PROJECT MEMORANDUM

Project Name:	SRWTP Advanced Treatment Cost Updates	**Date:**	August 19, 2010
Client:	SRCSD	**Project Number:**	7084A.00
Prepared By:	Elisa Garvey		
Reviewed By:	Katy Rogers, Steve McDonald		
Subject:	Modification of Flow basis for treatment train costs as previously presented in the "Advanced Treatment Alternatives for the Sacramento Regional Wastewater Treatment Plant" (Carollo, March 2009)		
Distribution:	Bob Seyfried, Vyomini Pandya		

Purpose

The purpose of this project memorandum is to provide cost estimates for the advanced treatment trains developed in the technical memorandum titled "Advanced Treatment Alternatives for the Sacramento Regional Wastewater Treatment Plant" (Carollo, March 2009) based on an average dry weather flow (ADWF) of 181 mgd.

Approach

As described in Carollo (2009), the advanced treatment trains include the following:

- Treatment Train A (Title 22 Treatment) - Microfiltration (MF) and UV Disinfection (UV)
- Treatment Train B (Nutrient Reduction) - Nitrifying Trickling Filters (NTF), Fluidized Bed Reactors (FBR), and Chlorine Disinfection
- Treatment Train C (Nutrient Reduction + Title 22 Treatment) - Nitrifying Trickling Filters, Fluidized Bed Reactors, Microfiltration and UV Disinfection
- Treatment Train E (Full RO and Ozonation) - Microfiltration, Reverse Osmosis, and Ozone/Peroxide

The planning level cost estimates presented in Carollo (2009) were based on an ADWF of 218 mgd. The costs presented in this memo are based on an ADWF of 181 mgd. The overall approach to developing planning level cost estimates is described in detail in Carollo (2009).

Results

Table 1 presents the resulting costs estimates for treatment trains A, B, C, and E assuming an ADWF of 181 mgd. A cost estimate for treatment train D was not included because in Carollo (2009), the flow for this treatment train was calculated to achieve a "no net increase" in pollutant loadings based on an increase in flow from 181 mgd to 218 mgd (ADWF). Therefore this treatment train is not applicable when evaluating only the 181 mgd (ADWF) condition.

Table 1 Treatment Train Cost Estimates based on an ADWF of 181 mgd

Treatment Process / Unit Process	Unit Project Cost (1) (2) ($/mgd capacity)	Unit Daily O&M Cost (3) ($/mg treated)	Total Project Cost @ 181 mgd (1)(2) ($ million)	Annual Project Cost (1) (2) (4) @ 181 mgd ($ million)	Total Annual O&M Cost @ 181 mgd (3) ($ million)	Total Annual Cost ($ million)
Treatment Train A - Microfiltration → UV Disinfection						
Microfiltration	$4,390,000	$600	$1,136	$91	$43	$134
Pump Station	$120,000	$13	$31	$2	$1	$3
UV Disinfection	$450,000	$31	$116	$9	$2	$12
Total	$4,960,000	$644	$1,284	$103	$46	$149
Treatment Train B -: NTF → FBR → Chlorine Disinfection						
NTF	$2,130,000	$200	$551	$44	$14	$59
FBR(5)	$652,000	$200	$169	$14	$14	$28
2 Pump Stations	$240,000	$26	$62	$5	$2	$7
Total	$3,022,000	$426	$782	$63	$31	$93
Treatment Train C -: NTF → FBR → Microfiltration → UV Disinfection						
NTF	$2,130,000	$200	$551	$44	$14	$59
FBR(6)	$652,000	$200	$169	$14	$14	$28
3 Pump Stations	$360,000	$39	$93	$7	$3	$10
Microfiltration	$4,390,000	$600	$1,136	$91	$43	$134
UV Disinfection	$450,000	$31	$116	$9	$2	$12
Total	$7,982,000	$1,070	$2,066	$166	$77	$243
Treatment Train E -: Microfiltration → Reverse Osmosis → Ozone/Peroxide						
Microfiltration	$4,390,000	$600	$1,136	$91	$43	$134
Reverse Osmosis (6)	$5,110,000	$1,400	$1,323	$106	$101	$207
2 Pump Stations	$240,000	$26	$62	$5	$2	$7
Ozone/Peroxide	$190,000	11	$49	$4	$1	$5
Total	$9,930,000	$2,037	$2,570	$206	$147	$353

(1) Project costs include engineering, administrative, legal and contingency. All costs in January 2009 dollars ENRCCI 9138.
(2) Capital costs sized to treat associated average day max month flow (ADMMF) of 259 MGD based on an ADMMF/ADWF peaking factor of 1.43.
(3) O&M costs sized to treat associated average day annual flow (ADAF) of 197 MGD, based on an ADAF/ADWF peaking factor of 1.09.
(4) Annual capital costs developed using a 20 year amortization period and 5 percent interest.
(5) FBR costs scaled from March 2005 memorandum (NPDES Permit No. CA 0077682 Provision E.6 Treatment Feasibility Studies, Draft March 2005
(6) Reverse osmosis costs include brine treatment and disposal. The assumed brine flow requiring treatment is 10% of the ADMMF.

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FINAL PROJECT MEMORANDUM

Project Name:	SRWTP Advanced Treatment Costs	**Date:**	September 28, 2010
Client:	SRCSD	**Project No.**	7084B.00
Prepared By:	Steve McDonald		
Reviewed By:	Elisa Garvey, Vincent Roquebert		
Subject:	Review of Project Memorandum titled: *"Verification of Estimated Microfiltration Costs for Proposed Changes to the Sacramento Regional Wastewater Treatment Plant",* (PG Environmental, LLC; August 27, 2010).		
Distribution:	Bob Seyfried, Vyomini Pandya		

PURPOSE

The purpose of this memorandum is to provide review comments on the project memorandum: *"Verification of Estimated Microfiltration Costs for Proposed Changes to the Sacramento Regional Wastewater Treatment Plant",* (PG Environmental, LLC; August 27, 2010), hereafter the "PG Environmental Report".

BACKGROUND

The Central Valley Regional Water Quality Control Board asked PG Environmental to evaluate the microfiltration cost estimate provided in the project memorandum titled, *"Technical Memorandum - Advanced Treatment Alternatives for the Sacramento Regional Wastewater Treatment Plant*", (Carollo Engineers, March 2009), hereafter the "Carollo 2009 Report".

The approach used in the PG Environmental Report to evaluate microfiltration cost estimate in the Carollo 2009 Report was based on "conducting a review of the available literature, eight unit construction cost estimates were identified that were used to evaluate the Carollo 2009 Report estimate", (pg.1, Section II, of the PG Environmental Report).

The findings in the PG Environmental Report are stated as follows:

- The literature estimates varied by approximately four orders of magnitude ($647 per million gallons per day or mgd to $3,200,000 per mgd).
- The estimates in the high end of the range were within the same order of magnitude as the estimate provided in the Carollo 2009 Report ($4,390,000 per mgd).

- The median unit cost estimate, inclusive of the Carollo estimate, is $776,000 per mgd (2009 U.S. dollars).

COMMENT ON APPROACH AND FINDINGS

It is important to remain mindful that the costs found in the literature are typically either construction costs (or equipment costs), as stated in the PG Environmental Report. Consequently, our comments on the overall approach and findings of the PG Environmental Report are as follows:

- The Carollo project cost estimate in the Carollo 2009 Report includes all environmental studies, engineering, legal, administrative, and contingencies to deliver a complete project. Therefore, the microfiltration cost estimate provided in the Carollo 2009 Report is a project cost estimate, and cannot be compared directly to the construction cost estimates in the PG Environmental Report. The project cost factor to convert construction cost to project cost used in the Carollo 2009 Report is 65 percent. Therefore, although the estimated microfiltration unit project cost is $4,390,000 in the Carollo 2009 Report, the associated estimated microfiltration unit construction cost is $2,660,000. This is the second highest unit cost of the nine estimates in the PG Environmental Report (including the Carollo estimate).
- The large and precedent-setting scale of the proposed microfiltration membrane facility for the Sacramento Regional Wastewater Treatment Plant (SRWTP) would require a custom designed and constructed superstructure, pretreatment facilities, peak flow equalization basins, and other supporting utilities and structures. Therefore, it is not appropriate to assume that the unit costs from significantly smaller microfiltration facilities (less than 10 mgd), typically with equipment skid-mounted membrane units and relatively minor site preparation requirements, can simply be scaled up to treat 181 mgd average dry weather flow.
- The variation in the eight literature values provided in the PG Environmental Report is actually five orders of magnitude (not four orders of magnitude as noted in the PG Environmental Report). This only further reinforces concerns that the literature values are not based on the same membrane application, type of construction, flux rates, and supporting facility assumptions, much less upon the site-specific conditions at SRWTP.
- The Gurian and the ESCWA references included in the PG Environmental Report, we suspect are for mechanical strainers (e.g., they can go down to the 10 microns and still be considered "microfiltration" units); and not for polymeric

membranes. We believe no supplier can provide a polymeric membrane filtration system for $647 or $7,840 per mgd. These estimates are not appropriate for comparison.

- The PB Water (Zenon) and PB Water (Memcor) are likely equipment cost only. Carollo recently bid a 28 mgd drinking water project at medium flux rate, with the low bid coming in at $295,219 per mgd (Note: this is for membranes and holders only, and for a relatively clean drinking water application allowing for higher flux rates than would be expected on secondary effluent from the SRWTP high purity oxygen activated sludge process).
- The remaining four references vary from approximately $800,000 to $3,100,000 per mgd. Further investigation of the detailed project descriptions and drawings would likely show that the differences in cost are due to the difference in the type of structure and supporting services (e.g., from slab on grade and canopy, to full building with odor control and noise attenuation in an urban environment).
- Therefore, the median unit construction cost of the remaining four literature references, inclusive of the Carollo estimate, is $1,991,000 per mgd, and the mean unit construction cost is $2,700,000 per mgd.

CONCLUSION

The estimated unit construction cost provided in the Carollo 2009 Report of $2,660,000 per mgd is at the higher end of the range of the four applicable references that are most appropriate for comparison, and is reasonable and appropriate for the construction of a 181 mgd microfiltration membrane filtration facility treating secondary effluent from the HPOAS process at SRWTP based on a planning-level, Class 5 estimate (AACE International Recommended Practice No. 17R-97, pg. 2).

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FINAL PROJECT MEMORANDUM

Project Name:	SRWTP Advanced Treatment Cost Updates	**Date:**	September 28, 2010
Client:	SRCSD	**Project No.**	7084B.00
Prepared By:	Elisa Garvey		
Reviewed By:	Steve McDonald		
Subject:	Responses to PG Environmental, LLC comments on the "*Advanced Treatment Alternatives for the Sacramento Regional Wastewater Treatment Plant*", (Carollo Engineers, March 2009).		
Distribution:	Bob Seyfried, Vyomini Pandya		

PURPOSE

PG Environmental, LLC prepared a "Technical Review of Estimated Costs for Proposed Changes to the Sacramento Regional Wastewater Treatment Plant" (August 18, 2010) (Technical Review) of the technical memorandum prepared by Carollo Engineers titled "Advanced Treatment Alternatives for the Sacramento Regional Wastewater Treatment Plant" (March, 2009) (Advanced Treatment Alternatives Memo). The Technical Review included comments on the treatment trains, and suggested modifications to some of the treatment trains. The purpose of this project memorandum is to provide additional clarifications, responses to the comments, and to provide comments on the proposed treatment train modifications included in the Technical Review.

BACKGROUND

The Advanced Treatment Alternatives Memo includes estimated capital and operations and maintenance costs (O&M) and estimated reductions of target pollutant for five different treatment trains at a planning-level of analysis. The treatment trains included addition of new treatment technologies to the existing secondary treatment processes at the Sacramento Regional Wastewater Treatment Plant (SRWTP). The target pollutants included: biochemical oxygen demand (BOD); total suspended solids (TSS); total dissolved solids (TDS); total organic carbon (TOC); ammonia-nitrogen; nitrate-nitrogen; total Kjeldahl nitrogen (TKN); total phosphorus; total recoverable copper; total mercury; and trace organic compounds, including endocrine disrupting compounds (EDCs), and pharmaceuticals and personal care products (PPCPs).

The following five treatment trains were developed and evaluated:

- **Treatment Train A (Title 22 Treatment) - Microfiltration (MF) and UV Disinfection (UV):** The treatment rationale was to implement treatment that will produce treated effluent that meets Title 22 standards and provides for multiple water reuse opportunities of SRWTP's entire flow. In order to implement this train,

- **Treatment Train B (Nutrient Reduction) - Nitrifying Trickling Filters (NTF), Fluidized Bed Reactors (FBR), and Chlorine Disinfection:** The treatment rationale was to significantly reduce nutrients in SRWTP's entire flow in response to potential concerns raised regarding nutrient loading in the Sacramento-San Joaquin Delta.
- **Treatment Train C (Nutrient Reduction + Title 22 Treatment) - Nitrifying Trickling Filters, Fluidized Bed Reactors, Microfiltration and UV Disinfection:** The treatment rationale was to produce treated effluent that meets Title 22 standards and provides for multiple water reuse opportunities of SRWTP's entire flow, and significantly reduces nutrients in SRWTP's entire effluent flow in response to potential concerns raised regarding nutrient loading in the Sacramento-San Joaquin Delta.
- **Treatment Train D ("No Net Increase") - Microfiltration, Reverse Osmosis (RO), and Ozone/Peroxide (Partial Flow):** The treatment rationale was to produce "no net increase" in loading of pollutants to the Sacramento River resulting from a 218 mgd (ADWF) discharge as compared to a 181 mgd (ADWF) discharge for use in the SRCSD's Antidegradation Analysis. Ozone/peroxide, in conjunction with RO, was added to the treatment train as these two processes provide multiple barriers of protection for the removal of trace organics.
- **Treatment Train E (Full RO and Ozonation) - Microfiltration, Reverse Osmosis, and Ozone/Peroxide:** The treatment train rationale was to apply the "no net increase" treatment train to the entire flow of the SRWTP.

These treatment trains were developed in March 2009, and at that time there was limited information on which of the target pollutants would be the driver for advanced treatment at the SRWTP. Therefore, the approach was to develop a series of treatment trains that were designed to remove different pollutants or combinations of pollutants to achieve different levels of effluent quality. The different levels of effluent quality were based on a range of possible future NPDES permit requirements for the SRWTP.

In contrast to the Advanced Treatment Alternatives Memo, the Technical Review prepared by PG Environmental, LLC focused on the ability of all treatment trains to produce effluent that meets CDPH requirements for pathogen removal, a nitrate limit of 10 mg/L (as N) and an ammonia limit of 1.8 mg/L (as N). Therefore, several of the issues raised in the Technical Review are explained by the differences in the original planning basis for developing the proposed treatment trains, as compared to the basis for evaluating the treatment trains in the Technical Review.

RESPONSES TO COMMENTS

The Technical Review includes comments throughout the document, specific comments on each of the treatment trains, and proposed modifications to Treatment Trains C and E. This section includes responses to the review comments as well as the proposed modifications to Treatment Trains C and E.

General

In general, the Technical Review includes critique of the costs developed in the Advanced Treatment Alternatives Memo, and includes proposed modifications to treatment trains on the basis of providing similar levels of treatment at lower capital costs. However, the Technical Review does not include estimated O&M costs associated with these proposed modified treatment trains and therefore does not provide an appropriate basis for comparison. The selection of any advanced treatment facility would need to consider the total life cycle costs that include capital and O&M costs.

Also, a review of the performance of the Modified Treatment Trains C and E compared to the performance of those in the Advanced Treatment Memo was not made in the Technical Review by PG Environmental. This performance comparison is important before an "equivalency" determination could be made.

Section II.A

Comment: *It is uncertain, which Treatment Train cost estimates are base on Class 5 versus Class 4.*

Response: The treatment trains that were developed consist, for the most part, of unit operations that are considered "advanced" in the wastewater industry relative to conventional secondary treatment processes. In addition, few of the advanced treatment trains identified have been constructed and operated at the scale of the SRWTP for a significant period of time. There are some unit operations, however, for which significant experience exists. This includes wastewater pump stations, chlorine disinfection, and UV disinfection. This experience was factored into the overall estimating contingencies when one or more of the unit operations were combined to create the overall treatment trains. Therefore, to clarify, the estimated costs developed for the combined treatment trains in the Advanced Treatment Alternative Memo are to be considered Class 5 estimates as described by the Association for the Advancement of Cost Engineering International (AACEI).

Section III

Comment: *Treatment Train E is the most costly and is not considered to be a cost-effective approach when considering the likely NPDES permit requirements.*

Response: At the time when Treatment Train E was developed, there was no information available on the future NPDES permit requirements for the SRWTP. Treatment Train E was designed to expand the concept of "no net increase" under Treatment Alternative D by treating the projected 218 mgd future flow to provide removal of all target pollutants, including TDS. Also, each of the five treatment trains were planned based on an assumed range of pollutant reduction requirements, as the "likely NPDES permit requirements" were unknown at that time.

Section IV. A.

Comment: *A major limitation in the performance of Treatment Train A is that it does not address the removal of inorganic nitrogen. Most ammonia will be converted to nitrate and be discharged as a nitrate loading. However it does treat the effluent to inactivate coliform bacteria and protozoan pathogens.*

Response: Treatment Train A was designed to produce treated effluent to meet Title 22 standards and to provide for multiple water reuse opportunities of SRWTP's entire flow. Title 22 standards do not require additional removal of inorganic nitrogen (beyond conventional secondary treatment), and therefore nutrient removal processes were not included in Treatment Train A.

Section IV. B.

Comment: *Treatment Train B does not address the issues associated with protozoan pathogens, although some removal of these microorganisms can occur in the biological nitrification and denitrification processes. Biofilters develop biological-growth that produces polymers. These slim growths act as adsorbents, capturing and retaining colloidal and soluble contaminants, but the efficiency of removal for microorganisms is low and variable. Treatment Train B also has limitations on the ability to achieve significant reduction of coliform bacteria, since there is no filtration to improve suspended solids removal. It does not appear that Treatment Train B will be able to consistently meet DPH recommendations.*

Response: Treatment Train B was designed to significantly reduce nutrients in SRWTP's effluent in response to potential concerns raised regarding nutrient loading in the Sacramento-San Joaquin Delta. This treatment train would produce effluent that would be discharged to the Sacramento-San Joaquin Delta (river discharge) as currently practiced. Treatment Train B was not designed to produce effluent quality that meets CDPH Title 22 standards for reuse. Therefore, the comments regarding removal of pathogens and consistent attainment of DPH recommendations are correct, since Treatment Train B was designed to significantly reduce nutrients only.

Section IV. C.
This section includes several comments on Treatment Train C. These comments are addressed separately below.

Comment: *A savings of approximately $260,000 in capital costs can be realized by replacing the UV Disinfection with Ozone/Peroxide Oxidation treatment (a chemical oxidation process). The Ozone/Peroxide Oxidation capital and O&M costs are roughly half of the costs for UV Disinfection. Ozone/Peroxide oxidation is effective for destroying the protozoan pathogens as well as various organic chemicals. Priority pollutants and other "chemicals of concern" (e.g., endocrine blockers) can be destroyed by oxidation given the proper ozone-peroxide dose and contact time. The ability to inactivate these compounds is only a function of chemical oxidant concentration and contact time. This process could be easily modified to address destruction of these compounds if future permits requirements are propagated for their removal.*

Response: Treatment Train C was designed to produce treated effluent that meets Title 22 standards and provides for multiple water reuse opportunities of SRWTP's entire flow, and significantly reduces nutrients in SRWTP's entire effluent flow in response to potential concerns raised regarding nutrient loading in the Sacramento-San Joaquin Delta.

The comment suggests replacing the UV system with an ozone peroxide system because the reported costs are significantly less for ozone peroxide than for a UV system. However, there are several issues with this proposed change:

- A non-proprietary ozonation system is not a CDPH approved disinfection technology under Title 22. Therefore, to meet Title 22 requirements for unrestricted reuse, SRCSD would need to demonstrate effectiveness of this process to obtain CDPH approval. Note that there is a proprietary ozone reactor that has been CDPH approved, but this reactor is designed for small systems.
- The comment suggests that UV can be replaced with ozone/peroxide oxidation at a lower cost without sacrificing treatment efficacy. We agree that an ozone peroxide system can be effectively designed to destroy pathogens and some trace organics. However, one important factor in the selection of UV disinfection was that it is CDPH approved for Title 22 water reuse, and attainment of Title 22 water reuse was an objective of treatment Train C.
- The project cost estimates for ozone/peroxide were developed in the context of Treatment Trains D and E, instead of Treatment Train C. In both Treatment Trains D and E the ozone peroxide process is preceded by reverse osmosis (RO). As noted in Appendix A (Table A17) of the Advanced Treatment Alternatives Memo (Carollo, March 2009), the assumed ozone dose for Treatment Trains D and E is 1 mg/L. This dose is similar to the doses used by Delta drinking water utilities for intermediate oxidation, and

assumes that the RO effluent would have a very low ozone demand. The required ozone dose significantly affects an ozone system project cost estimate. In the proposed modification to Treatment Train C, ozone peroxide would be preceded by media filtration instead of RO. This assumption of the use of media filtration is a concern at this level of planning given that the SRWTP is a high purity oxygen activated sludge (HPOAS) plant. The HPOAS process is associated with effluent variations that are site-specific and highly dependent on influent wastewater characteristics. The recommended approach to confirming the use of media filtration in satisfying the proposed requirements, and to establish design and sizing criteria, would be to perform pilot testing and a feasibility study. At this level of planning it is appropriate to assume a preliminary ozone dose in the range of 8 to 15 mg/L for ozonation of wastewater that is preceded by HPOAS and media filtration At this higher dose range, the project cost for ozonation would be comparable to, or greater than, a UV system. In addition, in the Technical Review the basis for costs are limited to capital costs. As noted previously, the selection of any advanced treatment process would need to consider the total life cycle costs that include capital and O&M costs.

In general, however, the comment of replacing UV with ozone/peroxide raises a valid issue. In any treatment train that SRCSD considers that includes replacement of the existing chlorination process with an alternative disinfection process, then a more detailed evaluation of disinfection alternatives, including UV, ozone and ozone/peroxide, would be conducted. This evaluation would consider that the SRWTP is a HPOAS plant and that there are existing facilities that provide an oxygen source, potentially reducing the cost of ozonation. In addition, evaluation would include pilot testing of these treatment processes to determine required UV doses and required ozone doses, as both of these parameters significantly affect performance and cost. However, the initial selection of UV for the purpose of disinfection was based on a level of evaluation that is consistent with a planning level analysis. The more detailed evaluation of disinfection alternatives should be conducted as part of future work if a change in the disinfection process at the SRWTP were to be considered.

<u>Comment</u>: *The MF process represents a very significant portion of the advanced treatment costs. The MF process is 55.1 percent of the total cost ($161 million of $292 million; from Table 4, page 14 of Carollo 2009 Report). The Carollo 2009 Report, appendix page APP-1, notes that SRCSD has performed pilot testing of MF and it was proven to be an effective advanced treatment for SRWTP's secondary effluent*[1]

1. *Note that the pilot testing data could have been used by SRCSD to provide a more refined cost estimate than a Class 5 estimate.*

Response: While pilot testing was conducted for SRTWP involving a pilot MF unit, it was intended for the purpose of comparing effluent quality to conventional sand filtration, and for producing high quality effluent for assessing the impact on final effluent quality for the design of alternative disinfection systems, but not on flux rates and other design parameters for sizing MF facilities. The AACE International Recommended Practices and Standards states that for a Class 5 estimate the level of project definition is 0 to 1%, while for a Class 4 estimate the level of project definition is 1 to 15%. Therefore, a Class 5 estimate is the appropriate level of definition at this time for the design of a full-scale MF system for SRWTP.

Comment: *There are four alternatives to Treatment Train C that, through implementation of one or some combination of these alternatives, the SRWTP may achieve the same effluent goals at a reduced cost.*

1. *Evaluate other filtration processes such as sand filters and mixed media filters to replace MF, with the goal of reducing total cost.*

2. *The UV Disinfection can be replaced with Ozone/Peroxide Oxidation. The Ozone/Peroxide Oxidation capital and O&M costs are expected to be approximately half of the costs of UV Disinfection. Another important aspect is that simple modifications to the operation, such as increasing ozone-peroxide concentrations, could result in improved removal of "chemicals of concern" in the effluent.*

3. *Evaluate low-cost modifications that can be made to the inlet and outlet structures of the secondary settling tanks to improve removal of suspended solids, colloidal material, and soluble organic compounds. Such options could include physical modifications to provide more appropriate hydrodynamics for good floc growth prior to the secondary sedimentation process.*

4. *Operational changes could be evaluated for improving the existing performance of secondary settling. These could enhance the removal of suspended particles and Cryptosporidium oocysts. This would include testing of various chemical coagulants, polymers, chemical oxidants, and pH levels to improve removal of suspended solids and Cryptosporidium oocysts.*

Response: Responses to the four comments presented above are addressed in order as follows.

1. Other filtration processes, including sand filtration and mixed media filtration, were considered in the development of Treatment Train C. We agree that conventional filtration followed by disinfection is an effective approach for meeting Title 22 standards

today, but not for the high-purity oxygen activated sludge (HPOAS) process used by SRTWP. The HPOAS process used by SRWTP is challenging in terms of capture of pin floc with conventional sand filtration performance. In fact, pilot testing at SRWTP of conventional sand filtration and MF, it was found that MF more consistently met Title 22 requirements.

2. This comment was addressed previously, where it was noted that the project cost of the ozone peroxide system was based on the costs presented for Treatment Trains D and E, where ozonation would be preceded by RO and therefore a lower ozone dose was assumed based on the low ozone demand expected in RO effluent water. At a higher ozone dose range, the project cost for ozonation would be comparable to, or greater than, a UV system.

3. The objectives of the Advanced Treatment Alternatives Memo did not include investigation of modifications to the existing treatment process that would potentially improve suspended solids removal because of the uncertainty of these kinds of improvements to reliably meet the levels of treatment and pollutant reductions required. In general, the further development of any of the advanced treatment alternatives would also include investigation into modifications of existing facilities in combination with new facilities that would potentially improve existing performance or would impact the selection or performance of advanced treatment processes.

4. The SRCSD runs a well managed and operated secondary treatment plant with adequate secondary settling capacity. While operational improvements are always worth investigation, the anticipated improvements in the removal of suspended solids with operational changes alone are not considered sufficient, by themselves, in reliably meeting the assumed range of future discharge requirements in the Advanced Treatment Alternatives Memo. Specifically, there are unique challenges in achieving significant improvements in the suspended solids reductions from the existing secondary treatment process employing the high-purity oxygen activated sludge. In addition, the SRWTP is continuously evaluating how operation changes could improve performance and reliability. Further development of any of the advanced treatment alternatives would also investigate operational changes that would potentially improve existing performance or would impact the selection or performance of advanced treatment processes.

Section IV. D.

Comment: *These advanced treatment processes will reduce coliform and pathogenic protozoan. However, the effluent from the advanced treatment would be blended with the remaining secondary effluent. The blended final effluent would not be expected to meet the DPH* *recommendations. As a result, this treatment train does not achieve any of the objectives of significant nutrient removal or requirements for coliform and pathogenic protozoan. Further, treating only a portion of the total SRWTP flow may constitute bypassing, and SRCSD has withdrawn its request for an increase in flow capacity. Therefore, this alternative was eliminated from further consideration.*

Response: Treatment Train D was designed to produce a "no net increase" in loading of pollutants to the Sacramento River resulting from a 218 mgd (ADWF) discharge as compared to a 181 mgd (ADWF) discharge for use in the SRCSD's Antidegradation Analysis. The result of Treatment Train D would be to keep the future mass loadings of target pollutants to the Sacramento River at 218 mgd to no greater than the mass loadings at today's permitted 181 mgd discharge. It is assumed that only a portion of the SRWTP's entire flow at 218 mgd would require additional treatment, and this treated flow would be blended with effluent not receiving such additional treatment to achieve "no net increase" in loadings. This treatment train was developed based on the assumption of continued discharge to the Sacramento River and the concept of providing "no net increase" in loadings. It was not designed to meet more stringent nutrient or pathogen removal requirements although these would be significantly removed from the incremental flow above 181 mgd.

Section IV. E.

Comment: *The MF and RO processes are not nearly as cost effective for ammonia and nitrate removal as the biological processes proposed in Treatment Trains B and C…*

From a cost standpoint, Treatment Train E is not the most cost-effective approach for treating municipal wastewater when considering the likely NPDES permit effluent limitations. Treatment Train E also has a very large carbon dioxide footprint, energy consumption….

The application of RO appears to be unnecessary, and is probably being considered because of the growing attention being given to "chemicals of concern" as well as priority pollutants. Based on the anticipated NPDES requirements, more cost-effective alternatives other than RO can be used by SCRSD to comply with potential requirements for "chemicals of concern".

The combined processes of MF, RO, and Ozone/Peroxide Oxidation will remove "chemicals of concern" such as endocrine blockers and many priority pollutants. If the goal is to reduce these "chemicals of concern" in the SRWTP effluent discharge, the cost of utilizing MF and RO should be compared with other alternatives. For example, sand or mixed media filters followed by activated carbon beds would prove effective in removing these chemicals and both of these technologies have been used in a number of tertiary treatment facilities. Also, the application of chemical oxidants with slow release catalysts have been developed for destroying priority pollutants…

One effective approach to removal of "chemicals of concern" is to design the Ozone/Peroxide Oxidation process to provide adequate chemical dosing and contact time to oxidize targeted chemicals to degradation products that result in their detoxification. Another approach is to add activated carbon adsorption beds. The addition of activated carbon beds would be compatible following either MF or mixed media filtration. Mixed media filtration and activated carbon have been used successfully in wastewater tertiary treatment plants. These combinations could be considered as alternative process sequences for Treatment Train E, if the removal of "chemicals of concern" is to be a future permit requirement.

Response: Treatment Train E was designed to expand the concept of "no net increase" under Treatment Alternative D by treating the projected 218 mgd future flow to provide removal of all target pollutants. One of the primary reasons that RO was included in Treatment Train E was to provide removal of TDS. In addition, Ozone/peroxide, in conjunction with RO, was added to the treatment train as these two processes provide multiple barrier protection for the removal of trace organics. This combination of treatment processes is the current best available technologies to remove trace organics. To our knowledge, there are no wastewater treatment plants of similar scale to the SRWTP that employ RO followed by ozone/peroxide.

Several of the specific comments are addressed below:

- We agree that MF/RO is not as cost effective of an approach to nutrient removal as biological nutrient removal processes. This comment is not relevant because the purpose for including MF/RO was to remove TDS, as well as other trace contaminants. RO is the best available technology for removal of TDS.
- As mentioned above, Treatment Train E was not designed to only meet the anticipated nitrate and ammonia limits, as this information was not available at the time of the development of the technical memorandum. As noted, Treatment Train E was designed to provide removal of TDS, as well as other trace contaminates.
- The goal is to not only remove "chemicals of emerging concern" but to also remove TDS. The suggested alternative treatment trains that consist of sand or mixed media filtration followed by activated carbon beds would not be effective at removing TDS.

Section V.A.

Comment: *Treatment Train M-C will achieve the same performance as Train C, but at a reduced cost by replacing MF with mixed media filters that have a preconditioning basin, using chemicals for flocculation and oxidation that will improve suspended particle removal. Cost savings is also realized by replacing the more costly UV Disinfection with Ozone/Peroxide disinfection. The process flow sequence is provided below.*

1. *Existing head works, followed by;*

2. *Existing pure oxygen system, followed by;*
3. *New NTF process, followed by;*
4. *New FBR for denitrification, followed by;*
5. *New chemical conditioning-flocculation basin, followed by;*
6. *New sand or mixed media filtration, followed by;*
7. *New Ozone/Peroxide Oxidation;*
8. *The Chlorine disinfection system would be abandoned*

Response: In the response to comments on Treatment Train C, these proposed modifications have been addressed previously above. Briefly, the use of sand or mixed media filtration instead of MF was considered for Treatment Train C. However, the HPOAS process used by SRWTP is challenging in terms of pin floc and conventional sand filtration performance. In Treatment Train C, replacing microfiltration with either sand or media filtration would potentially have an impact on final effluent quality with respect to particle concentrations and organic matter concentrations. Therefore, the poor performance of conventional sand filtration in reliably meeting Title 22 standards would make this alternative infeasible for SRWTP.

In any event, using ozone/peroxide instead of UV disinfection is not necessarily going to lead to cost savings. As noted before, the ozonation costs were based on a very low dose because the cost estimate was developed in the context of Treatment Trains D and E, where RO precedes ozonation. In addition, a non-proprietary ozonation or ozone/peroxide process would require CDPH approval to meet Title 22 standards. However, if alternative disinfection processes are considered for SRWTP in the future, a more detailed analysis of the costs of UV versus ozone/peroxide would likely be conducted. In addition, in the Technical Review the basis for costs are limited to capital costs. As noted previously, the selection of any advanced treatment facility would need to consider the total life cycle costs that include capital and O&M costs.

Section V.B.

Comment: *Treatment Train M-E is estimated to be $725 million less than Treatment Train E. Treatment Train M-E should be considered for two reasons. First, it utilizes MF rather than mixed media filters. It is recognized that SRWTP has conducted pilot studies with the MF process. The second reason is that mixed media filters require a relatively large footprint because of storage basins to hold wash and backwash waters for the filters. The cost savings for Treatment Train M-E results from removing the RO process and substituting NTF and FBR processes for ammonia and nitrate removal.*

If land availability is an issue, SRCSD could consider replacing the NTF option for nitrification with biofilters. Biofilters have a significantly smaller footprint than trickling filters, and they are *more consistent in performance for nitrogen removal.*

Proposed Treatment Train M-E will meet requirements of the anticipated NPDES permit as well as DPH recommendations. The effluent quality would be equivalent to that of Treatment Train C. The process sequence for Treatment Train M-E is:

1. *Existing head works, followed by;*
2. *Existing pure oxygen system, followed by;*
3. *New NTF process for nitrification, followed by;*
4. *New FBR for denitrification, followed by;*
5. *New microfiltration; followed by;*
6. *New Ozone/Peroxide Oxidation;*
7. *Chlorine disinfection system would be abandoned.*

Response: While the modified Treatment Train E provides a reasonable approach to meet anticipated NPDES permit as well as DPH recommendations, it would not provide removal of TDS, and therefore would not provide equivalent effluent quality as the Treatment Train E developed in the Advanced Treatment Train Alternatives Memo. As noted previously, TDS removal was one of the objectives in the development of Treatment Train E.

Section VI.A.

Comment: *General suggestion to conduct pilot studies, with the possibility of using the existing WRF, to refine cost estimates.*

Response: The next logical step, if the SRCSD is required to install advanced treatment, would be to conducting pilot studies as part of further evaluation of potential advanced treatment trains. The investment in advanced treatment at SRCSD would be significant, and therefore, an upfront investment in pilot testing to refine cost estimates, assess feasibility, and evaluate process performance would be performed and the use of the existing WRF for pilot testing is possible, but would depend on the advanced process trains that were being considered and the SRCSD's commitment to supply recycled water to end users.

Section VI.B.

Comment: Utilizing biofilters for nitrification is projected to cost approximately $832 million in capital or $2.68 million per mgd. This compares with $2.13 million per mgd for the NTF process. This is a minor cost increase compared to the total cost and would result in a significantly smaller footprint than the NTF. This would also offset the increased footprint of the suggested mixed media filters over MF. Biofilters for nitrification is a hardware change and not a biological process change. Performance would also be better since biofilters are more consistent in the degree of nitrification, resulting in the ability to achieve greater total nitrogen removal.

Response: The use of biofilters versus the NTF process is a decision that is best made during preliminary design. There are process considerations for both NTFs and biofilters that go beyond the scope and level of this evaluation. Since the cost of both is within the range of estimating accuracy, it is sufficient to leave the more conservative cost as a place holder until a more detailed feasibility assessment is made.

Engineers...Working Wonders With Water

FINAL PROJECT MEMORANDUM

Project Name:	SRWTP Advanced Treatment Cost Updates	**Date:**	September 30, 2010
Client:	SRCSD	**Project No:**	7084B.00
Prepared By:	Steve McDonald		
Reviewed By:	Elisa Garvey, B. Narayanan		
Subject:	Comments on the nitrate and ammonia effluent limit in the SRWTP Tentative Order R5-2010 (September 3, 2010)		
Distribution:	Bob Seyfried, Vyomini Pandya		

PURPOSE

The purpose of this memorandum is to comment on the ammonia and nitrate nitrogen effluent limits in the SRWTP Tentative Order R5-2010 (September 3, 2010) (Tentative Order). The Tentative Order includes monthly average and maximum day ammonia nitrogen effluent concentration limits of 1.8 mg/L (as N) and 2.2 mg/L (as N), respectively. The Tentative Order includes a monthly average nitrate effluent concentration limit of 0.26 mg/L (as N).

BACKGROUND

The "Advanced Treatment Alternatives for the Sacramento Regional Wastewater Treatment Plant" Technical Memorandum (Carollo, March 2009), developed effluent concentrations for five treatment trains (A through E). Treatment Train B estimated final effluent concentrations for an advanced treatment train alternative that includes nitrifying trickling filters (NTFs) and fluidized bed reactors (FBRs) to achieve nitrification and denitrification, respectively.

The Carollo (March 2009) Technical Memorandum is also referenced in the Memorandum titled "Analysis of Costs and Benefits of Advanced Treatment Alternatives for the Sacramento Regional Wastewater Treatment Plant", (Larry Walker Associates, May 2010).

It is important to note that the effluent concentrations estimated in the Carollo (March 2009) Technical Memorandum were for comparing relative pollutant reductions that might be achieved for a wide range of pollutants among the five different treatment alternatives (A through E). Further, these estimated effluent concentrations were based on a simple averaging of recorded SRWTP effluent values and the application of planning-level pollutant reductions, as described below. They should not be used as a basis for establishing effluent limitations for different averaging periods, and for processes for which pilot testing and confirmation of performance have not been performed.

OVERALL APPROACH TO ESTIMATING EFFLUENT CONCENTRATIONS

The overall approach to estimating final effluent concentrations In the Carollo (March 2009) Technical Memorandum, was to apply theoretical pollutant removal efficiencies associated with advanced treatment processes to the historically recorded SRWTP secondary effluent concentrations.

In Carollo (2009), secondary effluent mean concentrations and standard deviations for a range of pollutants were calculated based on SRWTP effluent data from June 2005 through July 2008. The mean and standard deviations were calculated based recorded data from June 2005 through July 2008, and therefore represent the mean and standard deviation recorded over a three-year averaging period.

Removal efficiencies for the different advanced treatment process train alternatives were estimated based on peer reviewed academic and professional journal articles, presentations from professional conferences, published and unpublished pilot plant data, available data from other treatment plants, treatment process manufacturers, and standard textbook references.

Given the wide range of values obtained from the diverse technical sources, best professional judgment was used to select pollutant reduction values for the planning-level purpose of comparing the relative performance of the alternative advanced treatment trains.

These planning-level pollutant reduction values were then applied to the mean SRWTP secondary effluent concentrations to predict final effluent ammonia and nitrate concentrations (among other pollutants) for the alternative advanced treatment trains over the same three-year averaging period. The existing process at SRWTP produces low nitrate concentrations due to the fact that the treatment process is not designed to achieve nitrification. With the implementation of NTFs, the nitrate concentrations in the NTF effluent would be greater than the concentrations in the effluent of the existing secondary treatment process, and this was accounted for in the estimated final effluent from the FBRs.

The resulting ammonia and nitrate concentrations estimated for Treatment Train B were 1.5 mg/L (as N) and 0.26 mg/L (as N), respectively, averaged over the entire data period.

As stated in the Carollo (2009) Technical Memorandum (Section 2, pg. 4), the estimated final effluent concentrations for the alternative advanced treatment trains were developed for planning purposes only. In addition, the Carollo (2009) Technical Memorandum states that additional pilot scale studies would be need to be performed to establish pollutant removal efficiencies for final design criteria should any of these advanced treatment processes actually be required and implemented for SRWTP. This is because the planning-level evaluation in the

Carollo (2009) Technical Memorandum did not consider influent and effluent variability, averaging periods, and other site-specific performance considerations.

DISCUSSION

Section IV.C.3.d.xx. (c) of the Fact Sheet (Attachment F, pg. F-71) of the Tentative Order, includes the following statements regarding the development of the ammonia and nitrate nitrogen effluent limitations:

> *This Order contains a final average monthly effluent limitation (AMEL) and maximum daily effluent limitation (MDEL) for ammonia of 1.8 µg/L and 2.2 µg/L, respectively, based on the NAWQC ammonia criteria for aquatic toxicity with no dilution credit.*
>
> *The removal of nitrate and nitrite (i.e., denitrification) is technologically feasible and is often used at POTWs. Therefore, due to the concerns of adverse effects to aquatic life from nitrogen this Order requires the wastewater is fully denitrified. An average monthly effluent limit of 0.26 mg/L for nitrate (as nitrogen) is included in this Order. This is based on the Discharger's study prepared by Larry Walker Associates, titled, "Technical Memorandum: Analysis of Costs and Benefits of Advanced Treatment Alternatives for the Sacramento Regional Wastewater Treatment Plant," dated May 2010.*
>
> *(Note: Underlining added for emphasis. Also, it is assumed that AMEL and MDEL limits were inadvertently labeled in ug/L instead of mg/L as noted in Table E-6 Effluent Limitations on page 13 of the Tentative Order).*

As can be seen in the citation from the Tentative Permit, the monthly average nitrate effluent limit is based on the requirement of full denitrification, and the Larry Walker Associates (2010) technical memorandum (and Carollo (2009) Technical Memorandum) is cited as the basis for establishing an average monthly effluent limit of 0.26 mg/L (as N).

The average monthly effluent limit of 0.26 mg/L for nitrate (as nitrogen) may not be technically feasible for SRWTP, and the estimated final effluent concentration for Treatment Train B as reported in Larry Walker Associates (2010), and developed in the Carollo (2009) Technical Memorandum, is not an appropriate reference for establishing effluent limits. The reasons for this follow:

- The purpose of the Carollo (2009) Technical Memorandum was to perform a planning-level comparison of the relative performance of alternative advanced treatment trains. As explained, the approach to estimating final effluent concentrations was to use a three-year averaging period and theoretical and literature value pollutant reductions for advanced treatment technologies. There is no mention in Carollo (2009) of establishing an appropriate effluent concentration limit for permitting purpose. Therefore, the Tentative Order adopted a nitrate effluent concentration limit based on a planning-level study that was developed for a different purpose.

- The Carollo (2009) Technical Memorandum states that the estimated final effluent concentrations were developed for planning purposes only, and that pilot studies would need to be performed to refine treatment process performance. This is due to, as stated in the Carollo (2009) Technical Memorandum, the wide variability in the information and data found in the literature and from other sources regarding pollutant reduction efficiencies. Therefore, the approach of estimating final effluent concentrations using removal efficiencies is an approximate approach, suitable for planning level analyses, but not for predicting effluent concentrations achievable on a consistent and reliable basis. In the absence of more detailed site-specific information and pilot data, best professional judgment was used in selecting pollutant reduction values for the purpose of completing a planning-level study to compare relative long-term pollutant loadings to the River. The source of the pollutant reduction values was not based on site-specific SRWTP considerations, nor was the application of best professional judgment based on comparing maximum effluent concentrations, or for developing final effluent permit limit concentrations for monthly and daily averaging periods.
- The average effluent concentration as reported in the Carollo (2009) Technical Memorandum is not the same as the effluent "not to exceed" concentration. This is a different point than the selection of an appropriate averaging period. Instead, the Carollo (2009) Technical Memorandum was based on best professional judgment in selecting pollutant reductions for comparing the relative average performance over a three-year period among the alternatives, and was not based on establishing a "not to exceed" effluent concentration over different (and shorter) averaging periods which typically exhibit greater variability.
- As noted, the 0.26 mg/L (as N) estimated final effluent concentration was based on applying an estimated pollutant removal efficiency to a secondary effluent mean concentration (with consideration of the change in nitrate concentrations due to implementing nitrification) from a three-year data averaging period. Not only is this approach an approximate one suitable only for planning-level analyses, the estimated final effluent concentration does not include any consideration for what can reasonably be achieved using a different averaging period, such as for a monthly or daily basis. Therefore, the use of a three-year average estimated final effluent concentration of 0.26 mg/L nitrate (as N) is not an appropriate basis for establishing a monthly average final effluent concentration.

CONCLUSION

The average monthly effluent limit of 0.26 mg/L SRWTP for nitrate (as nitrogen) included in the RWQCB Tentative Order R5-2010 (September 3, 2010) may not be technically feasible for SRWTP, and the estimated final effluent concentration for Treatment Train B as reported in Larry Walker Associates (2010), and developed in the Carollo (2009) Technical Memorandum, is not an appropriate reference for establishing this or any other effluent limits for the following reasons:

- The purpose of the Carollo (2009) Technical Memorandum was to perform a planning-level comparison of the relative performance of alternative advanced treatment trains.
- The purpose of the Carollo (2009) Technical Memorandum did not include establishing an appropriate effluent concentration limit for permitting purposes.
- The Carollo (2009) Technical Memorandum states that the estimated final effluent concentrations were developed for planning purposes only, and that pilot studies would need to be performed to refine treatment process performance. The estimation of final effluent concentrations were not based on site-specific SRWTP considerations, nor for developing final effluent permit limit concentrations for monthly and daily averaging periods.
- The average effluent concentration as reported in the Carollo (2009) Technical Memorandum is not the same as the effluent "not to exceed" concentration.
- The 0.26 mg/L (as N) estimated final effluent concentration based on a three-year data averaging period. The estimated final effluent concentration does not include any consideration for what can reasonably be achieved using a different averaging period, such as for a monthly or daily basis.

Appendix A

Technical Memorandum:

Advanced Treatment Alternatives for the Sacramento Regional Wastewater Treatment Plant Final March 2009

Sacramento Regional County Sanitation District
Engineering Support Services

TECHNICAL MEMORANDUM ADVANCED TREATMENT ALTERNATIVES FOR THE SACRAMENTO REGIONAL WASTEWATER TREATMENT PLANT

FINAL
March 2009

2700 YGNACIO VALLEY ROAD, SUITE 300 • WALNUT CREEK, CALIFORNIA 94598 • (925) 932-1710 • FAX (925) 930-0208)

Sacramento Regional County Sanitation District
Engineering Support Services

TECHNICAL MEMORANDUM
ADVANCED TREATMENT ALTERNATIVES
FOR THE SACRAMENTO REGIONAL WASTEWATER TREATMENT PLANT

TABLE OF CONTENTS

Page No.

LIST OF TABLES

LIST OF FIGURES

ADVANCED TREATMENT ALTERNATIVES FOR THE SACRAMENTO REGIONAL WASTEWATER TREATMENT PLANT

1.0 INTRODUCTION

The purpose of this technical memorandum (TM) is to support future decisions by the Sacramento Regional County Sanitation District (District) regarding potential implementation of advanced wastewater treatment that may be necessary to accommodate planned growth in the District's service area, and to meet potentially more restrictive regulatory requirements for continued discharge to the Sacramento River. This technical memorandum includes planning-level analyses of advanced treatment technologies for removal of target pollutants (TPs). These include: biochemical oxygen demand (BOD), total suspended solids (TSS), total dissolved solids (TDS), total organic carbon (TOC), ammonia-nitrogen, nitrate-nitrogen, total Kjeldahl nitrogen (TKN), total phosphorus, total recoverable copper, and total mercury. In addition, trace organic compounds, including endocrine disrupting compounds (EDCs) and pharmaceuticals and personal care products (PPCPs), are qualitatively evaluated using a "limits of technology" approach to identify the appropriate advanced treatment processes to treat a broad range of trace organic compounds.

Five different treatment trains were assessed at a planning-level of analysis for reductions of TPs, and associated costs. These are:

- Treatment Train A (Title 22 Treatment) - Microfiltration (MF) and UV Disinfection (UV)(218 million gallons per day [mgd])
- Treatment Train B (Nutrient Reduction) - Nitrifying Trickling Filters (NTF), Fluidized Bed Reactors (FBR), and Chlorine Disinfection (218 mgd)
- Treatment Train C (Nutrient Reduction + Title 22 Treatment) - Nitrifying Trickling Filters, Fluidized Bed Reactors, Microfiltration and UV Disinfection (218 mgd)
- Treatment Train D (No Net Increase) - Microfiltration, Reverse Osmosis (RO), and Ozone/Peroxide (48 mgd)
- Treatment Train E (Full RO and Ozonation) - Microfiltration, Reverse Osmosis, and Ozone/Peroxide (218 mgd)

Evaluations of treatment processes and treatment trains at 218 mgd assume that the existing secondary treatment facilities have been expanded to a 218 mgd average dry weather flow (ADWF) capacity, and therefore do not include the costs associated with achieving 218 mgd ADWF of secondary treatment capacity.

In each case where RO is evaluated, the assumption is a 90 percent recovery of flow. The remaining 10 percent brine flow is treated by thermal brine concentration, crystallization, and land disposal.

2.0 TREATMENT TRAINS

The treatment trains presented in this TM are shown in Figure 1 and are further discussed below. Additional discussion of each unit process is provided in the Appendix.

<u>Treatment Train A (Title 22 Treatment): MF and UV disinfection of 218 mgd (full flow)</u>. The treatment rationale is to implement treatment that will produce treated effluent that meets Title 22 standards and provides for multiple water reuse opportunities of SRWTP's entire flow. In order to implement this train, new MF and UV facilities would be required.

<u>Treatment Train B (Nutrient Reduction): Nutrient reduction via NTFs, FBRs, and chlorine disinfection of 218 mgd (full flow)</u>. The treatment rationale is to significantly reduce nutrients in SRWTP's entire flow in response to current concerns over nutrient loading in the Sacramento-San Joaquin Delta. Nutrient reduction by NTFs and FBRs is included for the purpose of achieving low effluent nutrient concentrations. The existing chlorination process at the Sacramento Regional Wastewater Treatment Plant (SRWTP) would be retained. However, new NTFs and FBRs would be required.

<u>Treatment Train C (Nutrient Reduction + Title 22 Treatment): Nutrient reduction via NTF and FBR combined with MF and UV disinfection of 218 mgd (full flow).</u> The treatment rationale is to produce treated effluent that meets Title 22 standards and provides for multiple water reuse opportunities of SRWTP's entire flow, and significantly reduces nutrients in SRWTP's entire effluent flow in response to current concerns over nutrient loading in the Sacramento-San Joaquin Delta. Nutrient reduction by NTFs and FBRs is included for the purpose of achieving low effluent nutrient concentrations. This treatment train would result in reduced pollutant loads to the river as well as increased reuse opportunities. New NTFs, FBRs, MF, and UV facilities would be required.

<u>Treatment Train D (No Net Increase): MF, RO, and ozone/peroxide of partial flow at 218 mgd to achieve "no net increase" of mass loading above the estimated mass loading at a flow of 181 mgd</u>. The treatment rationale is to produce no net increase in loading of pollutants to the Sacramento River resulting from a 218 mgd (ADWF) discharge as compared to a 181 mgd (ADWF) discharge. It is assumed that only a portion of the SRWTP's entire flow at 218 mgd would require additional treatment, and this treated flow would be blended with effluent not receiving such additional treatment to achieve "no net increase" in loadings.

The capacities of the advanced treatment processes in Train D are based on the limiting constituent among the TPs. The limiting constituent is total recoverable copper with a removal efficiency of 77 percent. To achieve a "no net increase" in recoverable copper

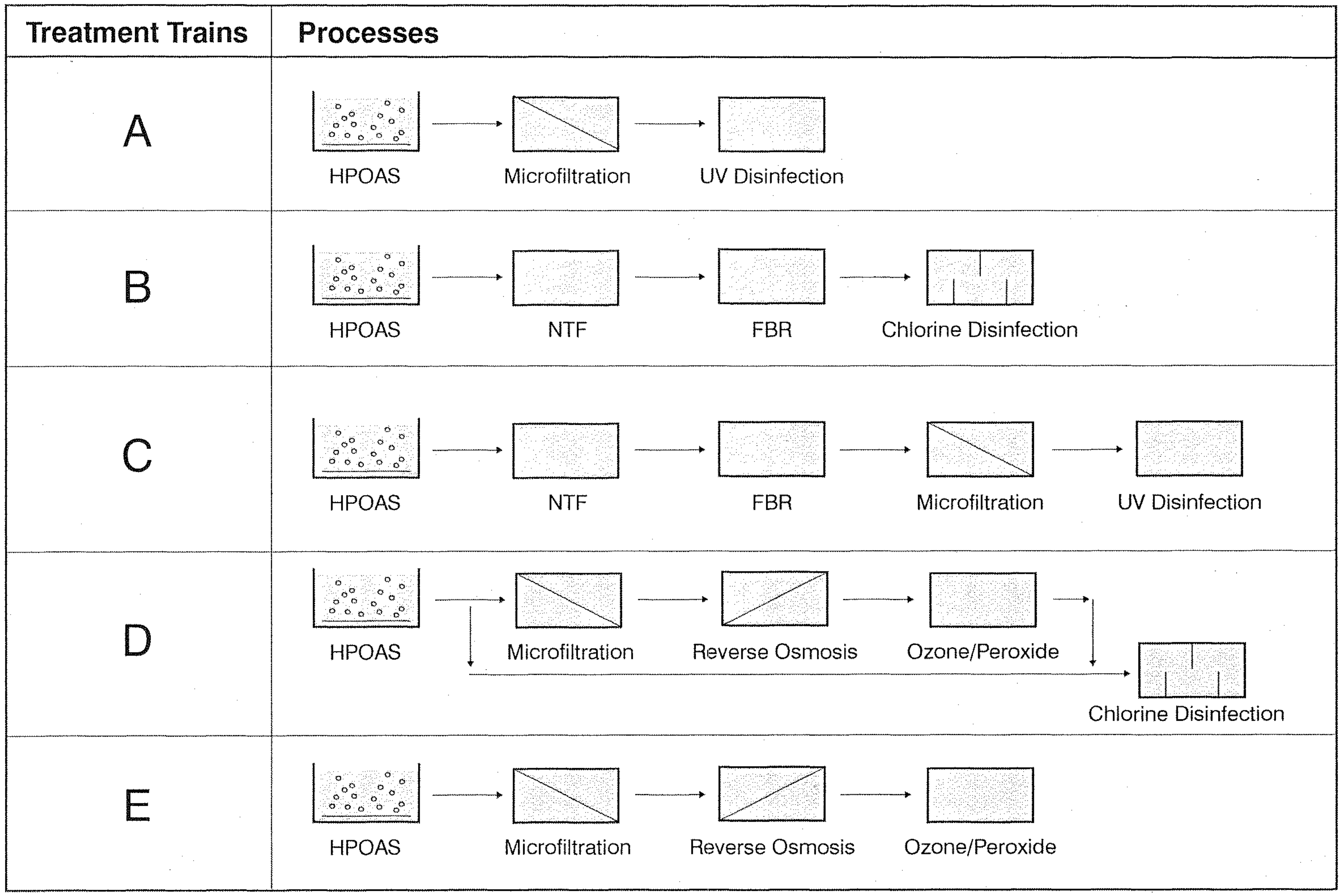

Figure 1
TREATMENT TRAINS
ADVANCED TREATMENT ALTERNATIVES FOR THE SACRAMENTO REGIONAL WASTEWATER TREATMENT PLANT
SACRAMENTO REGIONAL COUNTY SANITATION DISTRICT

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loading to the Sacramento River, approximately 48 mgd (ADWF) would need to be treated by the advanced treatment train and blended with the remaining 170 mgd (ADWF) of existing secondary effluent for discharge to the Sacramento River.

Ozone/peroxide, in conjunction with RO, is added to the treatment train as these two processes provide multiple barrier protection for the removal of trace organics. This combination of treatment processes is among the best available technologies to remove trace organics. In order to provide the free radicals required for ozone to be effective after RO treatment, hydrogen peroxide should be added with ozone. Since part of the goal of this train is to remove trace organics, ozone/peroxide should be used instead of UV disinfection since ozone/peroxide destroys trace organics while UV does not except at very high UV doses (well above doses required for disinfection). In addition, ozone/peroxide is easier to produce at SRWTP since the plant already has a pure-oxygen generation system in place.

Treatment Train E (Full RO + Ozonation): MF, RO, and ozone/ peroxide of 218 mgd (full flow). The only difference between Treatment Train D and E is the amount of flow treated. "Full RO + Ozonation" is assessed to address those who might request that Sacramento Regional County Sanitation District (SRCSD) treat its entire flow. Ozone/peroxide is added to the treatment train to reduce trace organics.

As discussed previously, Treatment Trains D and E include reverse osmosis. For both treatment trains, the selected approach for brine treatment and disposal includes thermal concentration, crystallization and offsite transport to a landfill. The quantities of solids that will require disposal are approximately 150,000 lbs/day and 670,000 lbs/day for Treatment Train D and Treatment Train E, respectively. Solids would require disposal in a Class II landfill, as a California designated waste.

Table 1 presents secondary effluent concentrations and standard deviations based on data collected from June 2005 through July 2008. Table 1 also includes final effluent concentrations for treatment trains A through E based on the estimated removal efficiencies achieved beyond secondary treatment for each of the treatment trains. It is assumed that the coefficients of variation for the advanced treatment train effluents would be similar to the coefficients of variation for the existing secondary treatment train effluent.

The estimated removal efficiencies beyond secondary treatment were developed based on reported literature values from academic and professional journals and conference proceedings, published and unpublished pilot plant data, and standard textbook references. The estimated final effluent concentrations are presented in this TM for planning purposes only. Additional pilot scale studies will be required to determine removal efficiencies for the TPs and the final design criteria, should any of these advanced treatment processes actually be required and implemented for SRWTP. In particular, there is uncertainty in metals reductions that can be achieved in full-scale facilities due to site-specific conditions. Raw wastewater contains additional metal-binding ligands, notably natural dissolved

Table 1 Final Effluent Concentrations
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

	Secondary Effluent Concentration		Final Effluent Concentrations				
			A (Title 22 Treatment)	B (Nutrient Reduction)	C (Nutrient Reduction and Title 22 Treatment)	D (No net Increase)	E (Full RO + Ozone/Peroxide)
	Mean	**Std. Dev**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**
Metals							
Copper, total recoverable, µg/L	4.3	0.7	2.5	1.4	0.8	3.6	1.0
Mercury, total, µg/L	0.0041	0.0010	0.0013	0.0030	0.0009	0.0033	0.0004
Conventional Parameters							
Total Dissolved Solids, mg/L	410	44	394	369	355	324	8
TOC, calculated, mg/L	17.5	5.6	11.9	13.1	8.9	14.0	1.4
TSS, mg/L	6.7	2.4	0.5	3.8	0.3	5.2	0.01
BOD, mg/L	7.6	2.4	1.7	4.3	0.9	6.0	0.03
Nutrients							
Nitrite (NO2), mg/L as N	0.018	0.012	0.017	<0.001 (1)	<0.001 (1)	0.014	0.003
Nitrate (NO3), mg/L as N	0.13	0.19	No Data	0.26	<0.26 (2)	<0.11 (3)	<0.03 (3)
Nitrite (NO2) + Nitrate (NO3), mg/L as N	0.1	0.2	No Data	No Data	No Data	No Data	No Data
Ammonia (NH3), mg/L as N	23.7	3.7	22.8	1.5	1.4	19.3	3.0
TKN, (NH3 + Organic N), mg/L as N	26.0	4.2	No Data	4.1	4.1 (2)	22.3 (3)	8.8 (3)
Total Phosphorus, mg/L as P	2.3	0.4	1.6	1.0	0.7	1.9	0.5

Notes:
(1) Estimated concentrations below value shown due to 99.9% removal achieved by nitrification and denitrification.
(2) Removal efficiency data is not available for microfiltration, therefore, estimated concentration is due to removal achieved by nitrification/denitrification only.
(3) Removal efficiency data is not available for microfiltration, therefore, estimated concentration is due to removal achieved by reverse osmosis only.

organic matter (DOM) and metastable reduced sulfur species (thiols and polysulfides). These colloidal material interactions and metals speciations can vary significantly in different wastewaters. Therefore, due to this uncertainty, the predicted metals reductions that are assumed in this planning-level assessment may not be achievable without additional investment in advanced treatment facilities and associated costs.

3.0 BASIS OF COST

Capital costs are based Class 5 and Class 4 estimates as outlined by the Association for the Advancement of Cost Engineering International (AACEI, formally known as the American Association of Cost Engineers)[1]. These estimate classes are presented in the AACEI Recommended Practice No. 18R-97.

Class 5 estimates are typically used for conceptual and screening purposes and are based on a project definition of 0 to 2 percent. A contingency is often used to compensate for lack of detailed engineering data and oversights (–20 percent to -50 percent on the low side, and +30 percent to +100 percent on the high side) depending on the technological complexity of the project, availability and accuracy of appropriate reference information, and the inclusion of an appropriate contingency determination.

Class 4 estimates are prepared for any number of strategic business planning purposes including, but not limited to, detailed strategic planning, confirmation of economic and/or technical feasibility, and preliminary budget approval or approval to proceed to the next stage. Limited information is available at the time when a Class 4 estimate is developed.

Therefore, Class 4 estimates typically use stochastic estimating methods such as parametric or other modeling techniques, and various factors. Subsequently, estimated costs have a fairly wide range of accuracy. Typical accuracy ranges for Class 4 estimates are –15 percent to –30 percent on the low side, and +20 percent to +50 percent on the high side, depending on the technological complexity of the project, availability and accuracy of appropriate reference information, and the inclusion of an appropriate contingency determination.

The costs presented are based on preliminary layouts, preliminary unit process sizes, and conceptual alternative configurations. Construction costs are estimated from unit costs developed from past SRCSD construction contracts, estimating guides, equipment manufacturers information, unit prices, and construction costs of similar facilities and configurations at other locations.

Operations and maintenance (O&M) costs are based on SRCSD and other similar facilities historical operating costs, estimated manpower needs, resource requirements, and equipment replacement and maintenance needs. A summary of the economic criteria to be used for estimating costs is presented in Table 2.

---

[1] "Recommended Practices and Standards," *Standard Cost Engineering Terminology*, AACEI.

Table 2	Economic Criteria Advanced Treatment Alternatives for the SRWTP Sacramento Regional County Sanitation District
Item	**Assumption**
Costs in Time and Place	Costs are based on January 2009 costs for Sacramento.
Escalation in Cost Index	The cost escalation for 2009 is assumed to be 3%.
Project Cost Factor	Total of 65 percent which includes the following: • 10 percent for design engineering. • 10 percent for construction management. • 15 percent for administration & legal (5 percent design staff support, 10 percent construction management - plant staff DERA project management). • 30 percent for project contingencies.
Interest Rate	5 percent for amortization purpose.
Amortization Period	20 years

3.1 Capital Costs

Capital costs presented in this TM are Class 5 and Class 4 estimates. Unless otherwise noted, the costs were developed using the 90th percentile of Carollo estimates and bid tabs for other Carollo projects. Costs are provided for each treatment process, and, as necessary, pump stations have been included.

While the estimated construction costs represent the average bidding conditions for many projects, variations in bidding climate at the time the facilities are constructed can affect actual construction costs. Further, the size of the facilities may be refined during preliminary design based on the most current operational information available. For these reasons, the actual construction costs may be lower or higher than originally estimated. As mentioned earlier, Class 4 and Class 5 estimates are not as accurate as estimates prepared in conjunction with preliminary or final design.

Engineering News Record (ENR) develops and publishes ENRCCIs for 20 cities in the U.S. and 2 in Canada. Sacramento is not one of the cities tracked by the ENR. Therefore, the ENRCCI for Sacramento was estimated by taking an average of the average ENRCCI for the U.S. 20 Cities and the San Francisco ENRCCI. Capital costs for Sacramento are based on an estimated ENRCCI of 9138, which is the average of the January 2009 U.S. 20 Cities ENRCCI of 8549 and the January 2009 San Francisco ENRCCI of 9726.

The construction costs presented include contractor's overhead and profit, and construction contingencies. Costs to the owner, such as engineering, legal, administrative, project contingencies, and construction management costs are added to the construction costs. A variable project cost factor of 65 percent is applied to the construction costs to arrive at the total estimated project capital cost. The project cost factor varies depending on the project scope. The basis for estimating capital costs is presented in Table 3. Both escalation and project cost factor adjustments discussed above are included in estimating total capital costs.

Table 3 Basis for Estimating Project Costs
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

Item	Estimated Cost[1]
Obtain Base Construction Cost from Carollo Project Bid Tabs and other Carollo project estimates. Adjust this cost to January 2009 cost for Sacramento, California.	"A"
• Add 15% of base construction cost to adjust to "mid range" of bids.	+15% of "A"
• Add 20% of base construction cost for "missed items."	+20% of "A"
• Adjust base construction field piping costs[2]	Varies
• Adjust base construction electrical/instrumentation.[2]	Varies
• Adjust base construction sheeting/shoring/piles.[2]	Varies
Subtotal Construction Cost	"B"
• Add 65% of Construction Cost as Project Cost Factor.[3]	+ 65% of "B"
Total Estimated Project Cost	"C"

Notes:
(1) Based on January 2009 costs for Sacramento, California (Estimated ENRCCI of 9138)
(2) Costs are adjusted based on site-specific conditions.
(3) Includes project contingencies, construction management, administrative, engineering and legal costs.

Construction cost represents the 90th percentile of past Carollo projects unless otherwise noted. Project costs include a 65 percent contingency as described above. Figure 2 presents a comparison of the unit capital costs for each unit treatment process.

3.2 Escalation Rate

Construction costs have historically escalated with time. This trend is expected to continue in the future. Prior to 2003, the use of cost indices such as ENRCCI was a good way to develop escalation estimates for future projects and future project components. These are commodity indices. However, the bidding market has become so complicated and risky that the typical indices are no longer valid for predicting complete project costs.

When China entered the market in 2003 and began using high percentages of significant commodities such as cement and steel, the supply in the U.S. became very constricted. This resulted not only in higher prices, but also in project delays that often cost far more

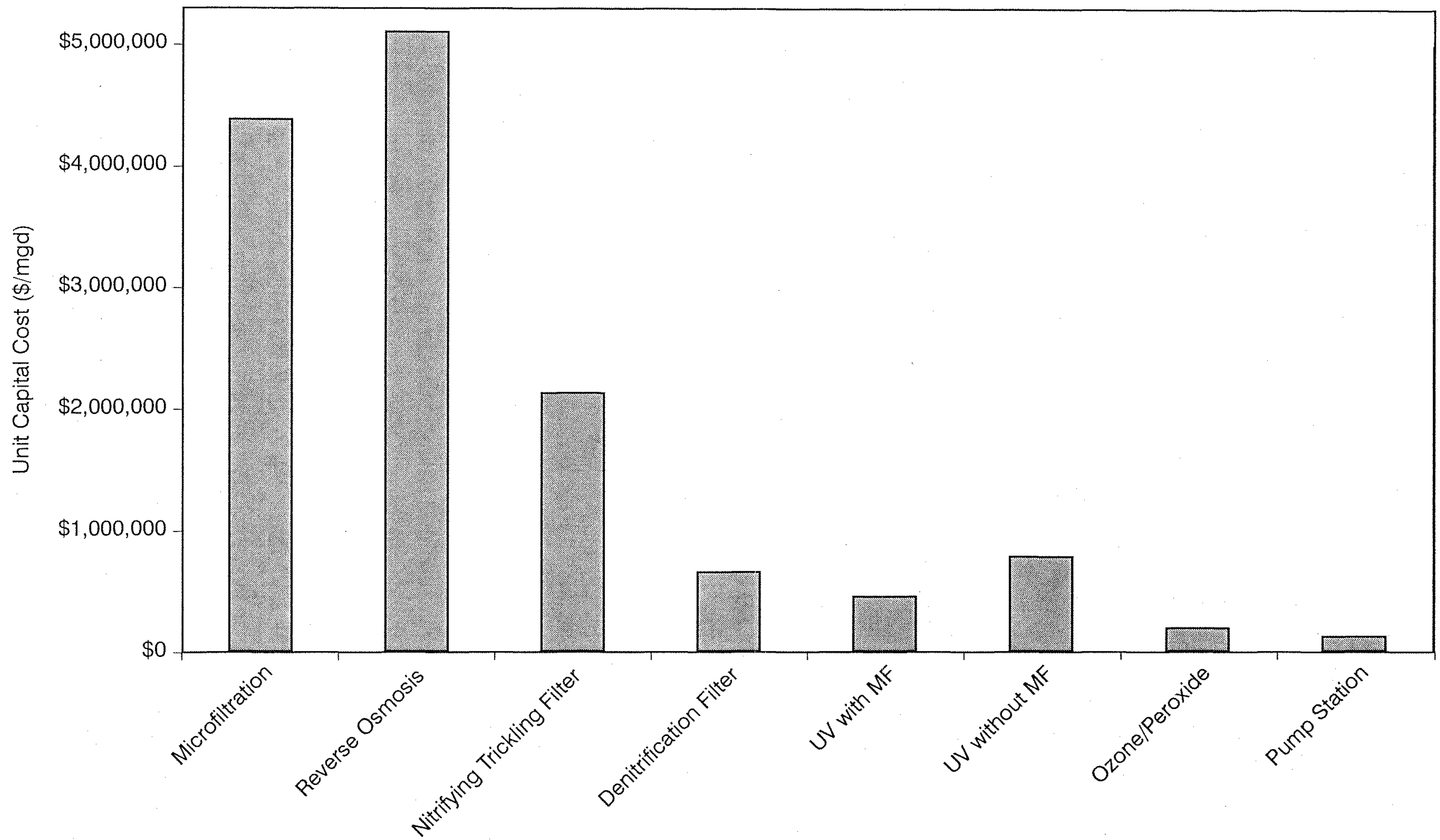

Figure 2
UNIT CAPITAL COSTS
ADVANCED TREATMENT ALTERNATIVES FOR THE SACRAMENTO REGIONAL WASTEWATER TREATMENT PLANT
SACRAMENTO REGIONAL COUNTY SANITATION DISTRICT

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than the increase in the commodity prices. Total project costs became more complicated and were driven even higher when the Hurricane Katrina struck the U.S. Gulf coast, shutting down much commodity production and distribution, and raising fuel prices.

While the ENRCCI index tracks rising commodity costs very accurately, they do not consider the following risks to the bidding contractor:

- Uncertainty in delivery of commodities to the project.
- Cost of commodities at time of bid differing from cost at time of shipment.
- Increased cost of freight due to rising fuel costs.
- Short supply of skilled labor and supervision.
- Short supply of qualified specialty subcontractors.

Prior to 2003, owners had been using 3 percent to 3.5 percent compounded annually as an escalation factor for Master Plans and Capital Improvement Plans. Currently, due to the economic recession in the United States, commodity prices and the competitive contractor bidding climate are favorable. However, the prevailing opinion among U.S. estimators in the municipal design disciplines at this time is that over the long term (5 to 20 years out), escalation will level off to around 3 percent compounded annually. Thus, the recommended annual escalation rate for SRCSD is 3 percent.

3.3 O&M Costs

O&M unit costs are estimated in January 2009 dollars and based on an ADAF flow of 237 mgd that corresponds with 218 mgd ADWF. Treatment Train D is based on 48 mgd ADWF, which corresponds to 52 mgd ADAF. Costs are provided for each treatment process, and, as necessary, pump stations have been included. The unit costs were obtained by averaging estimates for O&M costs for various Carollo projects, including previous estimates for SRCSD. Where appropriate, more recent Carollo projects were used without averaging. Projects for which O&M estimates were not averaged are noted. The unit costs presented will be used in developing O&M costs for each treatment alternative. Figure 3 presents a comparison of the unit O&M costs for each unit treatment process.

3.4 Total Annual Costs

When project alternatives are analyzed for cost effectiveness, it is necessary to compare both capital and O&M costs. Alternatives are then compared on a combined total annual cost basis. Capital costs are amortized over a 20-year period using an interest rate of 5 percent. Total annual cost is the sum of the amortized capital cost and the annual O&M cost. Costs are provided for each treatment process, and, as necessary, pump stations have been included.

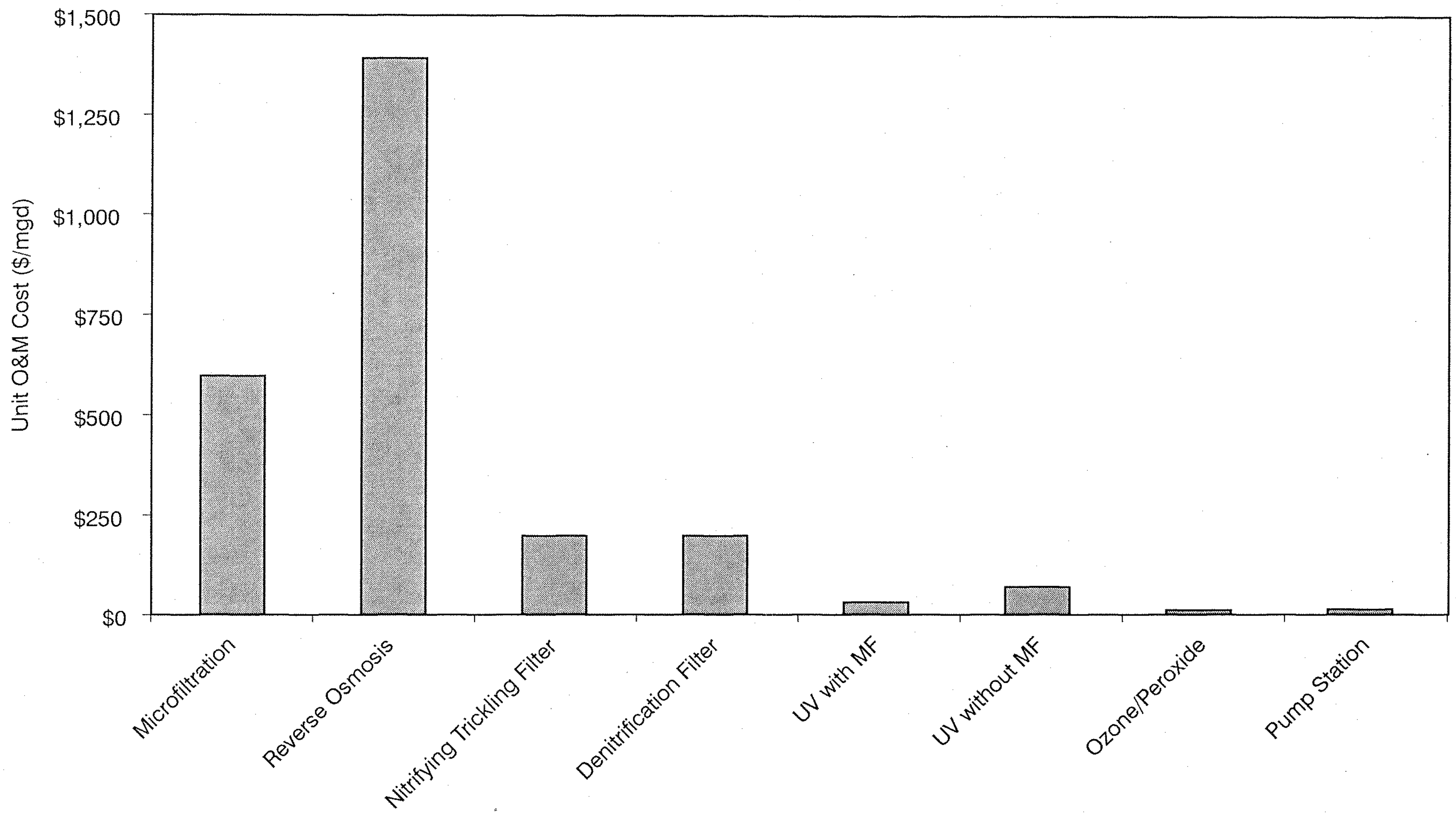

Figure 3
UNIT O&M COSTS
ADVANCED TREATMENT ALTERNATIVES FOR THE
SACRAMENTO REGIONAL WASTEWATER TREATMENT PLANT
SACRAMENTO REGIONAL COUNTY SANITATION DISTRICT

sr209f3-8184.ai

Table 4 presents the projects cost in dollars per mgd, daily O&M costs, total projects costs for the corresponding ADMMF for the ADWF of 218 mgd, total annual O&M cost, annualized capital cost and total annual cost for each process. Treatment Train D costs are based on 48 mgd ADWF, which corresponds to 67 mgd ADMMF. The costs presented are for the entire treatment process and include additional pre-treatment required for the various processes as well as any required disposal treatment. Figure 4 presents a comparison of the total annual cost for the treatment trains.

3.5 Future Costs and Present Value Sensitivity Analysis

The total project costs were escalated to the projected midpoint of construction for each treatment train A through E. Each treatment train was assumed to take eight years from the start of planning to start of operation with a start of operation year of 2020. The annual O&M cost at the assumed start date of construction and for the lifecycle of facility were also developed for treatment trains A through E. The lifecycle and amortization period were assumed to be 20 years. The escalation rate was assumed to be 3 percent. The future reinvestment costs and years were estimated assuming that 50 percent of the project cost would need to be reinvested throughout the useful life of the facilities, mainly for the mechanical and electrical components. Structural components were assumed to not require significant reinvestment. Reinvestment was assumed to occur on an annual basis.

Usually SRCSD evaluates costs using a discount rate of 5 percent. To better compare alternatives, a sensitivity analysis was preformed using a 3 percent and 7 percent discount rate. Total annual costs (capital, O&M, and repair and replacement (R&R)) were developed assuming 3 percent, 5 percent, and 7 percent discount rates and are shown in Tables 5, 6 and 7, respectively. Future costs are shown in Table 8. These future costs were then calculated for present value. Salvage value is the remaining value at the end of a facility's life. Present worth of salvage value assumes a discount rate, 3 percent escalation rate, and salvage of 50 percent of the original project cost. These present value costs are shown for the 3 percent, 5 percent, and 7 percent discount rates in Tables 9, 10, and 11, respectively.

3.6 Land Requirements

Land requirements are not assigned an economic value in this assessment, because it is assumed that the SRWTP has adequate land for tertiary treatment to accommodate average dry weather flow projections to 218 mgd.

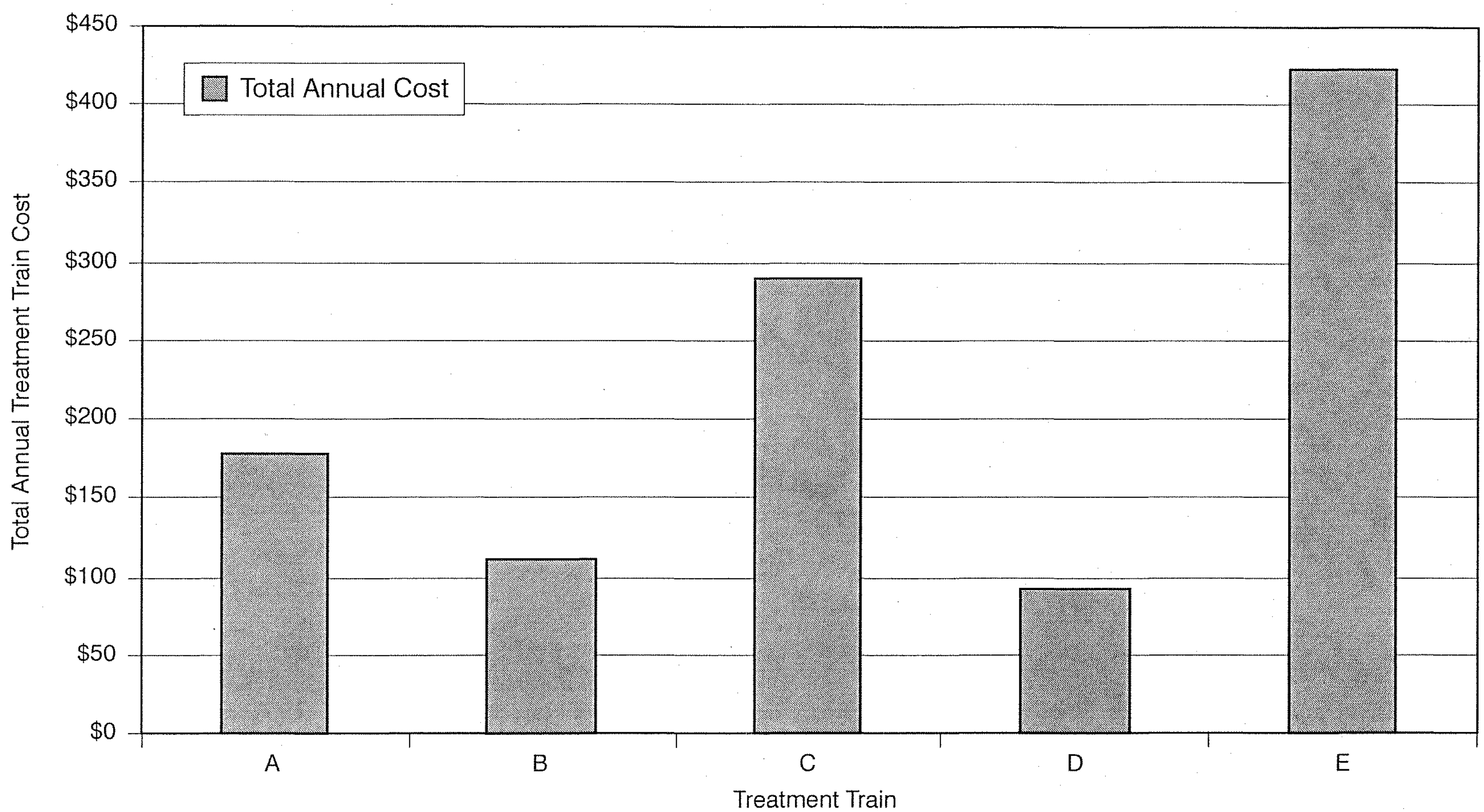

Figure 4
TOTAL ANNUAL COST OF TREATMENT TRAINS
ADVANCED TREATMENT ALTERNATIVES FOR THE
SACRAMENTO REGIONAL WASTEWATER TREATMENT PLANT
SACRAMENTO REGIONAL COUNTY SANITATION DISTRICT

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Table 4 Total Annual Cost
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

Treatment Process / Unit Process	Unit Project Cost[(1)(2)] ($/mgd capacity)	Unit Daily O&M Cost[(3)] ($/mg treated)	Total Project Cost @ 218 mgd[(1)(2)] ($ million)	Annual Project Cost @ 218 mgd ($ million)[(1)(2)(4)]	Total Annual O&M Cost @ 218 mgd[(3)] ($ million)	Total Annual Cost ($ million)
Treatment Train A - Microfiltration ->UV Disinfection (218 mgd)						
Microfiltration	$4,390,000	$600	$1,365	$110	$52	$161
Pump Station	$120,000	$13	$37	$3	$1	$4
UV Disinfection	$450,000	$31	$140	$11	$3	$14
Total	$4,960,000	$644	$1,543	$124	$56	$179
Treatment Train B - NTF -> FBR -> Chlorine Disinfection (218 mgd)						
NTF	$2,130,000	$200	$662	$53	$17	$70
FBR[(5)]	$650,000	$200	$202	$16	$17	$34
2 Pump Stations	$240,000	$26	$75	$6	$2	$8
Total	$3,020,000	$426	$939	$75	$37	$112
Treatment Train C - NTF -> FBR -> Microfiltration -> UV Disinfection (218 mgd)						
NTF	$2,130,000	$200	$662	$53	$17	$70
FBR[(5)]	$650,000	$200	$202	$16	$17	$34
3 Pump Stations	$360,000	$39	$112	$9	$3	$12
Microfiltration	$4,390,000	$600	$1,365	$110	$52	$161
UV Disinfection	$450,000	$31	$140	$11	$3	$14
Total	$7,980,000	$1,070	$2,482	$199	$93	$292
Treatment Train D[(6,7)] - Microfiltration -> Reverse Osmosis -> Ozone/Peroxide (48 mgd)						
Microfiltration	$4,390,000	$600	$294	$24	$11	$35
Reverse Osmosis[(8)]	$5,110,000	$1,400	$342	$27	$27	$54
2 Pump Stations	$240,000	$26	$16	$1	$0	$2
Ozone/Peroxide	$190,000	$11	$13	$1	$0	$1
Total	$9,930,000	$2,037	$665	$53	$39	$92

Table 4 Total Annual Cost
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

Treatment Process / Unit Process	Unit Project Cost[(1)(2)] ($/mgd capacity)	Unit Daily O&M Cost[(3)] ($/mg treated)	Total Project Cost @ 218 mgd[(1)(2)] ($ million)	Annual Project Cost @ 218 mgd ($ million)[(1)(2)(4)]	Total Annual O&M Cost @ 218 mgd[(3)] ($ million)	Total Annual Cost ($ million)
Treatment Train E - Microfiltration -> Reverse Osmosis -> Ozone/Peroxide (218 mgd)						
Microfiltration	$4,390,000	$600	$1,365	$110	$52	$161
Reverse Osmosis[(8)]	$5,110,000	$1,400	$1,589	$128	$121	$249
2 Pump Stations	$240,000	$26	$75	$6	$2	$8
Ozone/Peroxide	$190,000	11	$59	$5	$1	$6
Total	$9,930,000	$2,037	$3,088	$248	$176	$424

Notes:
(1) Project costs include engineering, administrative, legal and contingency. All costs in January 2009 dollars (ENRCCI 9138).
(2) Project costs sized to treat associated ADMMF of 311 mgd.
(3) O&M costs sized to treat ADAF of 237 mgd.
(4) Annual capital cost developed using a 20 year amortization period and 5 percent interest.
(5) FBR costs scaled from March 2005 memorandum (NPDES Permit No. CA 0077682 Provision E.6 Treatment Feasibility Studies, Draft March 2005
(6) Treatment Train D flow assumed to be 48 mgd ADWF, 52 mgd ADAF, and 67 mgd ADMMF. The No Net Increase train (Train D) assumes that approximately 22% of the flow goes through the treatment train, the remaining 78% goes through secondary and then disinfection.
(7) Treatment Train D includes chlorination for the entire flow, 218 mgd (ADWF). Total costs assumes that there is no additional project cost and O&M costs associated with chlorine disinfection because it is an existing process.
(8) Reverse osmosis costs include brine treatment and disposal. The assumed brine flow requiring treatment is 10% of the ADMMF.

Table 5 Annual Costs at 3% Discount Rate
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

Treatment Train	Annualized Project Cost @ 218 mgd(1)(2) ($ million)	Annual O&M Cost @ 218 mgd(1) ($ million)	Total Annual Capital and O&M Cost @ 218 mgd(3) ($ million)	Annual Reinvestment Costs(4) ($ million)	Total Annual Capital, O&M and R&R Cost @ 218 mgd(5) ($ million)
A	$104	$56	$159	$72	$231
B	$63	$37	$100	$44	$144
C	$167	$93	$259	$115	$375
D	$45	$39	$83	$31	$114
E	$208	$176	$384	$144	$527

Notes:
(1) Project cost and annual O&M cost in 2009 dollars.
(2) Project cost annualized assuming an escalation rate of 3 percent and amortization period of 20 years.
(3) Total annual cost includes annualized project cost and annual O&M cost in 2009 dollars.
(4) Annual reinvestment cost presents the annuity that must be annually expended to obtain the future reinvestment cost. Assumes a discount rate of 3%. Cost shown is in 2009 dollars.
(5) Total annual capital, O&M and R&R cost include the annualized capital, annual O&M, and annualized R&R cost assuming a 3 percent escalation and 20 year useful life. Cost shown in 2009 dollars.

**Table 6 Annual Costs at 5% Discount Rate
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District**

Treatment Train	Annualized Project Cost @ 218 mgd(1)(2) ($ million)	Annual O&M Cost @ 218 mgd(1) ($ million)	Total Annual Capital and O&M Cost @ 218 mgd(3) ($ million)	Annual Reinvestment Costs(4) ($ million)	Total Annual Capital, O&M and R&R Cost @ 218 mgd(5) ($ million)
A	$104	$56	$159	$58	$218
B	$63	$37	$100	$36	$135
C	$167	$93	$259	$94	$353
D	$45	$39	$83	$25	$109
E	$208	$176	$384	$117	$501

Notes:

(1) Project cost and annual O&M cost in 2009 dollars.

(2) Project cost annualized assuming an escalation rate of 3 percent and amortization period of 20 years.

(3) Total annual cost includes annualized project cost and annual O&M cost in 2009 dollars.

(4) Annual reinvestment cost presents the annuity that must be annually expended to obtain the future reinvestment cost. Assumes a discount rate of 5%. Cost shown is in 2009 dollars.

(5) Total annual capital, O&M and R&R cost include the annualized capital, annual O&M, and annualized R&R cost assuming a 3 percent escalation and 20 year useful life. Cost shown in 2009 dollars.

Table 7 Annual Costs at 7% Discount Rate
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

Treatment Train	Annualized Project Cost @ 218 mgd(1)(2) ($ million)	Annual O&M Cost @ 218 mgd(1) ($ million)	Total Annual Capital and O&M Cost @ 218 mgd(3) ($ million)	Annual Reinvestment Costs(4) ($ million)	Total Annual Capital, O&M and R&R Cost @ 218 mgd(5) ($ million)
A	$104	$56	$159	$47	$206
B	$63	$37	$100	$29	$129
C	$167	$93	$259	$76	$335
D	$45	$39	$83	$20	$104
E	$208	$176	$384	$94	$478

Notes:
(1) Project cost and annual O&M cost in 2009 dollars.
(2) Project cost annualized assuming an escalation rate of 3 percent and amortization period of 20 years.
(3) Total annual cost includes annualized project cost and annual O&M cost in 2009 dollars.
(4) Annual reinvestment cost presents the annuity that must be annually expended to obtain the future reinvestment cost. Assumes a discount rate of 7%. Cost shown is in 2009 dollars.
(5) Total annual capital, O&M and R&R cost include the annualized capital, annual O&M, and annualized R&R cost assuming a 3 percent escalation and 20 year useful life. Cost shown in 2009 dollars.

Table 8 Future Costs
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

Treatment Train	Year Online	Total Project Cost @ 218 mgd to Mid-Point of Construction(1) ($ million)	Total Annual O&M Cost @ 218 mgd at Assumed Start Date of Operation(2) ($ million)	Total Life Cycle O&M Cost @ 218 mgd ($ million)	Future Reinvestment Costs(3) ($ million)
A	2020	$1,897	$77	$2,212	$1,928
B	2020	$1,155	$51	$1,463	$1,174
C	2020	$3,052	$128	$3,675	$3,102
D	2020	$818	$54	$1,535	$832
E	2020	$3,798	$244	$6,995	$3,860

Notes:

(1) Mid-point of construction based on number of years to project start year and half of the number of years of construction; escalation rate of 3 percent.

(2) O&M cost at start of operation is the annual O&M cost in future dollars where the future year is the start year of operation; escalation rate of 3 percent.

(3) Future reinvestment cost assumes that reinvestment is required only for 50 percent of the 2009 project cost elements consisting of mechanical and electrical equipment. Assumes that structures will not require reconstruction.

Table 9 Present Value at 3% Discount Rate
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

Treatment Train	Present Worth of Total Project Cost at Mid-Point of Construction(1) ($ million)	Present Worth of O&M Cost Over Life of Project From Start of Operation(2) ($ million)	Present Worth of O&M and Capital ($ million)	Present Worth of Future Reinvestment Cost(3) ($ million)	Present Worth of Salvage Value of Originally Invested Facilities (4) ($ million)	Present Worth of Total Capital, O&M, and R&R Cost(5)
A	$1,543	$1,170	$2,713	$771	($771)	$2,713
B	$939	$774	$1,713	$470	($470)	$1,713
C	$2,482	$1,944	$4,426	$1,241	($1,241)	$4,426
D	$665	$812	$1,477	$333	($333)	$1,477
E	$3,088	$3,701	$6,789	$1,544	($1,544)	$6,789

Notes:

(1) Present worth of project cost of at mid-point of construction assumes a discount rate of 3 percent and escalation rate of 3 percent.

(2) Present worth of annual O&M at start of operation assumes a discount rate of 3 percent, an escalation rate of 3 percent, and a 20 year life.

(3) Present worth of future reinvestment cost assumes a discount rate of 3 percent, escalation of 3 percent, replacement of 50 percent of original project cost, and a useful life of 20 years.

(4) Present worth of salvage value assumes a 3 percent discount rate, 3 percent escalation rate, and salvage of 50 percent of the original project cost.

(5) Present worth of capital, O&M, and R&R presents the present worth of project cost at midpoint of construction, present worth of lifecycle cost of O&M, present worth of future reinvestment, and present worth of the salvage value assuming a 20 year life.

Table 10 Present Value at 5% Discount Rate
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

Treatment Train	Present Worth of Total Project Cost at Mid-Point of Construction[1] ($ million)	Present Worth of O&M Cost Over Life of Project From Start of Operation[2] ($ million)	Present Worth of O&M and Capital ($ million)	Present Worth of Future Reinvestment Cost[3] ($ million)	Present Worth of Salvage Value of Originally Invested Facilities[4] ($ million)	Present Worth of Total Capital, O&M, and R&R Cost[5]
A	$1,348	$1,170	$2,518	$425	($425)	$2,518
B	$821	$774	$1,595	$259	($259)	$1,595
C	$2,169	$1,944	$4,113	$684	($684)	$4,113
D	$582	$812	$1,393	$183	($183)	$1,393
E	$2,699	$3,701	$6,400	$851	($851)	$6,400

Notes:

(1) Present worth of project cost of at mid-point of construction assumes a discount rate of 5 percent and escalation rate of 3 percent.

(2) Present worth of annual O&M at start of operation assumes a discount rate of 5 percent, an escalation rate of 3 percent, and a 20 year life.

(3) Present worth of future reinvestment cost assumes a discount rate of 5 percent, escalation of 3 percent, replacement of 50 percent of original project cost, and a useful life of 20 years.

(4) Present worth of salvage value assumes a 5 percent discount rate, 3 percent escalation rate, and salvage of 50 percent of the original project cost.

(5) Present worth of capital, O&M, and R&R presents the present worth of project cost at midpoint of construction, present worth of lifecycle cost of O&M, present worth of future reinvestment, and present worth of the salvage value assuming a 20 year life.

Table 11 Present Value at 7% Discount Rate
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

Treatment Train	Present Worth of Total Project Cost at Mid-Point of Construction(1) ($ million)	Present Worth of O&M Cost Over Life of Project From Start of Operation(2) ($ million)	Present Worth of O&M and Capital ($ million)	Present Worth of Future Reinvestment Cost(3) ($ million)	Present Worth of Salvage Value of Originally Invested Facilities (4) ($ million)	Present Worth of Total Capital, O&M, and R&R Cost(5)
A	$1,181	$1,170	$2,351	$237	($237)	$2,351
B	$719	$774	$1,493	$144	($144)	$1,493
C	$1,901	$1,944	$3,845	$381	($381)	$3,845
D	$510	$812	$1,322	$102	($102)	$1,322
E	$2,365	$3,701	$6,066	$474	($474)	$6,066

Notes:

(1) Present worth of project cost of at mid-point of construction assumes a discount rate of 7 percent and escalation rate of 3 percent.

(2) Present worth of annual O&M at start of operation assumes a discount rate of 7 percent, an escalation rate of 3 percent, and a 20 year life.

(3) Present worth of future reinvestment cost assumes a discount rate of 7 percent, escalation of 3 percent, replacement of 50 percent of original project cost, and a useful life of 20 years.

(4) Present worth of salvage value assumes a 7 percent discount rate, 3 percent escalation rate, and salvage of 50 percent of the original project cost.

(5) Present worth of capital, O&M, and R&R presents the present worth of project cost at midpoint of construction, present worth of lifecycle cost of O&M, present worth of future reinvestment, and present worth of the salvage value assuming a 20 year life.

APPENDIX - REVIEW OF UNIT TREATMENT PROCESSES AND DESIGN CRITERIA

APPENDIX - REVIEW OF UNIT TREATMENT PROCESSES AND DESIGN CRITERIA

Membrane Filtration

Membrane filtration is a pressure driven process that achieves solid-liquid separation by using semi-permeable membranes to selectively block and strain the passage of various contaminants, including suspended particles, colloidal particles, persistent pathogens, bacteria and viruses, insoluble organic material, and dissolved organic material. There are several membrane filtration processes with varying removal efficiencies, including: microfiltration (MF), ultrafiltration (UF), and nanofiltration (NF). The primary difference between the processes is the pore size and the required pressure gradient.

Available membranes are flat sheets (asymmetric or composite), hollow fibers, or tubular membranes and are usually organic (polypropylene, cellulose acetate, aromatic polyamides, thin-film composite) when used for wastewater[1]. A module is a complete treatment unit for membranes and can be configured in tubular modules, hollow fiber, and spiral wound. As membrane fouling occurs, membranes are taken out of service and backwashed or chemically cleaned.

Microfiltration

MF removes pathogens, suspended solids, and turbidity in the micron size range due to the large nominal pore size (typical range 0.1 - 1 um), and can be used for pretreatment for reverse osmosis (RO) or NF in an integrated membrane system (IMS). MF systems are able to produce clean water with very low turbidity values. Appropriate pretreatment techniques can improve the rejection of organics.

In 2005, the SRWTP conducted pilot testing of MF along with several other membrane technologies. MF was proven to be an effective advanced treatment process for SRWTP secondary effluent.

[1] Metcalf & Eddy, Inc. (2003) *Wastewater Engineering*, 4th ed.; McGraw-Hill: New York.

Advantages and disadvantages of MF are listed below:

Advantages

- Very small footprint.
- Excellent filtrate quality.
- Good pretreatment for NF/RO.
- Product water quality is typically independent of water quality.
- Can select different pore size to achieve specific removals.

Disadvantages

- Uncertain membrane life.
- Lack of established, large wastewater membrane facilities.
- Vendor membranes not interchangeable.
- Requires disinfection downstream.
- More costly than sand filters.

Pollutants typically treated by this technology include:

- Suspended particles.
- Protozoa, bacteria and some viruses.
- Insoluble organic material.
- Dissolved organic material.
- Dissolved inorganic material.

MF does not effectively remove trace organics due to its pore size. Snyder et al. (2007) observed percent removals of less than 20 percent.

Design criteria used for planning purposes and initial project sizing are included in Table A1.

Table A1 Typical Design Criteria for Microfiltration
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

Filtration Process	Parameter	Units	Value
Microfiltration	Permeate flux	gfd	10-40

The sizing criteria for planning purposes are shown in Table A2. This is a conservative layout space requirement that assumes the following:

- Reasonable piping conveyance allowance.
- Backwash Tanks (if necessary).
- Chemical Tanks (for membrane filtration).
- Pumping system.

Table A2	Sizing Criteria for Microfiltration Advanced Treatment Alternatives for the SRWTP Sacramento Regional County Sanitation District
Filtration Process	**Value**
Microfiltration Area	100-800 sf/mgd

The design criteria for MF assumes treatment of the full 311 mgd of ADMMF and are provided below in Table A3.

Table A3	Summary Design Criteria for Microfiltration for ADMMF Advanced Treatment Alternatives for the SRWTP Sacramento Regional County Sanitation District
Parameter	**Value**
Flow Treated, mgd	311
Hydraulic Loading Rate, gpm/sf	3.7
Microfiltration	
Number of Trains	150
Number of Modules	23,100

Reverse Osmosis and Brine Treatment and Disposal

RO is a membrane separation process that relies on applied pressure to force water through a semi permeable membrane while restraining the passage of particulate and high molecular weight constituents. High pressure is required for RO to overcome the osmotic pressure caused by dissolved solids and to force the liquid through the membranes. Passage of water through the membrane results in a relatively ion free effluent stream and a concentrated waste stream (brine), which requires further treatment, and disposal. In order to reduce the brine stream, brine from the RO process is fed directly to a brine concentrator. Some potential brine disposal methods include ocean discharge, surface water discharge, crystallization and land application, deep well injection, evaporation ponds, and controlled thermal evaporation. The selected approach for brine treatment and disposal includes thermal concentration, crystallization, and landfill disposal.

There are different types of membranes (cellulose acetate, polyamide composite) and types of devices (tubular, spiral wound, hollow fiber) available. The capacity and performance of an RO membrane is dependent on the membrane composition and configuration; pressure, temperature, and concentration of the feed water; and recovery, product pressure, and time in operation. For optimal performance, the feed to the RO process should be pretreated to remove potential organic and inorganic foulants. Pretreatment techniques such as pH adjustment, chlorination, chemical precipitation, filtration, and addition of scale inhibiting chemicals can be used. Backwashing is also required to remove foulants that clog the membrane's pores.

Advantages and disadvantages of RO are listed below:

Advantages	Disadvantages
• Very effective at removing TDS. • Provides removal of TOC, as well as nutrients. • Provides disinfection.	• Energy intensive. • Requires extensive pretreatment. • Requires brine treatment, disposal and residuals handling. • Expensive relative to other treatment processes. • Lack of reliable, low cost methods for monitoring performance.

Pollutants typically treated by this technology include:

- Suspended particles.
- Protozoa, bacteria and viruses.
- Insoluble organic material.
- Dissolved organic material.
- Dissolved inorganic material including TDS.

RO membranes have a small nominal pore size (typically <0.001 um) that has been shown to effectively remove most trace organic compounds to less than detection limits (<10 ng/). Snyder et al. (2007) observed percent removals through RO membranes of greater than 80 percent for most trace organic compounds studied. While RO membranes provide significant removal of trace organic compounds, it is also important to consider treatment and/or disposal of brine that contains concentrated trace organic compounds.

Design criteria used for planning purposes and initial project sizing are included in Table A4.

Table A4 Typical Design Criteria for Reverse Osmosis
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

Parameter	Units	Value
Flux	gfd	10

The sizing criteria for planning purposes are shown in Table A5. This is a conservative layout space requirement that assumes the following:

- Reasonable piping conveyance allowance.
- Contact chambers.
- Chemical facilities.

Table A5	Sizing Criteria for Reverse Osmosis Advanced Treatment Alternatives for the SRWTP Sacramento Regional County Sanitation District	
Filtration Process	**Units**	**Value**
Reverse Osmosis Membrane Area	sf/mgd	2000-2500

Design criteria for the RO process assume treatment of the full flow of 218 mgd (ADWF) Table A6 provides a summary of the design criteria for this flow.

Table A6	Summary Design Criteria for Reverse Osmosis Advanced Treatment Alternatives for the SRWTP Sacramento Regional County Sanitation District	
Parameter	**Base Value**	**Alternative Value**
Flow Treated, mgd	311	311
Membrane	Cellulose Acetate	Polyamide
Flow Rate, gpm/membrane	1.5 to 4	1.5 to 4
Pressure, psig	400	250
Stages	3	3
Recovery, %	90	90

Ammonia Removal - Nitrifying Trickling Filters

Biological nutrient removal (BNR) consists of anoxic, anaerobic, and aerobic biological treatment processes designed to remove ammonia, nitrogen, and/or phosphorus from wastewater effluent. BNR can be employed as a suspended-growth process, such as activated sludge or oxidation ditches, or as a fixed-film process, such as trickling filters or biological aerated filters. The selection of a particular BNR process is based upon site-specific constraints, including odor, site availability, operational flexibility, regulatory requirements, and compatibility with existing processes.

Nitrification is an aerobic process for the conversion of ammonia to nitrate by nitrifying microorganisms. The nitrifying trickling filter (NTF) is an attached growth (biofilm) method that can be used to remove ammonia from secondary treated wastewater. The fluidized bed reactor (FBR) process is an attached growth (biofilm) method that can be used to remove ammonia from secondary treated wastewater. Secondary treated effluent is pumped and distributed to the top surface of the filter media. Various types of plastic media are used. Wastewater percolates downward through the filter media and is collected in the underdrain. Generally, the denitrifying step precedes the nitrifying step, with an internal recycle.

Advantages and disadvantages of NTF are listed below:

Advantages	Disadvantages
• No chemicals are added in the process.	• Large area required for the process. • Low temperature may affect nutrient removal performance, however, facilities can be sized appropriately to account for reduced performance.

Pollutants typically treated by biological nutrient removal include:

- Ammonia.
- Nitrogen.
- Phosphorous.
- BOD.

Table A7 provides typical design criteria for NTF for ammonia, nitrogen, and phosphorous removal.

Table A7 Typical Design Criteria for NTF
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

BNR Process	Parameter	Units	Value
Ammonia/Nitrogen/Phosphorus Removal	Anoxic HRT	hr	2-5
Ammonia/Nitrogen/Phosphorus Removal	Aerobic HRT	hr	4-12

The sizing criteria for planning purposes are shown in Table A8. This is a conservative layout space requirement that assumes the following:

- Reasonable piping conveyance allowance.

Table A8 Summary Sizing Criteria for NTF
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

BNR Process	Value
Ammonia/Nitrogen removal	3000 sf/mgd
Phosphorus Removal	9000 sf/mgd

The design criteria for NTFs for the 2020 ADMMF of 311 mgd is provided in Table A9.

Table A9	Summary Design Criteria for NTF for ADMMF Advanced Treatment Alternatives for the SRWTP Sacramento Regional County Sanitation District
Criteria	**Value**
Flow Treated, mgd	311
Number of Trickling Filters	12
Trickling Filter Diameter, ft	150
Media Depth, ft	22
Influent Ammonia-Nitrogen (NH_3-N) Concentration, mg/L	25
Hydraulic Loading, gpm/sf (without recirculation)	1.2
Nitrogen Loading, lb. NH_3-N Removed/1000cf/day	1.8

Biological Nutrient Reduction - Nitrifying Trickling Filters/Denitrifying Beds

Two steps are necessary for nitrogen removal. Nitrification is an aerobic process for the conversion of ammonia to nitrate by nitrifying microorganisms. Denitrification is an anoxic process for the conversion of nitrate to nitrogen gas. Generally, the denitrifying step precedes the nitrifying step, with an internal recycle. The nitrifying trickling filter (NTF) and fluidized bed reactor (FBR) processes are attached growth (biofilm) methods that can be used in sequence to remove nitrogen from secondary treated wastewater.

FBRs follow NTFs to provide denitrification in an anoxic environment. The FBR process is an attached-growth biological system that uses denitrifying biomass grown in a sand media to convert nitrate-nitrogen to nitrogen gas with the addition of a carbon food source (synthetic or side stream from upstream processes). Wastewater is fed upwards through a bed of sand at a sufficient enough velocity to fluidize the sand particles that are coated with a biofilm. As the biofilm grows in thickness, it causes the sand media to become lighter in overall density and accumulate at the top of the bed where it can be removed. Process efficiency is controlled by continuously removing the biomass from the lighter particles at the top and returning the clean sand to the bottom of the reactor.

Advantages and disadvantages of FBR are listed below:

Advantages

- No chemicals are added in the process.

Disadvantages

- Large area required for process.
- Low temperature may affect nutrient removal performance.

Pollutants typically treated by biological nutrient removal include:

- Nitrogen.
- Phosphorous.
- BOD.

The removal efficiencies of nutrients using NTF and FBR are provided in Table A10. Table A11 provides summary design criteria for biological nutrient removal. The sizing criteria for planning purposes are shown in Table A12. This is a conservative layout space requirement, which assumes the following:

- Reasonable piping conveyance allowance.

The design criteria for NTF/FBRs for the 2020 ADMMF of 311 mgd is provided in Table A13.

Table A10 Typical Nutrient Removal Rates for NTF and FBR
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

	Percent Removal			
Constituent	**Average**	**Minimum**	**Maximum**	**No. of Studies**
Nutrients				
Nitrogen	14	14	14	1
Phosphorus	33	26	39	2

Table A11 Typical Design Criteria for Nutrient Removal
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

BNR Process	Parameter	Units	Value
Nitrogen/Phosphorus Removal	Anoxic HRT	hr	2-5
Nitrogen/Phosphorus Removal	Aerobic HRT	hr	4-12
Phosphorus Removal	Anaerobic HRT	hr	0.5-2

Table A12 Sizing Criteria for Nutrient Removal
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

BNR Process	Value
Nitrogen Removal	3000 sf/mgd
Phosphorus Removal	9000 sf/mgd

Table A13 Design Criteria for Nutrient Removal for ADMMF Advanced Treatment Alternatives for the SRWTP Sacramento Regional County Sanitation District	
Criteria - Nitrifying Trickling Filters	**Value**
Flow Treated, mgd	311
Number of Trickling Filters	12
Trickling Filter Diameter, ft	150
Media Depth, ft	22
Influent Ammonia-Nitrogen (NH_3-N) Concentration, mg/L	25
Hydraulic Loading, gpm/sf (without recirculation)	1.2
Nitrogen Loading, lb. NH_3-N Removed/100cf/day	1.8
Criteria -Fluidized Bed Reactors	**Value**
Flow Treated, mgd	311
Number of Fluidized Beds	50
Fluidized Bed Diameter, ft	155
Media Depth, ft	10
Influent Nitrogen (N) Concentration, mg/L	30
Nitrogen Loading, lb. N Removed/1000cf/day	460

Ultraviolet Disinfection

Ultraviolet (UV) disinfection involves the use of UV light (radiation) between 220 and 320 nanometers (nm) wavelength to inactivate microorganisms. Contact time, UV dose, types of organisms, and water quality all affect the effectiveness of UV. UV dose is a measure of the amount of UV energy delivered to the microbes. The UV dose is a particularly important parameter. The UV dose is affected by the presence of UV absorbing compounds in the wastewater such as humic compounds, lignins, and suspended solids.

With UV disinfection, *Cryptosporidium* and *Giardia*, can be inactivated at relatively low doses, while bacterial spores and some virus are relatively resistant. Microbes within particles are shielded from UV light, and thus require a larger incremental dose per log reduction. The dose required to meet a given disinfection target is obtained from the dose-response of the target microbe. Upstream treatment and the resultant water quality impacts the dose necessary to meet indicator microbe disinfection requirements.

UV reactors used in wastewater applications can be either open or closed channel. Reactors contain lamps housed within quartz sleeves. UV systems typically contain reactors in series and in parallel. UV lamps include low-pressure low-intensity (LP), low-pressure high-intensity (LPHI), and medium-pressure high-intensity (MP) mercury arc lamps. Varying the input power will adjust the UV output of LPHI and MP lamps. Lamp sleeves foul over time and decrease the dose delivery by the reactor. Foulants must be removed regularly using manual or automatic cleaning systems. The cleaning frequency depends on the water quality (pH, hardness, iron, alkalinity) and lamp type.

Advantages and disadvantages of UV disinfection are listed below:

Advantages

- Effective against a wide range of pathogens. including cysts and oocysts (e.g. *Giardia* and *Cryptosporidium*).
- Inactivation does not depend on pH or temperature.
- No disinfection by-products (DBPs) or chlorine residual.
- Small footprint.
- No taste and odor
- Eliminates hazards associated with chemical disinfection.

Disadvantages

- Dose delivery depends strongly on UV transmittance.
- Disinfection by a given dose depends on water quality and upstream treatment. Must match upstream processes to disinfection target.
- No disinfectant residual.
- Energy intensive, especially for medium pressure systems.
- Poor reliability with some systems - lamps, ballasts, sensors, wipers.
- Algae growth with MP reactors.
- Some pathogens are UV resistant (e.g., Adenovirus).

Pollutants typically treated by this technology include:

- Protozoa, bacteria and some viruses.

Table A14 provides summary design criteria for UV disinfection.

Table A14 Typical Design Criteria for UV Disinfection
Advanced Treatment Alternatives for the SRWTP
Sacramento Regional County Sanitation District

Parameter	Units	Value
UVT	%	55% - 65%
Dose	mJ/cm^2	100 - 80

The design criteria for UV disinfection for the 2020 ADMMF of 311 mgd is provided in Table A15.

Table A15 Summary of Design Criteria for UV Disinfection Advanced Treatment Alternatives for the SRWTP Sacramento Regional County Sanitation District		
Parameter	**Value(1)**	**Value(2)**
UVT	55%	65%
Dose	100 mJ/cm^2	80 mJ/cm^2
Notes: (1) Assumes pre-treatment with conventional filtration. (2) Assumes pre-treatment with microfiltration.		

Ozone/Hydrogen Peroxide

In advanced oxidation processes, hydroxyl free radicals are generated and used to break down organic pollutants into simpler products. Ozone removes contaminants by chemical reactions via molecular ozone or the formation of free radicals (primarily the hydroxyl radical). Peroxide addition to the ozonation process promotes hydroxyl radical formation. With the addition of peroxide, the dominant oxidant becomes the hydroxyl radical, which reacts more universally, but generally with slower reaction rates for the compounds that are oxidized well by ozone alone (Huber et al., 2003). Compounds that react slowly with ozone show slightly improved removals with ozone/peroxide (Ternes et al., 2003).

Ozone is generated when oxygen (O_2) molecules are disassociated into oxygen or 'O' atoms by a high voltage current, which collide and form an unstable bond with other O_2 molecules. Since the ozone molecule is highly unstable, ozone must be generated and applied immediately on-site.

The basic process units in an ozonation treatment system are an ozone generator, contact chamber/reactor, LOX, ozone destructor unit, and ozone cooling system. The ozone off-gas needs to be scrubbed or can be recirculated back into the aeration tanks. There is no waste stream or brine that requires further treatment or disposal following treatment.

Advantages

- Provides oxidation of complex organic constituents, contributing to the removal of TOC and ammonia nitrogen.
- Potential for disinfection benefits, with the limitation that required detention times can not be achieved.

Disadvantages

- Limited applications in the wastewater industry.
- Potential formation of disinfection by-products.
- Refractory compounds may be transformed into compounds that will require further biological treatment.
- High concentrations of carbonate and bicarbonate in some wastewaters can reduce the process efficiency.
- May causes buildup of acid and TDS.
- May change pH.
- Must conduct pilot studies for efficacy and dose.

Ozone/peroxide has been shown to destroy a wide variety of trace organics, as well as TOC. Mechanisms for destruction of pathogens include cell lysis, direct destruction of cell wall, reactions with radical by-products of ozone decomposition, damage to constituents of nucleic acids, and depolymerization by breaking carbon-nitrogen bonds, according to the EPA. Pollutants typically treated by this technology include:

- Trace organics
- Protozoa, bacteria and viruses
- TOC

Recent pilot-scale and benchtop-scale studies have shown that ozone in conjunction with peroxide addition effectively destroyed greater than 80 percent of most compounds studied by Snyder et al. (2007), with the exception of some recalcitrant compounds. Ozone removes organic contaminants better with higher ozone doses, but this increases operational costs and bromate formation (Wert et al., 2007). These studies support that besides providing a barrier to pathogens, ozone with peroxide addition also provides the benefits of trace organics destruction.

Table A16 provides summary design criteria for ozone/peroxide. A contact time value of 1.0 mg-min/L is required by the California Department of Public Health.

The design criteria for ozone/peroxide for the 2020 ADMMF of 311 mgd is provided in Table A17.

Table A16 Typical Design Criteria for Ozone/Peroxide Advanced Treatment Alternatives for the SRWTP Sacramento Regional County Sanitation District

Parameter	Units	Value
Dose	mg/L	0.5-15
Contact Time	min	1 or 3

Table A17 Summary of Design Criteria for Ozone/Peroxide Advanced Treatment Alternatives for the SRWTP Sacramento Regional County Sanitation District

Parameter	Value
Dose	1 mg/L
Contact Time	1 min

APPENDIX REFERENCES

APPENDIX REFERENCES

1. Huber, M.M.; Canonica, S.; Park, G. Y.;VonGunten, U. Oxidation of pharmaceuticals during ozonation and advanced oxidation processes. *Environ. Sci. Technol.* 2003, 37, 1016-1024.

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4. Wert, E.; Rosario-Ortiz, F.; Drury, D.; Snyder, S. Formation of oxidation byproducts from ozonation of wastewater. *Water Research.* 2007, 41:1481-1490.

Appendix B – Impacts Modeling Background

WATER QUALITY IMPACTS ASSESSMENT

SRCSD has developed sophisticated modeling tools to assess potential impacts to water quality and aquatic life in the River and Delta that may result from future, proposed SRWTP discharges at flow rates above the currently permitted 181 mgd ADWF. These modeling tools were developed to address both NPDES permit requirements and increases in discharge flows as projected in the SRWTP 2020 Master Plan (Master Plan) (Carollo, 2002). These tools are useful in the examination of incremental impacts to water quality in the immediate vicinity of the SRWTP discharge point (near-field), and at various locations downstream in the Delta (far-field).

In October 2002, SRCSD conducted an Independent Technical Review (ITR) of its modeling tools. Three national modeling experts, with expertise in hydrodynamics/hydrology, probability/statistics, and water quality, formed the ITR Committee. The Committee evaluated the modeling tools and endorsed their use. On April 2, 2009, the Central Valley Regional Water Quality Control Board (Central Valley Water Board) provided a letter[2] to SRCSD approving the use of SRCSD's modeling tools for the NPDES permitting process and Draft 2009 Antidegradation Analysis (SRCSD, 2009a). This approval was based on an in-depth review of the modeling tools by a second group of national modeling experts commissioned by the U.S. EPA and Central Valley Water Board.

WATER QUALITY ASSESSMENT METHODOLOGY

Due to the complexities of the Sacramento River flows, SRWTP effluent, near- and far-field mixing, and tidally influenced flow patterns in the Delta, no single model was available to adequately describe water quality and quantify conditions in the River near the discharge and downstream in the Delta. The models used in support of the water quality analyses, and approved for use by the Central Valley Regional Water Board, included: (1) the U.S. Bureau of Reclamation (USBR) Project Simulation Model (PROSIM); (2) USBR's temperature models for the Sacramento River system; (3) the Fischer Delta Model (FDM); (4) a near-field 3-dimensional (3-D) dilution model, FLOWMOD; (5) a longitudinal dispersion model for the Sacramento River; and (6) the U.S. EPA's Dynamic Toxicity Model (DYNTOX). The relationship between these models is illustrated in **Figure A-1**. Similar to the water quality assessment performed for the Draft 2009 Antidegradation Analysis (SRCSD, 2009a) using SRCSD modeling tools, these same tools and assessment methodology were used to estimate changes in near- and far-field receiving water quality with implementation of each of the five advanced treatment trains in combination with the existing SRWTP secondary treatment processes. A thorough description of the modeling tools used to evaluate potential water quality impacts of the SRWTP discharge on downstream receiving waters is included in the SRCSD Draft 2009 Antidegradation Analysis (SRCSD, 2009a).

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[2] K. D. Landau, Assistant Executive Officer, California Regional Water Quality Control Board Central Valley Region (letter to Mary K. Snyder, District Engineer, April 2, 2009) Acceptance of Sacramento Regional County Sanitation District's Dynamic Mathematical Model for use in NPDES Permit Renewal for the Sacramento Regional Wastewater Treatment Plant.

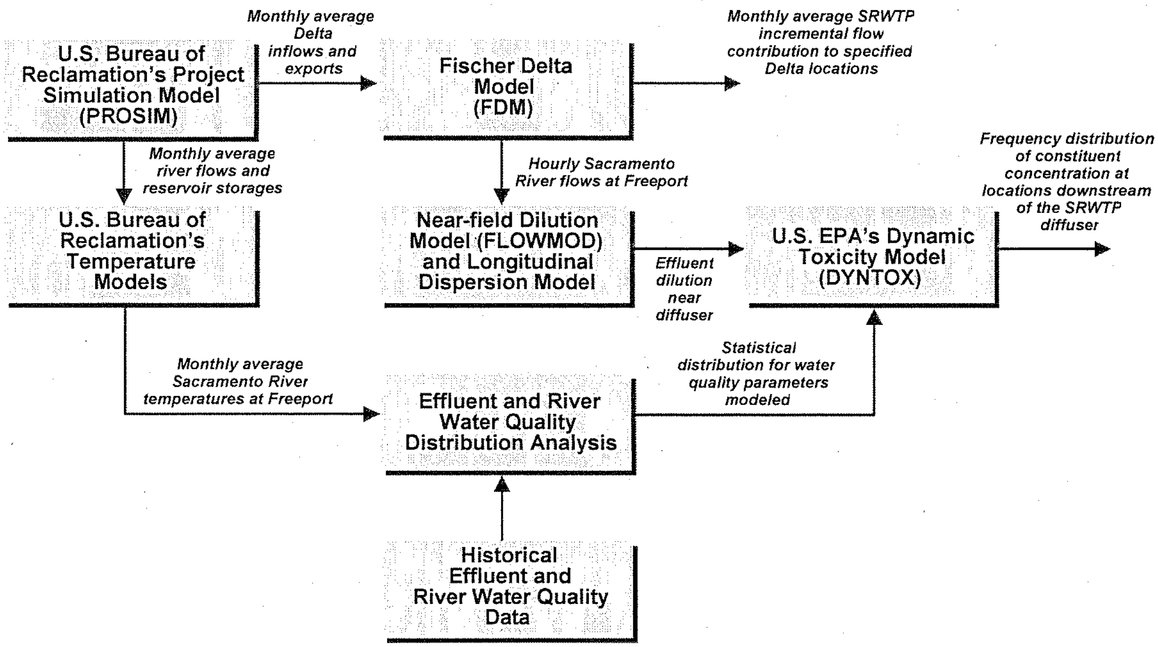

Figure A-1: Linkages between the Hydrologic and Water Quality Models used to Evaluate Water Quality Conditions in the Sacramento River and Delta under various Advanced Treatment Scenarios.

NEAR-FIELD MODELING

In support of the near-field modeling analysis, the FDM was used to simulate hourly flow rates for the Sacramento River at Freeport from the PROSIM 70-year record (1922 – 1991) of mean monthly flow output. Simulated monthly average Sacramento River flow rates from PROSIM were converted to hourly values using the DELFLO module of the FDM. DELFLO is the hydrodynamic component of the FDM that calculates flow distributions in a channel network. It utilizes the fixed grid method of characteristics to simulate the hydrodynamics of the Delta. Although DELFLO is run on a 90-second time step, Sacramento River flow rates at Freeport were "recorded" on an hourly basis. The simulated hourly flow data were used as input to the near-field water quality assessment using the 3-D dilution model and longitudinal dispersion model.

The computational fluid dynamics model, FLOWMOD (also referred to as the "3-D dilution model)", developed by Flow Science Incorporated (FSI) was used to simulate effluent concentrations in the Sacramento River within close proximity of the SRWTP diffuser. FLOWMOD was used to calculate the concentration of effluent in each grid cell of the model domain for specific combinations of river and effluent flows. Effluent concentrations were simulated for distances downstream of the diffuser of 30 ft, 60 ft, 100 ft, 175 ft, 350 ft, and 700 ft, the latter distance corresponding to the downstream boundary of the model. Results from the model defined the average effluent concentration in the area of impact downstream of the diffuser. Because the current analysis is concerned with overall constituent reduction with implementation of a particular advanced treatment train, and not with changes in in-plume constituent concentration between 30 ft and 700 ft, the current near-field analyses for ammonia and dissolved copper focus only on median modeled in-plume constituent concentrations 700 ft downstream of the SRWTP diffuser.

FAR-FIELD MODELING

In support of the far-field analysis, the FDM was used to simulate hourly SRWTP effluent contributions at 12 key locations throughout the Delta. These locations, shown in **Figure 2-2**, included the following: Greene's Landing/Hood, Emmaton, San Joaquin River at Stockton, CCWD Pumping Plant #1 Intake (a.k.a. CCWD Intake at Rock Slough), CCWD Los Vaqueros Intake, Clifton Court Forebay – Banks Delta Pumping Plant, Delta Mendota Canal Headworks, South Fork Mokelumne River, City of Stockton Delta Water Supply Project intake, CCWD Alternative Intake on Victoria Canal, Grant Line Canal, and Chipps Island. Of these 12 Delta sites, five were selected as water quality impacts assessment locations and seven were chosen as SRWTP percent effluent assessment locations based on availability of ambient water quality data. Only locations possessing sufficient ambient water quality data are amenable to concentration-based impacts assessments resulting from implementation of a particular treatment train in combination with the existing SRWTP secondary treatment process. The five far-field locations possessing sufficient ambient water quality data, covering the period[3] January 1998 through July 2008, to support a water quality impacts assessment due to the implementation of advanced treatment train alternatives at SRWTP include Green's Landing/Hood, Emmaton, CCWD Pumping Plant #1 Intake (a.k.a. CCWD Intake at Rock Slough), CCWD Los Vaqueros Intake, and Clifton Court Forebay – Banks Delta Pumping Plant.

Dynamic modeling techniques were used to estimate receiving water constituent concentrations downstream of the SRWTP discharge due to the proposed permitted condition (218 mgd ADWF) at the five water quality impacts assessment locations. Downstream receiving water constituent concentrations were modeled for a 218 mgd discharge condition under existing SRWTP secondary treatment processes, and in combination with each of the five advanced treatment trains listed in **Table 1-3**. The Sacramento River at Freeport location was used to determine upstream ambient water quality conditions used as one of the inputs to the dynamic model. Hourly SRWTP flow rates and historical astronomical tides (rather than a 19-year mean tide, as was used in the DEIR analysis (SCDERA, 2003)) were used as input to the FDM.

Far-Field Percent Effluent and Selection of Water Quality Impact Assessment Locations

Using the modeling package discussed in the above sections, the hourly percent contribution[4] of SRWTP effluent in the water column at select far-field locations can be modeled. Twelve far-field locations downstream of the SRWTP discharge were selected for modeling of hourly percent SRWTP effluent contribution as a means to identify the extent and magnitude of SRWTP

[3] It should be noted that the period January 1998 through July 2008 is the maximum period for data analyzed in this analysis. If data for a particular constituent at a particular location were only available from March 2001 through August 2006, then these data would comprise the data set evaluated in the analysis.

[4] Percent contribution of SRWTP effluent at a given location is defined as the percent of a volume of water taken from the water column at a particular location that is comprised of SRWTP effluent. For example, if the percent contribution of SRWTP effluent at location X is 3%, then 3% of a volume of water at that site is comprised of SRWTP effluent.

effluent reaching various far-field Delta locations. These sites were selected due to either their proximity to a drinking water intake, agricultural water supply intake, Delta water quality compliance point, or a location of general water quality interest in the Delta. These 12 far-field Delta modeling locations are shown in **Figure 2-2**, and include those sites labeled as "SRWTP percent effluent assessment locations", "water quality impacts assessment locations modeled for implementation of advanced treatment alternatives", and "water quality impacts assessment locations" (with the exception of the Sacramento River at Freeport location which was used to determine upstream ambient water quality conditions used as one of the inputs to the dynamic model).

The SRWTP percent effluent contribution simulations act as a first step used to calculate an incremental change in concentration of a constituent at a far-field location; however, the measured ambient concentration of a constituent in the far-field is not directly reflected by the SRWTP percent effluent contribution simulation. This is because the ambient concentration of a constituent measured at a far-field location is the sum of all individual source contributions of said constituent at that location, not solely the contribution of the constituent in SRWTP effluent. To fully evaluate the potential impact of the proposed permitted condition (218 mgd ADWF) on far-field locations throughout the Delta, with or without the implementation of advanced treatment at SRWTP, ambient data must be available for the constituents of interest at the far-field locations. Those sites labeled as "SRWTP percent effluent assessment locations" in **Figure 2-2** represent Delta locations for which adequate ambient water quality data covering the period January 1998 through July 2008 are not available, and therefore were not ultimately modeled in terms of potential constituent reductions due to the implementation of advanced treatment at SRWTP.

Distributions of the modeled percent effluent at far-field sites corresponding to the proposed permitted condition (218 mgd ADWF) are listed for select probabilities of recurrence in **Table A–1**. Of the five locations (see bolded location names in **Table A–1**) possessing sufficient ambient water quality data covering the period January 1998 through July 2008 that were modeled in terms of concentration-based water quality impacts under the proposed permitted (218 mgd ADWF) discharge condition, with and without the addition of a particular advanced treatment train added to existing SRWTP secondary treatment processes, only Greene's Landing/Hood and Banks Delta Pumping Plant are considered in this analysis. This is because consideration of these two locations illustrates the range of potential, ambient constituent reductions estimated for each of the five advanced treatment trains presented in **Table 1-3** when implemented with existing SRWTP secondary treatment processes. Because SRWTP percent effluent contributions projected from Emmaton, CCWD PP#1 at Rock Slough, and the Los Vaqueros Intake are between those estimated form Greene's Landing/Hood and Banks Delta Pumping Plant, it is expected that the three former locations would experience incremental constituent reductions intermediate to those that may occur at Greene's Landing/Hood and Banks Delta Pumping Plant with implementation of advanced treatment trains. To this end, only incremental constituent reductions at Greene's Landing/Hood and Banks Delta Pumping Plant are considered in this analysis because they represent the largest (Greene's Landing/Hood) and smallest (Banks Delta Pumping Plant) potential, incremental constituent reductions that may occur with implementation of advanced treatment of existing SRWTP secondary treated effluent among the five far-field locations for which sufficient ambient water quality data exist to calculate potential changes in ambient water quality.

The incremental change in constituent concentration at a given location attributable to an increase in SRWTP discharge rate is proportional to the increment of SRWTP percent effluent contribution at that location due to the increase in SRWTP discharge rate. Even though modeled, concentration-based results due to the discharge of 218 mgd ADWF under existing SRWTP secondary treatment processes alone or in combination with various advanced treatment trains were not generated for the South Fork of the Mokelumne River, for example, it is reasoned that the median 0.83% SRWTP effluent contribution (see **Table A–1**) estimated for this site as a result of the proposed permitted discharge (218 mgd ADWF) would have a lesser impact on ambient water quality at this location than the median 2.18% SRWTP effluent contribution estimated for the Sacramento River at Greene's Landing/Hood would have at that location under a 218 mgd ADWF SRWTP discharge rate. While the percent effluent assessment locations are not used to directly estimate changes in far-field ambient water quality due to the implementation of advanced treatment at SRWTP, the sites still provide useful information in terms of the potential for water quality impacts based on the amount of SRWTP effluent estimated to reach a particular far-field location.

Table A–1: Daily Average Percent SRWTP Effluent at Far-Field Locations for 218 mgd SRWTP Discharge Rate.

	Distribution of SRWTP Effluent Contribution			
Location	**Mean**	**5%**	**50%**	**95%**
Greene's Landing/Hood▲	**2.24**	**0.63**	**2.18**	**4.12**
Emmaton	**1.95**	**0.47**	**1.98**	**3.35**
San Joaquin River at Stockton	0.14	0.00	0.01	0.76
CCWD PP#1 at Rock Slough	**1.69**	**0.18**	**1.76**	**3.10**
Los Vaqueros Intake	**1.56**	**0.06**	**1.63**	**3.03**
Clifton Court Forebay – Banks Delta Pumping Plant▲	**1.50**	**0.04**	**1.55**	**3.11**
Delta Mendota Canal Headworks	0.93	0.01	0.96	2.05
South Fork Mokelumne River	1.25	0.00	0.83	3.66
City of Stockton Delta Water Supply Project Intake	1.58	0.02	1.68	3.23
CCWD Alternative Intake	1.27	0.00	1.37	2.67
Grant Line Canal	0.01	0.00	0.00	0.03
Chipps Island	1.31	0.44	1.33	2.10

▲ Only water quality changes at Greene's Landing/Hood and Banks Delta Pumping Plant due to the implementation of advanced treatment train alternatives are considered in this analysis because consideration of these two locations illustrates the range of potential, ambient constituent reductions estimated for each advanced treatment train.

Changes in the ambient water quality concentrations of the constituents of interest at Greene's Landing/Hood and Banks Delta Pumping Plant were estimated on a constituent-by-constituent basis by first subtracting the modeled concentration increment at a SRWTP discharge rate of 154 mgd[5] ADWF from the modeled concentration increment at a SRWTP discharge rate of

[5] A SRWTP effluent discharge rate of 154 mgd ADWF was used to approximate the current SRWTP discharge rate.

181 mgd. The resultant concentration increment (181 mgd modeled increment minus 154 mgd modeled increment) was then added to the median ambient concentration calculated for the constituent at a particular far-field location using ambient water quality data from that location measured during the period January 1998 through July 2008. The resultant ambient concentration is a modeled estimate of the median concentration of a constituent at a particular far-field location under the current permitted SRWTP discharge rate of 181 mgd ADWF, assuming no change in all non-SRWTP inputs of the constituent into the system. Estimated, far-field ambient water quality concentrations at the proposed permitted condition (218 mgd ADWF) under existing SRWTP secondary treatment processes were calculated by adding the difference between the 218 mgd secondary effluent modeled increment and the 181 mgd secondary effluent modeled increment to the median ambient concentration calculated for the 181 mgd ADWF discharge condition. Similarly, estimated, far-field ambient water quality concentrations at the proposed permitted condition (218 mgd ADWF) under existing SRWTP secondary treatment processes in combination with advanced treatment train alternatives were calculated by adding the difference between the 218 mgd secondary effluent plus advanced treatment modeled increment and the 181 mgd secondary effluent modeled increment to the median ambient concentration calculated for the 181 mgd ADWF discharge condition.