENT FACILITIES INTEGRATED MASTER PLAN

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CHAPTER 10: RECYCLE STREAM MANAGEMENT

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RECYCLE STREAM MANAGEMENT

10.1 PURPOSE

The purpose of this chapter is to describe the evaluation of alternatives for handling the recycle flows from dewatering at the Regional Water Quality Control Plant (RWQCP). The aim was to identify a project that could be used to improve secondary treatment operation as well as secondary effluent quality before expanding secondary treatment capacity. This chapter focuses on the treatment and management of the recycle flows from dewatering; it does not consider treatment options for other in-plant recycles such as filter backwash and Dissolved Air Flotation (DAF) underflow, which would not contain significant pollutant loads.

10.2 RECOMMENDATIONS AND CONCLUSIONS

- Both the Single Reactor High-Activity Ammonia Removal Over Nitrite (SHARON) Alternative and the SHARON combined with Anaerobic Ammonia Oxidation (ANAMMOX) Alternative require precise process control. There are only a few SHARON full-scale facilities and no known full-scale SHARON combined with ANAMMOX systems in operation in this country. The ANAMMOX biomass also has a very low growth rate, which means that it would take months to recover from process upsets. Based on these factors, neither the SHARON Alternative nor the SHARON combined with ANAMMOX Alternative appear to be feasible at this time.
- The Centrate and Return Activated Sludge (RAS) Re-Aeration Basin (CaRRB) system uses RAS from secondary treatment to supply biomass and alkalinity for recycle treatment. In this case, the CaRRB system could be housed in the old Chlorine Contact Basin and receive RAS from the two small Plant 2 secondary clarifiers. Analysis showed that this system could increase the capacity of the Plant 2 secondary treatment by approximately 2 mgd, but it could not treat the full recycle stream without exceeding the future effluent Total Inorganic Nitrogen (TIN) limits (10 mg/L). It would also be necessary to pump twice (clarifiers to CaRRB and CaRRB to Plant 2 Aeration Basins). Life-cycle cost for this option is more than twice as high as that of an equivalent capacity secondary treatment plant. Hence, CaRRB is not feasible.
- The Equalization (EQ) Basin Alternative would ensure an even nitrogen load throughout the week and will lead to improved process control. However, the cost of constructing and operating a new EQ basin is high and the benefits of having an EQ basin do not justify the costs. Operating the dewatering system 7 days a week and using the existing 24-hour EQ would achieve the same benefits for a fraction of the cost. Hence, no interim project is recommended. Expansion to 52 mgd, as described

in the remainder of this volume, would make recycle treatment obsolete as the recycle load has been included in the design.

- The City of Riverside (City) should proceed with a 7-days-per-week dewatering operation, in order to achieve lower average TIN concentration load into the aeration basins.

10.3 DESCRIPTION OF EXISTING FACILITIES

At the RWQCP, recycle streams are generated from thickening of Waste Activated Sludge (WAS) from the activated sludge process, backwash of tertiary filters, and the digested sludge dewatering process. Each of the recycle streams has different properties and it is important to account for the impacts these streams have on the wastewater treatment process.

Currently, the tertiary filter backwash water, centrate (from dewatering centrifuge), and filtrate (from dewatering belt filter presses) are combined in waste ponds where they are equalized over a 24-hour period. The combined recycle stream from the waste ponds is pumped into the screened influent upstream of the primary clarifiers. In the past, all flow was recycled to Plant 1 only, causing Plant 1 secondary effluent TIN concentrations to be consistently higher than those in the Plant 2 effluent. Since March 17, 2006, the recycle flows are split between Plant 1 and Plant 2 (with approximately 20 percent to Plant 1 and 80 percent to Plant 2). However, the flow split is not measured and the actual split may differ from this estimate. It may also change over time. It is recommended that these flows be metered in the future, so that the flow split can be quantified and controlled.

The recycle stream from the dewatering units (belt filter press and centrifuge) has a very high ammonia concentration that significantly increases the nitrogen load entering the secondary treatment process. Currently, the centrifuge at the RWQCP is operated continuously and is typically taken off-line for regular maintenance and operation work on Wednesdays. The belt filter presses are operated to dewater sludge when the centrifuge is out of service and/or when there is a need for extra dewatering capacity.

The DAF subnatant (from WAS thickening) is mixed with the RAS and is recycled to the Plant 2 aeration basins.

For a detailed description of the existing facilities, refer to Volume 4, Chapter 1 - Existing Facilities. The description of facilities for handling waste solids generated during the wastewater treatment process is discussed separately. The basis of design for the various solids handling processes is discussed in Volume 8, Chapter 3 - Design Criteria.

10.3.1 Recycle Characteristics

Using the influent quality and operating data, a Biotran model was calibrated (refer to Volume 8, Chapter 3 - Design Criteria). The calibrated model was used to project the future plant performance at an annual average influent flow of 40 mgd. The recycle flow was increased proportionally to account for future annual average flows of 52.2 mgd. An estimate for future recycle stream flows and characteristics was developed. Table 10.1 summarizes the estimated flow and water quality data for the recycle stream from the dewatering process. It was assumed that two-phase digestion would be used. Two-phase digestion allows for higher volatile solids reduction and consequently converts more of the organic nitrogen in the solids into ammonia-nitrogen. Thus, in terms of recycle nitrogen load, two-phase digestion presents the worst-case condition.

Table 10.1 Summary of the Dewatering Recycle Stream Characteristics
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

Parameter	Units	Dilute	Average	Thick
Digester Feed Condition				
Primary Sludge Concentration	%	3.5	4.0	5.0
TWAS Concentration	%	3.0	3.5	5.0
Belt Filter Press(1)				
Filtrate Flow	mgd	0.61	0.52	0.37
Washwater Flow	mgd	0.66	0.57	0.42
Recycle Flow	mgd	1.27	1.09	0.79
TSS	mg/L	768	894	1,225
NH_4-N	mg/L	580	667	884
Amount of N Recycled	lbs/day	6,125	6,049	5,853
Centrifuge(2)				
Centrate Flow	mgd	0.62	0.53	0.38
TSS	mg/L	784	915	1,265
Ammonia as N	mg/L	1,207	1,396	1,883
Amount of N Recycled	lbs/day	6,241	6,183	6,034

Notes:
(1) Recycle stream parameters when only belt filter presses are used for dewatering.
(2) Recycle stream parameters when only centrifuge is used for dewatering.

In Table 10.1, three conditions are presented: dilute, average, and thick. These conditions were derived based on different assumptions (see Table 10.1) for the feed solids content. Feed solids content directly impacts the digester performance and recycle characteristics entering the anaerobic digesters.

The data show that using the belt presses creates much more recycle flow than centrifuges due to the addition of wash water. However, it must be noted that the nitrogen load remains approximately equal. Future projects to thicken primary sludge and WAS using gravity belt thickeners would reduce the recycle volumes below what is shown in the table. As indicated, recycle solids and nitrogen loads would essentially remain constant. Table 10.2 summarizes the estimated impact of the recycle flow from the dewatering process on the organic and nitrogen loads to the secondary process.

Table 10.2 Summary of Impact of Recycle Stream on Wastewater Quality
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

Parameter	Units	Concentration	Load (Pounds per Day)
Influent Characteristics			
Daily Average Flow	mgd	52.2	-
BOD	mg/L	250	108,850
TSS	mg/L	250	108,850
TKN as N	mg/L	35.5	15,455
Ammonia as N	mg/L	21	9,142
Recycle Stream Characteristics[(1)]			
Daily Average Flow	mgd	0.53	-
BOD	mg/L	500	2,210
TSS	mg/L	915	4,045
TKN as N[(2)]	mg/L	1,396	6,170

Notes:
(1) Recycle stream parameters when only centrifuge is used for dewatering for average flow condition. For design purposes, this is considered the worst-case scenario.
(2) The main component will be NH_4-N, with organic-N is contributing only a small part to the Total Kjeldahl Nitrogen (TKN).

As shown, the impact of the recycle flow from the dewatering process on Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) loads are nominal. However, the impact on the total nitrogen load from the recycle stream is significant. Based on the estimates provided, the recycle contributes approximately 40 percent of the total nitrogen that the RWQCP treats. The additional nitrogen load increases the oxygen demand in the aeration basins. The recycle also lowers the BOD:TKN ratio in the aeration basin influent, making denitrification more challenging. This is one of the contributing factors to why Plant 1 effluent has historically had a much higher NO_3-N concentration than Plant 2, and also illustrates how an adjustable recycle flow split between the two plants can be used to optimize denitrification efficiency.

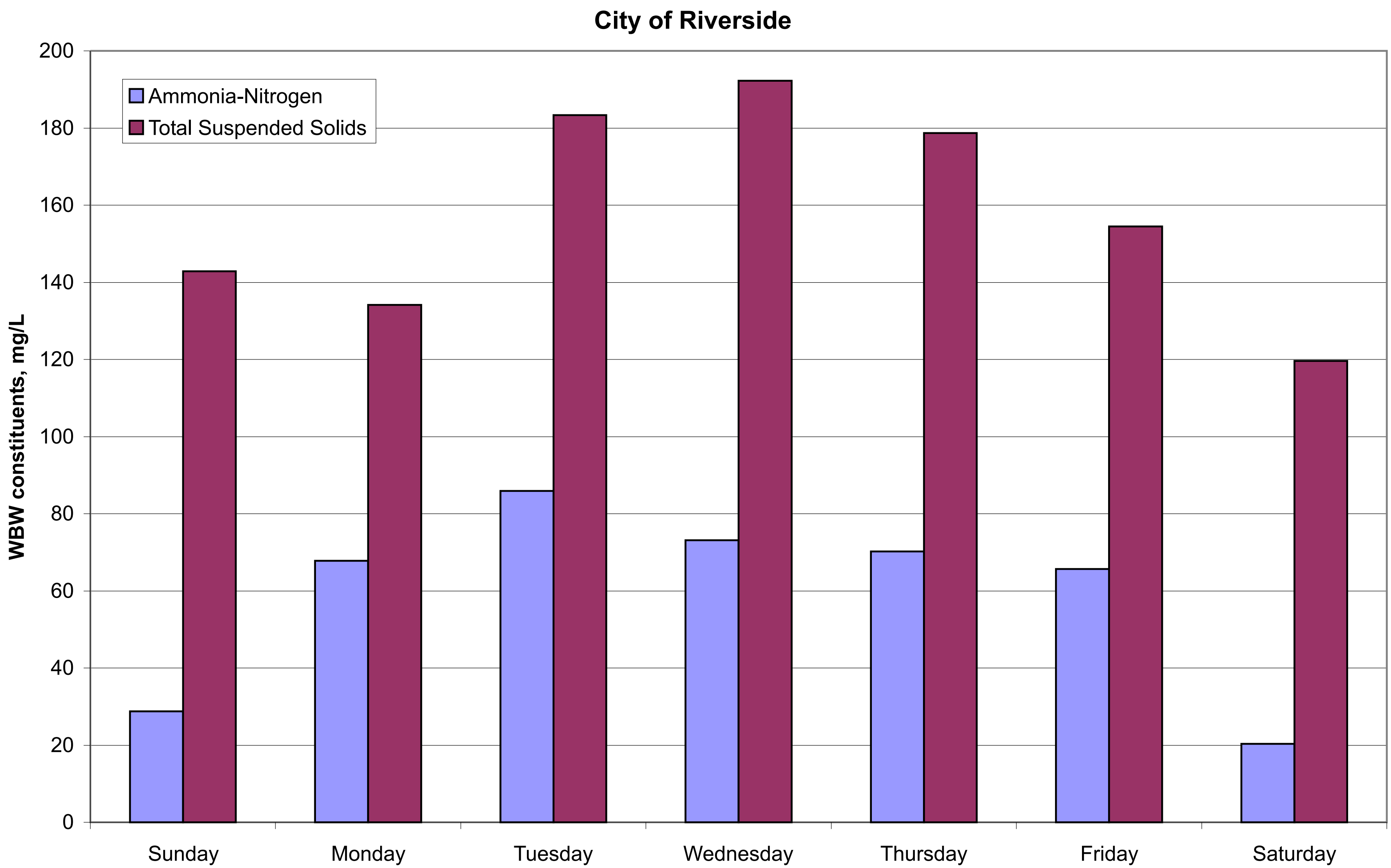
10.4 RECYCLE STREAM HANDLING ALTERNATIVES

The filtrate from the dewatering belt presses and centrate from centrifuges are currently combined with the filter backwash water. The combined flow is stored in backwash lagoons and is then pumped upstream of the primary clarifiers, which provides sufficient EQ to handle diurnal flow peaks. Since dewatering is only operated during the first few days of the week, the nitrogen load in the recycle stream tends to vary according to the day of the week. Figure 10.1 shows how both ammonia-nitrogen (NH_4-N) and TSS concentrations differ in the combined recycle stream according to the day of the week. On average, the NH_4-N concentration peaks at 86 mg/L on Tuesday, while dropping to 20 mg/L on Saturday. Figure 10.2 demonstrates that the effect of this weekday variation causes a variation of effluent nitrate nitrogen (NO_3-N) concentration. Plant 1 effluent NO_3-N, which used to receive the full combined recycle flow, varies from an average of 16 mg/L on Sunday to 24 mg/L on Wednesday. The result is that the combined effluent NO_3-N (not including NH_4-N) from Plants 1 and 2 exceed the TIN limit of 13 mg/L on average Wednesdays and Fridays, and is right at the limit on Thursdays. These findings agree with operator observations. If the recycle stream from the dewatering process were managed and treated separately, then the secondary treatment processes could be better controlled, resulting in reduced operational difficulties.

The high ammonia concentration in the recycle stream impacts the nitrification and denitrification of the liquid-stream process. The additional ammonia added via the recycle stream leads to a carbon-limited condition; which in turn leads to a reduced denitrification capacity. Either additional liquid-stream treatment capacity or a separate recycle stream treatment process is necessary to mitigate these influences.

Four alternatives, described in the following subsections, were considered for separate recycle stream treatment:

1. Alternative 1:
   EQ of recycle flow.
2. Alternative 2:
   Treatment of recycle flow using the SHARON process.
3. Alternative 3:
   Treatment of recycle flow using a combination of the SHARON and ANAMMOX processes.
4. Alternative 4:
   Treatment of recycle flow in the old Chlorine Contact Chamber (1958) using the CaRRB process.



WEEKDAY VARIATION IN NH_4-N AND TSS

FIGURE 10.1

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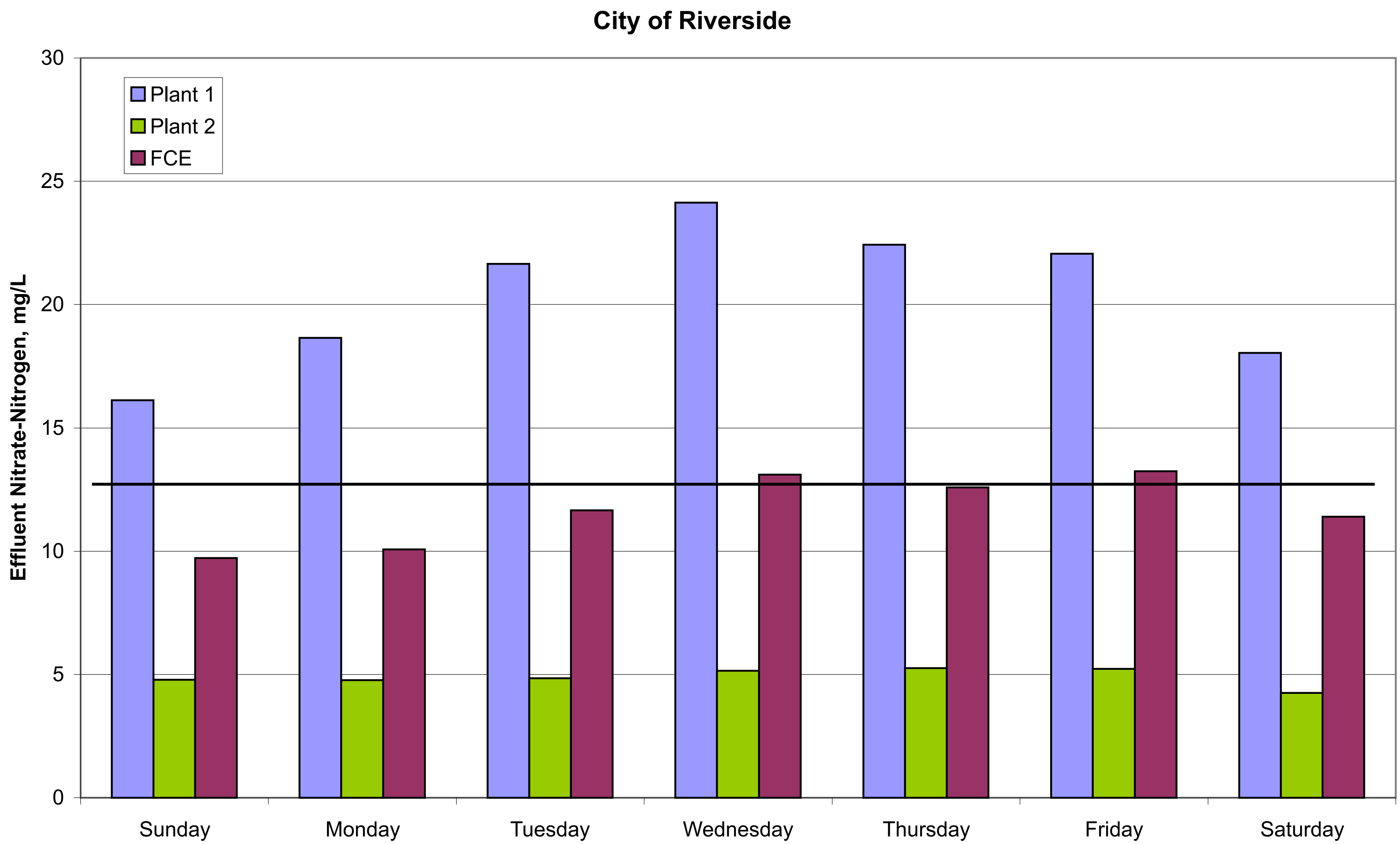

WEEKDAY VARIATION IN EFFLUENT NITRATE - NITROGEN

FIGURE 10.2

10.4.1 Alternative 1 - Equalization of Recycle Flow

This alternative considers EQ of the recycle stream (dewatering recycle only). Table 10.3 summarizes the estimated recycle flows and the EQ basin design information. The basin is sized for 7-day EQ. Currently, dewatering is performed only 4 days a week, depending on process requirements. For the analysis, it was therefore assumed that the dewatering recycle would be produced only 4 days a week, while equalized flow would be recycled 7 days a week.

Table 10.3 Equalization Basin Design
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

Parameter	Value
Recycle Flows	
Average Daily Recycle Flow[1] (A)	0.8 mgd
Weekly Recycle Volume (B)	5.6 mil gal
Dewatering Days Per Week (C)	4 days
Recycle Produced on Dewatering Days (D)	1.4 mgd
Centrate Returned on Dewatering Days (E)	3.2 mil gal
Equalization Basin Requirements	
EQ Volume Required = C x (D – A) = B - E	2.4 mil gal
SWD	24 feet
Length	170 feet
Width	130 feet

Notes:
(1) A conservative flow estimate was used to provide a margin of safety if continued use of belt filter presses is required. This is the constant rate at which recycle is ideally returned to the process.

Plant staff intends to switch entirely to centrifuges for dewatering because of higher cake solids concentration and other benefits. The belt presses would remain as a standby dewatering capacity. A recycle flow of 0.8 mgd was selected for this alternative to enable treatment of recycles when part of the digested solids are dewatered using belt presses. Figure 10.3 shows the area that would be required for an EQ basin. The location has not been set aside for this unit for reasons that will become apparent later.

As can be seen in Table 10.3, the volume required for 7-day EQ is significant. The EQ basin would also require aeration (to prevent odors from developing), mixing to prevent solids from accumulating, and effluent pumping. The odor potential of the recycle would

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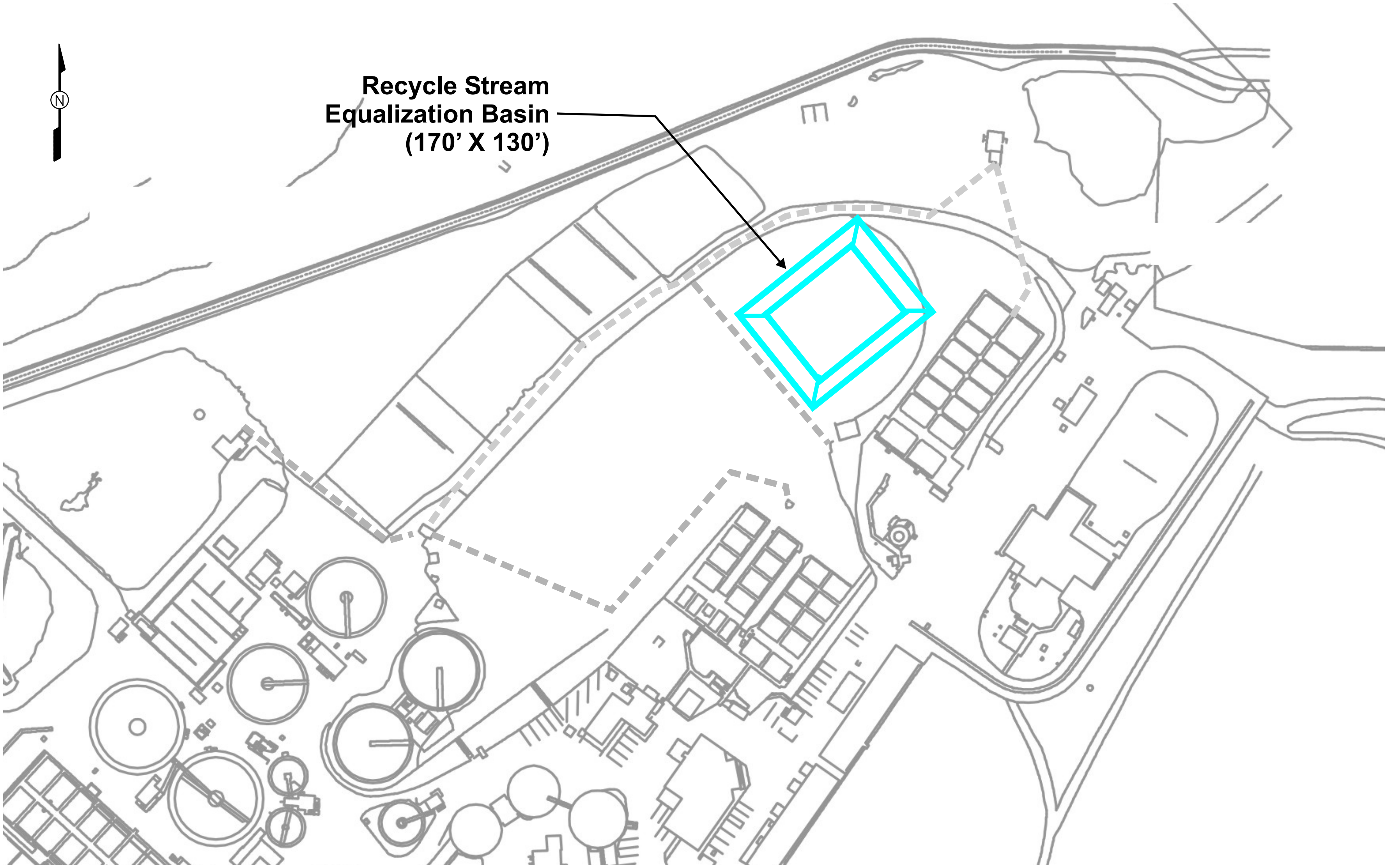

EQUALIZATION BASIN PROPOSED SITE LOCATION

FIGURE 10.3

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depend on how well the anaerobic digesters were performing. For example, an overloaded digester might turn acid and would result in high concentrations of volatile fatty acids in the recycle, which would produce significant odors. Likewise, the recycle suspended solids concentration would depend on solids capture during dewatering. In other words, some variation in recycle quality is probably unavoidable and could potentially make operation of an EQ tank very challenging.

The existing system, which allows for 24-hour EQ of filtrate (combined with filter backwash) would be adequate, if the sludge dewatering was operated 7 days a week, even if that would mean dewatering for only a couple of hours per day. From our discussions with City staff, it appears that this would be feasible. We recommend that the City proceed with a 7-days-per-week dewatering operation. This would ensure more stable operation and achieve a lower average TIN concentration in the plant effluent.

10.4.2 Alternative 2 - Single Reactor High-Activity Ammonia Removal Over Nitrite

The SHARON system has been used for the treatment of sidestreams from the dewatering process to achieve high total overall nitrogen removal. Figure 10.4 shows a process schematic of the SHARON process.

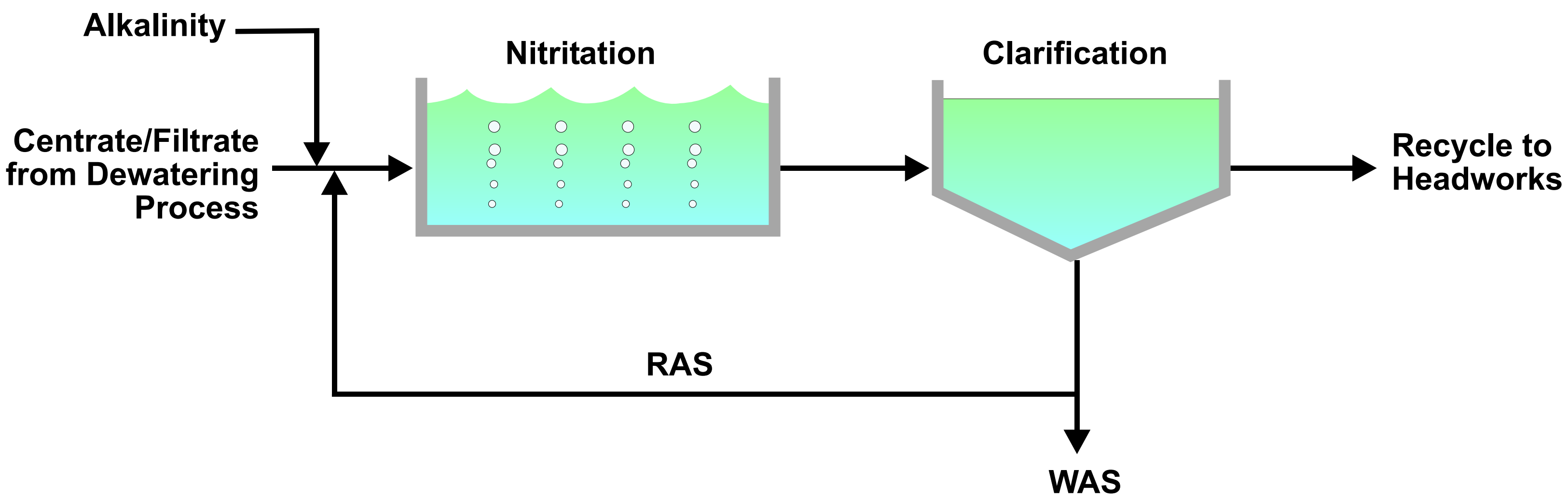
Conversion of ammonia to nitrate in wastewater treatment occurs as a two-step process, where ammonia is first oxidized to nitrite by Ammonia Oxidizing Bacteria (AOB). The nitrite is then oxidized to nitrate by Nitrite Oxidizing Bacteria (NOB). The two steps can be summarized by the two chemical reactions, excluding the production of biomass:

$$2\ NH_4^+ + 3\ O_2 + 4\ HCO_3^- \rightarrow 2\ NO_2^- + 6\ H_2O + 4\ CO_2 \text{ (Nitritation)} \qquad (1)$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^- \text{ (Nitratation)} \qquad (2)$$

SHARON is a high-rate process for the removal of total nitrogen operating with minimal Solids Retention Time (SRT). Due to differences in growth rates of the AOB and NOB at the process design temperature (30 degrees to 40 degrees Celsius, which conveniently coincides with the operating temperature for anaerobic digestion), a selection can be made wherein the NOB can be washed out of the system, while AOB are retained. In other words, the system is manipulated so that only the nitrite reaction (1) is allowed to take place.

The digested sludge would be at the required temperature. Contact with air, however, allows cooling due to evaporation. In a dry climate, such as is typical in Southern California, evaporation rates are higher, leading to more cooling. Should the sludge be dewatered using the belt presses (worst-case scenario), cooling would start during dewatering. Cooling would also take place during equalization. Due to the high capacity of the dewatering equipment, 24-hour equalization would still be required, as mentioned in Section 10.4.1. Some of the recycle would remain in the EQ basin for close to 24 hours, which would allow



SHARON PROCESS SCHEMATIC

FIGURE 10.4

ample time for cooling. Hence, it would be necessary to reheat the recycle upstream of the SHARON process. It was assumed the recycle would cool to the same temperature as the influent flow. In reality, the recycle temperature would vary during the day and may, under certain conditions (low air temperature, humidity, and high wind speed), be much cooler than influent flow. The long retention time in the SHARON basin makes significant further cooling very likely.

Figure 10.5 illustrates that a narrow range for SRT (and temperature) must be maintained for the SHARON process to work. Due to this narrow range, very precise process control is required for this alternative. The SHARON process can be designed so that SRT equals Hydraulic Residence Times (HRT) in a temperature ranging from 30 to 35 degrees Celsius, thereby eliminating the need for a clarifier. However, this means that it is not possible to control SRT and that SRT would fluctuate (as HRT does) with flow. It was therefore decided to include clarifiers in the analysis. Also illustrated in Figure 10.5, the temperature range at a given SRT, is equally narrow. This means that heating would need precise control. However, the inherent inertia in thermal systems would help stabilize variations in heat requirements. Using this mode of operation allows for a 25 percent reduction in oxygen demand, as indicated by comparing reaction (1) to the complete oxidation, reactions (1) and (2). This results in a similar reduction in the aeration energy required. Once the oxidation product (nitrite or nitrate) must be denitrified, there is also a difference, as can be seen in the associated chemical reactions, again excluding the effect of growth:

$$3\ C_6H_{12}O_6 + 24\ NO_2^- + 6\ CO_2 \rightarrow 24\ HCO_3^- + 6\ H_2O + 12\ N_2\uparrow \qquad (3)$$

$$5\ C_6H_{12}O_6 + 24\ NO_3^- \rightarrow 6\ CO_2 + 24\ HCO_3^- + 18\ H_2O + 12\ N_2\uparrow \qquad (4)$$

As can be seen, there is a 40-percent reduction in the required BOD for denitrification.

Our analysis indicated that the high NH_4-N concentration would require an external dose of alkalinity to prevent pH from dropping to the point where nitrification is inhibited. It is assumed that lime would be the cheapest source of alkalinity. The nitrite in the SHARON effluent is recycled to the aeration basins where it is then denitrified in the anoxic zones. Unconverted nitrite remaining in the effluent from the anoxic zones would be oxidized to nitrate in the downstream aerobic zone. Additionally, mainstream reactor cost savings are achieved, since this process reduces the ammonia-nitrogen load. Our analysis indicates that the capacity of the existing facilities would increase by 10 percent (to 44 mgd) if this alternative is used to treat the recycle. In order to function properly, the SHARON process would require an equalized feed. Therefore, the facilities required for SHARON are in addition to those shown in Table 10.3.

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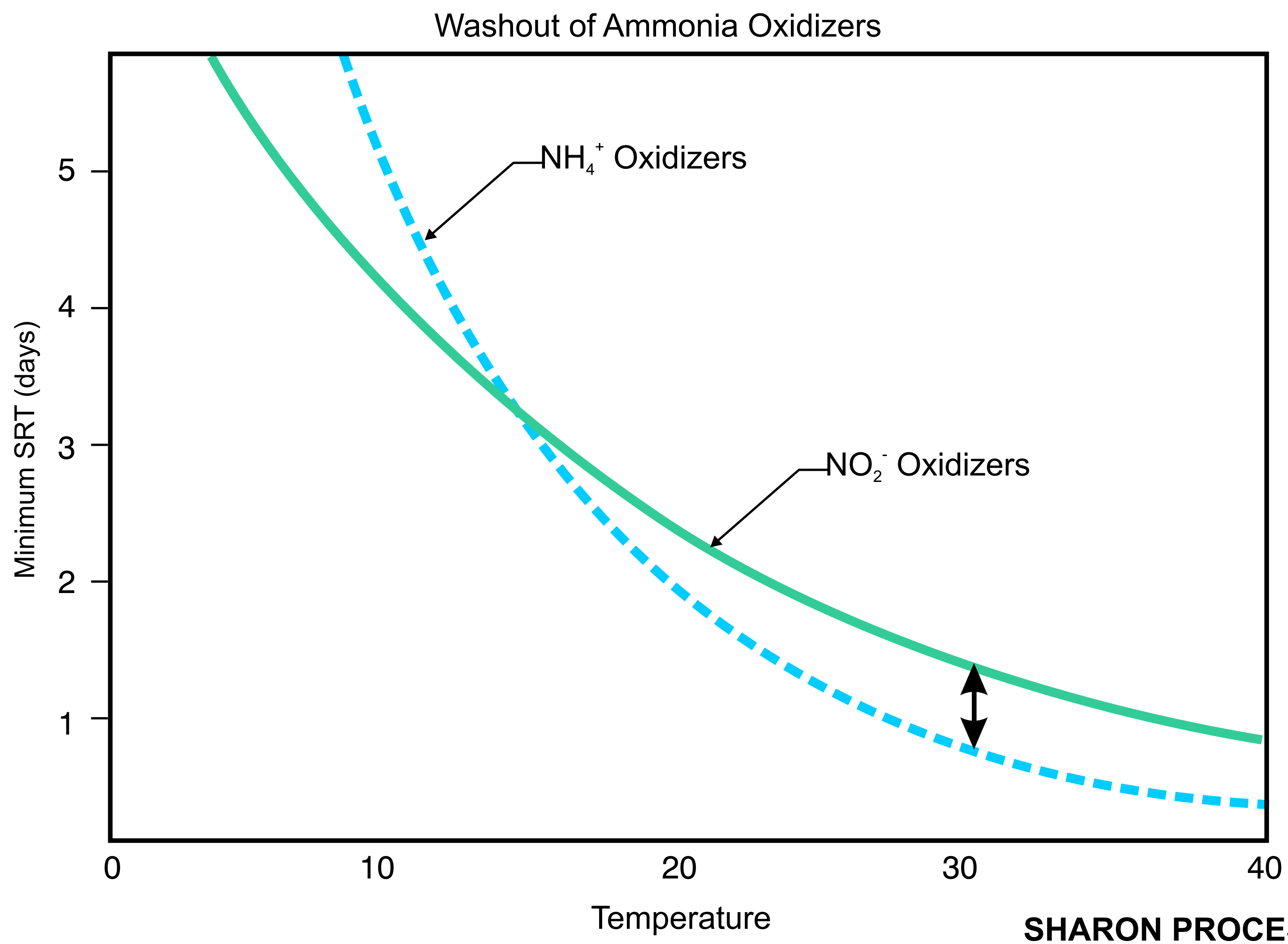

SHARON PROCESS SELECTIVE WASHOUT OF AMMONIA OXIDIZERS

FIGURE 10.5

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Table 10.4 summarizes the design of the SHARON process for treating recycle at the RWQCP.

Table 10.4 SHARON Process Design
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

Parameter	Value
Average Daily Recycle Flow(1)	0.8 mgd
MLSS	2,500 mg/L
SRT	1.5 days
Volume	465,800 gallons
Tank Dimensions	
SWD	15 feet
Length	91 feet
Width	45.5 feet
Process Requirement	
Oxygen Requirement	12,000 lbs/day
Lime Requirement	9,665 lbs/day
Heat Requirement (average)	5.1 MMBtu/hr
Heat Requirement (maximum)	7.5 MMBtu/hr
Projected Effluent Quality	
BOD	5 mg/L
TSS (depending on clarifier performance)	10 mg/L
NH_3-N	50 mg/L
NO_2-N	806 mg/L
NO_3-N	40 mg/L
Alkalinity	75 mg/L

Notes:
(1) A conservative flow estimate was used to provide a margin of safety if the City continues using belt filter presses.

The heat requirement represents 29 percent of the digester gas under average conditions and 42 percent under conditions of maximum demand, assuming conventional digestion.

10.4.3 Alternative 3 - Anaerobic Ammonia Oxidation Combined with Single Reactor High-Activity Ammonia Removal Over Nitrite

The ANAMMOX process is a relatively new biological process, wherein process conditions are created for a select group of microorganisms, the so-called ANAMMOX organisms, to oxidize ammonia using nitrite in place of oxygen. The ANAMMOX process can be represented by the following reaction, excluding growth:

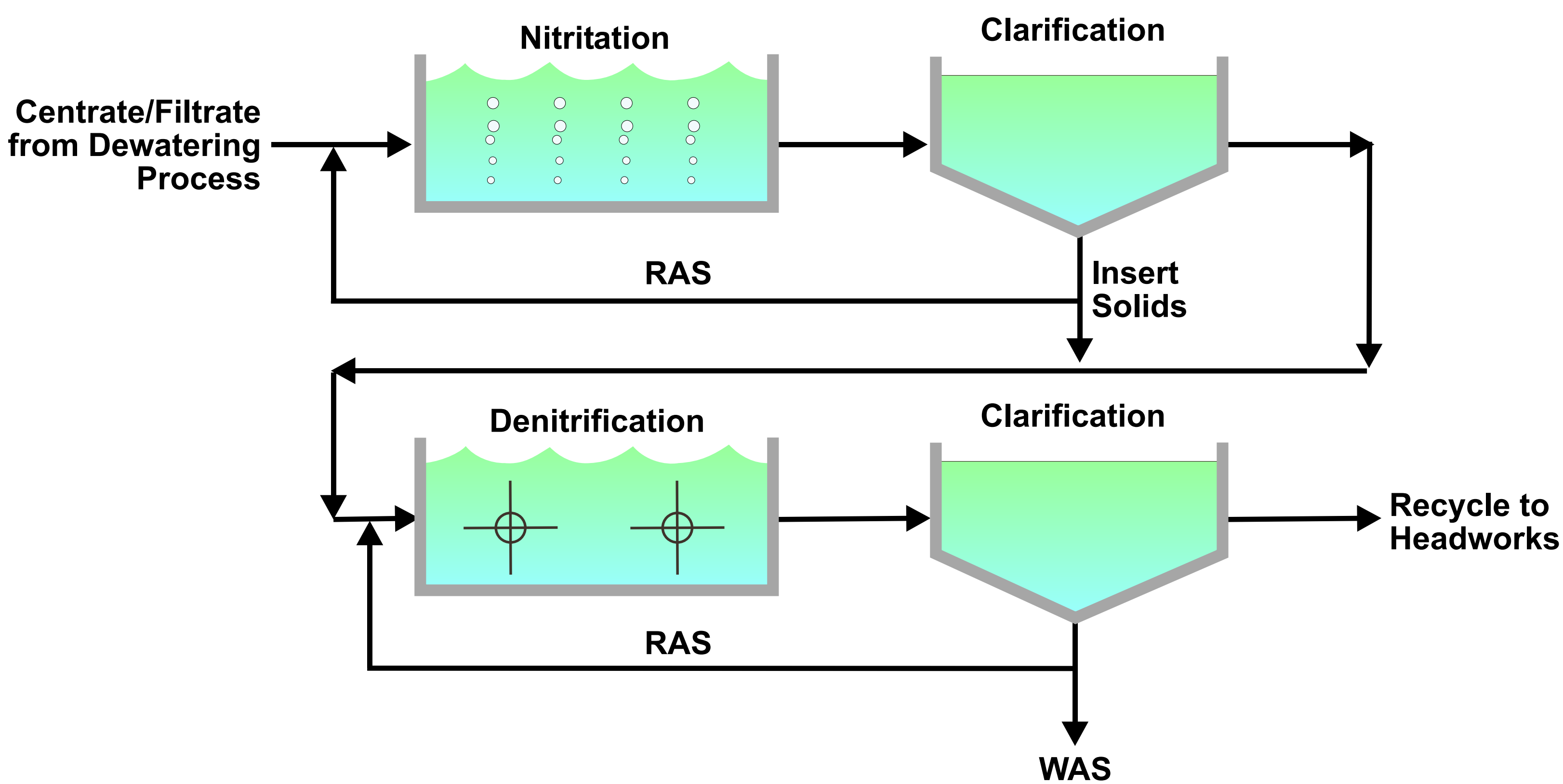
$$NH_4^+ + NO_2^- \rightarrow N_2 + 2\ H_2O \qquad (5)$$

The ANAMMOX organisms are autotrophic and are known to grow at higher temperatures (30 to 35 degrees Celsius) and have a low-growth rate (doubling time of approximately 10 days). Therefore, to cultivate a sizeable population of ANAMMOX organisms, an SRT of about 30 to 40 days, as a minimum, is required. As with the SHARON process, reheating of the recycle would be required.

Since ANAMMOX organisms use nitrite instead of oxygen, a nitrite source is necessary. Bench scale tests have shown effluent from the SHARON process, which is rich in nitrite, to be a very effective source of nitrite for the ANAMMOX organisms. Figure 10.6 shows a possible arrangement that could be effectively used for nitrogen removal using the combined SHARON and ANAMMOX processes. In order to use SHARON effluent as a feed for ANAMMOX, the SHARON system is designed to convert only 50 percent of the incoming NH_4-N to nitrite; the remainder is converted to molecular nitrogen in the ANAMMOX basin. Due to the lower conversion of ammonia to nitrite, our analysis indicates that there is no need for external alkalinity. Additionally, the air required for the SHARON process is reduced by 50 percent, compared to the full SHARON process. Process control requirements would be even greater than for a full SHARON process, as the reaction must be maintained at 50-percent conversion.

Unlike the SHARON process, the combined SHARON-ANAMMOX process would achieve full nitrogen removal, i.e., little or no denitrification of nitrite would be required in the existing aeration basins. This would allow the available BOD to be used more effectively for denitrification of nitrate produced in the aeration basins. This means that the required denitrification can be achieved in a smaller anoxic zone, which would leave a larger aerobic fraction in the aeration basin. The larger aerobic fraction allows for nitrification of a larger nitrogen mass (lb/d), which in turn translates into increased basin capacity. The SHARON-ANAMMOX process results in:

- A reduction of the required denitrification capacity in the anoxic zone.
- A 3-mgd capacity increase in the aeration basin, compared to SHARON alone.
- A 7-mgd capacity increase in the aeration basin, compared to no recycle treatment.



SHARON AND ANAMMOX PROCESS SCHEMATIC

FIGURE 10.6

The design of the ANAMMOX process for treating recycle at the RWQCP is summarized in Table 10.5.

Table 10.5 SHARON-ANAMMOX Process Design
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

Parameter	Value
SHARON Process	
Average Daily Recycle Flow through SHARON	0.8 mgd
MLSS	2,500 mg/L
SRT	1.5 days
Volume	232,900 gallons
Tank Dimensions	
SWD	15 feet
Length	65.0 feet
Width	32.5 feet
Process Requirement	
Oxygen Requirement	6,000 lbs/day
Heat Requirement (average)	5.1 MMBtu/hr
Heat Requirement (maximum)	7.5 MMBtu/hr
Projected Effluent Quality	
BOD	6 mg/L
TSS (depending on clarifier performance)	10 mg/L
NH_3-N	270 mg/L
NO_2-N	274 mg/L
NO_3-N	14 mg/L
Alkalinity	195 mg/L
ANAMMOX Process	
Average Daily Recycle Flow	0.8 mgd
MLSS	2,500 mg/L
SRT	37 days
Volume	867,100 gallons
Tank Dimensions	
SWD	15 feet
Length	124 feet
Width	62 feet

Table 10.5 SHARON-ANAMMOX Process Design Wastewater Collection and Treatment Facilities Integrated Master Plan City of Riverside	
Parameter	**Value**
Projected Effluent Quality	
BOD	6 mg/L
TSS (depending on clarifier performance)	10 mg/L
NH_3-N	25 mg/L
NO_2-N	20 mg/L
NO_3-N	2 mg/L
Alkalinity	195 mg/L

The effect of the low growth rate of the ANAMMOX biomass is reflected in the large basin requirement and the high SRT.

10.4.4 Alternative 4 - The Centrate and RAS Re-Aeration Basin Treatment Process

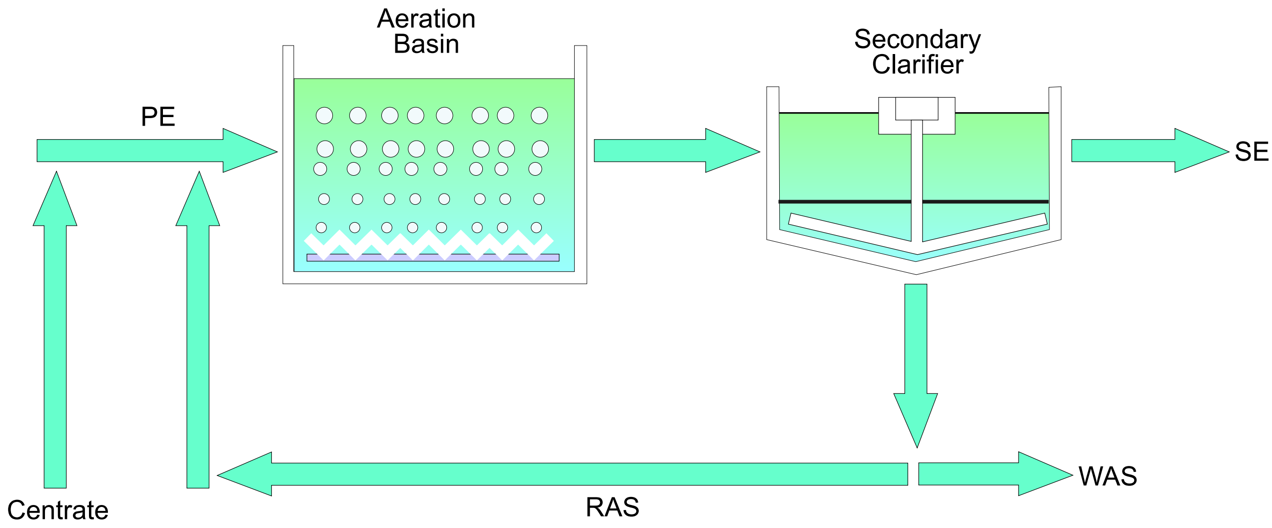
Activated sludge treatment can be used to reduce side stream centrate ammonia loads back to the main aeration basins. Conventional activated sludge systems treating side stream ammonia loads require clarifiers in order to concentrate biomass for return to the head of the process for seeding. Because the nitrifier growth rate is relatively slow, long SRTs are often required when treating high strength ammonia side streams.

Where RAS from a nitrifying system treating primary effluent is available, side stream clarifiers can be eliminated. Introducing RAS into an independent aeration basin prior to return to the main treatment plant is commonly termed sludge re-aeration. When RAS and centrate is combined in a separate basin, it is termed a CaRRB.

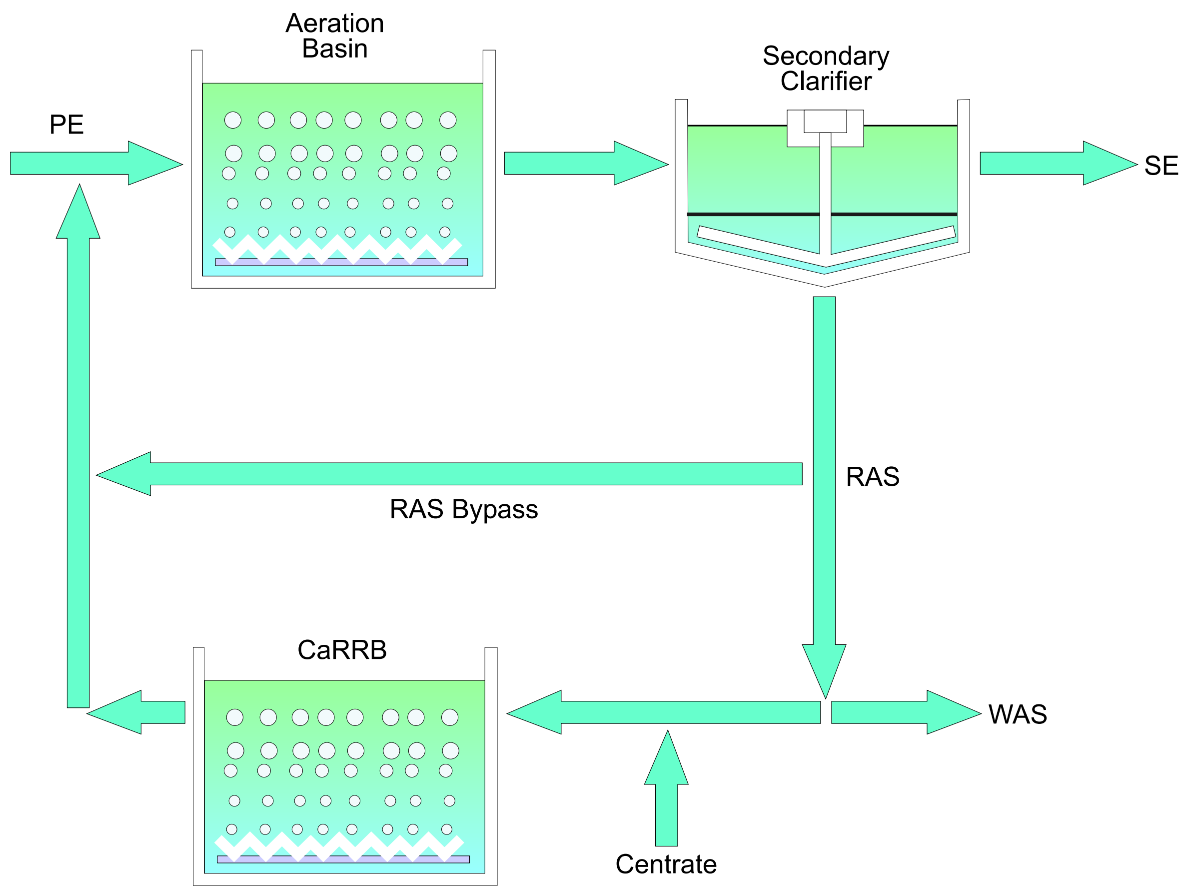
Figure 10.7 compares the CaRRB process with the conventional (existing) process. As can be seen, the main differences are the presence of the CaRRB basin and that the centrate and part of the RAS are rerouted to the CaRRB basin. After treatment, the combined stream is routed to the main aeration basins. A RAS bypass of the CaRRB basin would allow maximum flexibility and control.

The CaRRB system allows one to increase the SRT by inventorying active solids at RAS concentrations at the head of the aeration basins. This is similar to a step feed approach where solids vary from high concentrations at the head of the basin to lower concentrations at the end of the basin.

Other benefits of the CaRRB process include accelerated nitrifier growth rate in the main activated sludge aeration basins associated with nitrifier seeding from a high ammonia environment. CaRRB basins also provide a high biomass buffer to assimilate changes in



(A) Conventional Activated Sludge



(B) CaRRB

CaRRB PROCESS FLOW DIAGRAM

FIGURE 10.7

ammonia load prior to reaching the main aeration basins. Other agencies operating this process have reported reduced oxygen demand associated with incomplete conversion from nitrite to nitrate possibly due to ammonia inhibition. Where CaRRB basins are configured to allow for anoxic zones at the end of the basin, denitrification of nitrified centrate can be achieved. Nitrification/denitrification of centrate prior to feed into the main aeration basins will improve the BOD/TKN ratio.

Other agencies have successfully used centrate and RAS re-aeration for reduction of side stream ammonia loads from centrate. The Chino Basin Municipal Water District (now Inland Empire Water Reclamation District) has used this process successfully at their Carbon Canyon Wastewater Reclamation District. Successful treatment to low ammonia levels was achieved in a basin volume equivalent to 50 percent of the main aeration basins. However, they no longer use this procedure because their recycle streams are routed to another facility.

Perhaps the most significant agency to use centrate and RAS re-aeration as part of their activated sludge system to reduce return flow ammonia loads is the New York City Department of Environmental Protection (NYCDEP). NYCDEP performed a decade-long research and pilot-scale testing program to evaluate processes for reducing ammonia loads from centrate side streams. Since NYCDEP operates several regional biosolids processing centers that take solids from several plants, ammonia loads from centrate are relatively high. After years of pilot-scale and full-scale testing, the NYCDEP is moving to convert each of their 14 wastewater treatment plants (treating up to 1.8 bgd) to a centrate and RAS re-aeration design. NYCDEP is currently operating the centrate and RAS re-aeration process full-scale at their 85-mgd, 26th Ward Wastewater Treatment Plant.

The RWQCP is currently configured in a manner that allows CaRRB to be incorporated into the Plant 2 activated sludge process using the old Chlorine Contact Chamber (1958). Figure 10.8 shows a schematic of the CaRRB process and the Plant 2 activated sludge system. Table 10.6 shows the available volume in the old chlorine contact chamber.

Table 10.6 CaRRB Process Design
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

Parameter	Value
Average Daily Recycle Flow(1)	0.11 to 0.24 mgd
MLSS	4,500 to 14,000 mg/L
SRT	0.4 to 1.0 days
HRT	1.3 to 3.7 hours
Tank Dimensions	
SWD	8.0 feet
Length	79 feet

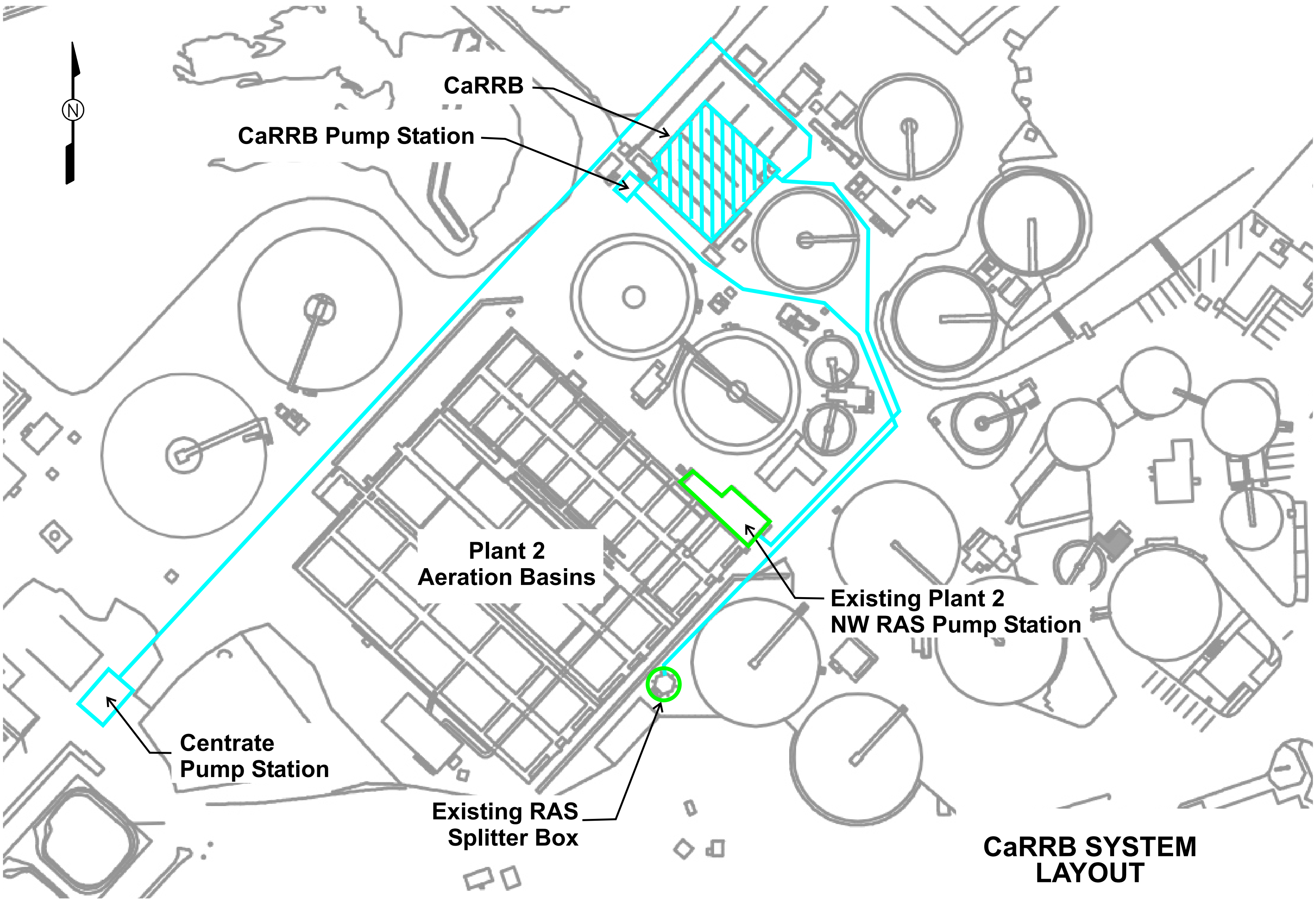
Table 10.6	CaRRB Process Design Wastewater Collection and Treatment Facilities Integrated Master Plan City of Riverside
Parameter	**Value**
Width	79 feet
Channel Width	15.5 feet
Volume	373,500 gallons
Process Requirement	
Oxygen Requirement	6,200 to 9,500 lbs/day
Projected System Performance, % of centrate NH_4-N converted to(2)	
NH_3-N	38 to 41
NO_2-N	6 to 20
NO_3-N	39 to 65
Effluent pH	5.6 to 6.5
Effluent Alkalinity, mg/L as $CaCO_3$	10 to 120

Notes:
(1) Only part of the filtrate/centrate can be accommodated in the CaRRB/Plant 2 system.
(2) Reporting CaRRB effluent concentrations can be misleading as the feed and effluent concentrations are affected by dilution with RAS.

The CaRRB process is operated much like the current activated sludge process by maintaining required biomass concentrations under aeration with centrate as substrate feed. Similar to the existing activated sludge process a continuous return stream of biomass through RAS is required. The CaRRB process uses biomass captured and concentrated in the existing Plant 2 secondary clarifiers with the existing RAS pumps used to return a portion of the RAS back to the CaRRB basin. Factors that may limit the degree of centrate nitrification in the CaRRB process:

- Alkalinity:
  Alkalinity is added by both the RAS and the centrate. Centrate generally contains a significant amount of alkalinity in the form of soluble ammonia, however, that alkalinity is used up in the nitrification reaction. When alkalinity is depleted, the pH in the aeration basin will drop and inhibit nitrification. Therefore, alkalinity is sometimes the limiting parameter that controls the degree of nitrification in CaRRB. Our modeling showed that the alkalinity available in the centrate and RAS mixed liquor is not the limiting factor. Supplemental alkalinity addition would not be required.

- Kinetics:
  The conversion efficiency is limited by the available volume in the old chlorine contact chamber.



CaRRB SYSTEM LAYOUT

FIGURE 10.8

carollo
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WASTEWATER COLLECTION AND TREATMENT FACILITIES INTEGRATED MASTER PLAN

CITY OF RIVERSIDE

- Aeration Capacity:
  It is assumed that it would be possible to supply enough air to maintain a Dissolved Oxygen (DO) concentration of 2.0 mg/L in the CaRRB at all times. Depending on operational parameters (RAS feed rate and Mixed Liquor Suspended Solids (MLSS) concentration) and other factors (such as wastewater temperature) this may be difficult to achieve.

- Plant 2 RAS Rate:
  As the Plant 2 RAS rate is increased, the RAS MLSS concentration will decrease. This will affect the MLSS concentration in the CaRRB. As with any activated sludge process, the reaction rate in CaRRB will be directly proportional to MLSS concentration. The Plant 2 RAS rate cannot be controlled by CaRRB requirements; it is determined by the requirements of the Plant 2 secondary clarifiers.

- RAS Flow Split:
  The system can be operated with all of the RAS returned to CaRRB or some of the RAS split between CaRRB and the aeration basins. The amount of RAS returned to CaRRB is an operational decision based on balancing several parameters including: overall nitrification capacity, CaRRB hydraulic retention time, centrate dilution with adequate RAS flows to prevent ammonia toxicity, centrate dilution to minimize struvite formation, biomass seeding requirements, and process stability. In order to provide centrate ammonia dilution and avoid ammonia toxicity, a minimum RAS to centrate dilution ratio of 20 or 30:1 is recommended. Ammonia toxicity would lead to high nitrite concentrations in the CaRRB with some nitrite eventually appearing in the secondary effluent. As nitrite-nitrogen exerts a high chlorine demand (5 mg Cl_2/mg NO_2-N), this needs to be avoided.

The biggest concern with CaRRB is that it appears to make denitrification more challenging in Plant 2. This is due to the fact that much of the nitrogen is returned to the aeration basins as nitrate, while the available BOD in the recycle stream has been consumed in the CaRRB.

10.5 COMPARISON OF RECYCLE TREATMENT ALTERNATIVES

10.5.1 Non-Economic Comparison

Advantages and disadvantages for the three alternatives discussed in this chapter are shown in Table 10.7.

Table 10.7 Advantages and Disadvantages of Screening Alternatives Wastewater Collection and Treatment Facilities Integrated Master Plan City of Riverside	
Advantages	**Disadvantages**
Alternative 1 - Equalization	
• Reduces peak recycle nitrogen loads by equalizing the flows. • Provides better control of recycle and lower peak loads.	• Additional storage space required. • Advantageous only if the dewatering is not carried out 7 days a week. • Odor from the EQ basin could be a nuisance.
Alternative 2 - SHARON	
• Lower oxygen requirement. • Lower carbon requirement for denitrification. • Increases nitrification capacity. • Increases plant capacity.	• Large basin required. • Precise process control required. • No known full-scale facilities in the United States. • Recycle reheating required.
Alternative 3 - SHARON and ANAMMOX	
• Lower oxygen requirement than SHARON alone. • No carbon requirement for denitrification. • Increases TN removal capacity.	• Low growth rates of ANAMMOX organisms. • Requires numerous basins. • Very precise process control required. • No known full-scale facilities. • Recycle reheating required.
Alternative 4 - CaRRB	
• Reseeds main ABs with nitifiers. • Increases overall SRT and/or clarifier capacity. • Increases plant capacity.	• Affected by RAS rate. • Only ~50% ammonia oxidation. • Affects Plant 2 denitrification potential. • Highest oxygen demand of alternatives.

A comparison of the three different recycle stream treatment alternatives discussed in this chapter is shown in Table 10.8. The EQ Alternative does not provide a reduction in the nitrogen load going to secondary treatment; it only provides the operators with a better tool for managing recycle flow. However, the nitrogen load is reduced for all other alternatives.

Table 10.8 Comparison of Recycle Treatment Alternatives
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

	Equalization	SHARON	ANAMMOX	CaRRB
Constructability	+	–	–	0
Maintenance Requirements	+	–	–	0

Table 10.8 Comparison of Recycle Treatment Alternatives
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

	Equalization	SHARON	ANAMMOX	CaRRB
Aeration Energy Input	+	–	–	–
Heat Input	+	–	–	+
Operating Experience	+	–	–	0
Process Complexity	+	0	–	0
Requirement for Precise Process Control	+	–	–	–
Recovery From Upset	+	0	–	+
Reduction in Nitrogen Load	–	0	+	0
Reliability	+	0	–	+
Capital Cost	–	0	–	0
O&M Cost(1)	0	+	+	0

Notes:
(1) O&M costs refer to the overall cost of treatment, not just the cost of treating the recycle stream.

Legend:
+ = Positive comparative characteristic.
– = Negative comparative characteristic.
0 = Neutral comparative characteristic.

10.5.2 Economic Evaluation

As the precise process control requirements and significant reheating requirements make the SHARON and ANAMMOX Alternatives unfeasible, they were not included in the economic evaluation.

A life-cycle cost analysis was performed for the remaining alternatives. The resulting costs were then compared to the costs of a new 1-mgd activated sludge system. Table 10.9 displays a summary of the results found in the cost analysis performed.

Table 10.9 Life-Cycle Cost of Recycle Treatment Alternatives
Wastewater Collection and Treatment Facilities Integrated Master Plan
City of Riverside

	New Activated Sludge System (1 mgd)	Equalization	CaRRB
Capital Cost	$2,882,000	$2,877,000	$10,165,000
Annual O&M Cost	$230,000	$110,800(1)	$299,000
Life-Cycle Cost(2)	**$6,830,000**	**$4,780,000**	**$15,559,000**

Notes:
(1) Includes only cost for pumping, aeration, and mixing.
(2) As present value, assuming a life-cycle period of 19 years, a discount rate of 6 percent, and an escalation rate of 6 percent for the first 5 years and 4 percent thereafter.

As shown in Table 10.9, the capital costs for a new activated sludge system and an EQ basin are comparable and the life-cycle costs are similar. As mentioned, the need for EQ can be avoided by operating the dewatering system 7 days a week, a strategy the City plans to implement. Thus, the benefits achieved from the construction of a separate EQ basin and the associated operational complexities do not justify the expenditure. The CaRRB Alternative has a much higher capital cost than the equivalent activated sludge, even when allowing for the fact that it would increase the Plant 2 capacity by 2.0 mgd. Hence, converting the 1958 chlorine chamber to CaRRB is not recommended.