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CITY OF SUNNYVALE

MASTER PLAN AND PRIMARY TREATMENT DESIGN

TECHNICAL MEMORANDUM

DISINFECTION:
MASTER PLAN

FINAL
March 2014

in association with

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CITY OF SUNNYVALE

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1.0 INTRODUCTION

This technical memorandum (TM) presents an analysis and selection of process alternatives for disinfection at the City of Sunnyvale's Water Pollution Control Plant (WPCP). The selected disinfection processes proposed for the WPCP are based on providing the needed improvements through buildout (2035) to meet the City's goals and objectives. The recommendations presented herein are an update to and expansion of the recommendations included in the City's WPCP Strategic Infrastructure Plan (SIP).

The evaluation was completed using a two step process: (1) a one-week internal peer review was held on September 9th through 12th, 2013 which was attended by process experts from the Carollo/HDR team and (2) a two-day workshop on October 14th and 15th, 2013, during which time the Carollo/HDR team presented the recommended liquid and solids treatment processes to the City staff. The key findings and recommendations developed for the disinfection process are summarized in this TM, as well as in the October workshop meeting minutes and presentation slides included in Appendix A.

2.0 SUMMARY OF RECOMMENDATIONS

The key findings and recommendations for the disinfection process include:

- Proceed with current upgrades to replace the existing gaseous chlorine disinfection system with a sodium hypochlorite disinfection system.

- Modify existing treatment process to provide continuous recycled water (RW) production and eliminate batch RW production.
  - Implement upstream process modifications such that all influent flow to the disinfection process meets Title 22 requirements (with the exception of those related to disinfection).
  - Maintain provisions to use chlorine contact tank (CCT) Nos. 1 and 2 for continuous RW production, as well as for treatment of effluent for Bay discharge. Operate one duty CCT to meet the anticipated RW demand and Title 22 requirements for disinfection. The standby CCT could be operated to treat effluent discharged to the bay (at reduced chlorine contact times) to meet Bay discharge water quality requirements.

- Implement an aqueous ammonia feed station to provide the capability to chloraminate the effluent to mitigate trihalomethane (THM) formation. The facility would be implemented when the THM concentration of the WPCP effluent approaches the regulated THM limits (which is anticipated to occur when the new activated sludge secondary process becomes operational in 2023±). If over time the ammonia addition becomes an operational issue (i.e., the ability to meet effluent standards becomes difficult), then replace the hypochlorite disinfection facility with a UV disinfection facility.

- Modify the sodium hypochlorite disinfection system to provide breakpoint chlorination or sequential chlorination to mitigate N-nitrosodimethylamine (NDMA) formation. Implement this when NDMA is regulated and the NDMA concentration of the WPCP effluent approaches regulated NDMA limits. Pilot test both alternatives to determine process viability. If NDMA and THM regulations cannot be met with breakpoint or sequential hypochlorite disinfection, replace the hypochlorite disinfection system with a UV disinfection system.

- Based on current technologies, provided space and support systems to install a low dose ozone system to perform as an advanced oxidation process (AOP) process in conjunction with the hypochlorite (or UV) disinfection system to address contaminants of emerging concern (CECs). Further investigation is warranted once potential CEC regulations are imminent.

Table 1 summarizes how these recommendations (the Master Plan recommendations) compare with the SIP recommendations. The subsequent sections of this TM summarize the rational for the Master Plan recommendations. These sections also include explanation as to why some SIP recommendations are no longer recommended for further consideration.

The analysis conducted in the October 2013 workshops and summarized herein was based on replacing the existing secondary treatment process (an oxidation pond system) with a new secondary treatment process which utilizes either a conventional activated sludge or membrane bioreactor (MBR) process to meet anticipated nutrient removal limits. The new secondary treatment plant would become operational in 2023±.

As part of the Master Plan, the City is considering implementation of a split-flow secondary treatment alternative. The split flow alternative allows for a phased approach to the secondary treatment improvements to provide more flexibility in dealing with future regulatory uncertainties. If split-flow treatment alternative is implemented, the findings and recommendations for the disinfection process would be based on the secondary process selected.

Table 1	Comparison of Master Plan and SIP Recommendations Master Plan and Primary Treatment Design City of Sunnyvale	
Process/ Technology	**Strategic Infrastructure Plan (SIP) (2011)**	**Master Plan (2014)**
Disinfection	• Convert the existing gaseous chlorine disinfection system to a sodium hypochlorite disinfection system	• Same as SIP
	• Replace the existing batch mode RW production process with a continuous RW production process	• Same as SIP
	• Replace the sodium hypochlorite disinfection system with a UV disinfection system for Bay discharge and recycled water (RW) production	• Continue use of the existing sodium hypochlorite disinfection system for Bay discharge and RW production until new regulations require implementation of additional or different disinfection process(es)
	• Provide separate UV disinfection systems for Bay Discharge and RW production	• Maintain provisions to use two of the existing chlorine contact tanks (CCTs) for RW production, as well as for treatment of effluent for Bay discharge
	Not addressed	• When the trihalomethane (THM) concentration of the effluent approaches regulated THM limits, implement an aqueous ammonia feed station to allow for chloramination of the effluent and mitigate THM formation. Convert to UV should this become an operational issue.
	Not addressed	• When N-nitrosodimethylamine (NDMA) limits occur, modify the sodium hypochlorite process to provide breakpoint or sequential chlorination. If these processes are deemed nonviable, replace the sodium hypochlorite system with a UV disinfection system.
	Not addressed	• When contaminants of emerging concern (CECs) become regulated, implement an ozone advanced oxidation process in conjunction with the sodium hypochlorite (or UV) disinfection system

If conventional activated sludge (AS) split-flow treatment is implemented, the findings and recommendations for the disinfection process would be as follows:

- Use only effluent treated by the new AS system for RW production. The effluent from the new AS system, which should have much higher quality than that from the existing pond system, would be routed to the existing dual media filters (DMFs). The following provisions would be required to isolate the higher quality AS effluent from the lower quality pond effluent at the DMFs:
  - Piping, gates, valves, and/or other equipment at the influent and effluent end of the filtration process.
  - Piping, gates, valves, pumping modifications, and/or other equipment at the influent end of the disinfection process.

If MBR split-flow treatment is implemented, the findings and recommendations for the disinfection process would be as follows:

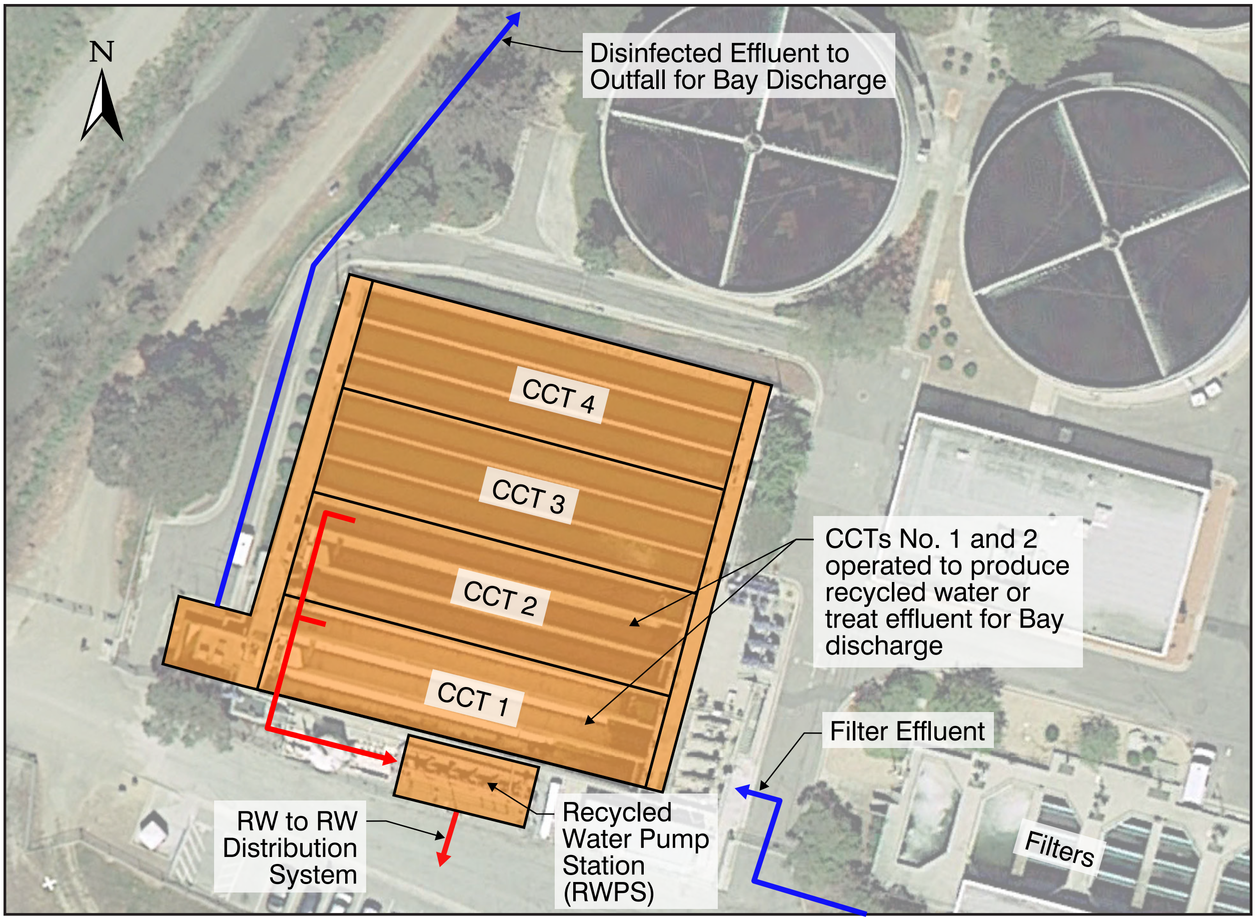
- Use only effluent treated by the new MBR system for RW production. The effluent from the new MBR system, which should have much higher quality than that from the existing pond system, would be routed to the existing CCTs. Piping, gates, valves, pumping modifications, and/or other equipment would be required at the influent end of the disinfection process to isolate the higher quality MBR effluent from the lower quality pond effluent.

3.0 BACKGROUND

The City currently operates four CCTs using gaseous chlorine as the primary disinfectant. Three CCTs were constructed in 1975 and a fourth was constructed in 1982. A layout of the existing system is presented in Figure 1. Each CCT was designed to provide 60 minutes of contact time at a flow of 8 million gallons a day (mgd) for effluent discharged to San Francisco Bay (Bay) and 120 minutes of contact at a flow of 4 mgd for RW production. The City currently operates CCT Nos. 1 and/or No. 2 to produce recycled water.

Flow is distributed to the CCTs through a common influent channel. Automatic slide gates at the influent end of each CCT are opened or closed to control which CCTs are used for disinfection. Wastewater flows through the CCTs, which provide the necessary contact time for disinfection. At the end of each CCT, the disinfected effluent flows over a weir into a common effluent channel where sulfur dioxide is used for dechlorination. The dechlorinated effluent is then discharge to the Bay.

To produce RW effluent, CCT Nos. 1 and/or 2 are operated to achieve a higher chlorine contact time to meet Title 22 requirements for RW. RW discharge valves and piping are located at the effluent end of these CCTs to convey RW effluent from these CCTs to the Recycled Water Pump Station (RWPS), which delivers RW effluent to a RW distribution system. Figure 1 includes a schematic of the RW piping.



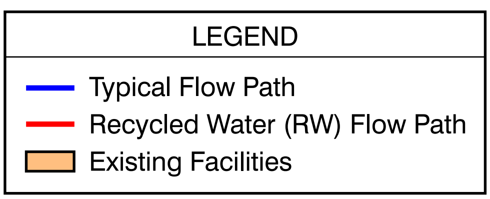


Figure 1
EXISTING DISINFECTION FACILITIES
DISINFECTION
MASTER PLAN AND PRIMARY TREATMENT DESIGN
CITY OF SUNNYVALE

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When operated to produce RW, the effluent weirs at the end of these CCTs are closed and the valves to the RW discharge piping are opened. The recycled water pump station (RWPS) conveys effluent directly from the CCTs through the RW discharge piping on an as-needed basis to meet RW demands. The pumping rate set at the RWPS controls the flow through the CCTs and therefore the total RW produced by the disinfection process. The remainder of the influent flow is sent to the remaining CCTs and is disinfected and then discharged to the Bay.

The City is currently in the process of converting the gaseous chlorine system to liquid sodium hypochlorite system following recommendations from the SIP. Since the SIP, the City engaged Hydroscience Engineers and Kennedy Jenks Consultants to conduct a Feasibility Study for Recycled Water Expansion (FSRWE), which was completed in April 2013. The FSRWE evaluated the demands from new recycled water clients in the City's service area, provided additional recommendations for addressing recycled water quality concerns, and identified a potential increase in RW demands from Apple.

3.1 Regulatory Considerations and Implications

The WPCP discharges disinfected effluent to the Bay through the Guadalupe Slough and provides RW through the RWPS, located at the south end of the CCTs. Bay discharge and RW quality requirements discussed in the SIP and FSRWE are summarized in Table 2:

Three groups of constituents are seen as potential candidates for further regulation in Bay discharge. In anticipated chronological order for regulatory compliance, these contaminants are:

- Trihalomethanes (THMs).
- N-nitrosodimethylamine (NDMA).
- Contaminants of emerging concern (CECs).

The limits and regulatory timelines for these constituents are uncertain at this time. To address limits, the disinfection alternative analysis considered processes that are accepted within the industry as viable processes to reduce these constituents below anticipated regulatory limits. To address timing, it was assumed the WPCP may have THM regulations in the permit cycle following the implementation of the new secondary treatment plant (~2024); NDMA regulations about one full permit cycle after the new secondary treatment plant is implemented (~2029); and CEC regulations in about three permit cycles (2029±). The assumed timing of these regulations is described in further detail in alternatives analysis section of this TM.

Table 2 Sunnyvale Final Effluent Water Quality Objectives
Master Plan and Primary Treatment Design
City of Sunnyvale

Parameter	**Bay Discharge**	**Recycled Water**[1]
cBOD (5-day, 20^{o} C)	20 mg/L Daily Maximum	20 mg/L Daily Maximum
	10 mg/L Monthly Average	10 mg/L Monthly Average
Bacterial Residual	<35 MPN/100 mL[2]	<2.2 MPN/100 mL[3] 7-day Median
		<23 MPN/100 mL[3] Single Sample in 30 Days
		<240 MPN/100 mL[3] Single Sample Maximum
Turbidity	n/a	<2 NTU Daily Average
		<5 NTU 95% of the time within a 24 hour period
		<10 NTU Instantaneous Maximum
CT (Chlorine Residual x Contact Time)	n/a	>450 mg/L-min
Contact Time	n/a	>90 minutes (modal)
Chlorine Residual	0.0 mg/L Instantaneous Maximum	5 mg/L

Notes:
(1) City of Sunnyvale Order No. 09-061.
(2) Enterococcus.
(3) Total Coliform.

Based on Carollo/HDR's experience in implementing recycled water projects with numerous other agencies, it is anticipated that these constituents will need to be addressed for recycled water as well in order to maintain a positive public perception of the RW supply.

3.2 SIP and FSWRE Recommendations

The Condition Assessment and Unit Process Performance Review TM from the SIP recommended an immediate conversion from the existing gaseous chlorine system to hypochlorite to mitigate the risk associated with a catastrophic failure of the chlorine storage tanks. As stated above, the City is in the process of converting the gaseous chlorine system to a hypochlorite disinfection system.

The SIP also recommended constructing a separate UV system to treat Bay discharge flows to decouple the RW and Bay discharge disinfection processes. No specific drivers were identified for the technologies during the SIP. The subsequent FSRWE agreed with the continued use of hypochlorite disinfection for RW production until regulatory drivers become a reality.

Both the SIP and FSRWE recommended replacing the existing batch mode RW production process with a continuous RW production process. The Draft 2013 Simultaneous Production of Recycled Water Study provided by HDR evaluated the possibility of creating a separate treatment train from the ponds for RW production. This system included isolating one fixed growth reactor (FGR), one air flotation tank (AFT), one dual media filter (DMF), and one CCT from the rest of the process for the treatment of RW. This alternative was found to be a high cost alternative. As a result, the City decided not to pursue the alternative at this time. The City did decide, however, to carry forward the long-term planning goal to transition from batch-mode RW production to continuous RW production.

4.0 ALTERNATIVE ANALYSIS

Given the existing gaseous chlorine disinfection process is currently being converted to a sodium hypochlorite disinfection system, the alternative analysis presented herein was based on expanding on the current sodium hypochlorite improvements to meet disinfection needs over the master planning period.

Based on the anticipated regulations and the findings of the SIP and FSWRE, both near-term and long-term disinfection alternatives were developed and evaluated. Near-term alternatives were developed to address the disinfection needs that are anticipated prior to the replacement of the existing secondary treatment system. Long-term alternatives were developed to address disinfection needs when the pond system is replaced by a new secondary treatment technology such as an activated sludge process. Long-term disinfection needs include meeting future THM, NDMA, and CEC limits, which are anticipated to take effect in phases. As a result, the long-term alternatives analysis was conducted in three phases (one phase for each constituent):

- Long-Term Phase 1 – Mitigate THM Formation.
- Long-Term Phase 2 – Mitigate NDMA Formation.
- Long-Term Phase 3 – Mitigate CEC Formation.

Table 3 summarizes the planning parameters that were assumed for the near-term and long-term alternatives.

Table 3	Near and Long-Term Flow Projections Master Plan and Primary Treatment Design City of Sunnyvale	
Description	**Near-Term**	**Long-Term**
Planning Period	Present-2023	2025-2035
Peak Flows Through Disinfection, mgd	< 22.9 (1)	34.7 (2)
Peak Recycled Water Demand, mgd	1.7 (3.0)(3)	3.6

Notes:

(1) In the near-term, the peak influent flow to the plant will be equalized in the ponds. Peak flow through the filters is anticipated to be approximately equal to the maximum month flow (MMF) plant influent flow. This is projected to be 22.9 mgd in 2025 as presented in the Flow and Loads TM.

(2) In the long-term, the peak influent flow to the plant will be equalized in equalization basins upstream of the secondary treatment process. The projected 2035 equalized peak day flow is shown here.

(3) Number in parentheses accounts for near-term RW demands from Apple.

4.1 Near-Term

As noted at the SIP Validation Workshop, there are no near-term drivers to move away from sodium hypochlorite disinfection. Therefore, it is recommended that the hypochlorite disinfection system currently being implemented continue to be used for the near-term (next 10± years). This system would be used for disinfection of effluent discharged to the Bay and effluent diverted for RW use.

Table 4 summarizes the operating criteria for the disinfection process over the near-term planning period. As shown in Table 4, one CCT has enough treatment capacity to meet the RW demand anticipated to occur over the planning period.

It is recommended process modifications be implemented to allow for continuous production of recycled water. These modifications include:

- Implement upstream process modifications such that all influent flow to the disinfection process meets Title 22 requirements (with the exception of those related to disinfection). These modifications include increasing the polymer dosing at the existing air flotation tanks and operating the existing dual media filters at a higher filter loading rate. These recommended modifications are described in further detail in the Filtration TM.

Table 4	Near-Term Chlorine Contact Tank Operating Criteria Master Plan and Primary Treatment Design City of Sunnyvale					
Condition		**Flow, mgd**	**Flow, mgd**	**Duty Contact Tanks, No.**	**Contact Time, min(1)**	**Required Contact Time, min**
2025 Average Annual Flow (AAF)	Bay Discharge	17.8	16.1 (14.8)(2)	2	60 (65)(2)(3)	30-60(4)
	RW(5)		1.7 (3.0)(2)	1	282 (160)(2)	90 modal
2025 Max Month Flow (MMF)(3)	Bay Discharge	22.9	22.9	2	42(6)	30-60(4)
	RW(5)		Negligible(7)	1	>282	90 modal

Notes:

(1) Each CCT has a volume of 0.33 million gallons.
(2) Number in parentheses accounts for near-term RW demands from Apple.
(3) One CCT will be on standby and available for maintenance.
(4) This contact time is not required by permit. It is an industry standard design value used to meet permit limits.
(5) RW = recycled water.
(6) Peak flows through the WPCP will be equalized in the pond process.
(7) RW demand is anticipated to be negligible during MMF, based on historical RW usage at the City during wet weather seasons (when MMF typically occur).

- Maintain provisions to use CCT Nos. 1 and 2 for continuous RW production, as well as for treatment of effluent for Bay discharge.
  - Continue using the existing RW discharge piping to convey RW effluent directly from CCT Nos. 1 and 2 to the Recycled Water Pump Station (RWPS). This piping isolates the RW effluent from the rest of the process flow. This piping also includes valves that can be closed to isolate effluent from CCT Nos. 1 and 2, should the effluent not be in compliance with RW water quality requirements.
  - Operate one duty CCT to meet the anticipated RW demand and Title 22 requirements. The standby CCT could be operated to treat effluent discharged to the bay (at reduced chlorine contact times) to meet Bay discharge water quality requirements.

Although each CCT has sufficient capacity to meet the anticipated RW demand, it is recommended that two CCTs be allocated for RW production so that one could be taken out of service for maintenance. It is important to note that CCTs dedicated for RW production can also be used to treat effluent for Bay discharge. In this mode, the RW discharge valve at the effluent end of the CCT would be closed to isolate the CCT effluent from the RW discharge piping. The CCT effluent gate would be opened to allow flow to pass to the effluent channel for Bay discharge and the chlorine contact time would be reduced to meet Bay discharge requirements.

4.2 Long-Term, Phase 1 – Mitigate THM Formation

4.2.1 Background

Trihalomethanes (THMs) are formed when chlorine reacts with total organic carbon in wastewater. As a result, THM formation commonly occurs in chlorine disinfection processes. The City has a Bay discharge limit for a specific THM – chlorodibromomethane. The chlorodibromomethane concentration of the WPCP effluent has historically been well below the permitted limit. However, this limit could be exceeded when the existing oxidation ponds are replaced with a new secondary treatment process.

The presence of ammonia in the disinfection process mitigates THM formation and the influent ammonia concentration to the disinfection process is expected to decrease when the new secondary treatment process is implemented. When ammonia and free chlorine are mixed, chloramine is formed. Chloramine is a disinfectant similar to chlorine, but it does not produce as many THMs as chlorine. Given the historical influent ammonia concentration to the disinfection process, it is expected that chloramine is being formed in the existing disinfection process. Chloramine provides for a stable disinfection dosing operation and reduces the chlorine concentration, which reduces THM formation.

The new secondary treatment process is anticipated to produce a nitrified secondary effluent by 2023±, which would result in a very low ammonia nitrogen concentration. The absence of ammonia nitrogen will reduce the formation of chloramine, which will increase the formation of THMs and the risk of a permit violation. A permit violation may cause additional THM limits to be included in the permit cycle following the implementation of the new secondary treatment process (~ 2024 permit cycle).

4.2.2 Recommendations

Given the existing treatment process meets the current THM limits, it is recommended an aqueous ammonia feed facility be implemented. This facility would inject a small dosage of ammonia to facilitate the formation of chloramines to mitigate THM formation. Ammonia dosing must be carefully controlled to avoid violations of ammonia effluent standards. Costs for this facility are included in the Program Implementation Plan.

Table 5 summarizes the operating criteria for the hypochlorite disinfection process over the long-term planning period.

The anticipated total nitrogen (TN) limit during the planning period is 8 milligrams per liter (mg/L), which could be difficult to meet if ammonia were added back into the final effluent. However, based on current assumptions for the ammonia dose required to achieve chloramination, it appears that the WPCP would be able to meet the anticipated TN limit.

Table 5 Long-Term Chlorine Contact Tank Operating Criteria Master Plan and Primary Treatment Design City of Sunnyvale

Condition		Flow, mgd	Flow, mgd	Contact Tanks, No.	Contact Time, min(1)	Required Contact Time, min
2035 AAF	Bay Discharge	20.4	16.8	2	57(2)	30-60
	Recycled Water(3)		3.6	1	133	90 modal
2035 Equalized Peak Day Flow(4)	Bay Discharge	34.7	34.7	3	41	30-60
	Recycled Water(3)		Negligible(5)	1	>133	90 modal

Notes:
(1) Each CCT has a volume of 0.33 million gallons.
(2) One CCT will be on standby and available for maintenance.
(3) RW = recycled water.
(4) After the conversion to an activated sludge secondary process, it is anticipated that the ponds will no longer be in service. The planning flows will thus need to account for the peak flows through the WPCP. The flow provided is based on an equalization capacity of 8 million gallons.
(5) RW demand is anticipated to be negligible during MMF, based on historical RW usage at the City during wet weather seasons (when MMF typically occurs).

It is recommended pilot testing of ammonia addition be conducted for up to a 6 month period to determine the seasonal impacts on the performance of this process. Testing would include bench-scale analysis followed by running a small-scale pilot disinfection process at the plant site to disinfect plant effluent. Pilot testing should be conducted once the new secondary treatment process is implemented. This would provide the City with the maximum amount of time to pilot test, design and implement a treatment process that complies with the required THM limits. If over time the ammonia addition becomes an operational issue (i.e., the ability to meet effluent standards becomes difficult), then it is recommended the hypochlorite disinfection facility be replaced with a UV disinfection facility.

4.3 Long-Term, Phase 2 – Mitigate NDMA Formation

4.3.1 <u>Background</u>

The introduction of ammonia into the CCT influent would increase the formation of NDMA. While NDMA is not currently regulated, an increase in effluent NDMA may introduce effluent NDMA limits in the permit cycle after ammonia addition is implemented (~2028). Should NDMA become a regulatory driver, ammonia addition would need to be discontinued. Discontinuing ammonia addition at the disinfection process will increase the potential for THM formation and could drive the need for conversion to UV.

4.3.2 Alternatives Considered

The following alternatives were considered to meet both THM and NDMA limits:

- Breakpoint chlorination.
- Sequential chlorination.
- UV disinfection.

4.3.2.1 Breakpoint Chlorination

This alternative would include expanding the hypochlorite disinfection facility to provide breakpoint chlorination to mitigate the formation of NDMA. The process would require a significantly higher hypochlorite dose, as well as more frequent hypochlorite dose adjustments.

Based on the experience at other agencies, it may be possible to meet THM limits using breakpoint chlorination. This would require THM levels to be closely monitored to ensure regulatory compliance. This alternative has the primary benefit of continuing the use of the existing disinfection process, which would have a lower cost than constructing a new disinfection process. Pilot testing would be required to determine the viability of this alternative to meet both THM and NDMA limits.

4.3.2.2 Sequential Chlorination

During the October 2013 workshop, sequential chlorination was suggested as an alternative to breakpoint chlorination. This alternative would include expanding the hypochlorite disinfection facility. Sequential chlorination is a two-step disinfection process that includes free chlorination followed by chloramination. The first step uses free chlorine to inactivate pathogens and react with NDMA precursors, thus reducing subsequent NDMA formation. The second step uses chloramines to provide further disinfection and prevent the formation of THMs. This process has been successfully demonstrated at the Los Angeles County Sanitation District (LACSD). The results from the LACSD study are included in Appendix B.

Sequential chlorination is a potential alternative, but pilot testing would be required to determine the viability of this alternative to meet both THM and NDMA limits. The primary benefit of this alternative is the ability to continue use of the existing disinfection process, which is lower cost than constructing a new disinfection process.

4.3.2.3 UV Disinfection

This alternative includes replacing the existing hypochlorite disinfection facility with a UV disinfection facility. An estimated UV dose of 25 millijoule per square centimeter (mJ/cm^2) would be required to meet the effluent water quality objectives at the WPCP.

A new UV disinfection process would have a significantly higher capital and O&M cost than the other alternatives. The primary benefit of this alternative is that it is widely accepted within the industry as a viable alternative to mitigate the formation of THMs and NDMA. UV has been implemented at numerous WWTPs in California to meet THM and NDMA limits.

4.3.3 Recommendations

It is recommended that breakpoint chlorination or sequential chlorination be implemented to mitigate NDMA formation in order to meet NDMA limits when they occur. These alternatives are recommended because: (1) they are the lowest overall cost; and (2) they extend the use of existing assets. Pilot testing would need to be conducted prior to implementation of either of these alternatives to determine their viability to meet both THM and NDMA limits. If NDMA and THM limits cannot be met with hypochlorite disinfection, then it is recommended that the hypochlorite disinfection facility be replaced with a UV disinfection facility.

It is recommended pilot testing of breakpoint chlorination and/or sequential chlorination be conducted for up to a six month period to determine the seasonal impacts on the performance of these processes. Testing would include bench-scale analysis followed by running a small-scale pilot disinfection process at the plant site to disinfect plant effluent. Pilot testing should be conducted once tentative NDMA limits are proposed for Bay discharge. This would provide the City sufficient time to pilot test, design, and implement a treatment process that complies with the NDMA limits.

4.4 Long-Term, Phase 3 – Mitigate CEC Formation

4.4.1 Background

The Southern California Coastal Water Research Project (SCCWRP) has completed a multi-year study to examine the aquatic impact of wastewater discharges to different surface water bodies. This study, funded by the State Water Resources Control Board (SWRCB), could result in regulatory guideline and/or limits for some dischargers.

The SWRCB is still approximately two years away from making a decision to require treatment facilities to monitor CECs. If the SWRCB decides to initiate a statewide CEC monitoring process, it would be at least three permit cycles (2029±) before guidelines for CEC regulation are established and included in discharge permits.

The removal of CECs requires the breakdown of organic constituents through an advanced oxidation process (AOP). These limits currently appear to be beyond the master planning period; however, provisions would need to be made during the master planning period to allow the WPCP to respond to these regulations when they become a reality.

4.4.2 Alternatives

The following AOP alternatives were considered in this evaluation:

- Ozone.
- Low-dose ozone in combination with hypochlorite disinfection.
- Low-dose ozone in combination with UV disinfection.
- High-dose UV in combination with hydrogen peroxide.

4.4.2.1 Ozone

Ozone is the most efficient current technology for CEC destruction. As part of a nearly $1.0 million research effort completed by the WateReuse Research Foundation in 2012 (Project 02-009), ozone was demonstrated as the most cost-effective solution for destruction of hormones and pharmaceuticals. A preliminary dose of 6 mg/L is anticipated to meet the future effluent objectives at the WPCP. It is recommended the City pilot test ozone technologies prior to implementing any full-scale facilities.

Ozone is an unstable molecule and thus needs to be generated on-site by reacting liquid oxygen in ozone generators. This process is energy intensive and requires facilities for both oxygen storage and ozone generation. Additionally, ozone is largely ineffective at removing NDMA. Therefore, the ozone process would need to be coupled with another technology to meet NDMA limits, should they become a reality.

4.4.2.2 Hypochlorite + Low Dose Ozone

Low-dose ozone systems can be used in conjunction with hypochlorite for CEC destruction. If the existing hypochlorite system is still in use at the WPCP and in good condition when CEC limits become a reality, it could be supplemented with a downstream ozone system to meet CEC limits. The potential of this treatment configuration to remove NDMA, however, is unknown. This alternative should not be given further consideration until its efficacy for NDMA removal is confirmed through extensive piloting.

4.4.2.3 UV + Hydrogen Peroxide

Hydrogen peroxide injection can be used in conjunction with UV for CEC destruction. In this process, the UV light creates an environment that breaks down the hydrogen peroxide to form highly reactive hydroxyl radicals, which assist in the breakdown of organic molecules. This alternative has the highest net present value (NPV) of all the AOP alternatives considered.

4.4.2.4 UV + Low Dose Ozone

By the time CEC regulations become a reality, a UV disinfection system may already be in place at the WPCP to meet THM and NDMA limits. If this is the case, a low-dose ozone facility could be added to the UV disinfection system. The existing UV system would serve as the primary disinfectant while the ozone would serve as the AOP and provide destruction of CECs. A preliminary ozone dose of 3 mg/L is estimated for effective destruction of CECs. In addition to having the lowest estimated lifecycle cost (i.e., net present value), this process configuration has the greatest potential for mitigating THMs, NDMA, and CECs.

4.4.3 Net Present Value Analysis

A net present value (NPV) evaluation of the alternatives was prepared and is summarized in Table 6. The net present value analysis includes capital cost and annual O&M costs including power, maintenance and labor costs. Based on this analysis, the UV and ozone system has the lowest NPV.

Table 6 AOP Net Present Value Comparison
Master Plan and Primary Treatment Design
City of Sunnyvale

Process	O_3	HOCl(1) + O_3	UV + H_2O_2	UV + O_3
Capital Cost	$27.0M	$20.7M(2)	$31.6M	$24.9M
Annual O&M Cost	$890K	$1.2M(2)(3)	$848K	$650K
NPV	$40M	$37M	$44M	$34M

Notes:
(1) Does not include cost for current hypo conversion project.
(2) Includes cost for aqueous ammonia addition.
(3) Assumes aqueous ammonia and low dose HOCl .
(4) The costs presented in this table are for alternative comparison only. Cost estimates exclude common facilities (e.g., common yard piping, etc.)
(5) The cost of electricity is assumed to be $0.20/kWh.
(6) NPV was calculated based on 22 year period prescribed in the Basis of Cost TM.

4.4.4 Evaluation Summary

Table 7 summarizes how each alternative meets the City's evaluation criteria for the Master Plan, which is described further in the SIP Validation TM.

Based on the analysis summarized in Table 7, it is recommended that provisions be made over the master planning period to accommodate implementation of a low dose ozone system that would operate in conjunction with a hypochlorite or UV disinfection system. Accommodating future implementation of a low dose ozone system with sodium hypochlorite or UV disinfection is recommended because: (1) these two alternatives have the lowest capital and O&M cost; and (2) they provide the greatest potential for mitigation of THMs, NDMA, and CECs.

Table 7 Evaluation Summary of Screening Alternatives Master Plan and Primary Treatment Design City of Sunnyvale				
Evaluation Criteria	**O_3**	**$HOCl^{(1)} + O_3$**	**$UV + H_2O_2$**	**$UV + O_3$**
Reliability	0	0	0	0
Ease of O&M	0	0	0	0
Maximize Resources	n/a	n/a	n/a	n/a
Power Usage	0	0	-	-
Flexibility	-	-	+	+
Ease of Implementation/ Compliance	0	+	0	0
Site Efficiency	+	-	+	+
Net Present Value (NPV)	0	+	-	+

Notes:
(1) Legend: + Better; 0 Neutral; - Worse.
(2) n/a = not applicable.

It is recommended a detailed technology review and pilot testing be conducted prior to the implementation of an ozone facility. It is recommended pilot ozone technologies (e.g., trailer-mounted units) be tested onsite for up to a six month period to determine the seasonal impacts on the performance the process. Pilot testing should be conducted once tentative CEC limits are included in the NPDES permit for Bay discharge. This would provide the City sufficient time to pilot test, design, and implement a treatment process that complies with the CEC limits.

5.0 IMPLEMENTATION AND SITE CONSIDERATIONS

Implementation and site considerations were developed for the two future disinfection scenarios that may occur based on the recommendations. These scenarios include:

- Scenario 1: Continued Use of Sodium Hypochlorite Disinfection.
- Scenario 2: Implementation of UV Disinfection.

5.1 Scenario 1: Continued Use of Sodium Hypochlorite Disinfection

Figure 2 includes a preliminary site layout of the recommended disinfection facilities included in Scenario 1: Continued Use of the Existing Sodium Hypochlorite Disinfection System. This figure shows how the existing facilities would be expanded to meet anticipated THM, NDMA and CEC regulations.

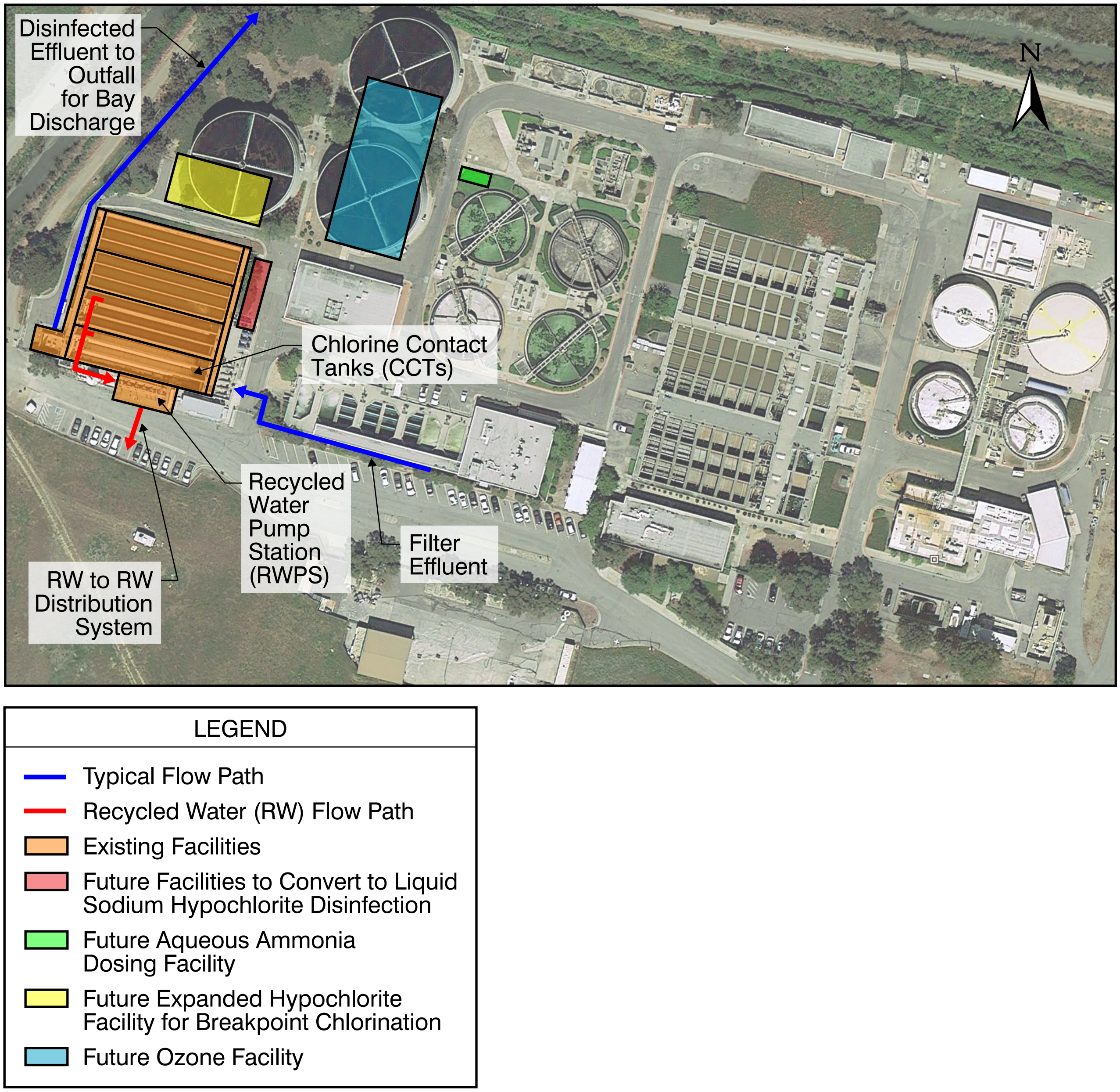


Figure 2
SCENARIO 1: CONTINUED USE OF SODIUM HYPOCHLORITE
DISINFECTION
MASTER PLAN AND PRIMARY TREATMENT DESIGN
CITY OF SUNNYVALE

sun0214f2-9265.ai

Implementation considerations for this scenario include:

- The liquid sodium hypochlorite disinfection system would provide adequate disinfection until the new secondary treatment process is implemented (2023±).
- When the new secondary treatment process is implemented (2023±), THM formation may increase. To mitigate THM formation, an aqueous ammonia feed station may need to be implemented at the same time or shortly after the new secondary treatment process is implemented.
- With the implementation of an aqueous ammonia feed station, NDMA formation may increase. To mitigate NDMA formation, the existing hypochlorite disinfection facility may need to be expanded to provide breakpoint chlorination (or sequential chlorination). These facilities may need to be implemented at the same time or shortly after the ammonia feed station is implemented.
  - As shown in Figure 2, these facilities would be located in the space currently occupied by the existing FGRs.
  - If split-flow treatment were implemented, the FGRs would remain in service until the split-flow treatment process is phased out and the new secondary treatment process is expanded to treat the full plant influent flow. If breakpoint chlorination is required before split-flow treatment is phased out, the future hypochlorite facilities shown in Figure 2 would need to be located elsewhere on the plant site. Alternatively, the City may decide to phase out split-flow treatment and expand the new secondary process when these disinfection facilities are required in order to optimize site space and locate these facilities as shown in Figure 2. The City would likely do this, if this approach were anticipated to be more cost effective over the long term.
- If CECs become regulated, an ozone facility would be implemented in the space currently occupied by the existing FGRs (as shown in Figure 2). In order to meet anticipated CEC regulations, it is assumed the full plant influent flow would need to be treated with the new secondary treatment process. As a result, the existing secondary pond process would no longer be in operation and the space currently occupied by the FGRs would be available for future facilities, such as an ozone facility.

5.2 Scenario 2: Implementation of UV Disinfection

Figure 3 includes a preliminary site layout of the recommended disinfection facilities included in Scenario 2: Implementation of UV Disinfection. This figure shows how the existing facilities would be replaced to meet anticipated THM, NDMA and CEC regulations.

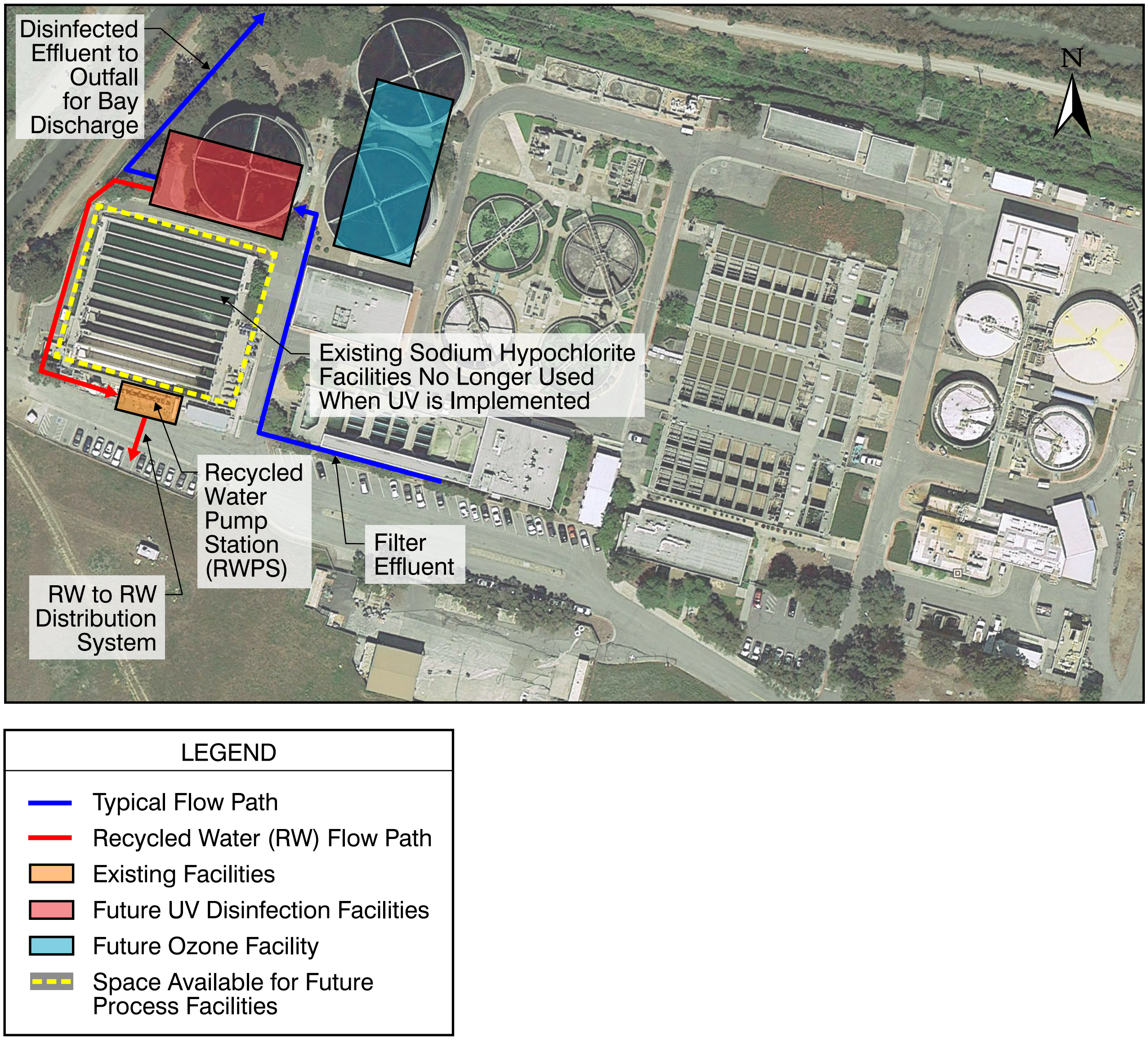


Figure 3
SCENARIO 2: IMPLEMENTATION OF UV DISINFECTION
DISINFECTION
MASTER PLAN AND PRIMARY TREATMENT DESIGN
CITY OF SUNNYVALE

sun0214f3-9265.ai

Implementation considerations for this scenario include:

- The liquid sodium hypochlorite disinfection system would provide adequate disinfection until the new secondary treatment process is implemented (2023±).

- Some time after the new secondary treatment process is implemented (2023±), THM and NDMA formation may increase. To mitigate THM and NDMA formation, the sodium hypochlorite facility may need to be replaced with a UV disinfection facility in order to meet THM and NDMA regulations.
  - As shown in Figure 3, the UV disinfection facility would be located in the space currently occupied by the existing FGRs.
  - If split-flow treatment were implemented, the FGRs would remain in service until the split-flow treatment process is phased out and the new secondary treatment process is expanded to treat the full plant influent flow. If UV disinfection is required before split-flow treatment is phased out, the future UV disinfection facilities shown in Figure 3 would need to be located elsewhere on the plant site. Alternatively, the City may decide to phase out split-flow treatment and expand the new secondary process when these disinfection facilities are required in order to optimize site space and locate these facilities as shown in Figure 3. The City would likely do this, if this approach were anticipated to be more cost effective over the long term.

- Similar to Scenario 1, if CECs become regulated, an ozone facility would be implemented in the space currently occupied by the existing FGRs (as shown in Figure 3). In order to meet anticipated CEC regulations, it is assumed the full plant influent flow would need to be treated with the new secondary treatment process. As a result, the existing secondary pond process would no longer be in operation and the space currently occupied by the FGRs would be available for future facilities, such as an ozone facility.

Any process upgrades to hypochlorite, ammonia, or ozone facilities would necessitate provisions for truck access and deliveries.

Additional site planning considerations are discussed in the Site Layout TM.

6.0 FINDINGS/RECOMMENDATIONS

It is recommended the following disinfection improvements be implemented:

- Proceed with current upgrades to replace the existing gaseous chlorine disinfection system with a sodium hypochlorite disinfection system.

- Modify existing treatment process to provide continuous RW production and eliminate batch RW production:

- Implement upstream process modifications such that all influent flow to the disinfection process meets Title 22 requirements (with the exception of those related to disinfection).
- Maintain provisions to use CCT Nos. 1 and 2 for continuous RW production, as well as for treatment of effluent for Bay discharge. Operate one duty CCT to meet the anticipated RW demand and Title 22 requirements for disinfection. The standby CCT could be operated to treat effluent discharged to the bay (at reduced chlorine contact times) to meet Bay discharge water quality requirements.

- Implement an aqueous ammonia feed station to provide the capability to chloraminate the effluent to mitigate THM formation. This facility would be implemented when the THM concentration of the WPCP effluent approaches the regulated THM limits (which is anticipated to occur when the new activated sludge secondary process becomes operational in 2023±). If over time the ammonia addition becomes an operational issue (i.e., the ability to meet effluent standards becomes difficult), then replace the hypochlorite disinfection facility with a UV disinfection facility.

- Modify the sodium hypochlorite disinfection system to provide breakpoint chlorination or sequential chlorination to mitigate NDMA formation. Implement this when NDMA is regulated and the NDMA concentration of the WPCP effluent approaches regulated NDMA limits. Pilot test both alternatives to determine process viability. If NDMA and THM regulations cannot be met with breakpoint or sequential hypochlorite disinfection, replace the hypochlorite disinfection system with a UV disinfection system.

- Based on current technologies, provided space and support systems to install a low dose ozone system to perform as an advanced oxidation process (AOP) process in conjunction with the hypochlorite (or UV) disinfection system to address contaminants of emerging concern (CECs). Further investigation is warranted once potential CEC regulations are imminent.

APPENDIX A – PROCESS ALTERNATIVES REVIEW WORKSHOP MINUTES AND SLIDES – OCTOBER 15, 2013

CONFERENCE MEMORANDUM

Project:	Master Plan and Primary Treatment Design	**Conf. Date:**	October 15, 2013
Client:	City of Sunnyvale	**Issue Date:**	October 31, 2013
Location:	West Conference Room		

Attendees:

City:
John Stufflebean
Kent Steffens
Craig Mobeck
Bhavani Yerrapotu
Bryan Berdeen
Dan Hammons
Melody Tovar
Manuel Pineda
Mansour Nasser
Alo Kauravlla

SCVWD:
Hossein Ashktorab
Luis Jaimes

Carollo/HDR/Subconsultants:
Jim Hagstrom
Jamel Demir
Jan Davel
Katy Rogers
Anne Conklin
Daniel Cheng
Scott Parker
Walid Karam
James Wickstrom

Boris Pastushenko
David Jenkins
Alex Ekster
J.B. Neethling

Dana Hunt
Hany Gerges
June Leng

Ray Goebel

Purpose: Process Alternatives Review Workshop (Workshop 2)

Distribution: Attendees **File:** 9265A.00

Discussion:
The following is our understanding of the subject matter covered in this conference. If this differs with your understanding, please notify us.

1. **FILTRATION**
   a. **Discussion**
      1) Regulatory Considerations and Implications
         a) The Basin Plan does not explicitly require filtration, but cites the use of filtration as a factor by which the South Bay treatment plants provide “equivalent protection” and hence qualify for an exception to the Basin Plan

prohibition on “shallow water” discharges. After some discussion, it was noted that the Master Plan will assume a filtration requirement for Bay discharge.

   b) At the moment, Apple’s recycled water quality requirements are very stringent, sometimes more than potable water requirements. However, they seemed open to adjusting their requirements during negotiations with SCVWD. It was agreed to move forward with the assumption to provide Title 22 quality recycled water to Apple.

   c) Some questions regarding TDS levels in WPCP influent. Overall water supply TDS is low. The City has discovered a pipe that is introducing Bay water to the collection system. The flow is estimated to be around 0.5 mgd and contributes 2,600 mg/l of TDS. The City is currently working to seal the leak, which should lower the influent TDS to the WPCP.

2) Long Term Alternatives

   a) Analysis indicates that it is viable to continue use of the existing dual media filters.

   b) A filter re-rating study should be perform to allow production of Title 22 quality water at higher filter loading rates (precedent set for this).

   c) The analysis of alternatives indicates that supplementing with potable water is the lowest NPV option.

   d) There was discussion on how peak flows would affect filter operation. It was noted that San Jose has loaded their filters at 9 gpm/sf during peak flows, and that the main considerations of peak flow loading is the exceedances of Title 22 filtration rate limits and a shortened filter run time.

   e) It was noted that potable water blending will provide additional reliability to the recycled water system.

3) Short Term Alternatives

   a) The existing chlorine contact basins can be modified to allow for a dedicated recycled water channel (eliminates batch operation).

   b) With this modification, the existing filters, supplemented by potable water, could meet the near-term recycled water demands.

   c) It was noted that the interim filtration requirements would need to be refined to consider the split treatment scenario.

   d) While MBR and UF were only presented as short term solutions, there was interest in determining how much these facilities would impact the future secondary treatment costs.

4) SCVWD staff indicated that their Board has just approved funding for an indirect potable reuse (IPR) study. Therefore, the City should include IPR in the future MP process planning considerations. It was noted that the decision for the secondary processes will need to be made in the spring of 2014. Therefore, SCVWD will need to provide a clear direction for IPR prior to that. All agreed that the consideration of IPR will impact the short and long term recommendations for the filtration process.

5) **It is recommended that the existing filter facilities continue to be utilized for both Bay discharge and recycled water needs.**

b. **<u>Decisions</u>**

1) Final decision on filtration approach will be pending SCVWD's IPR evaluation.

c. **<u>Action Items</u>**

1) Carollo needs to determine impacts of peak flows on the final recommendation.

2) A separate meeting will be scheduled between the City and the master plan team to discuss possible impacts of IPR.

2. **DISINFECTION**.

a. **<u>Discussion</u>**

1) Regulatory Considerations and Implications

a) Current disinfection requirements include effluent limits for total coliform (for recycled water) and enterococcus (for Bay discharge). CECs, THMs and NDMA are future long-term considerations.

2) Alternatives

a) Based on near-term Bay discharge and recycled water demands, continue transition from gaseous chlorine to HOCl disinfection.

(1) Dedicate three chlorine contact tanks (CCTs) to Bay discharge and one CCT to recycled water.

(2) Identified need to add aqueous ammonia feed station to disinfect fully nitrified AS effluent. This avoids break-point chlorination to maintain the required chlorine residual (and also mitigates THM formation). THMs will continue to be monitored.

(3) UV could become an alternative when NDMA and THMs are regulated (long-term issue).

(4) Ozone would be an effective AOP for CECs (whether added to HOCl or UV or as a standalone single treatment technology).

b) There was a discussion on whether or not to add ammonia to free chlorine after the new secondary process comes online. Carollo/HDR recommended that the Master Plan analysis assume that ammonia addition is needed for chloramination. When TN limits become a reality, one option is to evaluate a dual disinfection process – chloramination followed by free chlorine. This is currently done in LA County.

c) The group noted that CEC's could be a direct concern if IPR is implemented.

d) Two ideas were proposed to mitigate THM formation:

(1) Perform breakpoint chlorination to mitigate NDMA. It was noted that free chlorine would not be effective for NDMA control.

(2) Add ozone prior to the filters, which allows the filters to more effectively remove precursors for THMs.

e) Carollo/HDR concluded that building an MBR for the near term recycled water demands alone is not a cost effective option.

f) **Carollo/HDR recommended that master planning site space be reviewed and potentially allocated at the WPCP for not only the HOCl and aqueous ammonia facilities, but for potential UV and ozone facilities.**

3) Layouts

a) Based on accommodating potential IPR needs, It was noted that an 8,000 sf RO facility will most likely not fit on the WPCP site if conventional AS is selected (MBRs provide space for an RO facility.

b. **<u>Decisions</u>**

1) Continue with the conversion to HOCl disinfection.

2) In future, once the NAS system is operational, add aqueous ammonia to chloraminate.

3) If NDMA limits precludes the continued addition of aqueous ammonia, monitor THM formation. If THMs become an issue, consider conversion to UV.

4) Once CECs become regulated, consider installation of an ozone system.

c. **<u>Action Items</u>**

1) Carollo to evaluate additional disinfection alternative to minimize THM production – chloramination followed by free chlorine disinfection.

HEADWORKS

a. **<u>Summary of Recommendations</u>**

1) Provide bar screens before pumping.

2) Build headworks structure for build-out flows. Analyze the phasing of mechanical equipment based on flow requirements.

3) Provide odor control for entire headworks facility.

4) Pump station

a) Rectangular wetwell.

b) Dual wetwell configuration

c) Dry-pit pumps

d) Vertical non-clog or submersible non-clog pumps

5) Screening

a) 3/8-inch bar spacing.

b) 3 duty screens, 1 standby screen, 1 bypass channel.

c) Multiple-rake or catenary screen (Duperon).

6) Screenings Conveyance

a) Shaftless screw conveyors.

7) Screenings Washing

a) Auger with Spray Washing.

8) Grit Removal

a) Eutek HeadCell.

b) Two duty plus one standby unit with hydraulic capacity for peak hourly flow, and treatment capacity for peak day flow.

9) Grit Washing

a) Huber Coanda.

b) One standby unit.

b. **Discussion**

1) Influent Pumping

a) There was concern regarding the long shafts inherent to dry pit non-clog pumps. The meeting participants agreed that dry pit submersible pumps should be further evaluated since they do not have associated long shafts.

b) It was noted that the cleaning requirements for the wetwells will be minimal since daily flows should provide sufficient scour.

c) The Master Plan team noted the difficulty of expanding headworks structures. After some discussion, there was general consensus that the headworks structure should be constructed for the buildout flows during the upcoming design, whereas the equipment will be phased in as flows increase.

2) Screening

a) Question raised about getting screenings out (30 foot depth) – sufficient experience noted for this approach. Should be focus of next rounds of field trips.

b) The selection of screen spacing was discussed (trade off of finer materials capture vs. effective organics separation. It was noted to the City that once the new headworks is constructed, the plant will be faced with a new reality – dealing with screenings at the front end of the plant (and not downstream in places like the digesters).

c) The SIP showed that the screenings washing/compacting facility will be housed in a canopy. However, the current assumption is that the screenings washing/compacting facilities will be housed in a masonry building for odor control. There was general agreement regarding this approach.

d) The screens will lift rags and solids above grade, eliminating the need for an angled screw conveyor between the screens and the washer/compactor.

3) Grit Removal

a) The grit study found that the grit at Sunnyvale is larger than typical grit found at similar plants. However, the grit settles slower than typical grit of similar size. The result is that the required grit facilities (Headcell or aerated grit basin) would need to be 60% larger than an equivalently sized facility at a typical treatment plant.

b) The NPV analysis recommends the selection of the HeadCell technology based on cost and footprint. However, it was noted that inspection and maintenance considerations will need to be further refined.

4) Grit Washing
    a) There was general agreement that even though Coanda is 25 – 30% more expensive than a cyclone, it produces higher quality grit and should be selected.
    b) The City expressed the desire to have a standby Coanda unit. Carollo/HDR recommend having a standby unit.

c. **Decisions**

1) Provide screens ahead of influent pumping.
2) Select 3/8” bar spacing.
3) Build headworks structure for buildout flows but phase in additional equipment as flows increase.
4) Provide odor control at the headworks.
5) Provide a pump station with a rectangular, dual, dry-pit configuration.
6) Provide shaftless screw conveyors for screenings conveyance.
7) Provide auger with spray washing for screenings washing/compaction.
8) Provide a building to house the screening and grit handling equipment.
9) Provide HeadCell for grit removal.
10) Provide Coanda for grit washing and dewatering.

d. **Action Items**

1) Schedule site visits to influent pump stations that are configured with a rectangular dry pit.
2) Resolve pump selection as part of pre-design
3) Carollo to identify potential sole-source equipment issues associated with the headworks implementation.

3. **THICKENING**

a. **Summary of Recommendations**

1) Based on analysis of alternatives, rotating drum thickeners (RDTs) are the recommended technology for thickening of WAS only
2) Could be used for co-thickening if that is desired
3) Could be co-located with dewatering facility

b. **Discussion**

1) Odor control will need to be provided as part of this facility.

c. **Decisions**

1) Provide RDTs to thicken WAS.

d. **Action Items**

1) City to visit some RDT facilities.

4. **DIGESTION**

a. **Summary of Recommendations**

1) Modify to allow all digester to operate as primary units.

2) Potential need identified for two additional digesters (needs to be evaluated after AS plant comes on-line). New digesters would be the same size as Digester No. 4.

3) Provide space for either pre-process or post-processing technologies.

b. **Discussion**

1) Regulatory Considerations and Implications.

a) No current or near-term drivers for Class A sludge

b) 503 regs drive HRT detention time (minimum of 15 days), but criteria used is typically more like 20 days. Analysis of future digester needs is based on 20 days.

2) It was noted that space should be left for pre-processing (sonication) and post-processing (drying) because industry trends indicate that these technologies will gain traction in the future.

3) Brought up the possibility of producing green waste pellets. It was noted that SRCSD tried a pelletizing operation, but discovered that it was costing $350/ton to operate, which is very expensive.

4) Co-thickening primary sludge and WAS can bring the sludge up between 5%-6% prior to digestion (determine sensitivity on future digester needs).

5) Regarding the possibility of receiving FOG, Carollo/HDR's experience is that projected FOG loadings are typically double the actual amounts generated. It was also noted that the City's SMaRT station will be rebuilt around 2021/2022, and any food/FOG waste can be considered as part of that renewal effort.

c. **Decisions**

1) Provide space for primary sludge screening.

2) Provide space for two additional digesters with the same capacity as Digester No. 4.

3) Provide space for possible FOG station to receive FOG and liquefied food waste.

d. **Action Items**

1) Carollo/HDR to show the impact of FOG and food waste in digester gas projections during the plant energy balance exercise.

2) Carollo/HDR to determine sensitivity of digester capacity as a function of sludge thickness.

5. **DEWATERING**

a. **Summary of Recommendations**

1) Centrifuges were lowest NPV alternative – but screw presses still under consideration.

b. **Discussion**

1) The group discussed the O&M requirements between screw presses and centrifuges. It was noted that centrifuges are more labor intensive but screw presses are more costly. Operations staff felt that screw presses could be operated with less attention.

2) Implementing centrifuges or screw presses are both viable options for sludge dewatering. The decision is largely dependent on O&M preferences.

c. **Decisions**

1) Delay the decision of sludge dewatering technology, until City staff visits screw press and centrifuge dewatering facilities and determines technology preferences.

d. **Action Items**

1) Carollo to organize site visits to screw press and centrifuge dewatering facilities with City staff.

6. **ODOR CONTROL**

a. Summary of Recommendations

1) Provide bioscrubbers for odor control

2) Near Term – Implement odor control at headworks and primary sedimentation tanks.

3) Long Term – Implement odor control at thickening/dewatering facilities.

b. Discussion

1) Odor testing at the plant site revealed that there are no major issues with RSC and VOCs.

2) Field testing work indicated odor issues associated with the existing headworks/primary sedimentation tanks.

c. Decision Log

1) Provide odor control at the headworks and primary sedimentation tanks as part of the Phase 1 project.

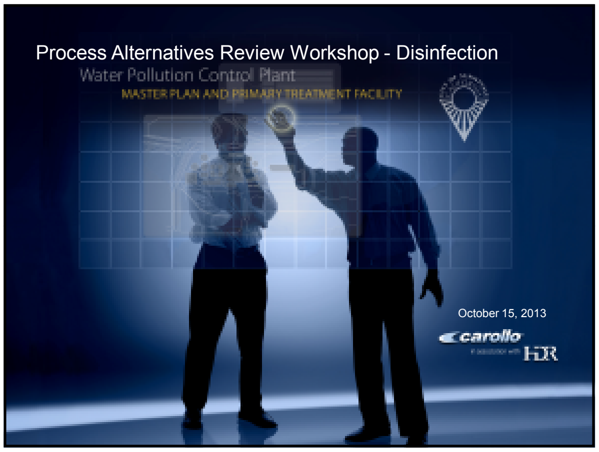
d. Action Items

1) None

Prepared By:

Daniel Cheng

DC:JD:dc



This workshop module will be a success if …

✓ Establish disinfection technology for:
- ✓ Recycled water
- ✓ Bay discharge

Agenda

- Future regulations and their anticipated impact
- SIP and other recommendations
- Alternatives analysis
- Recommendations
- Next steps

Regulations

Current Disinfection Requirements

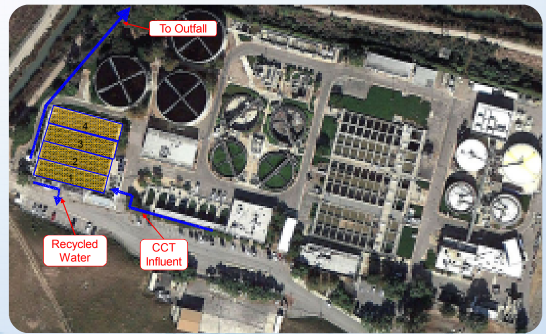
- Recycled Water:
  - Total Coliform: 2.2 MPN/100 mL
  - CT (chlorine residual x contact time) = 450 mg/L-min
    - 90 min contact time (modal)
    - 5 mg/L chlorine residual
- Bay Discharge:
  - Enterococcus: 35 MPN/100 mL

Additional Future Discharge Requirements

- Bay discharge:
  - Constituents of Emerging Concern (CECs)
  - THMs
  - NDMA
- Recycled water:
  - Public perception may require these be addressed also for recycled water production

SIP and Other Recommendations

Existing Chlorine Contact Tank Layout



SIP Recommendations

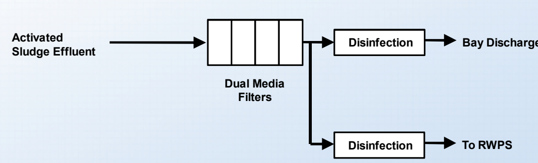
- Bay discharge:
  - Near Term: Transition from gaseous chlorine to HOCl disinfection
  - Long Term: Consider UV (not specific to the drivers)
- Recycled water:
  - Transition from current batch operation to continuous recycled water production
  - Near Term: Transition from gaseous chlorine to HOCl disinfection
  - Long Term: Consider UV (not specific to the drivers)

FSRWE (2013) Summary Findings

- Feasibility Study for Recycled Water Expansion (FSRWE) (2013) identified:
  - 1.7 mgd required by 2017
    - 3 mgd with Apple included (outside of service area, identified after the FSRWE)
  - 3.6 mgd required between 2017 and 2033 (without Apple)
  - Peak demands (up to 6.4 mgd) would be met with potable water

Alternatives Analysis

DMF-Only Alternative for Continuous Recycled Water Production – Long Term



Modifications to CCT to allow Continuous Recycled Water Production

CCT Capacity Evaluation (2035 Flows) - Bay Discharge

Condition	2035 Flow, mgd	Bay Discharge, mgd	Contact Tanks, no.	Contact Time, min	Required Contact Time, min
Summer: ADAF	20.4	16.8	3 CCTs	86	30-60
Winter: ADMMF	26.2	26.2	3 CCTs	55	30-60

Note:
ADAF = Average Day Annual Flow
ADMMF = Average Day Maximum Month Flow

CCT Capacity Evaluation (2035 Flows) - Recycled Water

Condition	2035 Flow, mgd	Recycled Water, mgd	Contact Tanks, no.	Contact Time, min	Required Contact Time, min
Summer: ADAF	20.4	3.6	1 CCT	133	90 (modal)
Winter: ADMMF	26.2	Small flow	1 CCT	>133	90 (modal)

Note:
ADAF = Average Day Annual Flow
ADMMF = Average Day Maximum Month Flow

Conclusions from Capacity Evaluation

- Sufficient CCT capacity to:
  - Dedicate 3 CCTs to Bay discharge
  - Dedicate 1 CCT to recycled water production (requires reroute piping to RW pump station)
- Future activated sludge removes ammonia
  - Increases chlorine demand
  - Increases potential for THM formation
  - Impacts disinfection efficiency/stability
- Recommend implementing aqueous ammonia feed

Future Regulations: CECs

- Requires an advanced oxidation process (AOP) :
  - Ozone (O_3)
  - Small-dose O_3 in combination with HOCl disinfection
  - Small-dose O_3 in combination with UV disinfection
  - High-dose UV in combination with peroxide (H_2O_2)

Future Regulations: THMs

- Currently in your permit (well within that limit)
- THM-formation typically offset by formation of chloramines (available ammonia in effluent)
- Addition of aqueous ammonia will avoid dramatic increases in chlorine dose requirements (and mitigate against THM formation if it should be a problem)
  - With a TN<8 mg/L regulation, continued addition of ammonia likely still possible, but will have a lower margin of safety of meeting the regulatory limit

Future Regulations: NDMA

Process	Potential for NDMA formation
Disinfection:	
HOCl with ammonification	High
HOCl	Low
UV	Very low
Advanced Oxidation Process (AOP):	
Ozone (O_3)	High
Small-dose O_3 + HOCl disinfection	Unknown
Small-dose O_3 + UV disinfection	Very low
High-dose UV + peroxide (H_2O_2)	Very low

Evaluation of Alternatives

	1 O_3	2 HOCl + O_3	3 UV + O_3	4 UV + H_2O_2
Reliability	0	0	0	0
Ease of O&M	0	0	0	0
Maximize Resources	n/a	n/a	n/a	n/a
Power Usage	0	0	-	-
Flexibility	-	-	+	+
Ease of Implementation/ Compliance	0	+	0	0
Site Efficiency	+	-	+	+
Net Present Value (NPV)	$40M ±	$37M ±(1)	$34M ±	$44M ±

1. a. Does not include cost for current hypo conversion project
   b. Includes cost for aqueous ammonia addition

\+ Better | 0 Neutral | - Worse

Evaluation of Alternatives

	1 O_3	2 HOCl + O_3	3 UV + O_3	4 UV + H_2O_2
Reliability	0	0	0	0
Ease of O&M	0	0	0	0
Maximize Resources	n/a	n/a	n/a	n/a
Power Usage	0	0	-	-
Flexibility	-	-	+	+
Ease of Implementation/ Compliance	0	+	0	0
Site Efficiency	+	-	+	+
Net Present Value (NPV)	$40M ±	$37M ±(1)	$34M ±	$44M ±

1. a. Does not include cost for current hypo conversion project
   b. Includes cost for aqueous ammonia addition

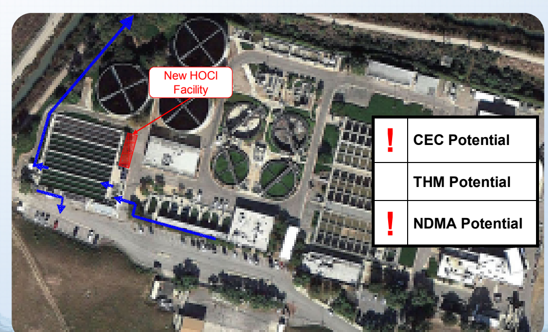
\+ Better | 0 Neutral | - Worse

Recommendations

Disinfection Planning Recommendations

- **Phase 1:** Near-Term (Prior to Activated Sludge)
  - Stay with chlorine disinfection
  - Continue with HOCl conversion

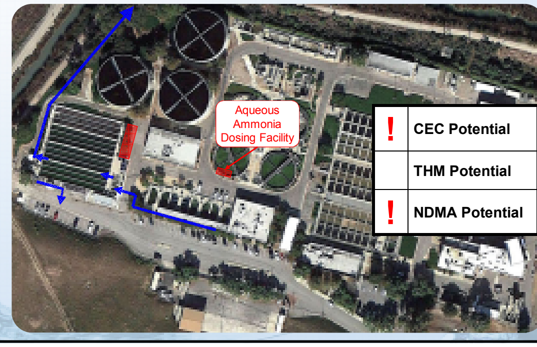
Phase 1 – New HOCl Facility



Disinfection Planning Recommendations

- **Phase 2:** Once NAS activated sludge plant comes online
  - Effluent ammonia will be low
    - Increases chlorine demand
    - Increases potential for THM formation
    - Impacts disinfection efficiency/stability
  - Add aqueous ammonia station

Phase 2 – Aqueous Ammonia Dosing Facility



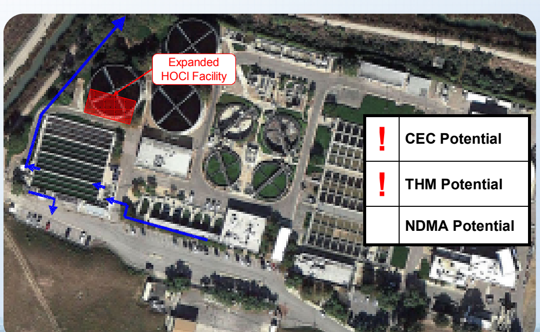
Disinfection Planning Recommendations

- **Phase 2:** Once NAS activated sludge plant comes online
  - Effluent ammonia will be low
    - Increases chlorine demand
    - Increases potential for THM formation
    - Impacts disinfection efficiency/stability
  - Add aqueous ammonia station
  - With a TN<8 mg/L regulation:
    - Continued addition of ammonia likely still possible, but will have a lower margin of safety of meeting the regulatory limit

Disinfection Planning Recommendations

- **Phase 3A:** When NDMA becomes a regulatory driver:
  - Abandon aqueous ammonia, and increase HOCl dose
  - If THM regulations are in effect, monitor effluent THMs

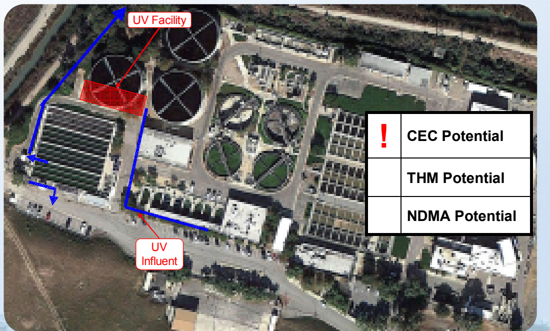
Phase 3A – Expand HOCl Facility



Disinfection Planning Recommendations

- **Phase 3A:** When NDMA becomes a regulatory driver:
  - Abandon aqueous ammonia, and increase HOCl dose.
  - If THM regulations are in effect, monitor effluent THMs
- **Phase 3B:** When NDMA and THMs become a regulatory driver:
  - Convert to UV disinfection

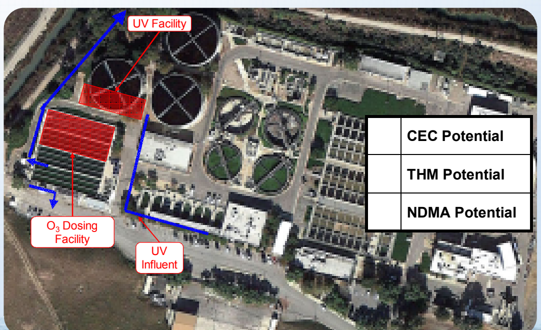
Phase 3B – Conversion to UV



Disinfection Planning Recommendations

- **Phase 4:** When CEC regulations become a reality (2025±):
  - Add a small O_3 facility (based on current technology)
  - Leave space and identify power and support utility requirements

Phase 4 – Add Ozone to UV for AOP



Summary of Recommendations

- Conversion to HOCl disinfection is appropriate
- After the transition to activated sludge treatment (low effluent ammonia):
  - Add aqueous ammonia for process stability, and to mitigate against THM formation
- When NDMA regulations are in effect:
  - Stop aqueous ammonia addition (increases HOCl addition, and increases THM-formation likelihood)
  - If THMs are too high, convert to UV disinfection
- When CECs are in effect, add O_3

Full Site Layout – Conventional Activated Sludge with West Rectangular Clarifiers

Full Site Layout – MBR Activated Sludge

Next Steps

Next Steps

- Continue the conversion to HOCl
- Develop CIP project for modifications to the CCTs

This Meeting will be a Success if …

✓Establish disinfection technology for:
  - ✓Recycled water
  - ✓Bay discharge

End

APPENDIX B – LACSD SEQUENTIAL CHLORINATION STUDY

Volume 9, Fall 2009

Environmental Engineer:
Applied Research and Practice

SEQUENTIAL CHLORINATION: A NEW APPROACH FOR DISINFECTION OF RECYCLED WATER

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AMERICAN ACADEMY OF ENVIRONMENTAL ENGINEERS®

Sequential Chlorination: A New Approach for Disinfection of Recycled Water

Stephen R. Maguin, P.E., BCEE, Philip L. Friess, P.E., BCEE, Shiaw-Jy Huitric, P.E., Chi-Chung Tang, Ph.D., P.E., BCEE, Jeff Kuo, Ph.D., P.E., and Naoko Munakata, Ph.D.[1]

ABSTRACT

Recycled water must be properly disinfected to protect public health. The most widely practiced recycled water disinfection technology is chloramination. However, chloramines are precursors to the carcinogen N-nitrosodimethylamine (NDMA). To address this concern, engineers at the Sanitation Districts of Los Angeles County (Districts) developed the two-step "sequential chlorination" process. In the first step, free chlorine is added to fully nitrified secondary effluent to inactivate pathogens and to react with NDMA precursors, thus reducing subsequent NDMA formation. Chloramines are then added to media filtered effluent to stop formation of trihalomethanes (THMs) and haloacetic acids and to provide further disinfection.

The sequential chlorination process was extensively tested for disinfection efficacy and disinfection byproduct (DBP) formation in the laboratory, at the pilot scale, and at several water reclamation plants operated by the Districts. Results indicate that the process (1) provides effective disinfection against total coliform bacteria and viruses at chlorine contact times well below those required by California regulations for disinfected tertiary recycled paper; (2) reduces NDMA formation by 50 to 85% in comparison to chloramination; (3) produces effluent consistently meeting the total THM limit for recycled water; (4) generates insignificant amounts of cyanide (a DBP of concern); and (5) causes no aquatic toxicity.

INTRODUCTION

The Sanitation Districts of Los Angeles County (Districts) operate 11 wastewater treatment plants serving over five million residents in the Los Angeles County, California. The 11 plants treat a combined average daily flow of approximately 500 million gallons per day (MGD). Seven of the 11 plants are tertiary water reclamation plants (WRPs) that produce over 150 MGD of recycled water. Typical treatment processes at these tertiary WRPs include primary sedimentation, activated sludge with biological nitrogen removal, media filtration, chlorine disinfection, and dechlorination. Approximately one-third of the recycled water is currently reused for groundwater replenishment, landscape and agricultural irrigation, wildlife habitat maintenance, and industrial process water supply; the remainder is discharged to surface water.

Recycled water must be properly disinfected. The disinfection method must be effective for pathogen inactivation, and should minimize the generation of potentially harmful disinfection byproducts (DBPs). In California, disinfection requirements are specified in California Title 22 water recycling criteria. For groundwater replenishment, the recycled water must meet drinking water standards.

Historically, chlorination is the most widely practiced wastewater disinfection technology. Depending on the ammonia level in the water, chlorine may be present as either free chlorine or chloramines. At the Districts' tertiary WRPs, either free chlorine or chloramines may be used for disinfection because these plants are designed to remove nitrogen. Secondary effluents of these plants are considered fully nitrified and usually contain <1 mg NH_3-N/L. Until recently, chloramination was practiced at these WRPs because chloramines produce lower levels of trihalomethanes (THMs) than free chlorine (Kuo *et al.*, 2003). Low levels of ammonia nitrogen (typically 1.0 to 1.5 mg NH_3-N/L) were added to fully nitrified secondary effluent, followed by chlorine addition (8 to 10 mg Cl_2/L) upstream of the media filters. Additional chlorine could be added downstream of the filters, if necessary, to maintain sufficient chlorine residual in the chlorine contact tank effluent.

Chloramination has provided effective disinfection. However, researchers recently found that chloramines generate N-nitrosodimethylamine (NDMA), a chemical with high carcinogenic potency (Mitch *et al.*, 2003; Choi and Valentine, 2004; Mitch and Sedlak, 2004; Sedlak *et al.*, 2005). NDMA precursors are chloramines and dimethylamine, a component in the cationic polymer commonly added to the return activated sludge or to the mixed liquor entering the secondary clarifiers to enhance settling and for foam control. In previous work, the Districts attempted to reduce NDMA formation by replacing the cationic polymer with emulsion polymers that do not contain dimethylamine; although this change reduced NDMA formation, the alternative polymers were less effective than the cationic polymer as a settling aid, caused operational issues with the media filters, and were not considered a practical solution for reducing NDMA formation (Huitric *et al.*, 2006). Free chlorine and chloramines may also produce other DBPs such as cyanide (Kavanaugh *et al.*, 2003; Zheng *et al.*, 2004a & 2004b).

Due to these concerns, the Districts decided to replace chloramination with a new disinfection method that would continue to protect public health with its high disinfection efficacy, minimize DBP (specifically THM, NDMA, and cyanide) formation, and have no adverse impact to

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the environment (i.e., no aquatic toxicity). The new disinfection method should be easily and cost-effectively implemented by using existing infrastructure and practice. To meet these objectives, the Districts' staff conceived the idea of "sequential chlorination" in which chlorine is applied in two steps, as shown in Figure 1.

In the first step of sequential chlorination, free chlorine is added to fully nitrified secondary effluent. Free chlorine rapidly inactivates bacteria and viruses because it is a strong oxidant (Tchobanoglous *et al.*, 2003). It also reacts with NDMA precursors to make them less available for subsequent NDMA formation (Schreiber and Mitch, 2005). Furthermore, free chlorine residual helps to control biofouling on the filter media. In the second step of the process, ammonia and additional chlorine are added to filtered effluent to form chloramines. Chloramines minimize THM formation and provide additional bacterial and viral disinfection. The only change in system configuration from chloramination to sequential chlorination was to relocate the ammonia addition line from upstream to downstream of the media filters.

OBJECTIVES AND SCOPE

The main objective of the study was to evaluate the disinfection performance and DBP formation of the sequential chlorination process. The evaluation was conducted in four phases (Huitric *et al.*, 2007, Huitric *et al.*, 2008). Because DBP formation prompted this investigation, the first two phases focused on DBP formation, first at the laboratory scale (Phase I), then at the plant scale (Phase II). Phase II also examined regulatory compliance with respect to microbial inactivation and aquatic toxicity. The last two phases continued to study disinfection efficacy at the laboratory scale (Phase III) and pilot scale (Phase IV) with the specific goal of meeting California Title 22 virus inactivation requirements for "disinfected tertiary recycled water." Table 1 summarizes the specific objectives and scope of each phase of the study.

FIGURE 1
Sequential Chlorination at the Districts' Tertiary Water Reclamation Plants

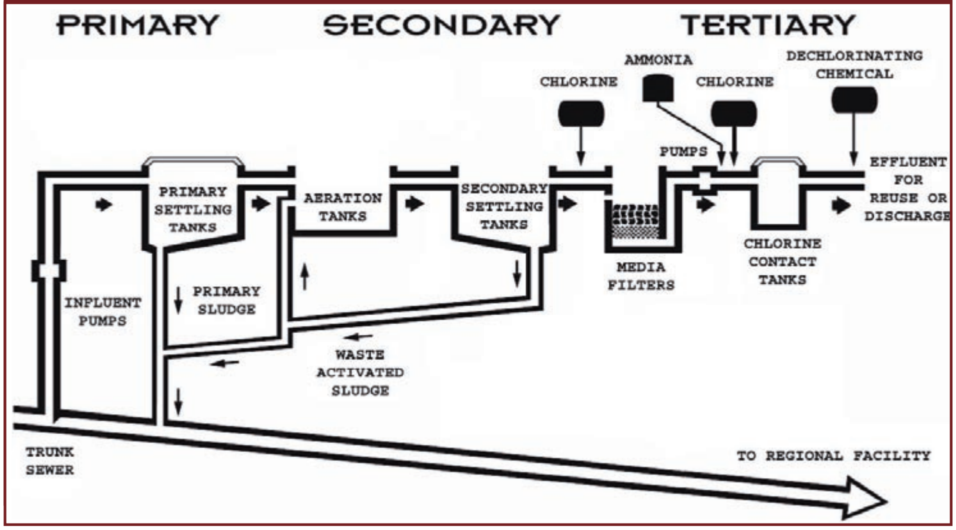


TABLE 1
Sequential Chlorination Research Objectives and Scope

Phase	Objectives	Scope
I	Evaluate DBP formation by sequential chlorination	Laboratory experiments using secondary effluent samples from Long Beach WRP
II	• Verify DBP formation results from laboratory study • Evaluate microbial (coliform and enteric virus) inactivation and aquatic toxicity • Determine operating conditions (i.e., chlorine dose and residual) for full-scale operation	Plant-scale testing at Long Beach WRP, San Jose Creek WRP*, and Whittier Narrows WRP
III	Determine chlorine doses and contact times needed to meet California Title 22 requirements for "disinfected tertiary recycled water" (5-log inactivation of poliovirus or MS2 coliphage and total coliform <2.2/0.1 L)	Laboratory experiments using secondary effluent samples from San Jose Creek WRP* seeded with surrogate viruses (poliovirus and MS2 coliphage)
IV	Verify virus inactivation results from laboratory experiments	Pilot-scale testing using secondary effluent from San Jose Creek West WRP seeded with MS2 coliphage

*San Jose Creek WRP includes two separate treatment systems, San Jose Creek East WRP and San Jose Creek West WRP.

MATERIALS AND METHODS

Phase I – Laboratory Experiments on DBP Formation

The focus of the Phase I experiments was to determine DBP formation from sequential chlorination and compare that with DBP formation from chloramination. Specific DBPs evaluated included THMs, NDMA, and cyanide. Microbial analyses were not conducted in these bench-scale experiments. Fully nitrified secondary effluent samples from the Districts' Long Beach WRP were used for the experiments. The samples were disinfected by chloramination and sequential chlorination. Figure 2 shows the test plan, including the ammonia and chlorine doses, contact times, and the water quality parameters analyzed. This procedure was repeated five times to evaluate the consistency of the results.

Phase II – Plant-scale Testing on DBP Formation and Disinfection Efficacy

Plant-scale studies were conducted at several WRPs operated by the Districts. Table 2 summarizes the average flow treated and the type of nitrification/denitrification (NDN) processes employed at these WRPs.

Each plant was tested for several weeks during which extensive sample collection and analysis was conducted. Samples were analyzed for chemical parameters (ammonia, THMs, NDMA, and cyanide), microbial indicators (total coliform and enteric virus), and aquatic toxicity. For NDMA analysis, 24-hour composite samples were collected. All other samples were grab samples. Typically, two sets of samples were collected on a daily basis; secondary effluent samples were collected around 7:30 a.m. and 9:30 a.m., and chlorinated final effluent samples at 10:30 a.m. and 12:30 p.m. The time difference was to account for the hydraulic retention time in the filters and in the chlorine contact tanks. Samples were also collected immediately downstream of the media filters (filtered effluent samples) to evaluate disinfection efficacy of free chlorine added upstream of the filters.

Phase III – Laboratory Experiments on Disinfection Efficacy

It was not feasible to demonstrate high levels of virus inactivation (5 logs required by California regulations for "disinfected tertiary recycled water") by sequential chlorination at plant-scale because indigenous virus concentrations are usually lower than 10^5/0.1L in Districts' tertiary WRP secondary effluent, and it was not practical to seed the amount of virus needed for the demonstration. Consequently virus inactivation by the sequential chlorination process was studied initially at the laboratory scale. The experiments were conducted with fully nitrified secondary effluent samples collected from the San Jose Creek WRP. Two indicator viruses, MS2 coliphage and poliovirus, were seeded to the samples, and three disinfection schemes were tested:

1. Chlorination: to simulate the first step of sequential chlorination;
2. Chloramination: to simulate the second step of sequential chlorination; and
3. Sequential chlorination: to simulate overall sequential chlorination process with free chlorine addition followed by chloramines (ammonia then chlorine) addition.

FIGURE 2
Schematic Diagram for Sequential Chlorination Bench-Scale Experiments

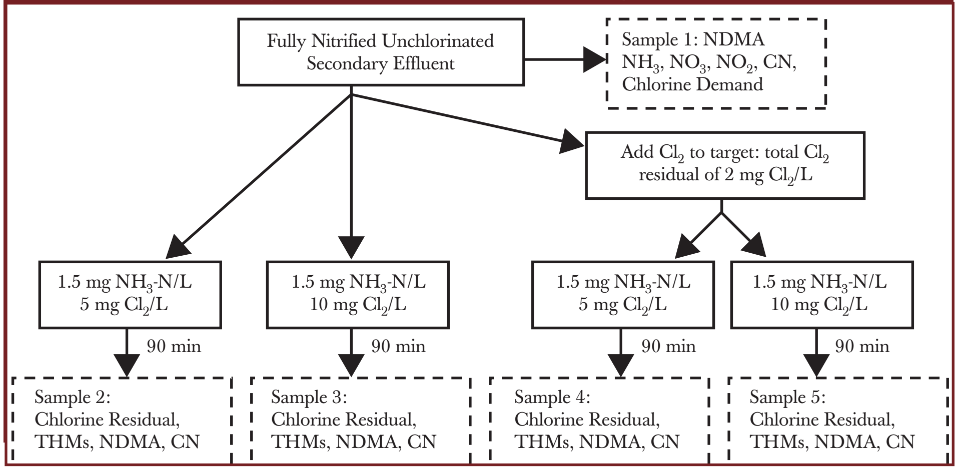


TABLE 2
Full-Scale Sequential Chlorination Testing: Facility Information

Test Facility	Test Period	Average Flow (MGD)	NDN Process
San Jose Creek East WRP	01/23/07 - 02/16/07	55	Step Feed
San Jose Creek West WRP	10/02/06 - 10/30/06	30	Step Feed
Whittier Narrows WRP	11/01/06 - 12/01/06	8	Modified Ludzack-Ettinger
Long Beach WRP	05/22/06 - 06/27/06	20	Step Feed

In each experiment, a portion of the effluent sample was first analyzed to obtain the baseline water quality parameters as well as total coliform concentrations. The rest of the sample was seeded with poliovirus and MS2 coliphage, and thoroughly mixed for at least 20 minutes. After mixing, initial virus concentrations were determined by collecting an aliquot of the sample before any chlorine treatment. For the free chlorine experiments, chlorine was added to the sample. Chloramine experiments added ammonia followed by chlorine. The sequential chlorination experiments added chlorine first, followed by ammonia then more chlorine. At pre-determined contact times, total and/or free chlorine residuals were measured. Samples were then dechlorinated using sodium thiosulfate, and analyzed for viruses as well as total coliform.

Phase IV – Pilot-scale Testing of Virus Inactivation

To verify the results from the Phase III study, the Districts conducted pilot-scale testing on virus inactivation at the San Jose Creek WRP. Figure 3 is a schematic diagram of the pilot-scale chlorine contact system constructed for the study. The system included two channels with 1-foot by 1-foot cross-sections. The length of the channels varied by experiment, as described below. Baffles were installed near the inlet of each channel to provide uniform flow distribution. Tracer tests were performed prior to any virus testing to determine modal contact times corresponding to several test flow rates. During virus testing, the channels were covered, as are the full-scale chlorine contact tanks at the plant, to avoid any effects from sunlight, wind, or dust.

Two types of tests were conducted with nitrified secondary effluent. One tested virus inactivation by free chlorine alone and used a single 24-foot long channel with an effluent flow rate of 8 gallons per minute (gpm). The other tested sequential chlorination and used two channels; the first channel was 12 feet long, used a flow rate of 22 gpm, and was dosed with free chlorine, while the second channel was 36 feet long, used a flow rate of 6 gpm, and was dosed with chloramines. In both types of experiments, virus (M2 coliphage) was mixed into the effluent with a static inline mixer. Following mixing, a sample was collected for analysis of initial virus concentration.

For the free chlorine experiments, chlorine was added upstream of the channel, and mixed into the flow using static inline mixers. Free chlorine residuals were measured at all sampling points within the channel. Samples were collected at four points along the length of the channel (corresponding to four different contact times), dechlorinated, and delivered to the laboratory for virus analysis. For the sequential chlorination experiments, chlorine was also added upstream of the first channel. Ammonia was then added to the end of the first channel, followed by more chlorine addition upstream of the second channel to form chloramines (Figure 3). Free and/or total chlorine residuals were measured at selected locations in each channel. Samples were collected at the end of each channel, dechlorinated, and delivered to the laboratory for virus analysis.

Water Quality

Table 3 provides water quality data for the secondary effluents used in this study. During Phase II at the full-scale plants, water quality samples were not taken specifically for this project; data in Table 3 were taken from routine monitoring samples for process control. During Phase III, some samples were taken in the morning when the effluent flow through the WRP was low and some samples were taken at noon (high flow); no performance differences were observed, so the data were combined for this paper. For Phases III and IV, pH values were also measured, with values of 7.2 ± 0.2 in both phases.

Mixing and Sampling

The rate at which chlorine is mixed into the effluent may affect disinfection efficacy and DBP formation. Consequently, mixing in the laboratory, pilot, and full-scale systems was evaluated through the calculation of the product Gt, where G is the velocity gradient and t is the mixing time. The Gt values for the three systems were of the same order of magnitude

FIGURE 3
Schematic Diagram of Pilot-Scale Chlorine Contact System

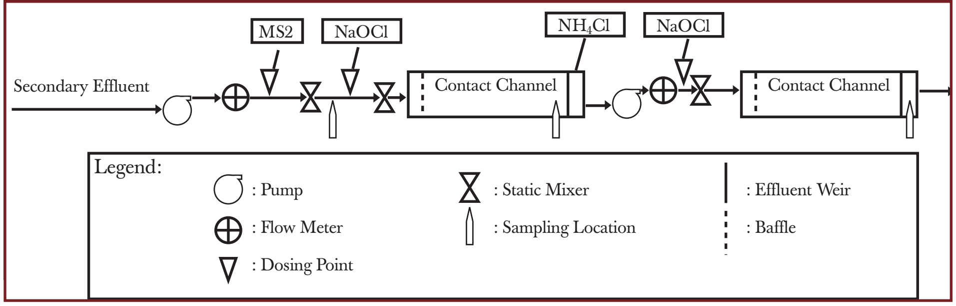


TABLE 3
Water Quality Data

	WRP[a]	Turbidity (NTU)	Ammonia Nitrogen (mg N/L)	Nitrate Nitrogen (mg N/L)	Nitrite Nitrogen (mg N/L)	Chlorine Demand (mg/L)
Phase I: Laboratory	LB	—	0.4 ± 0.3	5.2 ± 2.7	0.22 ± 0.20	—
Phase II: Full-Scale	LB	1.1 ± 0.1	<1[b]	5.6 ± 0.7	0.02 ± 0.01	—
	SJCE	2.0 ± 0.8	1.2 ± 0.6	2.2 ± 0.9	1.30 ± 0.40	—
	SJCW	1.4 ± 0.4	<1[b]	6.1 ± 1.1	0.09 ± 0.03	—
	WN	1.6 ± 0.6	<1[b]	7.2 ± 1.0	0.02 ± 0.00	—
Phase III: Laboratory	SJCE & SJCW	1.0 ± 0.3	0.2 ± 0.1	2.0 ± 1.2	0.06 ± 0.03	3.9 ± 0.5
Phase IV: Pilot-Scale	SJCW	0.8 ± 0.2	<0.10[c]	4.0 ± 1.2	0.05 ± 0.01	3.4 ± 0.4

—: Not measured.
[a]Abbreviations: LB: Long Beach. SJCE: San Jose Creek East. SJCW: San Jose Creek West. WN: Whittier Narrows.
[b]All ammonia samples from LB, SJCW, and WN during Phase II had concentrations below the reporting limit of 1 mg N/L; ammonia analysis in Phases III and IV had a lower reporting limit (0.10 mg N/L).
[c]14 samples were below the reporting limit of 0.10 mg N/L; one sample had an ammonia concentration of 0.13 mg N/L.

TABLE 4
Results of Bench-scale Study to Evaluate DBP Formation

Sample Number	Sample Description	Chlorine Residual (mg/L)	Cyanide (µg/L)	Total THMs (µg/L)	NDMA (ng/L)
1	Unchlorinated Secondary Effluent	—	<5	—	100 - 140
2	Chloramination	2.8 - 3.3	<5	3 - 5	300 - 1,300
3	Chloramination	4.6 - 5.8	<5	7 - 11	1,100 - 5,400
4	Sequential Chlorination	3.4 - 7.0	<5	56 - 65	110 - 230
5	Sequential Chlorination	0.5 - 3.0	<5	63 - 72	100 - 200

TABLE 5
Comparison of NDMA Concentrations in Chlorinated Effluents

Test Facility	Chloramination			Sequential Chlorination		
	No. of samples	NDMA (ng/L)		No. of Samples	NDMA (ng/L)	
		Range	Median		Range	Median
San Jose Creek East WRP	34	1,000 - 5,000	2,050	18	200 - 590	310
San Jose Creek West WRP	28	400 - 3,700	985	21	260 - 650	440
Whittier Narrows WRP	28	52 - 850	320	17	37 - 590	160
Long Beach WRP	21	500 - 3,200	1,400	30	93 - 880	425

(calculations not shown), indicating that the mixing should be similar across the systems; the full-scale system had slightly better mixing, with Gt values 1-3 times higher than at laboratory or pilot-scale.

Samples for NDMA, THMs, and microbial analyses were collected in amber glass jugs, amber glass vials, and sterilized plastic containers, respectively. Plastic containers were used for other samples. Samples for microbial and NDMA analyses were dechlorinated by adding sodium thiosulfate in the sample containers. Samples for THM analysis were first quantitatively dechlorinated and then poured into the sample vials. The quantitative dechlorination procedure avoided over-dechlorination, which may damage the analytical instrument.

Chemicals and Microorganisms

Chlorine was applied as sodium hypochlorite. Sodium hypochlorite, 4-6% by weight (Fisher Scientific, Pittsburgh, PA), was diluted to different strengths and standardized in the laboratory for each bench and pilot scale experiment. For bench scale experiments, ammonia standard (1,000 mg NH_3-N/L) obtained from Environmental Resource Associates (Arvada, CO) was used as received. Ammonia solutions used for pilot-scale experiments were made in the laboratory using ammonium chloride powder (99.5% purity) from EMD Chemicals (Gibbstown, NJ). MS2 coliphage (American Type Culture Collection #15597B1) was purchased from GAP EnviroMicrobial Laboratory in Canada. Poliovirus was cultured in the Districts' Microbiology Laboratory, using CHAT type-1 poliovirus (American Type Culture Collection #VR192, a predecessor to the currently available #VR1562).

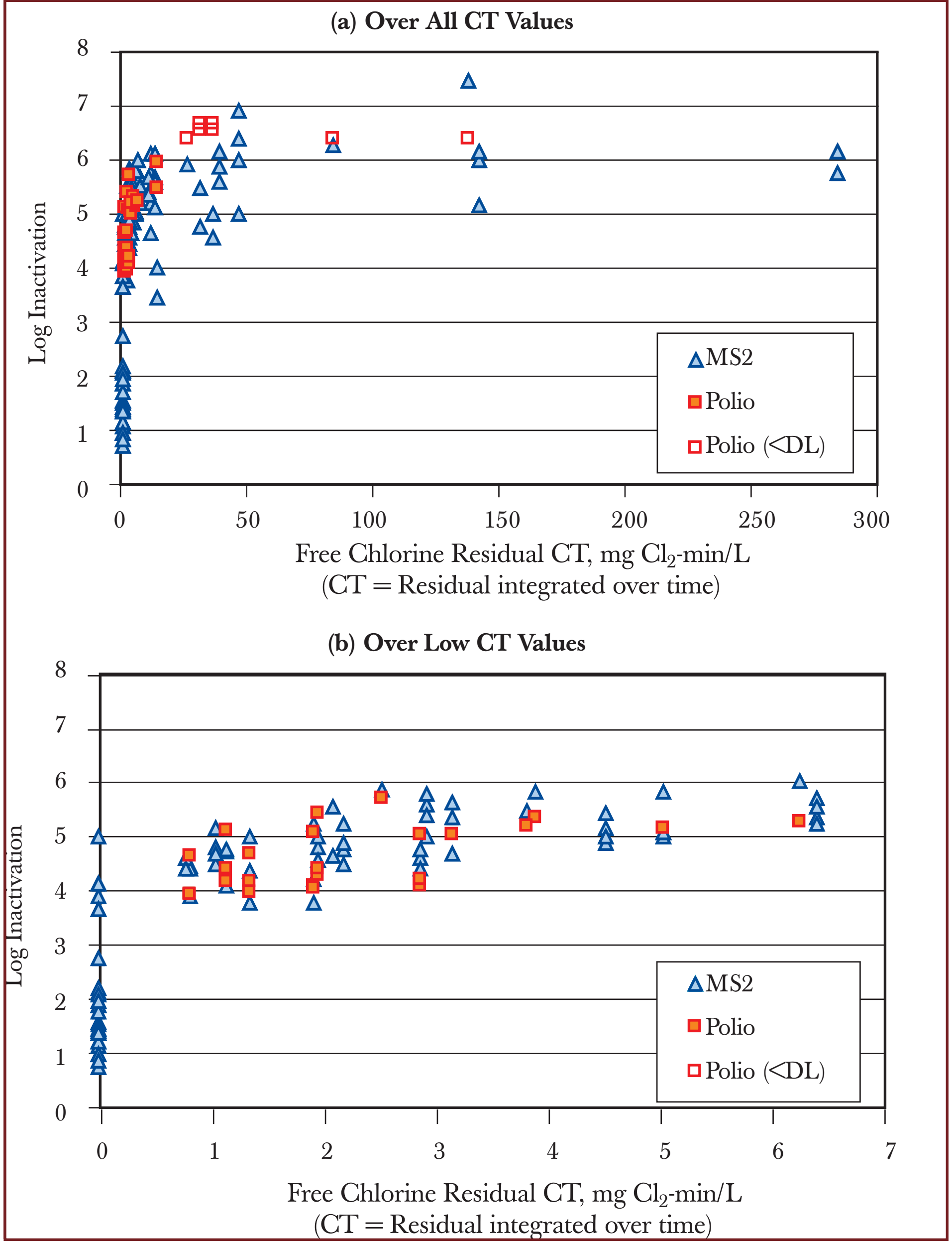
Laboratory Analyses

The Districts' laboratories conducted all chemical analyses for this project, and are certified by the California Department of Public Health for these analyses. NDMA analysis used EPA Method 1625, which employs liquid-liquid extraction followed by chemical ionization isotope dilution gas chromatography/mass spectrophotometry; the reporting limit is 2 nanograms per liter (ng/L) in secondary and final effluent

TABLE 6
Total Coliform Results from Full-Scale Chlorination Testing

Test Facility	Filtered Effluent (After Free Chlorine)		(Sequential Chlorination)	
	No. of Samples	Total Coliform (CFU/0.1 L)	No. of Samples	Total Coliform (CFU/0.1 L)
San Jose Creek East WRP	19	1 - >200	19	<1 - 2
San Jose Creek West WRP	28	<1 - 115	21	<1 - 1
Whittier Narrows WRP	13	1 - 400	15	<1 - 2
Long Beach WRP	22	<1 - 2	26	<1 - 1

FIGURE 4
Laboratory Experiment Results of Virus Inactivation by Free Chlorine



samples. THM analysis used EPA Method 8260 and the reporting limit for each THM species is 2 microgram per liter (µg/L). Free and total chlorine residuals were measured using a colorimeter test kit manufactured by Hach Company (Loveland, Colorado). Free chlorine analysis used EPA-approved Alternative Method 8021, with a factory-reported detection limit of 0.02 mg Cl_2/L. Chloramine analysis used EPA approved Alternative Method 8167, with a factory-reported detection limit of 0.1 mg Cl_2/L. Total cyanide measurements were conducted using the Midi Distillation System followed by manual colorimetric analysis [EPA 335.4, Standard Method 4500-CN-C (American Public Health Association, 1998)]. The method detection limit is 1 µg/L, and laboratory reporting limit is 5 µg/L.

For enteric virus, the laboratories adapted the procedure described in EPA's *Manual of Methods for Virology* for sample collection and concentration; Standard Methods 9510 C and 9510 G were used for poliovirus quantification. The reporting limit of enteric viruses is typically 0.001 IU (infectious unit) per liter. The detection limit for poliovirus analysis depends on the sample volume. EPA Method 1601 was used to measure the concentration of MS2 coliphage. The typical detection limit is 2 MPN/0.1L. Total coliform analysis used Standard Method 9222B, a membrane filter (MF) procedure. The MF method was chosen because the membrane filter technique is highly reproducible and usually yields numerical results more rapidly than the multiple-tube fermentation procedure (American Public Health Association, 1998). The detection limit for the MF method is 1 colony forming unit (CFU)/0.1 L.

Chronic toxicity testing was conducted using concurrently collected secondary effluent (prior to chlorine addition) and final effluent (disinfected) samples. Tests were conducted on *Pimephales promelas* and *Ceriodaphnia dubia* and followed procedures described in *Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms* (EPA, 2002). Potential chronic toxicity as a result of sequential chlorination was determined by comparing survival and sub-lethal effects on the two test organisms in secondary effluent samples versus those in disinfected final effluent samples.

FIGURE 5
Laboratory Experiment Results of Total Coliform Inactivation by Free Chlorine

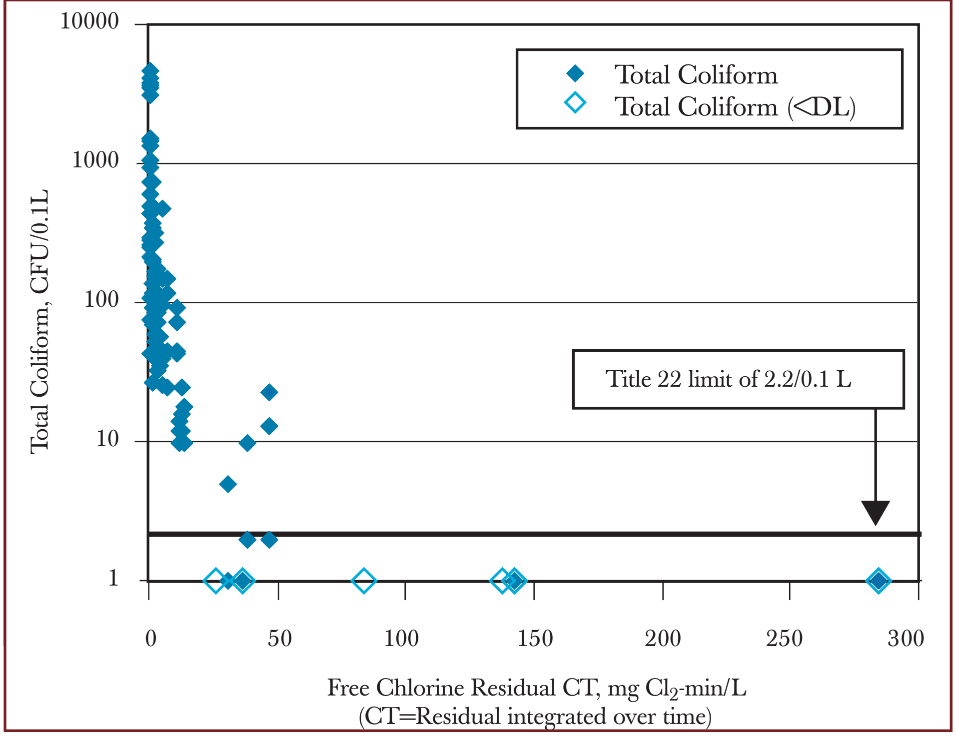
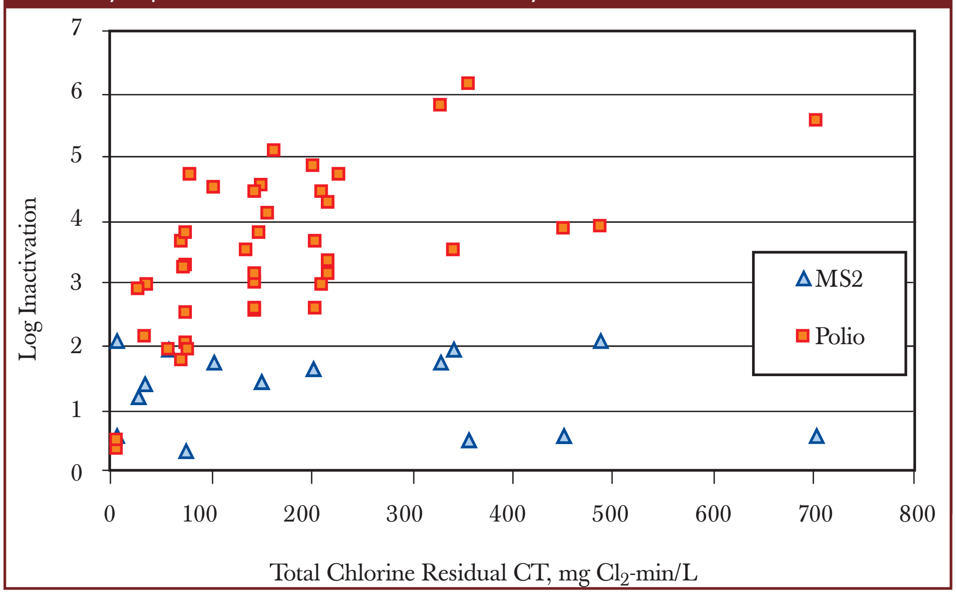


FIGURE 6
Laboratory Experiment Results of Virus Inactivation by Chloramines



RESULTS AND DISCUSSION

Phase I

As indicated in Table 4, sequential chlorination resulted in significantly reduced NDMA levels (100 – 230 ng/L), as compared to the levels from chloramination (300 – 5,400 ng/L). Sequential chlorination resulted in higher total THM concentrations; however, these concentrations were below the drinking water standard for total THMs, 80 µg/L. Neither chloramination nor sequential chlorination generated cyanide concentrations above the laboratory reporting limit.

Phase II

Because the laboratory DBP results were promising, the Districts tested the sequential chlorination process at several of their WRPs. Operating conditions were as follows: chlorine dose added to nitrified secondary effluent was typically 5 mg Cl_2/L. This chlorine dosage exceeded chlorine demand of the secondary effluent and resulted in approximately 1 mg Cl_2/L of total chlorine residual. Following filtration, ammonia was dosed at approximately 1 mg N/L. Chlorine was then added at a chlorine to ammonia nitrogen mass ratio of approximately 5:1 to form chloramines, which resulted in approximately 4.5 mg Cl_2/L of total chlorine residual immediately after chlorine addition.

Table 5 compares the NDMA concentrations in the final effluent under chloramination (historical data, 2004 – 2006) and sequential chlorination. The table shows that sequential chlorination yielded much lower NDMA concentrations at all four WRPs. Reduction of median NDMA concentrations ranged from 160 ng/L (~50%) at Whittier Narrows WRP to 1,740 ng/L (~85%) at San Jose Creek East WRP. The extent of NDMA reduction appeared to be related to the polymer doses. Among the WRPs tested, the Whittier Narrows WRP used the least amount of polymer, had the lowest NDMA concentrations under chloramination, and experienced the smallest reduction in NDMA concentrations with sequential chlorination.

As expected, total THM concentrations were higher under sequential chlorination. Out of 161 samples analyzed during the sequential chlorination testing, the total THM concentrations ranged from 7.0 to 75 µg/L; median concentration was 35 µg/L. These levels were well within the drinking water standard, 80 µg/L. Out of 162 samples collected for cyanide analysis, all but two samples (from the same WRP; the highest value was 9 µg/L) had concentrations below the laboratory reporting limit of 5 µg/L.

Table 6 summarizes the total coliform results from the Phase II study. Typical total coliform concentration in unchlorinated secondary effluents is approximately 10^4/0.1 L. Free chlorine and filtration reduced total coliform concentrations by at least two to three orders of magnitude. However, the filtered effluent total coliform levels could still exceed the California Title 22 standard of 2.2/0.1 L for unrestricted reuse (except at the Long Beach WRP). The total coliform concentrations after subsequent chloramination, however, were consistently in compliance with the standard. At the Long Beach WRP, three filtered effluent samples were collected and analyzed for indigenous enteric virus. None of the samples detected enteric virus (detection limit = 0.001 IU/L).

A total of 14 sets of secondary and chlorinated final effluent samples (final effluent samples were dechlorinated in

FIGURE 7
Laboratory Experiment Results of Total Coliform Inactivation by Chloramines

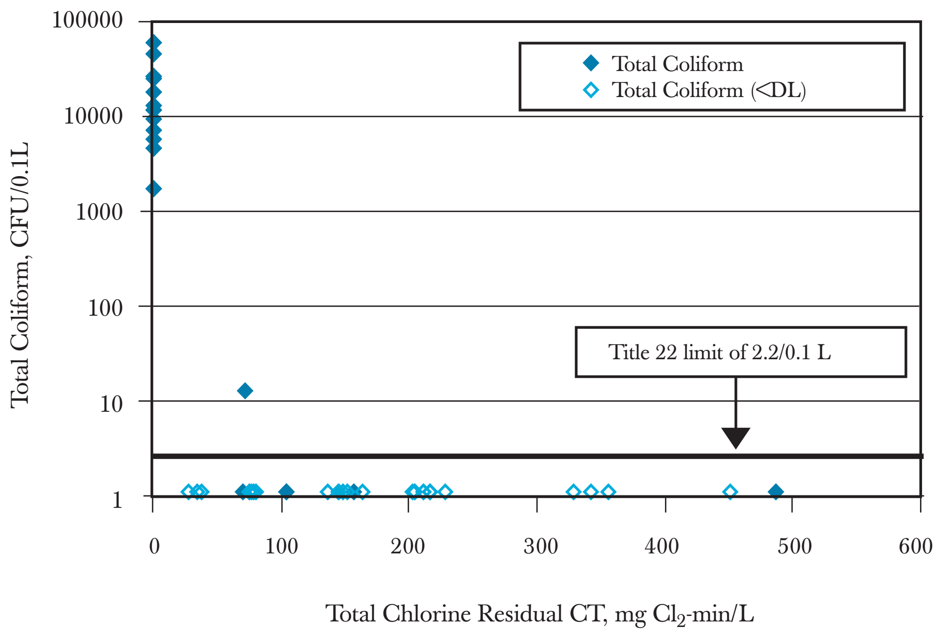
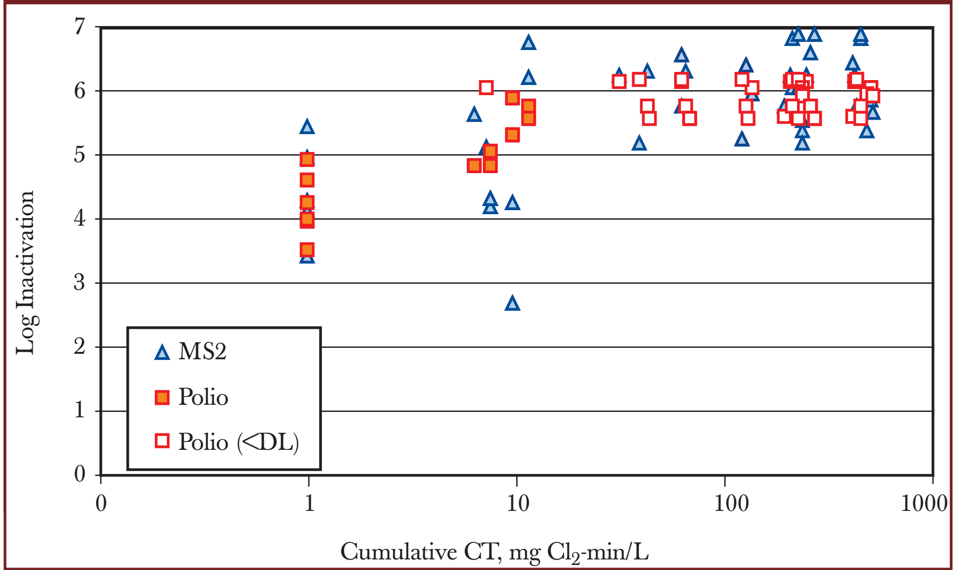


FIGURE 8
Laboratory Experiment Results of Virus Inactivation by Sequential Chlorination



the laboratory) were collected for chronic toxicity testing. The results indicated no aquatic toxicity resulting from sequential chlorination.

In summary, the Phase II study results confirmed that sequential chlorination reduced the formation of NDMA while maintaining acceptable levels of THMs and cyanide, meeting Title 22 total coliform requirements, and producing no aquatic toxicity to the receiving water.

Phase III

Chlorination Experiments

Free chlorine disinfection was tested on 16 fully nitrified secondary effluent samples collected from the San Jose Creek WRP. Chlorine doses were between 1.5 and 10 mg Cl_2/L, contact times were between 1 and 90 minutes. Free chlorine residual CT values were calculated by integrating free chlorine residual concentration over contact time. Figures 4(a) and 4(b) show MS2 and poliovirus inactivation results with free chlorine for all CT values and for low CT values, respectively. Points with a zero CT value represent conditions in which free chlorine residual was not detected, i.e., when chlorine doses were lower than the chlorine demand.

Free chlorine generally inactivated MS2 and poliovirus to a similar degree. Most disinfection occurred at or shortly after the time that free chlorine was added (Figure 4(b)). For CT values ≥ 1 mg Cl_2-min/L, MS2 inactivation was ≥ 4-log in 96% (78 of 81) of the samples and poliovirus inactivation was ≥ 4-log in 97% (29 of 30) of the samples. As CT increased above 1 mg Cl_2-min/L, MS2 disinfection increased slowly and leveled off at approximately 6-log inactivation. Poliovirus disinfection also increased slowly as CT increased above 1 mg Cl_2-min/L, but could not be quantified, because poliovirus concentrations in treated samples were below the detection limit (DL).

Inactivation of total coliform was also evaluated. At CT values above 50 mg Cl_2-min/L, disinfection of total coliform consistently met the Title 22 requirement, as indicated in Figure 5.

FIGURE 9
Laboratory Experiment Results of Total Coliform Inactivation by Sequential Chlorination

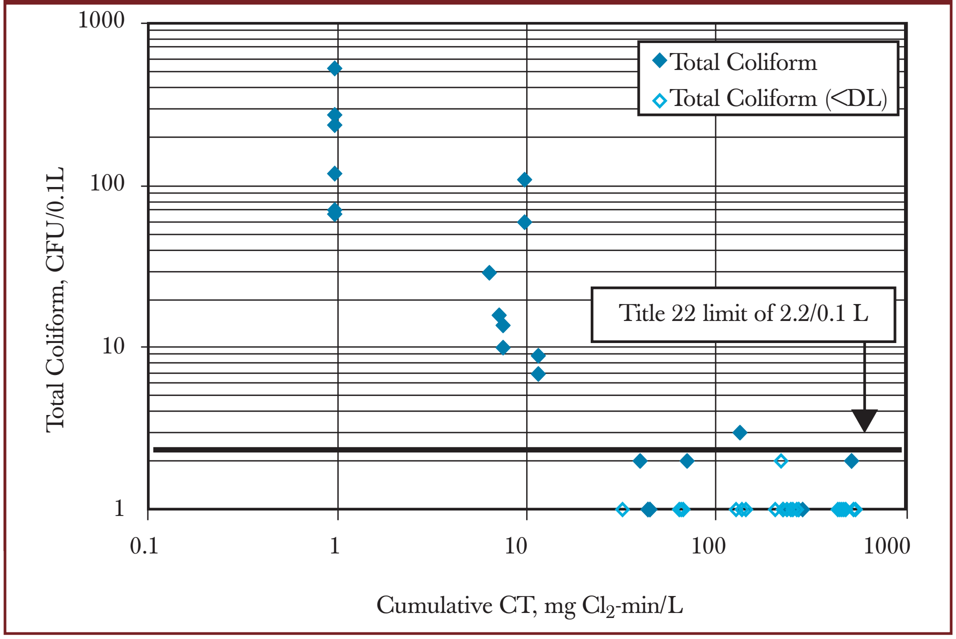
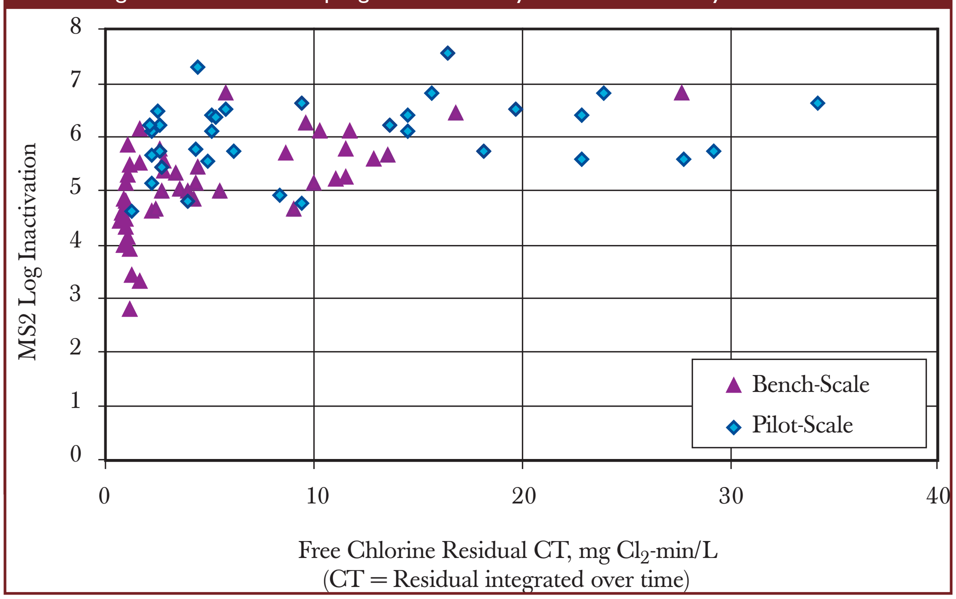


FIGURE 10
Pilot Testing Results of MS2 Coliphage Inactivation by Free Chlorine Only



Chloramination Experiments

The chloramination step of sequential chlorination was tested on 16 fully nitrified secondary effluent samples collected from the San Jose Creek WRP. These samples were dosed with 1 to 3 mg N/L followed by 5 to 10 mg Cl_2/L. The dosed chlorine to ammonia nitrogen mass ratio ranged from 3.3 to 5.3 mg Cl_2/mg N, and contact times ranged from 1 to 90 minutes. The total chlorine residual CT values, ranging from 6 to 774 mg Cl_2-min/L, were calculated as the product of total chlorine residual and contact time. As shown in Figure 6, chloramines were clearly weaker disinfectants than free chlorine, and yielded lower inactivation values for both microorganisms, especially MS2 coliphage. Disinfection of poliovirus generally increased with total chlorine residual CT values, but MS2 coliphage was resistant to chloramines. Little or no improvement in disinfection performance was observed with increasing CT values.

Chloramines effectively disinfected total coliform, as indicated in Figure 7. Total coliform concentration was consistently below the Title 22 requirement at CT value above approximately 100 mg Cl_2-min/L.

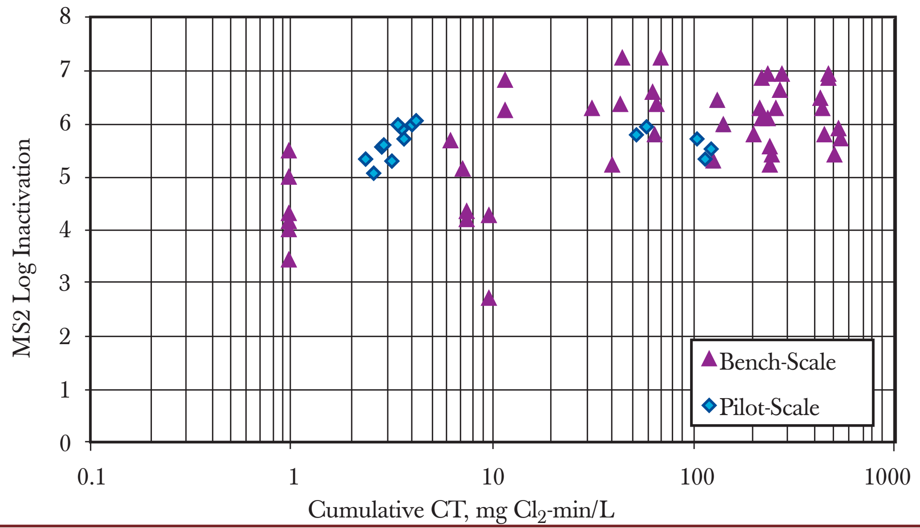
Sequential Chlorination Experiments

Eight experiments were conducted to evaluate the total virus inactivation by sequential chlorination, in which samples were disinfected in two steps. In the first step, 5 to 5.5 mg Cl_2/L of sodium hypochlorite was added to the samples for contact times up to 10 minutes (free chlorine residual CT values between 1 and 10 mg Cl_2-min/L). Ammonia was then added and followed by additional hypochlorite, to form chloramines. Ammonia doses were 0.5 to 1.5 mg N/L, hypochlorite doses were 2.5 to 5.0 mg Cl_2/L, and the dosed chlorine to ammonia mass ratio ranged from 3.3 to 5.0 mg Cl_2/mg N. Chloramine contact times were between 1 and 90 minutes. The cumulative CT values, ranging from 6 and 541 mg Cl_2-min/L, were calculated as the sum of the free chlorine CT value and the total chlorine residual CT value from chloramination.

Virus inactivation results from the sequential chlorination process are shown in Figure 8. In most cases, the first step of sequential chlorination (free chlorine) achieved >4-log inactivation of both MS2 and poliovirus, consistent with results from the free chlorine experiments discussed above. In the few cases that free chlorine did not achieve >4-log inactivation, subsequent chloramination provided additional disinfection. As indicated in Figure 8, inactivation of both poliovirus and MS2 was >5-log in all cases where the cumulative CT value was greater than 15 mg Cl_2-min/L. Beyond this CT value, virus inactivation was not strongly affected by the cumulative CT value. Poliovirus levels were below detection following chloramine addition. MS2 is resistant to chloramines, so additional chloramine contact time has insignificant effect on its inactivation.

Total coliform was also measured in these experiments; results are shown in Figure 9. Total coliform levels decreased rapidly up to a cumulative CT value of 15 mg Cl_2-min/L. Above a cumulative CT value of 30 mg Cl_2-min/L, total coliform levels were <2.2/0.1 L in 31 of 32 samples.

FIGURE 11
Pilot Testing Results of MS2 Coliphage Inactivation by Sequential Chlorination



Phase IV

Ten experiments were conducted to test free chlorine disinfection of seeded virus in the pilot-scale contactor. Free chlorine doses ranged from 3.7 to 5.8 mg Cl_2/L, and the modal contact times ranged from 2 to 10 minutes (based on tracer test results); free chlorine residual CT values were calculated by integrating free chlorine residual concentration over contact time. As shown in Figure 10, free chlorine alone, the first step of the sequential chlorination process, achieved >5-log MS2 inactivation in all but four samples. The minimum MS2 inactivation observed was 4.6-log. These results were consistent with those obtained from the bench-scale experiments (also plotted in Figure 10 for comparison).

Five experiments were conducted to test the overall sequential chlorination disinfection of seeded virus in the pilot-scale contactor. In the first channel, chlorine doses ranged from 4.1 to 4.3 mg Cl_2/L, and the modal contact time was approximately 2.4 minutes (based on tracer test results). The cumulative CT values were calculated as the sum of the free chlorine CT value (calculated by integrating free chlorine residual concentration over contact time) and the total chlorine residual CT value from chloramination (calculated as the product of total chlorine residual and contact time). At the end of the first channel, ammonium chloride (1.1 to 1.2 mg N/L) was added to stop free chlorine reaction. Then, at the beginning of the second channel, more chlorine (3.6 to 5.5 mg Cl_2/L) was applied to form chloramines. Samples were collected at the end of each channel for virus analysis.

Figure 11 shows the results from these experiments. Free chlorine, the first step of sequential chlorination, achieved >5-log MS2 inactivation; the chloramines added in the second step had a marginal effect on MS2 inactivation. These results were in general agreement with those obtained from the bench-scale experiments, also plotted in Figure 11 for comparison.

CONCLUSIONS

The sequential chlorination process is a new approach for disinfection of fully nitrified effluent produced by wastewater treatment and reclamation facilities. The process can be implemented using existing chloramination infrastructure with minor modifications. Plant-scale testing results have shown that the process significantly reduces NDMA formation in comparison to chloramination. By lowering the NDMA levels in the recycled effluent, sequential chlorination could help save the costs of downstream advanced oxidation process for NDMA removal in indirect potable reuse applications. The process does result in a moderate increase in THM formation, but the levels of total THMs are well below the drinking water standards. Sequential chlorination generates insignificant amounts of cyanide and does not cause aquatic toxicity.

Because of the use of free chlorine, the sequential chlorination process is more efficient than chloramination with respect to pathogen inactivation. Sequential chlorination can achieve the same level of pathogen inactivation as chloramination, but with a much shorter chlorine contact time. This could lead to savings in chlorine contact tanks construction for new projects, creation of available space in existing chlorine contact tanks for other uses (e.g., storage, flow equalization), or an increase in treatment capacity.

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