NATIONAL WATER RESEARCH INSTITUTE

Final Report

of the May 11-12, 2009, Meeting of the

Independent Advisory Panel

for the

City of San Diego Indirect Potable Reuse/Reservoir Augmentation (IPR/RA) Demonstration Project

September 17, 2009
Fountain Valley, California

Disclaimer

This report was prepared by an NWRI Independent Advisory Panel, which is administered by the National Water Research Institute (NWRI). Any opinions, findings, conclusions, or recommendations expressed in this report were prepared by the Panel. This report was published for informational purposes.

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INTRODUCTION

In 2009, the City of San Diego (City) requested that the National Water Research Institute (NWRI) of Fountain Valley, California, form an Independent Advisory Panel (Panel) to provide expert peer review of the technical, scientific, regulatory, and policy aspects of the proposed Indirect Potable Reuse/Reservoir Augmentation (IPR/RA) Demonstration Project (referred to hereinafter as "Demonstration Project") under development by the City of San Diego, California. The purpose of the Demonstration Project is to evaluate the feasibility of using advanced treatment technology to produce recycled water that can be sent to a local reservoir, blended with other raw water, and later, after treatment, distributed as potable water.

For the sake of clarity, the term "**advanced treated recycled water**" will be used throughout the report. Other terms synonymous with advanced treated recycled water include: recycled water, reclaimed water, and repurified water. It should be noted that the term "recycled water" is used in Title 22 of the California Code of Regulations.

Specifically, the Demonstration Project involves:

- Designing, constructing, and operating a 1-million gallon per day (MGD) advanced water treatment plant at the North City Water Reclamation Plant.
- Conducting a study to establish residence time, water quality parameters, and conditions of advanced water treatment in San Vicente Reservoir.
- Defining the State of California State regulatory requirements for a full-scale project.
- Performing a pipeline alignment study.
- Conducting a public education and outreach program, including tours as part of public outreach.

Further, as part of the Demonstration Project, it will be important to:

- Determine the effectiveness of select advanced treatment processes in removing contaminants of concern.
- Determine water quality requirements for augmenting San Vicente Reservoir.
- Establish the assimilative capacity of San Vicente Reservoir.
- Develop a monitoring program to evaluate flow and overall performance of the treatment processes being evaluated.
- Gather and analyze operating data to refine capital operation and maintenance estimates for a full-scale system.
- Review existing water quality at the intake to the drinking water treatment plant as a frame of reference.
- Propose a water quality treatment and monitoring scheme to the California Department of Public Health (CDPH).
- Secure regulatory approval from CDPH.

If the Demonstration Project meets regulatory requirements and provides evidence of the viability of the indirect potable reuse/reservoir augmentation process, the City would then explore the feasibility of constructing a full-scale AWT plant and pipeline to send advanced treated recycled water to San Vicente Reservoir.

CHARGE TO PANEL

The charge to the Panel was to consider the following:

- Assist the City and CDPH to establish a pathway to move from the draft groundwater regulations to surface water augmentation criteria. This effort includes recommending criteria (or suggested regulations) and verifying the various optional advanced water treatment (AWT) and reservoir strategies that, in combination as multiple barriers, would ensure safe drinking water at consumer taps.
- Assist the City in developing the Demonstration Project work plan. This effort includes verifying the reservoir limnology and detention study and AWT demonstration plan.

PANEL MEMBERSHIP

The Panel is comprised of 10 members:

- *Panel Chair:* George Tchobanoglous, Ph.D., P.E., NAE, University of California, Davis (Davis, CA)
- Michael A. Anderson, Ph.D., University of California, Riverside (Riverside, CA)
- Richard J. Bull, Ph.D., MoBull Consulting (Richland, WA)
- Joseph A. Cotruvo, Ph.D., Joseph Cotruvo Associates (Washington, D.C.)
- James Crook, Ph.D., P.E., Water Reuse Consultant (Boston, MA)
- Richard Gersberg, Ph.D., San Diego State University (San Diego, CA)
- Sunny Jiang, Ph.D., University of California, Irvine (Irvine, CA)
- Audrey D. Levine, Ph.D., P.E., DEE, U.S. Environmental Protection Agency (Washington, D.C.)
- David R. Schubert, Ph.D., The Salk Institute for Biological Studies (La Jolla, CA)
- Michael P. Wehner, Orange County Water District (Fountain Valley, CA)

The Panel members were selected to represent a broad range of disciplines and experience. Brief biographies of the Panel members may be found in Appendix A

MEETING SCHEDULE

The first Panel meeting was held on May 11-12, 2009, at the North City Water Reclamation Plant in San Diego, California. The second Panel meeting has not been scheduled at this time.

MEETING AGENDA AND SUMMARY

The agenda for the first Panel meeting is provided in Appendix B. A complete list of Panel meeting attendees is included in Appendix C. The focus of the first meeting was on presentations by City staff detailing past studies and framing the discussion for the Demonstration Project. The following topics were discussed:

- Panel charge.
- Project background.
- Regulatory parameters.
- Proposed San Vicente Reservoir Study concept.
- Preliminary demonstration AWT concept.

Adequate time was allowed at the meeting for the Panel to interact and prepare the first draft outline for this report.

REPORT ORGANIZATION

This report of the Panel has been organized into the following sections:

1. Introduction
2. Goals and Guiding Principles
3. Project Background
4. Water Quality Considerations
5. Regulatory Issues
6. AWT Demonstration Plant
7. Reservoir Characteristics and Modeling
8. California Department of Public Health Requirements for Reservoir Augmentation
9. Public Outreach

The organization of the report is designed to meet the terms of engagement for the Panel. The goals and guiding principles (Section 2) define the basis for evaluating the effectiveness of the Demonstration Project. The project background is reviewed in Section 3. Water quality considerations are examined in Section 4. Regulatory issues are reviewed in Section 5. The features of the AWT Demonstration Plant are examined in Section 6. Reservoir characteristics and modeling are assessed in Section 7. CDPH requirements for reservoir augmentation are discussed in Section 8. Strategies for developing a public outreach program are recommended in Section 9.

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GOALS AND GUIDING PRINCIPLES

The purpose of the Demonstration Project is to evaluate the feasibility of using one or more treatment technologies to produce advanced treated recycled water from tertiary wastewater effluent that can sent to a local reservoir, blended with other water sources, and later, following water treatment, distributed as potable water.

In developing the project plan, it is of critical importance to define the overall goals of the project and the guiding principles that will be used to evaluate the results of specific studies designed to meet the goals.

GOALS FOR THE PROJECT

The Panel recommends the following project goals:

1. Protect public health and the environment.
2. Demonstrate the performance of several appropriate advanced treatment technologies with respect to water quality.
3. Demonstrate the safety and reliability of the advanced treatment technologies.
4. Demonstrate the safety and reliability of introducing advanced treated recycled water into a drinking water reservoir.
5. Demonstrate that wastewater can be managed in a sustainable manner.

GUIDING PRINCIPLES FOR THE DEMONSTRATION PROJECT

Complementary to the project goals, a series of guiding principles are needed to ensure that specific project findings are consistent with the project goals. While these principles are specifically directed at the project plan, they are based on knowledge that the Panel has accumulated from experience associated with planning and implementing wastewater collection, treatment, and reuse systems in California and elsewhere, and they may well evolve based upon the availability of new information as it develops. Further, the guiding principles must reflect the vision that the public and the City have for the Demonstration Project.

The guiding principles are as follows:

1. **Meet Current Regulatory Requirements**
   The advanced treated recycled water produced from the proposed AWT Demonstration Plant must meet applicable drinking water Maximum Contaminant Levels (MCLs) for regulated chemicals and pathogens, California Title 22 Water Recycling Criteria, CDPH Draft Groundwater Recharge Reuse Regulations, and California Notification Levels.

2. **Provide Flexibility to Meet Future Requirements**
   The AWT Demonstration Plant must provide flexibility to evaluate several technologies to accommodate future treatment requirements.

3. **Assess Process Variability**
   Sufficient performance tests must be conducted to evaluate the variability of alternative AWT treatment processes to provide adequate data for risk assessment, as well as compare the costs of alternative approaches.

4. **Promote Water Sustainability**
   The project should promote environmental stewardship that includes the use of advanced treated recycled water in the context of sustainable water resources management.

5. **Provide for Training and Education Opportunities**
   To the extent possible, the AWT Demonstration Plant should be designed to allow for training and educational opportunities for the staff.

6. **Develop Guidelines for Reservoir Augmentation.**
   Guidelines must be developed for reservoir augmentation that the City can present to CDPH for their review and adoption.

7. **Maximize Benefit to Citizens**
   Every effort and means should be made to apply the guiding principles in a manner that provides the highest value to the citizens of the City of San Diego.

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PROJECT BACKGROUND

Water is essential for San Diego's growing economy, quality of life, and future. The vast majority of the City's water (about 85 percent) is imported from outside sources, making the reliability of its water supply vulnerable to impacts from shortages and susceptible to price increases. In 2007, a Federal judge ruled that State and Federal projects pumping water from the Bay Delta to Southern California users, including San Diego, will be cut to protect an endangered fish, the delta smelt. Additionally, the Colorado River – the San Diego region's other major supply – has been suffering from prolonged drought. It is apparent that the future availability of imported water supplies may be subject to serious constraints and could be reduced during both water shortages and drought.

FUTURE REQUIREMENTS

Even with aggressive conservation efforts, it is estimated that the City will need between 10 to 18 percent more water by 2030.[1] For years, the City has attempted to diversify and enhance its existing water supply.[2] In 1997, the City prepared the *Strategic Plan for Water Supply* and, in 2002, updated it with a more detailed *Long-Range Water Resources Plan*. In both documents, the need for the City to develop additional local water supply sources as a means of providing reliability and protection from water supply shortages was identified.

2004 WATER REUSE STUDY

In 2004, the San Diego City Council directed the City Manager to conduct a study to evaluate options for increasing the beneficial use of the City's recycled water. In the *Water Reuse Study* conducted in 2005, it was found that the strategy of using IPR, also known as reservoir augmentation using advanced treated recycled water, both "maximizes the use of the available recycled water supply" and provides the "lowest overall unit cost" of the reuse strategies that were evaluated.

The IPR/reservoir augmentation strategy presents the City with a unique opportunity to maximize the utilization of currently available (and unused) capacity of the City's recycled water. In doing so, IPR/reservoir augmentation will provide for the future a reliable and locally produced water supply not subject to restrictions that may be imposed on imported water during times of drought and supply cutbacks.

INDIRECT POTABLE REUSE/RESERVOIR AUGMENTATION (IPR/RA) DEMONSTRATION PROJECT

In keeping with this strategy for the future, the San Diego City Council in December 2007 approved moving forward with an Indirect Potable Reuse/Reservoir Augmentation (IPR/RA)

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[1] San Diego County Grand Jury: Water Conservation Report, 2008.
[2] The 2005 City of San Diego Urban Water Management Plan.

Demonstration Project, which will put the City on a path to (1) achieve a more reliable and local source of water, and (2) minimize wastewater discharges into the ocean. In this manner, the Demonstration Project is a win-win situation for both a reliable local water supply and the environment, and is consistent with the benefits identified by local both environmental groups and the U.S. Environmental Protection Agency (EPA).

The Demonstration Project is intended to produce advanced treated recycled water by treating the City's tertiary effluent from the North City Water Reclamation Plant (NCWRP) using technologies that may include membranes and advanced oxidation. The advanced treated recycled water will be blended with the tertiary treated water currently produced at the North City Water Reclamation Plant and put into the existing recycled water distribution system.

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WATER QUALITY CONSIDERATIONS

The sources of water, their corresponding water quality, the impact of trace constituents, and the benefits of source identification and control within the local sewershed (wastewater collection area) are discussed in this section.

SOURCES OF RAW WATER FOR POTABLE USE

Currently, the City of San Diego relies on two sources of water for 85 percent of its potable water supply: the Colorado River and State Water Project. The Colorado River collects water from an extensive watershed in over six western states, while the State Water Project delivers water from the Sacramento-San Joaquin River Delta. Water from these sources is distributed to the San Diego region through the Metropolitan Water District of Southern California (MWD). Once delivered to San Diego, the water is either redistributed directly by the San Diego County Water Authority (the region's wholesaler) to local water districts, where it is treated for immediate use, or stored in local reservoirs prior to treatment and distribution.

These two large watersheds not only supply the City's potable water, but also supply water to other cities, municipalities, and rural areas, and water to support irrigation and industry. The majority of the wastewater from "upstream" communities, stormwater runoff, and agricultural return flows and drainage is returned to these sources of water supply. Each wastewater treatment facility is permitted through the National Pollutant Discharge Elimination System (NPDES).

On the Colorado River and its tributaries, there are more than 250 wastewater discharge permits in use and over 400 approved. A map of the NPDES permits that discharge into these water sources is shown in Figure 4-1. Each permit specifies water quality and flow limits. All of the tertiary treated wastewater from Las Vegas is discharged into Lake Mead and the Colorado River. At the point where MWD withdraws its water from the Colorado River, a portion of this water has been through at least one or more wastewater facilities. Similarly, as shown in Figure 4-1, wastewater discharges into the Sacramento and San Joaquin rivers and their tributaries are also significant. San Vicente Reservoir also supports recreational activities that can introduce additional contaminants into the water.

<u>Variations in Water Quality</u>

All of the City's current water supply sources vary in quality due to seasonal variations in flow, water withdrawals, wastewater discharges, and other inputs. An important issue to evaluate is how the quality of advanced treated recycled water that will be derived from the Demonstration Project compares to existing sources and whether it has the potential to impact reservoir water quality.

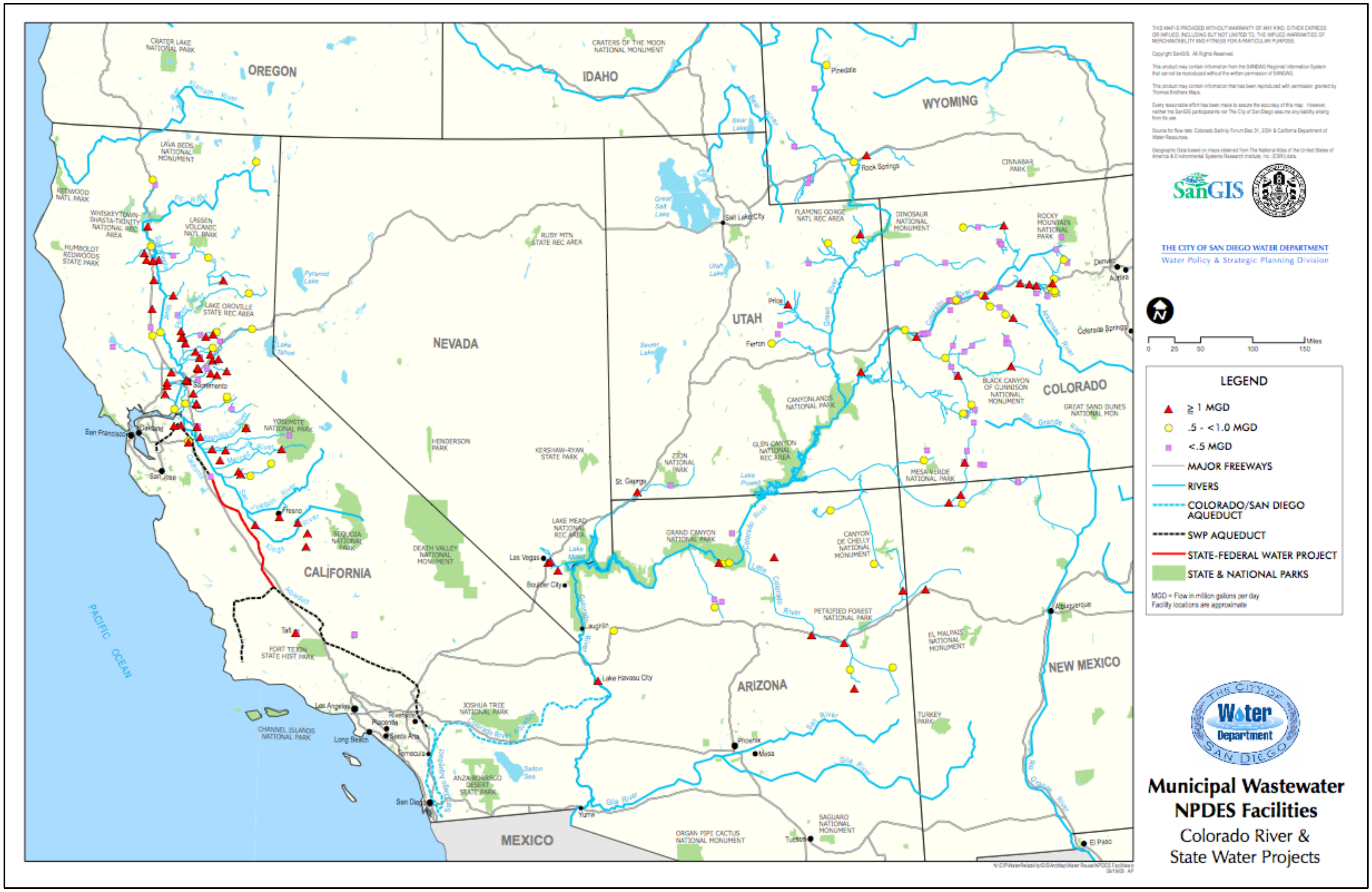

Figure 4-1. Municipal wastewater NPDES permits that discharge treated wastewater into sources of San Diego's water supply.

What are the differences in the quality of water, defined in terms of chemical components, from the Colorado River, State Water Project, MWD water delivered to San Diego, water in San Vicente Reservoir, and that which will be produced by the Demonstration Project? Key water quality parameters include minerals, salts, dissolved organic constituents, metals, pathogens, and other contaminants of concern to potential health or environmental risks. A summary of water quality data[3] from each of these sources and the tertiary effluent from the North City Water Reclamation Plant (NCWRP) is provided in Appendix D. The City's water reflects the characteristics of the Colorado River, State Water Project, and local sources, depending on the relative contribution from each source. For instance, total organic carbon (TOC) and bromide levels differ in the imported water, San Diego source water, and NCWRP tertiary effluent before reverse osmosis (RO) treatment (see Figure 4-2). However, based on recent experience at Orange County's Groundwater Replenishment System, it is anticipated that both TOC and bromide will be significantly lower following RO treatment.

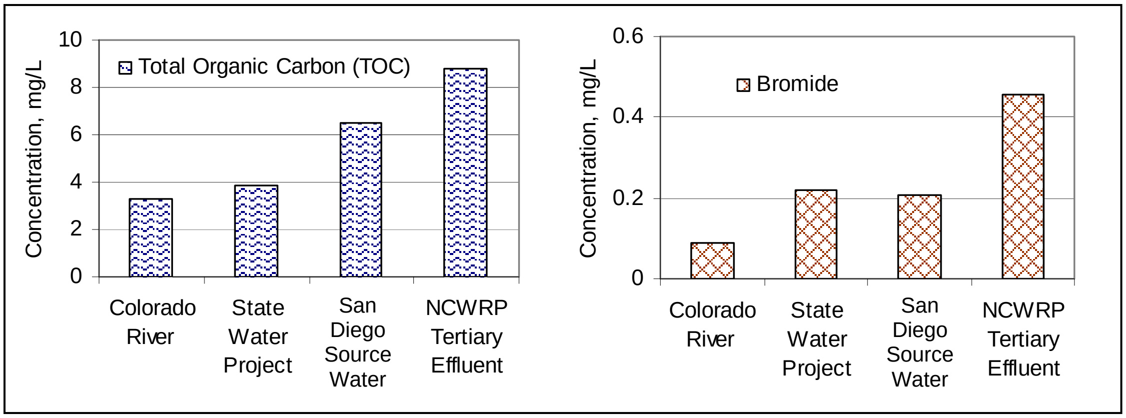

Figure 4-2. Comparison of annual averages of TOC and bromide in the City's three water sources and NCWRP tertiary effluent. Note that the TOC following RO treatment of NCWRP tertiary effluent will typically be less than 0.5 mg/L.

Presence of Trace Constituents

Under a project sponsored by NWRI, MWD has also been measuring 49 endocrine active compounds, pharmaceuticals, and personal care product ingredients at multiple locations along the Colorado River Aqueduct, State Water Project, and Lake Skinner. The blend at Lake Skinner makes up 95 percent of the water that the San Diego Water Authority receives. MWD will have a report finalized in October 2009 that includes the monitoring results.

Based on the data collected by the City, with the exception of trace amounts of trihalomethanes, pharmaceuticals and other monitored organic compounds were not found in advanced treated recycled water from the NCWRP test project [which included RO, ultraviolet (UV) light disinfection, and advanced oxidation] (see Appendix D).

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[3] MWH (2007). *Final Report of City of San Diego Advanced Water Treatment Research Studies (August 2007)*. Prepared for the City of San Diego and Aqua 2030 Research Center.

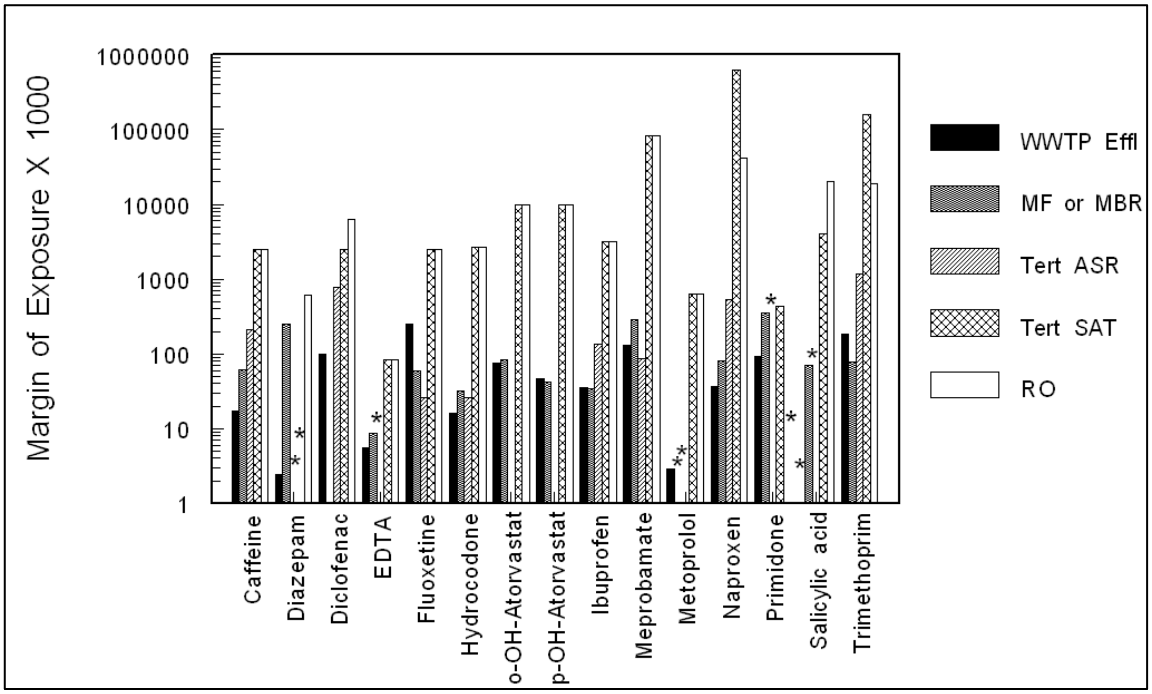
ASSESSMENT OF THE IMPACT OF TRACE CONSTITUENTS

Although pharmaceuticals and ingredients in personal care products have been found in drinking water at low levels (and essentially none after treatment by RO), concerns have been expressed relative to the occurrence of these constituents in municipal wastewater. A study being conducted for the WateReuse Foundation (WRF-06-004) is examining an industry-wide database on the occurrence of a wide variety of water contaminants in wastewaters subjected to various levels of treatment. In the waters studied, 31 pharmaceuticals and seven hormones were assayed using current sensitive analytical methods. The margins of exposure (MOE) for the 14 pharmaceuticals that occurred in one or more of the waters above limits of quantitation (LOQ), typically in the nanogram per liter (ng/L) range, are shown in Figure 4-3.

The MOE was calculated at the highest concentration reported in the database for each water type. The MOE is the ratio of the lowest therapeutic dose to the dose that would be obtained from drinking the indicated water, using standard assumptions related to water consumption [adult = 2 liters per day (L/day), 10-kilogram (kg) child = 1 L/day]. MOE values are frequently used in risk assessment to compare the lowest dose that results in adverse health effects (LOAEL) to the level to which the general population or a selected sensitive group is exposed. Therefore, the larger the MOE, the less the exposure compared to the lowest therapeutic dose that is used as a benchmark. A MOE value of 1,000 or above from the therapeutic dose as a LOAEL would have an extremely low human health risk, if any. Genotoxic carcinogens would be evaluated by a quantitative risk based approach rather than with MOEs.

As shown in Figure 4-3, even in secondary or tertiary treated wastewaters, drugs do not occur at concentrations that would be of concern. These margins are increased exponentially by treatments that are typically employed in treating water intended for potable reuse. It should be noted that when a chemical was measured in wastewaters prior to treatment and not detected after treatment, the detection limit was utilized rather than zero. Therefore, the very high MOEs reported after RO treatment or tertiary treatment (followed by soil aquifer treatment) are artificially suppressed by this calculation. Note that MOEs for all drugs listed are in the range from 100,000 to 625,000,000. The relatively low MOE value for ethylenediamine tetraacetic acid (EDTA) reflects two facts: (1) its major uses are not as a drug; and (2) the dose used for calculating the MOE was an injected dose rather than an oral dose. EDTA is used widely as a food additive and in detergents and other consumer projects. Therefore, EDTA is not a chemical of concern in processed recycled water.

The effectiveness of the treatment barriers that will be employed in the Demonstration Project are illustrated by these data. It is important to realize that based on the removal of these drugs, other chemicals that have similar properties (e.g., molecular weight, charge, and shape) will also be removed by these barriers. Therefore, these treatments will reduce the number of “unknown” chemicals in the product water to a similar extent as the group shown in Figure 4-3. Concern can now focus on the much smaller group of compounds that have low molecular weight and have high toxicological potency [e.g., N-nitrosodimethylamine (NDMA)] that are not well removed by membranes. In the case of NDMA, many IPR systems follow RO by treatment with UV light to ensure that the concentrations of this chemical are controlled to a very low level in the product water that is ultimately used as a potable water source.



*Data for the indicated treatment level is not in the industry database.

Figure 4-3. Margins of exposure (MOEs) for drugs in wastewater receiving varying degrees of treatment. WWTP Effl = Wastewater treatment plant effluent (secondary); MF or MBR = Following multifiltration or membrane bioreactor treatment; Tert ASR= Tertiary treated wastewater injected into aquifer for storage and recovery (average residence time of 14 days); Tert. SAT = Tertiary wastewater receiving soil aquifer treatment (i.e., penetrating through a vadose zone); RO = Tertiary wastewater receiving RO treatment. EDTA = Ethylenediamine tetraacetic acid; p-OH-atorvastat = p-hydroxy-atorvastatin; o-OH-atorvastat = o-hydroxy-atorvastatin.

CONSTITUENT SOURCE IDENTIFICATION WITHIN WASTEWATER COLLECTION SEWERSHED

One of the concerns related specifically to the Demonstration Project is the fact that the sewershed for the wastewater collection system includes a high density of biotech companies and hospitals. Therefore, the potential exists for wastewater to include different types of constituents than might be present from other sources. Typically, monitoring programs for advanced treated recycled water do not have the capacity to monitor every possible contaminant; thus, uncertainties exist about what chemicals might be discharged and whether the chemicals are removed through treatment and have the potential to directly enter the City's drinking water.

The Panel believes that this scenario is unlikely and poses little risk for the following reasons:

1. The City has an active industrial wastewater control program that will need to be expanded for the NCWRP sewershed before full-scale IPR is implemented. The

Orange County Sanitation District in Fountain Valley, California, as well as other agency programs, can be used for guidance. The City is also actively engaged and speaking with relevant dischargers, as well as actively monitoring constituents of concern in the wastewater discharged to the collection system.

2. Most of the companies in the collection area are research and development facilities, a university, and research institutes. While these types of laboratories use and make a large number of different chemicals, these are not produced or released in large quantities; therefore, it is unlikely that any single compound is used in sufficient quantity to reach a significant concentration in San Vicente Reservoir, even without treatment.

3. If any drug did enter the treatment plant, it would most likely be removed by the entire multiple barrier process that also could include RO (see Appendix D).

Given these conditions and safeguards, it is very unlikely that the source of the wastewater will pose a health risk to San Diego residents.

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REGULATORY ISSUES

To implement an IPR program, a number of California Department of Public Health (CDPH) and Regional Water Quality Control Board requirement and regulations must be met. The key requirements and regulations are discussed below.

CALIFORNIA DEPARTMENT OF PUBLIC HEALTH

Key requirements for advanced treated recycled water to be used to augment San Vicente Reservoir are: (1) it be safe and appropriate as a source of blending water to be used with the current water sources; and (2) it not degrade San Vicente Reservoir with respect to potential algae blooms from nutrients [nitrogen (N) and phosphorus (P) loadings] and its approved fishing and other recreational uses.

1996 Proposed Framework for Regulating IPR by Surface Water Augmentation

In 1996, CDPH and the California Department of Water Resources jointly published a document entitled, *A Proposed Framework for Regulating the Indirect Potable Reuse of Advanced Treated Reclaimed Water by Surface Water Augmentation in California*.[4] The committee that wrote the framework concluded that planned IPR of advanced treated recycled water by augmentation of surface water supplies would not adversely affect drinking water quality if the following conditions were met:

- Approved AWT processes have been applied.
- All relevant water quality standards are achieved.
- Advanced treated recycled water is retained in a storage reservoir for sufficient time before treatment in a water treatment plant.
- Downstream drinking water treatment plant operations will not be negatively impacted.
- There are multiple barriers for the removal of pathogens and toxic chemicals. The report states that source control of discharges into the wastewater collection system, conventional wastewater treatment, membrane treatment, disinfection, reservoir retention, and surface water treatment are effective physical and chemical barriers.

The report includes six criteria considered by the authors of the report to be critical to safe and reliable IPR of advanced treated recycled water by augmentation of surface water supplies. These criteria are as follows:

- Meet operating criteria with best available technology (BAT) (i.e., AWT via RO or equivalent).
- Maintain appropriate residence time based on reservoir dynamics.

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[4] California Potable Reuse Committee (1996). *A Proposed Framework for Regulating the Indirect Potable Reuse of Advanced Treated Reclaimed Water by Surface Water Augmentation in California*. California Department of Health Services and California Department of Water Resources, Sacramento, CA.

- Maintain AWT plant operational reliability to consistently meet primary drinking water standards.
- Comply with applicable CDPH groundwater recharge criteria for injection.
- Maintain reservoir water quality.
- Provide an effective source control program for discharges into the wastewater collection system.

The requirement to meet drinking water standards (specifically, drinking water MCLs) in the advanced treated recycled water, use of BAT, and the requirement to comply with CDPH groundwater recharge criteria are extremely conservative for the type of project being considered. Because the rationale for several recommendations in the 1996 Indirect Potable Reuse Surface Water Augmentation in California document [except for some Title 22 proposals for wastewater (Ct of 450 and 5 logs of MS2 removal)] was not provided, it is difficult to link the assumptions to the current knowledge of water quality produced by various AWT processes. Other than recommending the use of BAT, which can be a moving target and may not be directly health based (and is often the most expensive approach), in general, little or no indication of specific water quality goals, contaminant removal targets, or risk reduction targets is given in the proposed Framework Document. Also, limited multiple barrier credit is given for the multiple functions in the reservoir stage for microbial and chemical mitigation. Thus, the Framework Document is an expert consensus document, but lacking in complete scientific justification. Assuming that any specifications should be health based or environmentally based, other possible principles that would ensure safe drinking water at the tap may be plausible and could be considered in the water quality requirements for reservoir augmentation.

CDPH Draft Groundwater Recharge Reuse Regulations

CDPH has prepared Draft Groundwater Recharge Reuse Regulations (draft recharge regulations) for IPR. The most current published version of the regulations is dated August 5, 2008.[5] As stated in the 1996 framework document summarized above, one of the criteria for using advanced treated recycled water for IPR for surface water augmentation is that the project complies with applicable draft recharge regulations for injection. The critical requirements of the draft recharge regulations that must be complied with include water quality and treatment, TOC, residence time in the reservoir, monitoring, and recycled water contribution (dilution). While studies have been conducted in the past to estimate residence time in the reservoir and expected dilution of the advanced treated recycled water prior to pumping the reservoir water to the water treatment plant, it is likely that CDPH would require more definitive information on these parameters.

For example, the draft recharge regulations require a 6-month retention time of the advanced treated recycled water prior to use as drinking water. The rationale for this requirement is that it serves as one of the multiple barriers against viruses and purportedly provides a 6-log reduction of viruses in subsurface aquifers. An argument could be made that a 6-month retention time is excessive due to the extensive log removals of all microbial pathogens in the

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[5] As of August 11, 2009, PDF of the Draft Groundwater Recharge Reuse Regulations (updated August 5, 2008) can be found at the California Department of Public Health's website at: http://www.cdph.ca.gov/healthinfo/environhealth/water/Pages/Waterrecycling.aspx

recycled water treatment processes that are being proposed for this project and the surface water treatment processes downstream of the reservoir.

CDPH Recycled Water Requirements for Restricted Recreational Impoundments

Because noncontact water recreation (fishing and boating) is allowed in San Vicente Reservoir, the CDPH Water Recycling Criteria for restricted recreational impoundments would apply. Thus, the advanced treated recycled water must be produced from water that has received secondary treatment. The treatment and microbial water quality that is proposed for this project greatly exceed that required in the Water Recycling Criteria for restricted recreational impoundments.

REGIONAL WATER QUALITY CONTROL BOARD

The Federal Clean Water Act and the California Porter-Cologne Water Quality Control Act require that the Regional Water Quality Control Board adopt a water quality control plan to guide and coordinate the management of water quality in the region. The purpose of the plan is to: (1) designate beneficial uses of the region's surface and ground waters; (2) designate water quality objectives for the reasonable protection of those uses; and (3) establish an implementation plan to achieve the objectives.[6]

Designated Beneficial Uses

The designated beneficial uses of San Vicente Reservoir include:

- Municipal and Domestic Supply (MUN).
- Agricultural Supply (AGR).
- Industrial Process Supply (PROC).
- Industrial Service Supply (IND).
- Contact Water Recreation: fishing from shore or boat is permitted, but other water contact recreational (REC-1) uses are prohibited.
- Warm Freshwater Habitat (WARM).
- Cold Freshwater Habitat (COLD).
- Wildlife Habitat (WILD).

The beneficial use designations in the Basin Plan are not prescriptive as to how the water may or may not be used. Rather, beneficial uses set the level and purpose for which water quality should be protected. The regulation of body contact recreation in drinking water source reservoirs is under the purview of CDPH through the Health and Safety Code. While body contact recreation generally is prohibited in drinking water source reservoirs, the Health and Safety Code specifically exempts San Vicente Reservoir and other drinking water source reservoirs in San Diego County if certain conditions are met, as indicated in the following excerpt from the Health and Safety Code[7]:

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[6] California Regional Water Quality Control Board (2007). *Water Quality Control Plan for the San Diego Basin (9) 2007*. California Regional Water Quality Control Board, San Diego Region.

[7] California Health and Safety Code Website: http://www.leginfo.ca.gov/cgi-bin/displaycode?section=hsc&group=115001-116000&file=115825-115850 (accessed 9/11/09).

> 115830. All water supply reservoirs of a public agency, whether heretofore or hereafter constructed, shall be open for recreational use by the people of this state, subject to the regulations of the department.
>
> 115840. (a) In San Diego County, recreational uses shall not, with respect to a reservoir in which water is stored for domestic use, include recreation in which there is bodily contact with the water by any participant, unless both of the following conditions are satisfied:
> (1) The water subsequently receives complete water treatment, including coagulation, flocculation, sedimentation, filtration, and disinfection, before being used for domestic purposes.
> (2) The reservoir is operated in compliance with regulations of the department, as provided in Section 115830.
> (b) The recreational use may be subject to additional conditions and restrictions adopted by the entity operating the water supply reservoir, if the conditions and restrictions do not conflict with regulations of the department and are designed to further protect or enhance the public health and safety.

San Vicente Reservoir conforms to the above conditions, and CDPH has approved Contact Water Recreation (REC-1) – including full-body contact recreation – in the reservoir.

Based upon these beneficial uses, water quality objectives have been defined for the San Vicente Hydrologic Area (Table 5-1).

Table 5-1. Water Quality Objectives Defined for the San Vicente Hydrologic Area (in mg/L, or as noted)[8]

TDS	Cl	SO_4	%Na	N&P	Fe	Mn	MBS	B	Odor	Turb (NTU)	Color (Units)	F
300	50	65	60	a	0.3	0.05	0.5	1.0	none	20	20	1.0

[a] Concentrations of nitrogen and phosphorus, by themselves or in combination with other nutrients, shall be maintained at levels below those which stimulate algae and emergent plant growth. Threshold total Phosphorus (P) concentrations shall not exceed 0.05 mg/L in any stream at the point where it enters any standing body of water, nor 0.025 mg/L in any standing body of water. A desired goal in order to prevent plant nuisances in streams and other flowing waters appears to be 0.1 mg/L total P. These values are not to be exceeded more than 10 percent of the time unless studies of the specific body in question clearly show that water quality objective changes are permissible and changes are approved by the Regional Board. Analogous threshold values have not been set for nitrogen compounds; however, natural ratios of nitrogen to phosphorus are to be determined by surveillance and monitoring and upheld. If data are lacking, a ratio of N: P=10:1 shall be used. Note - Certain exceptions to the above water quality objectives are described in Chapter 4 in the sections titled Discharges to Coastal Lagoons from Pilot Water Reclamation Projects and Discharges to Surface Waters.

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[8] California Regional Water Quality Control Board (2007). *Water Quality Control Plan for the San Diego Basin (9) 2007*. California Regional Water Quality Control Board, San Diego Region.

Water Quality Objectives

The water quality objectives include limits on biostimulatory substances (N and P), although explicit values for N (thought to be the limiting nutrient in San Vicente Reservoir) are not specified. Monitoring can provide the necessary information to identify N and P concentrations that limit excessive aquatic growth, minimize nuisance conditions, and protect beneficial uses. Therefore, the development of site-specific water quality objectives for N and P may be appropriate for this project.

Because full body-contact recreation is allowed, the REC-1 water quality objectives apply. In waters designated for contact recreation (REC-1), the fecal coliform concentration based on a minimum of not less than five samples for any 30-day period, shall not exceed a log mean of 200/100 mL, nor shall more than 10 percent of total samples during any 30-day period exceed 400/100 mL.

National Pollutant Discharge Elimination System (NPDES)

Dischargers to surface waters must also obtain a NPDES permit. The permit application must describe the wastes to be discharged, the setting for the discharge, and the method of treatment or containment. The process includes a 30-day public comment period, with the discharger legally obligated to publish the public notice for 1 day in the largest circulated newspaper in the municipality, followed by a public hearing. Therefore, public outreach in advance of any NPDES permit application will be crucial to the viability of the project.

6

AWT DEMONSTRATION PLANT

The City is planning to build and operate an AWT Demonstration Plant to evaluate the performance and reliability of several potential treatment systems, assess the quality of the advanced treated recycled water, and determine operating and maintenance requirements and costs. The AWT Demonstration Plant will also serve as a focal point for engaging the public through outreach and educational opportunities. The design of the AWT Demonstration Plant with respect to the stated treatment objectives, process selection, monitoring, and microbial considerations are addressed in this section.

AWT DEMONSTRATION PLANT PLANNING ISSUES

Planning for an AWT Demonstration Plant involves a number of interrelated issues including identifying treatment objectives, securing adequate funding, and establishing suitable monitoring requirements. These topics are introduced in the following discussion; monitoring is addressed in greater detail later in this section.

Treatment Objectives

The AWT Demonstration Plant should be designed to be modular, with a focus on meeting several treatment objectives, as outlined in Table 6-1.

Table 6-1. Treatment Objectives for the Proposed AWT Demonstration Plant

Treatment Objective	Potential Technologies	Sequence (Source of Process Influent)	Possible Monitoring Parameters
Control pathogens	Membranes: UF, MF, RO Disinfection: Chlorine, UV, Chlorine Dioxide	Secondary effluent or filtered secondary effluent	Indicators (bacteria, phages), pathogens (bacteria, viruses, cryptosporidia)
Control discharge of nutrients and emerging chemical contaminants into reservoir	Tertiary treatment (baseline), Membranes, Advanced oxidation	Filtered secondary effluent or UF or MF	Commonly detected PPCPs and EDCs; chemical compounds discharged from industries and hospitals in the service area
Control water quality in transmission line from treatment plant to reservoir	Secondary disinfection, corrosion control, scaling potential	Test all locations	Indicators of corrosivity and scale
Demonstrate equivalency to the CDPH treatment requirements for groundwater injection	Undisinfected filtered secondary effluent, UF, MF, RO, Advanced oxidation, Disinfection	Effluent from each stage	Parameters used by CDPH (TOC, indicators, etc.)

Table 6-1. Treatment Objectives for the Proposed AWT Demonstration Plant (con't)

Provide data for evaluating potential health risks	Undisinfected filtered secondary effluent UF, MF, RO Advanced oxidation Disinfection	Effluent from each stage	Disinfection byproducts, National Primary Drinking Water standards, selected emerging contaminants

Adequate Funding

It is important that the investment in the AWT Demonstration Plant include resources for the comprehensive monitoring program. Monitoring of routine water quality parameters, such as TOC, turbidity, conductivity, pH, alkalinity, and microbial indicators, can provide insight into the consistency of the treatment performance. Periodic monitoring of a suite of pathogens in treated water, including viruses, protozoan parasites, and bacteria, can provide information on the entire process and the effectiveness of disinfection, and can also inform risk assessment efforts. Systematic monitoring of parameters regulated under the Safe Drinking Water Act should be a component of the monitoring program, with an emphasis on disinfection byproducts (trihalomethanes, haloacetic acids, bromate, chlorite, and chlorate), nitrite and nitrate, metals including lead and copper, arsenic and other metalloids, and trace constituents typically associated with municipal wastewater. The monitoring program should include more intensive monitoring of compounds that have been identified in tertiary effluent.

Monitoring Requirements

Large amounts of performance data, obtained from related projects (e.g., the Groundwater Replenishment System), can be used to develop an efficient monitoring program. In parallel with monitoring regulated contaminants, a statistically sound monitoring program should be developed to evaluate the extent to which the treatment systems can control other contaminants of concern, such as pharmaceuticals, personal care products, endocrine active chemicals, and chemical compounds that might be discharged from industries and hospitals in the service area. The monitoring effort should focus on the parent compounds and their metabolites or breakdown products and the fate of these constituents through treatment. A well-designed monitoring program will enable the City to develop scientifically sound data that can be used to identify the combination of treatment technologies that will control any potential health risks associated with wastewater-derived chemical and microbial constituents. The frequency of monitoring should be adequate to enable statistical analysis of the data and provide the public with confidence on the performance of the treatment technologies and the extent to which wastewater-derived contaminants are controlled.

PROCESS SELECTION FOR THE AWT DEMONSTRATION PLANT

The AWT Demonstration Plant will provide the City an opportunity to develop data on the efficacy of several advanced treatment technologies. It will simulate the water quality, hydraulics, loading, and operations of the proposed full-scale plant and allow for public outreach through tours, hands-on activities, and the dissemination of performance data. The overall capacity should be based on providing the appropriate hydraulic loading rate across all of the AWT Demonstration Plant processes to allow for the adequate testing of treatment performance and reliability. Specific issues related to advanced treatment technologies are discussed below.

Treatment Technologies

Based on experience from other IPR projects, such as the Groundwater Replenishment System, the AWT Demonstration Plant should be designed to provide a rigorous evaluation of multiple technologies that can meet the City's stringent water quality objectives. Undisinfected tertiary effluent from the North City Plant will be the influent to the AWT Demonstration Plant. A key focus of the AWT Demonstration Plant is to ensure that any potential health risks associated with human pathogens and chemical contaminants are controlled before any use is made of the advanced treated recycled water. The treatment technologies to be evaluated in the AWT Demonstration Plant may include several membrane processes, advanced oxidation, disinfection (primary and secondary), and corrosion/scale control, as outlined in Table 6-1.

Membranes for Treatment and RO Pretreatment

It is anticipated that low-pressure membranes [either microfiltration (MF) or ultrafiltration (UF)] will serve as discrete unit processes, as well as pretreatment for the reverse osmosis (RO) treatment step that will be evaluated. As these membrane technologies have evolved, the performance, costs, operating, and energy requirements have become similar for both MF and UF. From the City's perspective, the goal is to provide a reliable and cost-effective pretreatment for RO treatment; therefore, it is important to understand the benefits and tradeoffs associated with this step. Both MF and UF have demonstrated records of bacteria, viruses, and protozoa removal. It is generally believed that MF alone without disinfection can remove 1-4 logs of bacteria and protozoa, and 0-2 logs of viruses. UF is shown to remove ~4 logs of bacteria and perhaps an equal reduction of viruses. However, filtration efficiencies vary with the manufacturer of the filtration device and physical/chemical characteristics of the tertiary effluent. A wide range of values is reported in older literature, which may be due to differences in the performance of membranes and imperfections or failure of the membrane; however, it would be expected that the current membranes are more consistent in manufacture and more reliable than they were in 1998. While either MF or UF can provide adequate pretreatment for RO, UF may provide additional disinfection credit, particularly for viruses. Native phage can be used to establish a basis for a limited degree of virus disinfection credit. If additional virus removal credit is desired, the demonstration testing will need to include spiking with a test virus like MS2 phage. If disinfection is not used in pretreatment, aerobic spores may be a good surrogate for C*ryptosporidium* removal.

Integrity Testing

The integrity of the MF/UF system is critical to ensuring the adequate removal of particulates. Monitoring of several parameters can be used to evaluate integrity. Online monitoring of pressure changes across the membranes is a good diagnostic tool for detecting breaches in the membranes. In addition, online monitoring of turbidity and UV absorbance could be used to track the performance of the MF/UF system, and to protect RO membrane elements from excessive fouling.

Reverse Osmosis (RO)

The RO process will provide a barrier for controlling a wide range of contaminants, including salts, trace elements, bulk organics (as indicated by TOC), and trace organics, including pharmaceuticals, endocrine active compounds, ingredients in personal care products, pesticides, and most other compounds of current interest among regulators, the media, and general public. Although RO is also a highly effective microbial barrier, the disinfection credit that will be allowed by CDPH will depend on test results. Operating parameters that have been used to monitor membrane integrity include operating pressure, TOC, and conductivity. Although turbidity is often mentioned, it is not sensitive enough to provide early warning. Testing of the RO system performance should include selected trace organic contaminants, as well as TOC as a surrogate for organics removal. Elements that are less efficiently removed by RO, like boron, should be included, as well as specific compounds of concern (like nitrate and nitrite) where target concentrations for the reservoir may be even lower than drinking water standards. Chloramines used for fouling control in the MF/UF and RO systems should be tested through the system to understand the concentration of chloramines needed to control biofouling and understand any role that they might play in the formation of disinfection byproducts, such as NDMA, or any effect that they might have on the efficiency of other processes, like UV photolysis and advanced oxidation, if they are utilized in the treatment train.

The entire treatment train and RO process provide a robust barrier for microbial pathogens. RO treatment perhaps is most efficient in removing protozoa cysts. It should be noted that newer type of RO systems may have significantly improved performance for microbial removal. However, imperfections in the membranes, coupled with the potential for leaks to occur around the seals and connectors, can cause the breakthrough of microorganisms, particularly viruses, if not removed by prior processes in the sequence. Thus, as a precautionary procedure, disinfection following RO treatment will be required. It is important to note that disinfection following RO treatment serves as an additional barrier within the water reclamation facility. Additional data will be useful for assessment following RO treatment. A comparison of the performance characteristics of RO to other membrane processes is shown in Table 6-2.

Table 6-2. Comparison of Membrane Process Performance Characteristics

Membrane Type	Nominal Pore Size (in µm) (approximate)	Constituents Removed
Microfiltration	0.1 to 1	Particulates, bacteria, protozoa
Ultrafiltration	0.001 to 0.1	Viruses, large and high MW organics (e.g., pyrogens)
Nanofiltration	+/-0.001	Multivalent metal ions, some organics
Reverse Osmosis	0.0001 to 0.001	Seawater and brackish water desalination, salts, and organics > ~ 100 Daltons

Source: www.watertreatmentguide.com, modified (accessed August 11, 2009).

Both bacteria and viruses are readily controlled by typical disinfection processes (e.g., utilizing chlorine), and these would be especially effective in RO-treated water with low TOC and low disinfectant demand. The organisms of particular concern, therefore, are one-celled parasites such as *Giardia* and, especially, *Cryptosporidium,* which is completely resistant to chlorine disinfection and must be removed by filtration or other means. These organisms are more than 1,000 times the size of viruses and, therefore, are well removed by membrane filtration processes. They also have finite life spans that are significantly affected by time and water temperature in their environment.

UV System

The UV system will provide three functions: disinfection, direct photolysis, and advanced oxidation. It is important that the unit provide treatment that will simulate the full-scale system and ensure that the UV dose is proportional to the flow. As full-scale units like the Trojan UV Phox system do not scale well, a large pilot-scale system rather than a portion of a full-scale UV train may be needed to determine the necessary dose to achieve CDPH requirements.

A testing program should be developed to assess the performance and effectiveness of UV for indicator chemicals for each of the functions cited above. Seeded phage testing may be needed to demonstrate disinfection performance. However, validation testing performed by manufacturers like Trojan may already satisfy this need. Testing performed by other agencies may also help to satisfy CDPH requirements. If the UF system is granted sufficient disinfection credit, the UV system testing may be able to focus on only the photolysis and AOP requirements, although in the past CDPH has not accepted membranes in lieu of a discrete disinfection process for groundwater recharge IPR projects.

The draft recharge regulations specify performance requirements for UV photolysis. The UV will need to be capable of at least 1.2-log reduction of NDMA with the same dose of UV that would be provided in the full-scale design, in accordance with the draft recharge regulations. The log reduction is based on comparing the concentration of NDMA derived from source wastewater before and after UV photolysis, and thus is independent of the concentration of NDMA found in the influent or formed by chloramine addition in the recycling plant.

For AOP, it may be necessary to demonstrate the capability of reducing 1,4-dioxane or another suitable indicator chemical by at least 0.5 log, even if this compound is not present in AWT Demonstration Project feedwater. The 1,4-dioxane serves as a marker for some low molecular weight compounds that could penetrate through RO and resist direct photolysis; however, it may not be reflective of others, such as halogenated hydrocarbons (e.g., TCE, PCE). The inclusion of AOP in the testing program is based on concerns with unknown contaminants and originated with the Independent Advisory Panel for West Basin Municipal Water District’s Seawater Barrier Water Conservation Project, which was likely based on experiences at the Groundwater Replenishment System. However, the need for AOP in the AWT treatment process must be established based on the results of the testing program.

UV irradiation is among the most effective methods for pathogen disinfection in water with low turbidity. However, recent studies showed some viruses are more resistant to UV disinfection than previously expected. The EPA recently recommended that a delivered UV dose of 186 millijoules per square centimeter (mJ/cm^2) is required for 4-log inactivation of DNA viruses; prior to January 2006, a UV dose of 40 mJ/cm^2 was considered sufficient. In the Groundwater Rule (promulgated in January 2007), it was noted that UV is not sufficient as a stand-alone treatment for 4-log inactivation of viruses. Both of these rules are based on adenoviruses, which are currently thought to be the most UV-resistant class of viruses and are, therefore, used as a standard for viral inactivation requirements. However, adenovirus outbreaks have not been documented in waterborne disease surveillance collected and reported by the U.S. Centers for Disease Control and Prevention (CDC). Also, it is very unlikely that viruses or other pathogens will survive the earlier processes in the train, and also not in the subsequent reservoir and drinking water treatment processes.

The scaling of the UV reactor design will require consulting with UV manufacturers. It may be possible to provide the same UV dose, but given reactor flow dynamics at different velocities, assuring the scalability of the UV system could be critical.

Water Stabilization

Evaluating the stabilization of RO water may be necessary depending on the pipeline materials used to transmit advanced treated recycled water to San Vicente Reservoir. As an example, the Groundwater Replenishment System relies on a combination of decarbonation and lime addition to stabilize the water. Decarbonation towers are used like air stripping to remove carbon dioxide, which raises the pH from the reduced pH required for RO treatment. Lime addition further raises the pH and adds alkalinity to reduce the corrosivity of the product water. The lime-stabilized water will subsequently not erode the cement mortar-lined surface of the Groundwater Replenishment System pipeline and it is less likely to mobilize other contaminants. At a minimum, the pH of the plant effluent will need to be stabilized to meet requirements for discharge into San Vicente Reservoir.

Size of AWT Demonstration Plant

To accommodate all of the goals of the AWT Demonstration Plant, it is critical that it is sized appropriately. As a minimum, the overall capacity and operating conditions should be based on supplying each treatment unit with water over the range of hydraulic loading rates likely to be experienced at the full-scale plant. The capacity should allow for a range of treatment scenarios, meeting monitoring requirements, and supplemental performance testing. To assure that the AWT Demonstration Plant is fully scalable, the elements, pressure vessels, and configuration of the plant's systems should be the same as would be implemented at full scale. For example, pressure vessels for RO should be 8-inch in diameter, unless the City wants to explore the use of larger (e.g., 16-inch) RO membranes. To accommodate the size and likely configuration of the RO system (3-2-1 configuration), the AWT Demonstration Plant should be sized at a minimum of 0.8 MGD. Ultimately, these elements should be validated by the City's design consultant.

MONITORING

Monitoring is a fundamental component of any IPR project. The implementation of an IPR project is dependent on monitoring to meet regulatory and operational requirements. The rationale for monitoring, its use in treatment process evaluation, and in identifying emerging contaminants is discussed below.

The Need for Monitoring

It is important to recognize that monitoring plays an important part in the selection of unit processes used in treatment and to ensure that the process is performing as expected in the fully operating treatment plant. Routine monitoring is important for documenting the following: (1) performance of individual water treatment processes being evaluated, and (2) sources of contamination within the overall system that are unrelated to the use of wastewater as a water source. Because monitoring can be very expensive, it is important to have a clear logical basis for determining appropriate monitoring schemes. Monitoring approaches for the Demonstration Project would likely be more extensive and more frequent than for the ultimate full-scale process.

In addition to routine water quality parameters, the monitoring of specific chemical and microbial contaminants can help to identify potential health risks. The City should provide a robust process for screening potential contaminants. The value in supplemental monitoring can address public concerns about the safety of advanced treated recycled water and also help in optimizing treatment performance. For example, the monitoring of a select group of pharmaceuticals can serve multiple purposes. In most cases, the levels of pharmaceuticals in wastewater are well below levels that are known to cause health concerns, especially in the final product water; however, because some of these pharmaceuticals routinely appear in wastewater, and sensitive analytical methods are available for them, they provide convenient measures of how treatment processes are performing. Further, because, pharmaceuticals and endocrine active chemicals are in the news and are of concern to the public, they may be monitored to instill public confidence in the quality of the water that is being produced. Therefore, it is important to explicitly state the reason why each constituent is included in a monitoring program even though the project is still in a demonstration rather than implementation phase. The plan for monitoring should be robust and provide information that can help the public understand why each constituent is being monitored. Methods for data validation and statistical analysis should also be explained.

Selection of Constituents

During the Demonstration Project, a wider group of analytes should be monitored than envisioned for final operation, recognizing that many commonly measured constituents will not be present in either the municipal wastewater or product water. With ongoing advances in analytical methods, coupled with increasing public and scientific interest in emerging contaminants, the City has an opportunity to be proactive in identifying potential health concerns, augmenting treatment performance evaluations, and, at the same time, addressing some of the concerns of the public about those constituents.

Monitoring must include all inorganic, organic, and microbial constituents for which there are Federal or State regulations for drinking water that specify concentrations of concern from a health effects perspective. Many of these constituents will not be found in the product water, but it is important that the product water demonstrably meets or exceeds existing drinking water standards if the constituent will not be removed by a later step in the process.

Also important are constituents that might occur either uniquely in the City's municipal wastewater or occur in greater amounts than seen in other locations. The occurrence of such chemicals can only be identified by a wastewater collection system source control program that is designed to aggressively identify and control such constituents. Those constituents that may be introduced into the wastewater in quantities that might lead to significant concentrations in the municipal wastewater should be included in the Demonstration Project's monitoring plan.

Finally, there are a large number of constituents that have been measured conventionally in ambient waters based on decisions that were made in the 1970s (commonly referred to as "priority pollutants"). Some of these chemicals are still used widely, but have been controlled at their source. Others are efficiently removed by conventional wastewater treatment, and still others are unlikely to occur in municipal wastewater because of changing use patterns or the fact that these chemicals are no longer produced in quantities that are likely to impact water quality. Continued monitoring of all these constituents, when local history and national experience widely demonstrate that they do not occur, may not be the best use of limited resources for monitoring. The Demonstration Project's monitoring plan should initially include these constituents at an appropriate frequency, but a decision process should be established to reduce the frequency of monitoring for those chemicals that are not detected at detection limits protective of human health. The resources that these analyses consume are better directed in an aggressive program for identifying and effectively dealing with emerging contaminants, particularly those that might be particular to San Diego or might occur in higher concentrations elsewhere.

While the major focus of the monitoring program will be on the quality of the final product water both in the AWT Demonstration Plant and the full-scale plant, some of these constituents should be monitored at various stages in the treatment process, such as "critical control points," to ensure that unit processes are performing as expected. The selection of these parameters should be based upon whether they will provide information relative to the expectations of the effectiveness of specific unit processes for reducing concentrations of groups of constituents. Specific considerations for selecting constituents for process monitoring should include:

1. Reliable occurrence in municipal wastewater at measurable concentrations.
2. Analytical methods that are sufficiently robust to measure substantial removals (orders of magnitude reductions in concentration).
3. Being representative of a variety of physical and chemical properties.

It is noted that considerable efforts have been made in classifying such chemicals in the past 5 to 10 years that are available in the literature, and chemicals have been identified that are useful surrogates for this purpose.

Emerging Contaminants

"Emerging contaminants" is a term applied to those constituents whose occurrence have been noted in recent years and are not part of normal monitoring requirements. At present, the focus has been on endocrine active compounds, pharmaceutical ingredients, personal care product ingredients, and microbial pathogens of particular concern. The ingestion of many of these constituents does not necessarily represent hazards to health, but they reflect a cycle of discovery, public awareness, and eventual resolution triggered by the improvement of analytical methods with ever-lower detection limits.

In addition, treatment processes can also produce constituents of potential health concern, particularly by halogenation, oxidation, or disinfection. It is widely recognized that chlorine and other disinfectant chemicals react with natural organic matter and inorganic constituents (e.g., bromide, nitrogen compounds, etc.) to form byproducts that may pose health risks at sufficient levels. Several disinfection byproducts (DBPs) are currently regulated (trihalomethanes, haloacetic acids, bromate, chlorite, and chlorate). In addition, other DBPs that have been identified include dialkyl-nitrosamines, as a result of the treatment of waters containing specific precursors with chloramine; the most prominent example is the formation of NDMA. Some of these may represent a health hazard in some circumstances (e.g., NDMA), while most occur at concentrations much below those that would be of health concern.

The Panel anticipates that disinfection byproducts will be a continuing issue, even where water is treated with sophisticated technologies, such as RO, because one effect of disinfectant reactions is frequently to reduce molecular weight.

For no other reason than maintaining public confidence, it is important that disinfection byproducts be included in the monitoring program for the AWT Demonstration Plant. For a similar project, the West Basin Municipal Water District's Independent Advisory Panel developed a list of emerging contaminants that illustrates an effective approach to identifying a set of chemicals that should be considered for these analyses. The rationale was based upon developing a set of chemicals that represent the following:

- A variety of chemical and physical properties.
- A high probability of occurrence in wastewater.
- Knowledge as to what unit processes should effectively reduce their concentrations in the water.

For information purposes only, Appendix E provides a table of recommended emerging contaminants to monitor from West Basin's Independent Advisory Panel.

The Panel recommends that the City undertake a similar process in selecting contaminants for the Demonstration Project. The Panel does not suggest that West Basin's list of specific contaminants should be used in San Diego. The list selected for monitoring in San Diego should be developed based upon a determination of what actually occurs in San Diego wastewater and informed by the experience of other potable reuse projects (e.g., Orange County Water District's Groundwater Replenishment System and Santa Ana River projects).

MICROBIOLOGICAL CONSIDERATIONS

The control of microorganisms is of fundamental concern in the selection of treatment processes for the Demonstration Project. This control is demonstrated by effective monitoring. Both of these issues are considered in the following discussion.

Monitoring Issues

To demonstrate the effectiveness of the treatment technologies for controlling health risks due to microbial pathogens, a robust monitoring program is needed to quantify the levels of bacteria and viruses after each step of treatment.

It is recommended that samples be taken at each step of treatment at a frequency that would provide statistically significant results and tested for fecal indicator bacteria and coliphage. In addition, as fecal indicator bacteria and coliphage are only a small fraction of a microbial community in the wastewater, they are likely below the limit of detection after the first step of treatment; however, other bacteria and viruses may remain in low concentrations. To demonstrate bacterial and viral removal at each step of treatment without artificially inoculating target microbes (bacteria or phages) in the feedwater, total bacterial and viral direct counting using epifluorescence microscopy can be used to indicate the efficiency of bacteria and virus removal during a testing program limited to several months of testing. This method is a common indicator of ecological conditions in the aquatic environment and is used widely in limnology and oceanography research. The total counts can be performed semi-automatically.

A seeding study is not recommended because seeding conditions can be different from the environmental matrix present in the treatment train. A seeding study can only be performed a limited number of times and is considerably more labor- and time-intensive than the routine monitoring of indicator bacteria, coliphage, and total counts of microbial density.

The recommended initial monitoring and sampling regime at start-up is shown in Table 6-3. Monitoring frequencies and organisms tested would be reassessed periodically based upon the performance of the AWT Demonstration Plant.

Monitoring Program

The direct monitoring of pathogens, although time and labor intensive, will provide additional assurance to the public on the quality of the finished water. Quarterly samplings of a large volume of water samples are recommended to test for pathogens. The pathogens recommended for testing include *E. coli O157*, Salmonella, *Cryptosporidium*, and adenoviruses.

The goal of the monitoring program is to collect routine microbial quality data at each step of the AWT. These data can be used to assess seasonal variability of plant performance, if any. The monitoring program is also designed to best represent operating conditions for the full-scale treatment plant. A similar monitoring plan can be used during full-scale operation to validate the treatment performance of the AWT.

Table 6-3. Recommended Initial Monitoring and Sampling Regime for the AWT Demonstration Plant

Monitoring Parameters	Methods	Volume of Sample				Recommended Monitoring Frequency
		Tertiary Effluent (mL)	MF or UF Filtrate (mL)	RO Permeate (mL)	Post UV Effluent (mL)	
Total coliform	EPA method	Dilute as needed	100	100	100	Daily
F-coliphage	EPA 1604	5x10	5x100	5x100	5x100	Weekly
Somatic coliphage	EPA 1604	5x10	5x100	5x100	5x100	Weekly
Total bacterial direct counts	Epi-fluorescence microscopy with SYBR-green.[a] ATP measurements	Dilute as needed	1 to 10	1 to 10	1 to 10	Daily via ATP
Total viral direct counts	Epi-fluorescence microscopy with SYBR-green	Dilute as needed	1 to 10	1 to 10	1 to 10	Weekly

[a] Noble, R.T., and J.A. Fuhrman (1998). “Use of SYBR Green I for Rapid Epifluorescence Counts of Marine Viruses and Bacteria.” *Aquat. Microb. Ecol*., 14 (1998), pp. 113–118.

7

RESERVOIR CHARACTERISTICS AND MODELING

The storage of advanced treated recycled water in a surface reservoir prior to withdrawal, further treatment, and use in a potable water supply is recognized to provide several benefits.[9] First of all, the surface water serves to dilute any trace constituents remaining in the advanced treated recycled water after treatment. At the same time, this blending results in the loss of the identity of the advanced treated recycled water, something potentially important to public perception. The storage of advanced treated recycled water in the surface reservoir also promotes further reduction in any residual trace contaminants through natural chemical, physical, photochemical, and microbiological reactions and transformations, and time and temperature-related die off. Finally, the routing of advanced treated recycled water through a surface storage reservoir provides a substantial lag time between the release from the water AWT Demonstration Plant and its arrival at the drinking water treatment plant. Thus, this lag time offers time and flexibility in responding to any problems at the AWT Demonstration Plant. Consequently, the reservoir serves as an important environmental buffer and barrier.[10] Reservoir characteristics and modeling are examined in this section.

RESERVOIR CHARACTERISTICS

The existing San Vicente Reservoir has a capacity of 90,000 acre feet (AF) and is scheduled to be expanded to 247,000 AF in the future, with construction planned to begin in 2010 and be completed in 2013. Therefore, it will have a large assimilative capacity, and the retention time in the expanded reservoir is expected to be a year or longer, depending primarily on the volume of water in the reservoir and inflows and outflows. The preference is that residual organic components that may be present in the advanced treated recycled water would be biodegradable or otherwise degraded in the reservoir (e.g., by solar radiation), and that any potentially harmful microorganisms in the water would be eliminated by die off, sedimentation, and other natural purification processes in the reservoir. It is recognized that, in any case, the reservoir water will undergo subsequent complete conventional drinking water treatment when it is extracted for public water supply use.

The effectiveness of the reservoir as a barrier is dependent upon a number of different hydraulic and limnological factors. Particular emphasis is placed on avoiding "short-circuiting" that result in rapid direct movement from inlet to outlet. Such short-circuited transport would minimize dilution, lag time, and loss of contaminants through natural reactions, rendering the surface storage reservoir less effectual as an environmental barrier. The proposed implementation strategy at San Vicente Reservoir makes use of the thermocline to isolate (except during periods of mixing) incoming advanced treated recycled waters inserted into the epilimnion from water withdrawn from the hypolimnion for delivery to the drinking water treatment plant. Nonetheless, it is important to characterize as fully as possible

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[9] NRC (1998). *Issues in Potable Reuse: The Viability of Augmenting Drinking Water Supplies with Reclaimed Water.* National Academy Press, Washington, DC. 263 pp.

[10] Ibid.

the hydrodynamics of the reservoir, specifically evaluating horizontal and vertical advective and dispersive transport of advanced treated recycled water within the reservoir.

RESERVOIR MODELING

Numerical modeling will be of critical importance in the siting of the inlet and evaluation of the potential for short-circuiting. It is proposed to use the Estuary Lake and Coastal Ocean Model (ELCOM) to study the characteristics of the reservoir. The ELCOM model[11] is a three-dimensional hydrodynamic model that is accepted widely by the scientific community. The City's reservoir modeling consultant, Flow Science, has considerable experience with this model (e.g., in modeling studies of Boulder Basin on Lake Mead and a large number of other applications). ELCOM can also be linked to the CAEDYM model that simulates water quality and biological properties.[12] The proposed ELCOM-CAEDYM model serves as the ideal tool to site the new inlet delivering advanced treated recycled water to San Vicente Reservoir, quantify the distribution of advanced treated recycled water in the reservoir over space and time, and evaluate potential impacts on water quality there. The model should also be used to design the reservoir monitoring program, including locations, depths, and frequency of sampling.

Detention Time and Fraction of Advanced Treated Recycled Water

The detention time and fraction of advanced treated recycled water in San Vicente Reservoir are two criteria specified in the CDPH conceptual approval letter from August 31, 1994. CDPH stipulated that advanced treated recycled water would comprise no more than 50 percent of the water withdrawn over any 36-month period (blending requirement), while also maintaining a 12-month theoretical hydraulic detention time.[13] A simple equation was used in the initial project to calculate the percentage of advanced treated recycled water from the ratio of the volumes of advanced treated recycled water and total water from all sources discharged to the reservoir to evaluate compliance with the CDPH blending requirement.[14] Based upon the operational scenarios described in that report,[15] an average of 26.9 percent of the water withdrawn over a 36-month period was predicted to be advanced treated recycled water. Based upon the projected inflows to the enlarged San Vicente Reservoir (140,000 acre feet per year [AF/yr] of imported water, 7,000 AF/yr of natural runoff, and 15,000 AF/yr recycled water), one may calculate a substantially lower percentage of advanced treated recycled water (9.3 percent). Therefore, it seems clear that the operation of the larger San Vicente Reservoir should readily meet a similar theoretical blending requirement. Based on the most recent draft of the CDPH groundwater recharge regulations (which are based on actual blending, not theoretical blending), it can be expected that CDPH will not allow the City to use theoretical blending as a basis for meeting the blending requirement.

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[11] CWR (2007). *Estuary, Lake and Coastal Ocean Model: ELCOM.* V2.2 User Manual. Centre for Water Research, University of Western Australia. 43 pp.

[12] Hipsey, M.R., J.R. Romero, J.P. Antenucci and D. Hamilton (2006). *Computational Aquatic Ecosystem Model: CAEDYM v2.3 Science Manual.* Centre for Water Research, University of Western Australia. 90 pp.

[13] Welch, M.R. (1998). *San Vicente Reservoir Management Program: City of San Diego Water Repurification Project.* Final Report.

[14] Ibid.

[15] Ibid.

Theoretical Blending Ratio and Inlet Location

The theoretical blending ratio is a convenient and valuable characteristic for an IPR project, although it will be important to demonstrate adequate mixing and avoidance of short-circuiting that could result in much higher proportion of advanced treated recycled water reaching the outlet. The design of the conveyance and reservoir system, and its operation, needs to be evaluated rigorously. For example, while the theoretical blending ratio approach averages over time, it is recognized that inflows from imported water, runoff, and advanced treated recycled water will vary seasonally. A simple water balance calculation was made to evaluate the seasonal changes in the fraction of advanced treated recycled water in the enlarged San Vicente Reservoir. Assuming a completely mixed reservoir using the projected monthly imported water, runoff and advanced treated recycled water flows, and an average withdrawal flow determined assuming water balance on an annual basis (i.e., no annual increase or decrease in storage), the percentage of advanced treated recycled water in a well-mixed San Vicente Reservoir will exhibit some strong seasonal trends. The reservoir was assumed to be filled to emergency plus carryover storage (~150,000 AF) before advanced treated recycled water flows were started. The percentage of advanced treated recycled water increased over the first year before declining in the winter associated with large dilutional imported flows, although the percentage of advanced treated recycled water subsequently increased as imported flows ended in May while recycled water flows continued. The percentage of advanced treated recycled water thus oscillated seasonally from 7.7 to 11.4 percent around a nominal value of approximately 9.5 percent (similar to the value of 9.3 percent calculated from annual flows).

More importantly, the effects of delivery of advanced treated recycled water to a seasonally stratified reservoir would be expected to yield a more complex composition of the outflow over time. The mixing of AWT-enriched epilimnetic water into the hypolimnion in the fall may increase the percentage of advanced treated recycled water by as much as 7 percent. It is important to characterize the fraction of advanced treated recycled water in the outflow over time and under different design and operational conditions. Flow Science and their application of the ELCOM-CAEDYM model are well suited for this analysis.

Detention Time Analysis

The detention time for advanced treated recycled water in the reservoir was also identified as an important system characteristic.[16] A 12-month theoretical detention time was specifically stipulated in a CDPH conceptual approval letter (detention time requirement). A mean theoretical reservoir detention time of 20.1 months was calculated for the earlier project.[17] The theoretical detention time for the enlarged reservoir appears to be similar based upon information provided (12 to 19 months over the nominal storage range). However, it is generally recognized that the detention time in the context of the proposed operation of San Vicente Reservoir is less well defined. While the theoretical detention is still useful in a general sense, ELCOM-CAEDYM should be used to develop a more complete statistical representation of travel times and storage times in the reservoir. For example, cumulative distribution or probability distribution functions should be developed to describe fully these

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[16] CDPH (1994). Letter regarding conceptual approval of water repurification. August 31, 1994.

[17] Welch, M.R. (1998). *San Vicente Reservoir Management Program: City of San Diego Water Repurification Project.* Final Report.

reservoir attributes. This will provide a more useful index of the potential lag time afforded by the routing of advanced treated recycled water through the reservoir.

In addition to lag time, the detention time also affords opportunity for reduction in wastewater-derived contaminants. While no removal credits are expressly assigned for the reservoir barrier, sufficient information exists to make some predictions about removal of key contaminants. For example, inactivation rate constants for common microbial contaminants are available, as well as rate laws for biodegradation, photolysis, volatilization, sorption, and settling (e.g., Schwarzenbach et al., 2003[18]). There is merit in selecting two or three different contaminants, found at relatively high levels in the untreated wastewater and/or likely to evade complete removal at the plant if a problem develops, to use as an example and evaluate their loss in the reservoir. These calculations could be done within ELCOM-CAEDYM or separately. In either case, these calculations can highlight the possible role the reservoir can play as an additional treatment process in this water system. Moreover, calculations (as well as monitoring data) demonstrating low concentrations of wastewater-derived contaminants following treatment, dilution, and further loss within the reservoir can also ameliorate concerns about recreational contact with the water.

Assessing Water Quality and Impact of Nutrients

At the same time, some of the nutrients, N and P, at very low concentrations, are likely to be released into the lake with AWT inflows. As a result, water quality impacts need to be evaluated. The reservoir is strongly N-limited, suggesting that N inputs in particular may help stimulate algal growth.[19] The CAEDYM model should be suitably calibrated and validated using available monitoring data for San Vicente Reservoir. Following satisfactory calibration and validation, reservoir water quality should be evaluated with and without advanced treated recycled water. Simulations should also compare current conditions to that of the enlarged reservoir. Since anoxia develops in the hypolimnion, the impacts of hypolimnetic oxygenation on reservoir water quality should be included. Understanding water quality in the reservoir will be important in anticipating treatment requirements at the drinking water treatment plant, assessing potential taste-and-odor problems associated with blue-green algal blooms, and defining future ecological conditions and recreational quality and aesthetics. If degradation of water quality was predicted to result from advanced treated recycled water inputs to the reservoir, this information could be used to modify the treatment train to remove additional quantities of N and P from the effluent.

While ELCOM-CAEDYM simulations are best suited for an analysis of predicted water quality in San Vicente Reservoir, it is nonetheless illustrative to make some preliminary calculations to explore any possible water quality impacts. A key feature of the project is the release of advanced treated recycled water into the surface of the lake, thereby using the thermocline to isolate the outlet, minimize short-circuiting, and maximize lag time and reaction. The warm, photic epilimnion is also the zone of maximum phytoplankton production in lakes. Assuming the reservoir is stratified for 9 months of the year with an average epilimnetic thickness of 10 meters (m), the epilimnetic volume (near full pool) will be

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[18] Schwarzenbach, R.P., P.M. Gschwend and D.M. Imboden (2003). *Environmental Organic Chemistry*, 2nd ed. John Wiley & Sons, New York, NY. 1000 pp.

[19] Welch, M.R. (1998). *San Vicente Reservoir Management Program: City of San Diego Water Repurification Project.* Final Report.

around 50,000 AF. With uniform seasonal AWT inflows, approximately 11,250 AF of advanced treated recycled water will be added to the epilimnion. At the same time, evaporation will remove about 1.2 m (or about 6,300 AF) from the surface of the lake (based upon evapotranspiration – or ET_o – from the CIMIS meteorological station #153 at Escondido, CA). The 10-m average thickness accounts roughly for the deepening of the thermocline that occurs through hypolimnetic entrainment during the summer and fall, so the volume of the epilimnion will, for these calculations, assume to be somewhere near 55,000 AF. Further assuming a total N concentration of 1.0 mg/L in the AWT effluent that is essentially all in readily available inorganic forms (NO_3-N and perhaps low concentrations of NH_4-N), this translates to a theoretical Total Inorganic Nitrogen (TIN) concentration in the fall due to advanced treated recycled water inputs of 0.2 mg/L. With N-limitations in the reservoir and assuming an average composition of algae of 40 C:7 N:1 P (the Redfield ratio) and a chlorophyll:carbon ratio of 10 to 50 microgram per milligram (µg/mg) carbon (C),[20] one may estimate an additional 11 to 57 micrograms per liter (µg/L) chlorophyll a production in the epilimnion of San Vicente Reservoir by the fall due to advanced treated recycled water inputs. This entire inventory of chlorophyll would not remain in the epilimnion due to grazing by zooplankton, settling, and other loss processes, but this could nonetheless represent a significant reduction in transparency. Specifically, stimulating blue-green algal production could also promote geosmin and 2-Methylisoborneol (MIB) production, taste-and-odor compounds with very low thresholds that are not generally removed at drinking water treatment plants. Predictions from the calibrated and validated CAEDYM model that include zooplankton grazing and algal setting, biological nitrogen fixation as well as atmospheric N deposition directly onto the lake surface, will provide important water quality predictions of impacts from advanced treated recycled water inputs.

See Appendix F for Flow Science’s scope of work.

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[20] Chapra, S.C. 1997. *Surface Water-Quality Modeling.* McGraw-Hill, Singapore.844 pp.

8

CALIFORNIA DEPARTMENT OF PUBLIC HEALTH REQUIREMENTS FOR RESERVOIR AUGMENTATION

Implementing an IPR project involving surface water augmentation will require that a number of regulatory requirements be met. The purpose of this section is to: (1) identify the key criteria for reservoir augmentation; (2) suggest augmentation guidelines; and (3) identify microbial water quality goals consistent with the regulatory requirements.

The following guidelines and goals are suggested, but will be resolved based on AWT Demonstration Plant test results and modeling results.

KEY CRITERIA FOR RESERVOIR AUGMENTATION

The key criteria for reservoir augmentation should be that the advanced treated recycled water being introduced will: (1) have no known or anticipated adverse environmental or health impacts with a margin of safety; (2) be appropriate as a blending contributor to the source water for subsequent drinking water treatment and allow assurance that the drinking water that is ultimately produced will meet all standards and guidelines with a margin of safety; and (3) not degrade the reservoir water with respect to potential algae blooms from nutrients (N and P loadings) and its approved fishing and other recreational uses.

The entire process of producing advanced treated recycled water and drinking water should consist of multiple barriers to ensure reliable and safe drinking water quality for consumers. Those multiple barriers include components in:

- Wastewater source water pretreatment and discharge requirements.
- Treatment to produce the advanced treated recycled water.
- Natural processes, including sedimentation, photolysis, metabolism, and die off of microorganisms.
- Oxidation/reduction.
- Residence time and dilution in the reservoir that will eliminate or reduce any residual microbial and chemical contaminants to well below any levels of concern.

Finally, the drinking treatment process includes several additional redundant barriers and should ensure that the final product water is safe and protective of public health. Going beyond these principles is a political choice that probably does not have any discernable effect on the water quality and level of health protection.

SUGGESTED AUGMENTATION GUIDELINES

Some elements of the specifications or guidelines for key components of advanced treated recycled water include:

Pathogenic Microorganisms

- Appropriate surrogate and indicator organisms for bacteria, virus, and protozoa.
- Disinfectant related Ct [chlorine residual × time (milligrams-minutes/L)] values.
- UV dose and intensity values for disinfection/treatment processes.
- Time and temperature dependent reservoir die off.
- Turbidity.

Organic Chemicals

- MCLs, California Notification Levels, and Health Advisories at the intake to the drinking water treatment plant.
- Biodegradability or lack of biodegradability.
- Sedimentation.
- Redox/conversion.

Inorganic Chemicals

- Meet all MCLs, California Notification Levels, and Health Advisories.

Environmental

- Nitrogen/ ammonia/nitrate to prevent algae blooms and eutrophication.
- Phosphorus to prevent algae blooms and eutrophication.
- TOC (also, possible treatment surrogates).

Source Protection Plans

- Pretreatment and discharge controls in the wastewater system.
- San Vicente Watershed Protection Plan.

MICROBIAL WATER QUALITY GOALS

Some elements of the specifications or guidelines for microbial quality are as follows:

Advanced Treated Recycled Water from the AWT Demonstration Plant

- Meet CDPH microbial drinking water standards.
- 4-log virus removal using MS2 as Ct determinant.
- Requirements in CDPH draft groundwater recharge reuse regulations:

Reservoir Water

- Less than 1 *Cryptosporidium*/100 L at drinking water intake – as a conservative application of EPA's Bin 1 classification for surface water treatment.

Finished Drinking Water

- Meet CDPH microbial drinking water standards.
- Meet log removal treatment requirement per vulnerability as measured by the Long Term 2 Surface Water Treatment Rule (LT2 rule).
- 4-log virus removal using MS2 as Ct determinant.

See Appendix G for background information on the survival of *Cryptosporidium* as a function of water temperature.

9

PUBLIC OUTREACH

Public acceptance (or lack thereof) can play a critical role in determining whether or not a proposed IPR project comes to fruition. Therefore, outreach with the public will be an important aspect of the Demonstration Project. The Panel suggests the following strategies in developing a successful outreach program.

- At present, the City has already begun engaging with the public through presentations and other communications regarding the Demonstration Project. The City should continue to build on outreach efforts, emphasizing the need for the Project and highlighting the benefits to the reliability of the City's water supply.

- The City should conduct interviews with representatives from other communities where IPR projects have been implemented to develop an understanding of the outreach strategies employed. The approaches used in successful IPR projects, such as the Orange County Water District's Groundwater Replenishment System and West Basin Municipal Water District's Water Reliability 2020 Program, can provide a starting point for tailoring best practices and guidelines.

- The City should develop a communication plan for the Demonstration Project. The plan might include the following elements:
    - ***Project objectives***.
    - ***Public opinion research*** (surveys, focus groups, articles, expert opinions, etc.).
    - ***Planning*** (to lay the groundwork for the communication and outreach process).
    - ***Challenges*** (to identify communication strategies to address challenges facing the project and/or outreach).
    - ***Messages*** (overarching themes to help focus the communication efforts).
    - ***Audiences*** (to identify strategies to address the concerns of different audiences [media, business, government, etc.] and address the identified challenges, with primary focus on reaching active leaders and groups within the community).
    - ***Information materials*** (information pieces that are tailored to different stakeholders to convey important messages about the project, such as websites, printed materials, newsletters, white papers, blogs, and more).
    - ***Construction relations*** (to ensure the community understands the need for construction in the full-scale phase and what impact this will have).
    - ***Evaluation*** (includes measurable objectives to determine if the outreach program goals were met).

- The City has expressed interest in providing public tours of the AWT Demonstration Plant. The Panel agrees that tours would be a useful element of the Demonstration Project's outreach program to build confidence in the project and the quality of advanced treated recycled water that is produced.

- The Demonstration Project should be given a name that markets itself to the public, like Singapore's NEWater and the Groundwater Replenishment System.

APPENDIX A: Panel Biographies

GEORGE TCHOBANOGLOUS, Ph.D., P.E., NAE (Panel Chair)

Professor Emeritus
University of California, Davis (Davis, California)

For over 37 years, wastewater expert George Tchobanoglous has taught courses on water and wastewater treatment and solid waste management at the University of California, Davis, where he is Professor Emeritus in the Department of Civil and Environmental Engineering. He has authored or coauthored over 350 publications, including 13 textbooks and five engineering reference books. Tchobanoglous has been past President of the Association of Environmental Engineering and Science Professors and currently serves as a national and international consultant to both government agencies and private concerns. Among his honors, he received the Athalie Richardson Irvine Clarke Prize from NWRI in 2003, was inducted to the National Academy of Engineers in 2004, and received an Honorary Doctor of Engineering degree from the Colorado School of Mines in 2005. Additionally, he has participated on other Independent Advisory Review Panels with NWRI, including, Orange County Sanitation District Achieving Full Secondary Treatment, Los Osos Wastewater Management Plan, Monterey Regional Pollution Control Agency Groundwater Recharge Program, and Orange County Water District Santa Ana River Monitoring Panel. Tchobanoglous received a B.S. in Civil Engineering from the University of the Pacific, an M.S. in Sanitary Engineering from the University of California, Berkeley, and a Ph.D. in Environmental Engineering from Stanford University.

MICHAEL A. ANDERSON, Ph.D.

Professor of Applied Limnology and Environmental Chemistry
Department of Environmental Sciences
University of California, Riverside (Riverside, California)

Michael Anderson, a Professor of Applied Limnology and Environmental Chemistry, has taught courses at the University of California, Riverside, since 1990. His research focus includes water and soil sciences, with particular emphasis in applied limnology and lake/reservoir management; surface water quality and modeling; fate of contaminants in waters, soils, and sediments; and environmental chemistry. His most current research project involves managing Quagga Mussels in the reservoirs of the Colorado River Aqueduct, funded by the Metropolitan Water District of Southern California. He also recently completed a U.S. Army Corps of Engineers project on predicted water quality and public health impacts resulting from pathogen inputs near water intakes on Lake Tahoe. In addition, he has served on various panels and workgroups, including as member of the California Department of Water Resource’s Salton Sea Hydrologic Technical Workgroup (2007-2008). Anderson received a B.S. in Biology from Illinois Benedictine College, M.S. in Environmental Studies from Bemidji State University, and Ph.D. in Environmental Chemistry from Virginia Tech.

RICHARD BULL, Ph.D.
Consulting Toxicologist
MoBull Consulting (Richland, Washington)

Since 2000, Richard Bull has been a Consulting Toxicologist with MoBull Consulting, where he conducts studies on the chemical problems encountered in water for water utilities, as well as federal, state, and local governments. Bull is a retired Professor of Pharmacology/Toxicology from Washington State University, where he maintains Adjunct Professor appointments in the College of Pharmacy and the Department of Environmental Science. Formerly, he served as a senior staff scientist at DOE's Pacific Northwest National Laboratory, Professor of Pharmacology/Toxicology at Washington State University, and Director of the Toxicology and Microbiology Division in the Cincinnati Laboratories for the U.S. Environmental Protection Agency. Bull has published extensively on research on central nervous system effects of heavy metals, the carcinogenic and toxicological effects of disinfectants and disinfection by-products, halogenated solvents, acrylamide, and other contaminants of drinking water. He has also served on many international scientific committees convened by the National Academy of Sciences, World Health Organization, and International Agency for Research on Cancer regarding various contaminants of drinking water. Bull received a B.S. in Pharmacy from the University of Washington and a Ph.D. in Pharmacology from the University of California, San Francisco.

JOSEPH A. COTRUVO, Ph.D.
President
Joseph Cotruvo & Associates, LLC (Washington, D.C.)

Joe Cotruvo is President of Joseph Cotruvo & Associates, an environmental and public health consulting firm, and is active in the World Health Organization (WHO)/NSF International Collaborating Centre for Drinking Water Safety and Treatment. Previously, he served as Director of the Criteria and Standards Division of the U.S. Environmental Protection Agency (EPA) Office of Drinking Water, where he developed the *Drinking Water Health Advisory System* and *National Drinking Water-Quality Standards and Guidelines*. He was also Director of the EPA's Risk Assessment Division and a former Vice President at NSF International. At present, Cotruvo is a member of WHO Drinking Water Guidelines development committees and a manager of WHO's Desalination Guidance project. He is also engaged in studies on antiterrorism and water supplies through the American Water Works Association Research Foundation and in studies of presystemic metabolism of bromate. In addition, he is active in water reuse applications. Recently, he was appointed to the Board of Directors of the District of Columbia Water and Sewer Authority, where he chairs the committee dealing with water quality and other aspects. Cotruvo received a B.S. in Chemistry from the University of Toledo and a Ph.D. in Physical Organic Chemistry from Ohio State University, and also post doctoral studies.

JAMES CROOK, Ph.D., P.E.
Environmental Engineering Consultant (Boston, Massachusetts)

Jim Crook is an environmental engineer with more than 37 years of experience in state government and consulting engineering arenas, serving public and private sectors in the U.S. and abroad. He has authored more than 100 publications and is an internationally recognized expert in water reclamation and reuse. He has been involved in numerous projects and research activities involving public health, regulations and permitting, water quality, risk assessment, treatment technology, and all facets of water reuse. Crook spent 15 years directing the California Department of Public Health's water reuse program, during which time he developed California's first comprehensive water reuse criteria. He also spent 15 years with consulting firms overseeing water reuse activities and is now an independent consultant specializing in water reuse. He has served on several advisory panels and committees convened by the National Academy of Sciences, NWRI, and others. Among his honors, he was selected as the American Academy of Environmental Engineers' 2002 Kappe Lecturer and the WateReuse Association's 2005 Person of the Year. Crook received a B.S. in Civil Engineering from the University of Massachusetts and both an M.S. and Ph.D. in Environmental Engineering from the University of Cincinnati. He is a registered professional engineer in California and Florida.

RICHARD GERSBERG, Ph.D.
Professor and Head, Division of Occupational and Environmental Health
Graduate School of Public Health
San Diego State University (San Diego, California)

Richard Gersberg serves as a Professor and Head of the Division of Occupational and Environmental Health at San Diego State University. He specializes in water quality research and limnology, and has broad experience working with both chemical and microbiological pollutants and risk assessments. Prior to joining the California State University system in 1986, he was Director of Research for the San Diego Region Water Reclamation Agency and both a Project Manager and Environmental Consultant for Ecological Research Associates. Among his most recent activities, Gersberg was a member of the CALFED Bay-Delta Authority (CBDA) Science Program, in cooperation with California Sea Grant. He has also been actively involved in projects on the effects of global climate change on the coast of San Diego, California, and risk assessment regarding consuming fish and ocean recreation in Imperial Beach, California. He is currently the Principal Investigator of an EPA and SCERP-funded study to use polymerase chain reaction (PCR) methods do quantitate the levels of hepatitis A virus and enteroviruses in the recreational ocean waters near the U.S-Mexico border, and to examine the removal of these viruses (and selenium) by constructed wetlands treating the contaminated New River before it enters the Salton Sea, California. Gersberg received a B.S. in Biology from the City College of the City University of New York, an M.S. in Biology from the University of Houston, and a Ph.D. in Microbiology from the University of California, Davis.

SUNNY JIANG, Ph.D.
Associate Professor, Civil & Environmental Engineering
The Henry Samueli School of Engineering
University of California, Irvine (Irvine, California)

Sunny Jiang, an Associate Professor of Environmental Engineering, has taught courses at the University of California, Irvine, since 1998, on water quality, environmental biotechnology, water pollution microbiology, and microbial ecology. She is particularly interested in microbial dynamics and interactions in the aquatic environment. Her current research project on investigation of seawater desalination biofouling, funded by the WateReuse Foundation, is applying molecular biology methods for identification of the marine bacteria that are causing biofilm production. This work is likely to contribute to the development of biofouling precursor and strategies for biofouling prevention. Jiang is also interested in understanding the source and transport of fecal contamination and human waste in coastal water. Her group has developed rapid and sensitive methods for the detection and quantification of human virus contamination in aquatic samples. Jiang has published over 50 articles in the field of environmental microbiology and microbial ecology. She served on WHO Desalination Guideline development committee and is serving on National Research Council Water Reuse Committee. Jiang received a B.S. in Biochemistry from Nankai University in Tianjin, China, and an M.S. and Ph.D. in Marine Science from the University of South Florida.

AUDREY D. LEVINE, Ph.D., P.E., DEE
National Program Director, Drinking Water Research
Office of Research and Development
U.S. Environmental Protection Agency (Washington, D.C.)

Audrey Levine is a professional engineer with over 25 years of broad-based technical experience within academic, government, industry, and consulting settings. Her areas of interest include water quality, water treatment and distribution systems, treatment technologies, water reuse, green infrastructure, and the water-energy-climate nexus. Since 2006, she has served as National Program Director, Drinking Water Research, in the Office of Research and Development for the U.S. Environmental Protection Agency, where she is responsible for coordinating the Agency's intramural and extramural drinking water research program focused on characterizing and managing health risks to advance the safety and reliability of the drinking water that is provided to the public. She also serves on multiple interagency committees and workgroups related to water quality and availability. The author of numerous technical publications, Levine is currently working on developing integrated multi-disciplinary research approaches relevant to water system sustainability, emerging contaminants, and water infrastructure. Levine received a B.A. in Biological Sciences from Bates College, an M.S. in Public Health and Environmental Health Science from Tulane University, and a Ph.D. in Civil Engineering from the University of California, Davis.

DAVID R. SCHUBERT, Ph.D.
Professor and Chair, Cellular Neurobiology Laboratory
The Salk Institute for Biological Studies (La Jolla, California)

David Schubert, Professor and Head of the Cellular Neurobiology Laboratory, is interested in understanding the molecular basis of nerve cell death and developing drugs that block nerve cell death in Alzheimer's disease, Parkinson's disease, stroke, and other age-associated brain disorders. The focus of the drug development program is the use of biologically active natural products, compounds that occur normally in plants, as a starting point for the synthesis of chemical derivatives that are more potent and have better pharmacological properties than the plant product. His lab also works on amyloid protein, a toxic substance that accumulates in the brains of Alzheimer's patients. In addition to his laboratory work, Schubert is a member of San Diego County Science Advisory Board, a group that advises the Board of Supervisors on science-based issues. He is also a frequent contributor to the *Union-Tribune* editorial page on the subject of science policy. Schubert received a B.A. in Chemistry/Biochemistry from Indiana University and a Ph.D. in Cell Biology from the University of California, San Diego, with Postdoctoral work in Cell Biology/Genetics at Institut Pasteur in Paris, France.

MICHAEL P. WEHNER
Assistant General Manager
Orange County Water District (Fountain Valley, California)

Mike Wehner has over 32 years experience in water quality control and water resources management. He has been with the Orange County Water District (OCWD) since 1991, currently serving as Assistant General Manager. Among his responsibilities, he directly manages the Water Quality and Technology Group, including Laboratory, Water Quality, Research and Development, and Health and Regulatory Affairs Departments. He is also involved with numerous aspects with the Groundwater Replenishment System (the nation's largest IPR project), including providing technical guidance on treatment and quality, as well as managing monitoring programs for the purification facility and receiving groundwater. He was also manager of OCWD's 8-year Santa Ana River Water Quality and Health Study, which evaluated the impact of using effluent-dominated river waters for groundwater recharge. Prior to joining OCWD, Wehner spent 20 years with the Orange County Health Care Agency. He received a Masters of Public Administration from California State University Long Beach and a B.S. in Biological Sciences from the University of California, Irvine.

APPENDIX B: Meeting Agenda

NATIONAL WATER RESEARCH INSTITUTE

Independent Advisory Panel Meeting
City of San Diego Indirect Potable Reuse/ Reservoir Augmentation (IPR/RA) Demonstration Project
PRELIMINARY DRAFT Meeting Agenda
May 11-12, 2009

Meeting Location	**On-Site Contacts:**
City of San Diego's North City Water Reclamation Plant 4949 Eastgate Mall San Diego, CA. 92121	**Jeff Mosher (NWRI)** Cell: (714) 705-3722

Meeting Objectives:

1. Provide an overview of the project, review project history and previous work.
2. Review the regulatory framework for Indirect Potable Reuse (IPR).
3. Review the Demonstration Project work plan.
4. Review work plan for the San Vicente Reservoir Study.
5. Develop findings and recommendations regarding the AWT and reservoir studies.

Day 1 – Monday May 11, 2009

8:00 am	**Arrive**	**North City Water Reclamation Plant (NCWRP)**
8:30 am	Introductory remarks - Review agenda - Review schedule for panel report	Jeff Mosher (NWRI) George Tchobanoglous (Panel Chair)
8:40 am	Overview of Panel Charge	Marsi Steirer (City of San Diego)
9:00 am	Project Background - Project Overview/History - NCWRP Description - Past AWT Pilot Study Results - San Vicente Reservoir Description - Past San Vicente Reservoir Study Results	City Staff
10:30 am	**Break**	
10:45 am	Regulatory Parameters - Framework State Guidelines - Reservoir Augmentation	Tom Richardson (RMC)
12:00 noon	**Lunch (NCWRP tour – Time permitting)**	

1:00 pm	Proposed San Vicente Reservoir Study Concept - Goals and objectives - Description of model - Case study - Modeling Tasks for San Vicente Reservoir	Jeff Pasek (City of San Diego) Imad Hannoun (Flow Science)
2:00 pm	Discussion	George Tchobanoglous (Panel Chair)
2:45 pm	**Break**	
3:00 pm	Preliminary Demonstration AWT Concept - Goals/Objectives - Treatment technologies	Bill Pearce (City of San Diego)
4:00 pm	Open Discussion: - Issues for discussion - Panel recommendations - Preparation of Panel report	George Tchobanoglous (Panel Chair)
5:00 pm	**Adjourn**	

Day 2 – Tuesday May 12, 2009

8:00 am	**Arrive**	**North City Water Reclamation Plant**
8:30 am	San Vicente Reservoir – “Virtual Tour” Presentation	City Staff
9:30 am	Closed Panel Discussion - Issues for discussion - Panel recommendations - Prepare detailed outline and preliminary conclusions	George Tchobanoglous (Panel Chair)
12:00 noon	**Lunch**	
12:30 pm	Discussion with City Staff - Report outline	
1:00 pm	Closed Panel Discussion - Draft panel report	
3:00 pm	**Adjourn**	

APPENDIX C: Meeting Attendees

Panel:

- *Panel Chair:* George Tchobanoglous, Ph.D., P.E., University of California, Davis (Davis, CA)
- Michael A. Anderson, Ph.D., University of California, Riverside (Riverside, CA)
- Richard J. Bull, Ph.D., MoBull Consulting (Richland, WA)
- Joseph A. Cotruvo, Ph.D., Joseph Cotruvo Associates (Washington, D.C.)
- James Crook, Ph.D., P.E., Water Reuse Consultant (Boston, MA)
- Richard Gersberg, Ph.D., San Diego State University (San Diego, CA)
- Sunny Jiang, Ph.D., University of California, Irvine (Irvine, CA)
- Audrey D. Levine, Ph.D., P.E., DEE, U.S. Environmental Protection Agency (Washington, D.C.)
- David R. Schubert, Ph.D., The Salk Institute for Biological Studies (La Jolla, CA)
- Michael P. Wehner, Orange County Water District (Fountain Valley, CA)

NWRI:

- Jeff Mosher, Executive Director
- Gina Melin Vartanian, Outreach and Communications Manager

City of San Diego:

- Jeff Pasek
- William Pearce
- Alma Rife
- Marsi Steirer
- Anthony Van

City Consultants:

- Tish Berge, RMC
- Imad A. Hannoun, Flow Science
- Susan C. Paulsen, Ph.D., PE, Flow Science
- Tom Richardson, RMC

California Department of Public Health:

- Brian Bernados
- Heather Collins
- Robert Hultquist
- Sean Sterchi

California Regional Water Quality Control Board:

- John Robertus

San Diego County Water Authority:

- Toby Roy

City of Escondido

- Lori Vereker

Helix Water District

- Mark Umphres

APPENDIX D: Water Quality Comparison of Source Waters to San Diego

The source for the table on “Water Quality Comparison” is the Final Report entitled, *City of San Diego Advanced Water Treatment Research Studies*, prepared by MWH for the City of San Diego and Aqua 2030 Research Center in August 2007.

Appendix D: Water Quality Comparison of Source Waters to San Diego - Colorado River (CR), State Project Water (SPW), City of San Diego (SD)

Constituent	*Metric Units*	*Units*	*Maximum Contaminant Level (MCL)*	*Colorado River Yearly Average*^{2}	*State Water Project Yearly Average*^{2}	*San Diego Source Water Yearly Average*^{5A}	*NCWRP Tertiary Effluent Average*^{5B}	*NCWRP UV + Peroxide Average*^{6}
Inorganics and Physical Parameters								
Asbestos	MFL	MFL	7	ND	ND	ND**	na	ND^{h}
Bicarbonate	mg/L	ppm	none	159	107	142	na	7.88^{h}
Boron	mg/L	ppm	1^{d}	0.14	0.18	0.115	0.379	0.275$^{g, p}$
Bromide	mg/L	ppm	none	0.09	0.22	0.207	0.455	ND^{g}
Calcium	mg/L	ppm	none	71	25	50.7	na	ND^{h}
Carbonate	mg/L	ppm	none	0	0	3.51	na	ND$^{h, l}$
Chloride	mg/L	ppm	250^{a}	87	70	100	255	6.9
Cyanide	mg/L	ppm	0.2	ND	ND	ND	na	ND^{h}
Fluoride	mg/L	ppm	2^{a}	0.34	0.13	0.28	na	ND^{h}
Free Carbon Dioxide	mg/L	ppm	none	1.5	1.8	2.9**	na	3.86$^{h, ,j}$
Magnesium	mg/L	ppm	none	29	14	25.6	na	ND^{h}
Nitrate as NO_3	mg/L	ppm	45	0.9	2.3	0.85	45.3	5.3^{p}
Nitrate as N	mg/L	ppm	10	na	na	ND**^{l}	na	1.0$^{h, p}$
Nitrite, N	mg/L	ppm	1	na	na	0.078	na	ND^{h}
Phosphorous	mg/L	ppm	none	na	na	0.041	na	na
Potassium	mg/L	ppm	none	4.9	3.1	5.10	19.4	ND
Silica	mg/L	ppm	none	8.5	10.5	11.3	16.0	0.607^{g}
Sodium	mg/L	ppm	none	95	53	79.6	190	6.0^{h}
Sulfate	mg/L	ppm	250^{a}	245	45	142	241	0.722
Foaming Agents (Detergents, Surfactants, MBAS)	mg/L	ppm	0.5^{a}	ND	ND	ND	na	ND^{h}
Total Organic Carbon (TOC)	mg/L	ppm	none	3.30	3.89	6.49	8.77	ND^{g}
Total Dissolved Solids (TDS)	mg/L	ppm	500^{a}	620	275	508	998	40
Total Hardness as $CaCO_3$	mg/L	ppm	none	297	118	234	356	ND^{l}
Total Alkalinity as $CaCO_3$	mg/L	ppm	none	131	88	123	144	6.96
H^{+} Concentration (pH)	pH	pH	6.5-8.5^{a}	8.24	8.00	8.33	na	6.6^{h}
Specific Conductance (Conductivity)	μmho/cm	μmho/cm	900^{a}	1003	505	1117	1957	58

Appendix D: Water Quality Comparison of Source Waters to San Diego - Colorado River (CR), State Project Water (SPW), City of San Diego (SD)

Constituent	Metric Units	Units	Maximum Contaminant Level (MCL)	Colorado River Yearly Average[2]	State Water Project Yearly Average[2]	San Diego Source Water Yearly Average[5A]	NCWRP Tertiary Effluent Average[5B]	NCWRP UV + Peroxide Average[6]
Inorganics and Physical Parameters (continued)								
Color	CU	CU	15[a]	5	14	15	na	ND[h]
Turbidity	NTU	NTU	5[a]	3.8	3.5	1.76	na	0.20[h]
Alkalinity_Partial	mg/L	ppm	none	na	na	3.71	ND	ND[g]
Hardness_Ca	mg/L	ppm	none	na	na	128	201	3.37[g]
Radionuclides[8,9]								
Gross Alpha	pCi/L	pCi/L	15	4.05	1.93	<3**	na	<3[h]
Gross Beta	pCi/L	pCi/L	50	4.04	3.20	3.4**	na	<3[h]
Radium226	pCi/L	pCi/L	5[f]	ND	ND	na	na	na
Radium228	pCi/L	pCi/L	5[f]	ND	ND	<1**	na	<1[h]
Strontium90	pCi/L	pCi/L	8	ND	ND	na	na	na
Tritium	pCi/L	pCi/L	20,000	ND	ND	na	na	na
Uranium, Total	pCi/L	pCi/L	20	2.74	0.54	na	na	na
Radon 222	pCi/L	pCi/L	none	49	39	na	na	na
Metals								
Aluminum	µg/L	ppb	200[a]	93	87	26.7	11.6	ND
Antimony	µg/L	ppb	6	ND	ND	ND	ND[l]	ND[h]
Arsenic[12]	µg/L	ppb	10	3.0	2.3	ND[l]	2.18	ND
Barium	µg/L	ppb	1,000	151	41	65.6	55.7	ND
Beryllium	µg/L	ppb	4	ND	ND	ND	ND	ND
Cadmium[12]	µg/L	ppb	5	ND	ND	ND	ND	ND
Chromium	µg/L	ppb	50	ND	ND	ND	na	ND[h]
Chromium 6	µg/L	ppb	50	ND	0.12	na	na	na
Copper	µg/L	ppb	1,300[d] (1,000[a])	ND	ND	7.01	6.66	ND[l]
Iron	µg/L	ppb	300[a]	17	20	58.1	na	ND[h]
Lead[12]	µg/L	ppb	15[d]	ND	ND	ND	ND[l]	ND
Lithium	µg/L	ppb	none	47	ND	na	na	na

Appendix D: Water Quality Comparison of Source Waters to San Diego - Colorado River (CR), State Project Water (SPW), City of San Diego (SD)

Constituent	Metric Units	Units	Maximum Contaminant Level (MCL)	Colorado River Yearly Average[2]	State Water Project Yearly Average[2]	San Diego Source Water Yearly Average[5A]	NCWRP Tertiary Effluent Average[5B]	NCWRP UV + Peroxide Average[6]
Metals (continued)								
Manganese	μg/L	ppb	500[d] (50[a])	ND	6	34.7	107	ND[l]
Mercury[12]	μg/L	ppb	2	ND	ND	ND	na	ND[h]
Molybdenum	μg/L	ppb	none	6	3	na	na	na
Nickel	μg/L	ppb	100	3	ND	1.11	5.81	ND
Selenium	μg/L	ppb	50	ND	ND	ND	3.31	ND
Silver	μg/L	ppb	100[a]	ND	ND	ND	ND	ND
Strontium	μg/L	ppb	8	1100	255	na	na	na
Thallium	μg/L	ppb	2	ND	ND	ND	ND	ND
Vanadium	μg/L	ppb	50[d]	2.8	3.9	1.89	3.3	ND[g]
Zinc	μg/L	ppb	5,000[a]	ND	ND	2.72	29.1	ND
Oxygenates								
diisopropyl ether (DIPE)	μg/L	ppb	none		ND	ND	ND	ND
ethyl-tert-buty-ether (ETBE; tert butyl ethyl ether)[13]	μg/L	ppb	none		ND	ND	ND	ND
methy-tert-butyl-ether (MTBE)	μg/L	ppb	5[a]		ND	ND	ND	ND
t-Butyl alcohol (TBA)[13]	μg/L	ppb	12[d]		ND	ND	ND	ND[g]
tert-amyl-methyl-ether (TAME)[13]	μg/L	ppb	none		ND	ND	ND	ND
Volatile Organic Compounds (VOCs)								
benzene	μg/L	ppb	1		ND	ND	ND	ND
bromobenzene	μg/L	ppb	none		ND	ND	ND	ND
bromochloromethane	μg/L	ppb	none		ND	ND	ND	ND
bromomethane (methyl bromide)	μg/L	ppb	none		ND	ND	ND	ND
bromoethane (ethyl bromide)	μg/L	ppb	none		na	ND**	na	ND[h]
n-butylbenzene	μg/L	ppb	260[d]		ND	ND	ND	ND
sec-butylbenze	μg/L	ppb	260[d]		ND	ND	ND	ND
tert-butylbenzene	μg/L	ppb	260[d]		ND	ND	ND	ND
carbon disulfide	μg/L	ppb	160[d]		ND	na	na	na

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Constituent	*Metric Units*	*Units*	*Maximum Contaminant Level (MCL)*	*Colorado River Yearly Average*^{2}	*State Water Project Yearly Average*^{2}	*San Diego Source Water Yearly Average*^{5A}	*NCWRP Tertiary Effluent Average*^{5B}	*NCWRP UV + Peroxide Average*^{6}
Volatile Organic Compounds (VOCs) (continued)	□							
carbon tetrachloride	µg/L	ppb	0.5		***ND***	***ND***	***ND***	***ND***
chlorobenzene (monochlorobenzene)	µg/L	ppb	70		***ND***	***ND***	***ND***	***ND***
chloroethane	µg/L	ppb	none		***ND***	***ND***	***ND***	***ND***
chloromethane (methyl chloride)	µg/L	ppb	none		***ND***	***ND***	***0.537***	***ND***
2-chlorotoluene (o-chlorotoluene)	µg/L	ppb	140^{d}		***ND***	***ND***	***ND***	***ND***
4-chlorotoluene (p-chlorotoluene)	µg/L	ppb	140^{d}		***ND***	***ND***	***ND***	***ND***
dibromomethane (methylene dibromide)	µg/L	ppb	none		***ND***	***ND***	***ND***	***ND***
1,2-dichlorobenzene(o-dichlorobenzene; 1,2-DCB)	µg/L	ppb	600		***ND***	***ND***	***ND***	***ND***
1,3-dichlorobenzene (m-dichlorobenzene; 1,3-DCB)	µg/L	ppb	600^{d}		***ND***	***ND***	***ND***	***ND***
1,4-dichlorobenzene (p-dichlorobenzene; 1,4-DCB)	µg/L	ppb	5		***ND***	***ND***	***0.20***	***ND***
dichlorodifluoromethane (Freon 12)^{13}	µg/L	ppb	1,000^{d}		***ND***	***ND***	***ND***	***ND***
1,1-dichloroethane	µg/L	ppb	5		***ND***	***ND***	***ND***	***ND***
1,2-dichloroethane (1,2-DCA)	µg/L	ppb	0.5		***ND***	***ND***	***0.331***	***ND***
1,1-dichloroethene (1,1-dichloroethylene; 1,1-DCE)	µg/L	ppb	6		***ND***	***ND***	***ND***	***ND***
cis-1,2-dichoroethene (cis-1,2-dichloroethylene; cis-1,2-DCE)	µg/L	ppb	6		***ND***	***ND***	***ND***	***ND***
trans-1,2-dichloroethene (trans-1,2-dichloroethylene; trans-1,2-DCE)	µg/L	ppb	10		***ND***	***ND***	***ND***	***ND***
1,2-dichloropropane (1,2-DCP)	µg/L	ppb	5		***ND***	***ND***	***ND***	***ND***
1,3-dichloropropane	µg/L	ppb	none		***ND***	***ND***	***ND***	***ND***
2,2-dichloropropane	µg/L	ppb	none		***ND***	***ND***	***ND***	***ND***
1,1-dichoropropene	µg/L	ppb	none		***ND***	***ND***	***ND***	***ND***

Appendix D: Water Quality Comparison of Source Waters to San Diego - Colorado River (CR), State Project Water (SPW), City of San Diego (SD)

Constituent	*Metric Units*	*Units*	*Maximum Contaminant Level (MCL)*	*Colorado River Yearly Average*[2]	*State Water Project Yearly Average*[2]	*San Diego Source Water Yearly Average*[5A]	*NCWRP Tertiary Effluent Average*[5B]	*NCWRP UV + Peroxide Average*[6]
Volatile Organic Compounds (VOCs) (continued)								
cis-1,3-dichloropropene	µg/L	ppb	0.5[c]		***ND***	***ND***	***ND***	***ND***
trans-1,3-dichloropropene	µg/L	ppb	0.5[c]		***ND***	***ND***	***ND***	***ND***
1,3-dichloropropene (1,3-dichloropropylene) Total	µg/L	ppb	0.5[c]		***ND***	***ND***	***ND***	***ND***
ethylbenzene	µg/L	ppb	300		***ND***	***ND***	***ND***	***ND***
hexachlorobutadiene	µg/L	ppb	none		***ND***	***ND***	***ND***	***ND***[h]
isopropylbenzene	µg/L	ppb	770[d]		***ND***	***ND***	***ND***	***ND***
p-isopropyltoluene (4-isopropyltoluene)	µg/L	ppb	none		***ND***	***ND***	***ND***[l]	***ND***
methylene chloride (dichloromethane; DCM)	µg/L	ppb	5		***ND***	***ND***	***0.276***	***ND***
methyl ethyl ketone (MEK; 2-butanone)	µg/L	ppb	none		***ND***	***ND*****	***na***	***ND***[h]
methyl isobutyl ketone (MIBK; 4-methyl-2-pentanone)	µg/L	ppb	120[d]		***ND***	***ND*****	***na***	***ND***[h]
naphthalene	µg/L	ppb	17[d]		***ND***	***ND***	***ND***	***ND***
n-propylbenzene	µg/L	ppb	260[d]		***ND***	***ND***	***ND***	***ND***
styrene	µg/L	ppb	100		***ND***	***ND***	***ND***	***ND***
1,1,1,2-tetrachloroethane	µg/L	ppb	none		***ND***	***ND***	***ND***	***ND***
1,1,2,2-tetrachloroethane	µg/L	ppb	1		***ND***	***ND***	***ND***	***ND***
tetrachloroethene (tetrachloroethylene; PCE)	µg/L	ppb	5		***ND***	***ND***	***ND***	***ND***
toluene	µg/L	ppb	150		***ND***	***ND***	***ND***	***ND***
1,2,3-trichlorobenzene	µg/L	ppb	none		***ND***	***ND***	***ND***	***ND***
1,2,4-trichlorobenzene (1,2,4-TCB)	µg/L	ppb	70		***ND***	***ND***	***ND***	***ND***
1,1,1-trichloroethane (1,1,1-TCA)	µg/L	ppb	200		***ND***	***ND***	***ND***	***ND***
1,1,2-trichloroethane	µg/L	ppb	5		***ND***	***ND***	***ND***	***ND***

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Constituent	*Metric Units*	*Units*	*Maximum Contaminant Level (MCL)*	*Colorado River Yearly Average^{2}*	*State Water Project Yearly Average^{2}*	*San Diego Source Water Yearly Average^{5A}*	*NCWRP Tertiary Effluent Average^{5B}*	*NCWRP UV + Peroxide Average^{6}*
Volatile Organic Compounds (VOCs) (continued)	□							
1,1,2-trichloroethene (trichloroethylene; 1,1,2-trichloroethylene; 1,1,2-TCE)	µg/L	ppb	5		***ND***	***ND***	***ND***	***ND***
trichlorofluoromethane (fluorotrichloromethane; freon 11)	µg/L	ppb	150		***ND***	***ND***	***ND***	***ND***
1,1,2-trichloro-1,2,2-trifluoroethane (1,1,2-trichlorotrifluoroethane; freon 113)	µg/L	ppb	1,200		***ND***	***ND***	***ND***	***ND***
1,2,3-Trichloropropane (1,2,3-TCP)	µg/L	ppb	.005^{d}		***ND***	***ND*****	***na***	***ND^{h}***
1,2,4-trimethylbenzene	µg/L	ppb	330^{d}		***ND***	***ND***	***ND***	***ND***
1,3,5-trimethylbenzene	µg/L	ppb	330^{d}		***ND***	***ND***	***ND***	***ND***
vinyl chloride	µg/L	ppb	0.5		***ND***	***ND***	***ND***	***ND***
m-xylene	µg/L	ppb	1750^{b}		***ND***	***ND***	***ND***	***ND***
o-xylene	µg/L	ppb	1750^{b}		***ND***	***ND***	***ND***	***ND***
p-xylene	µg/L	ppb	1750^{b}		***ND***	***ND***	***ND***	***ND***
xylenes (total)	µg/L	ppb	1750^{b}		***ND***	***ND***	***ND***	***ND***
Organochlorine Pesticides								
Aldrin^{12}	µg/L	ppb	0.002^{d}		***ND***	***ND***	***ND***	***ND***
α–BHC^{12}	µg/L	ppb	0.015^{d}		***ND***	***na***	***na***	***na***
β–BHC^{12}	µg/L	ppb	0.025^{d}		***ND***	***na***	***na***	***na***
δ–BHC^{12}	µg/L	ppb	none		***ND***	***na***	***ND***	***na***
γ–BHC (Lindane)^{12}	µg/L	ppb	0.2		***ND***	***ND***	***ND***	***ND***
Chlordane^{12}	µg/L	ppb	0.1		***ND***	***ND***	***ND***	***ND***
Chlorothalonil (1,3-dicyano-2,4,5,6-tetrachlorobenzene)	µg/L	ppb	none		***ND***	***na***	***na***	***na***
4,4'-DDD (Dichlorodiphenyldichloroethane)	µg/L	ppb	none		***ND***	***na***	***na***	***na***

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Organochlorine Pesticides (continued)								
4,4'-DDE[12]	µg/L	ppb	none		***ND***	***na***	***na***	***na***
4,4'-DDT[12]	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Dieldrin[12]	µg/L	ppb	0.002[d]		***ND***	***ND***	***ND***	***ND***
Endosulfan I[12]	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Endosulfan II[12]	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Endosulfan sulfate[12]	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Endrin	µg/L	ppb	2		***ND***	***ND***	***ND***	***ND***
Endrin aldehyde	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Heptachlor[12]	µg/L	ppb	0.01		***ND***	***ND***	***ND***	***ND***
Heptachlor epoxide[12]	µg/L	ppb	0.01		***ND***	***ND***	***ND***	***ND***
Hexachlorobenzene	µg/L	ppb	1		***ND***	***ND***	***ND***	***ND***
Hexachlorocyclopentadiene	µg/L	ppb	50		***ND***	***ND***	***ND***	***ND***
Methoxychlor[12]	µg/L	ppb	30		***ND***	***ND***	***ND***	***ND***
Propachlor	µg/L	ppb	90[d]		***ND***	***ND***	***ND***	***ND[g]***
Toxaphene[12]	µg/L	ppb	3		***ND***	***ND***	***ND***	***ND***
Polychlorinated biphenyls (PCB)12	µg/L	ppb	0.5		***ND***	***ND***	***ND***	***ND***
Trifluralin[12]	µg/L	ppb	none		***ND***	***ND***	***ND***	***ND[g]***
Carbamates	☐							
Aldicarb	µg/L	ppb	3[e] (7[d])		***ND***	***ND***	***ND***	***ND***
Aldicarb Sulfone	µg/L	ppb	2[e]		***ND***	***ND***	***ND***	***ND***
Aldicarb Sulfoxide	µg/L	ppb	4[e]		***ND***	***ND***	***ND***	***ND***
Baygon (Propoxur)	µg/L	ppb	30[d]		***ND***	***ND***	***ND***	***ND***
Carbofuran (Furadan)	µg/L	ppb	18		***ND***	***ND***	***ND***	***ND***
Carbaryl[12]	µg/L	ppb	700[d]		***ND***	***ND***	***ND***	***ND***
3-Hydroxycarbofuran	µg/L	ppb	none		***ND***	***ND***	***ND***	***ND***
Methiocarb	µg/L	ppb	none		***ND***	***ND***	***ND***	***ND***

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Carbamates (continued)	☐							
Methomyl[12]	µg/L	ppb	none		*ND*	*ND*	*ND*	*ND*
Oxamyl	µg/L	ppb	50		*ND*	*ND*	*ND*	*ND*
Organophosphorous Pesticides and Triazine Herbicides								
Alachlor[12]	µg/L	ppb	2		*ND*	*ND*	*ND*	*ND*
Atrazine[12]	µg/L	ppb	1		*ND*	*ND*	*ND*	*ND*
Bromacil	µg/L	ppb	none		*ND*	*na*	*na*	*na*
Butachlor	µg/L	ppb	none		*ND*	*na*	*na*	*na*
Diazinon	µg/L	ppb	6[d]		*ND*	*na*	*na*	*na*
Dimethoate	µg/L	ppb	1[d]		*ND*	*na*	*na*	*na*
Metolachlor	µg/L	ppb	none		*ND*	*na*	*na*	*na*
Metribuzin[12]	µg/L	ppb	none		*ND*	*na*	*na*	*na*
Molinate	µg/L	ppb	20		*ND*	*ND*	*ND*	*ND*
Prometon	µg/L	ppb	none		*ND*	*na*	*na*	*na*
Prometryn	µg/L	ppb	none		*ND*	*na*	*na*	*na*
Simazine	µg/L	ppb	4		*ND*	*ND*	*ND*	*ND*
Thiobencarb	µg/L	ppb	70 (1[a])		*ND*	*ND*	*ND*	*ND*
Organochlorine Herbicides								
Acifluorfen	µg/L	ppb	none		*ND*	*ND*	*ND*	*ND*
Bentazon	µg/L	ppb	18		*ND*	*ND*	*ND*	*ND*
Chloramben	µg/L	ppb	none		*na*	*ND*	*ND*	*ND*[g]
2,4-D	µg/L	ppb	70		*ND*	*ND*	*ND*	*ND*
2,4-DB	µg/L	ppb	none		*ND*	*ND*	*ND*	*ND*
3,5-Dichlorobenzoic Acid	µg/L	ppb	none		*ND*	*ND*	*ND*	*ND*
Dacthal (DCPA)	µg/L	ppb	none		*ND*	*ND***	*na*	*na*
Dalapon	µg/L	ppb	200		*ND*	*ND***	*ND*	*ND*
Dicamba	µg/L	ppb	none		*ND*	*ND*	*ND*	*ND*

Appendix D: Water Quality Comparison of Source Waters to San Diego - Colorado River (CR), State Project Water (SPW), City of San Diego (SD)

Constituent	*Metric Units*	*Units*	*Maximum Contaminant Level (MCL)*	*Colorado River Yearly Average*[2]	*State Water Project Yearly Average*[2]	*San Diego Source Water Yearly Average*[5A]	*NCWRP Tertiary Effluent Average*[5B]	*NCWRP UV + Peroxide Average*[6]
Organochlorine Herbicides (continued)								
Dichlorprop	µg/L	ppb	none		***ND***	***ND***	***ND***	***ND***
Dinoseb	µg/L	ppb	7		***ND***	***ND***	***ND***	***ND***
MCPA	µg/L	ppb	none		***na***	***ND***	***ND***	***ND***[g]
MCPP	µg/L	ppb	none		***na***	***ND***	***ND***	***ND***[g]
Pentachlorophenol[12]	µg/L	ppb	1		***ND***	***ND***	***ND***	***ND***
Picloram	µg/L	ppb	500		***ND***	***ND***	***ND***	***ND***
2,4,5-TP (Silvex)	µg/L	ppb	50		***ND***	***ND***	***ND***	***ND***
2,4,5-T	µg/L	ppb	none		***ND***	***ND***	***ND***	***ND***
Fumigants	☐							
Dibromochloropropane (1,2-dibromo-3-chloropropane; DBCP)	µg/L	ppb	0.2		***ND***	***ND***	***ND***	***ND***
Ethylene dibromide (EDB; 1,2-dibromoethane)[12]	µg/L	ppb	0.05		***ND***	***ND***	***ND***	***ND***
Semi-Volatile Organic Compounds (SVOCs)								
Benzo(a)pyrene[12]	µg/L	ppb	0.2		***ND***	***ND***	***ND***	***ND***
Di(2-ethylhexyl)adipate (Bis(2-ethylhexyl)adipate)	µg/L	ppb	400		***ND***	***ND***	***ND***	***ND***
Di(2-ethylhexyl)phthalate (Bis(2-ethylhexyl)phthalate; DEHP)[12]	µg/L	ppb	4		***ND***	***ND***	***ND***	***ND***
Trihalomethanes								
Chloroform (trichloromethane)[12]	µg/L	ppb	none		***na***	***0.81***	***1.34***	***1.9***
Bromodichloromethane (BDCM)	µg/L	ppb	none		***na***	***0.67***	***0.414***	***0.6***
Bromoform (tribromomethane)	µg/L	ppb	none		***na***	***0.113***	***ND***	***ND***
Chlorodibromomethane (Dibromochloromethane)	µg/L	ppb	none		***na***	***0.20***	***0.36***	***ND***
Total THMs	µg/L	ppb	80		***na***	***1.80***	***2.11***	***2.4***[k, p]

Appendix D: Water Quality Comparison of Source Waters to San Diego - Colorado River (CR), State Project Water (SPW), City of San Diego (SD)

Constituent	*Metric Units*	*Units*	*Maximum Contaminant Level (MCL)*	*Colorado River Yearly Average*[2]	*State Water Project Yearly Average*[2]	*San Diego Source Water Yearly Average*[5A]	*NCWRP Tertiary Effluent Average*[5B]	*NCWRP UV + Peroxide Average*[6]
Haloacetic acids (HAAs)								
Dibromoacetic acid	µg/L	ppb	none		***na***	***na***	***ND***	***ND***[g]
Dichloroacetic acid	µg/L	ppb	none		***na***	***na***	***ND***	***ND***[g]
monobromoacetic acid	µg/L	ppb	none		***na***	***na***	***ND***	***ND***[g]
monochloroacetic acid	µg/L	ppb	none		***na***	***na***	***ND***	***ND***[g]
trichloroacetic acid	µg/L	ppb	none		***na***	***na***	***2.60***	***ND***[g]
HAA5 (Total HAAs)	µg/L	ppb	60		***na***	***na***	***2.60***	***ND***[g]
Miscellaneous								
Diquat	µg/L	ppb	20		***ND***	***ND*****	***ND***	***ND***
Diuron	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Endothall	µg/L	ppb	100		***ND***	***ND*****	***na***	***ND***[h]
Glyphosate	µg/L	ppb	700		***ND***	***ND***	***na***	***ND***[h]
Dioxin (2,3,7,8-TCDD)[12]	µg/L	ppb	0.00003		***ND***	***ND*****	***na***	***ND***[h]
1,4-Dioxane	µg/L	ppb	3[d]		***ND***	***ND*****	***na***	***ND***[h, I]
2-methylisoborneol(MIB)	µg/L	ppb	none		***ND***	***4.7***	***na***	***na***
4-isopropyltoluene (Cymene)	µg/L	ppb	none		***na***	***ND***	***na***	***na***
4-nitrophenol	µg/L	ppb	none		***na***	***ND***	***ND***	***ND***[g]
dibenzo(a,h)anthracene	µg/L	ppb	none		***na***	***ND***	***na***	***na***
Diethyl phthalate (DEP)[12]	µg/L	ppb	none		***na***	***ND***	***ND***	***ND***[g]
Dimethyl phthalate	µg/L	ppb	none		***na***	***0.068***	***ND***	***ND***[g]
Di-n-butyl phthalate (DBP)[12]	µg/L	ppb	none		***na***	***0.103***	***ND***	***ND***[g]
Acenaphthylene	µg/L	ppb	none		***na***	***ND***	***ND***	***ND***[g]
Anthracene	µg/L	ppb	none		***na***	***ND***	***ND***	***ND***[g]
Benzo(A)anthracene	µg/L	ppb	none		***na***	***ND***	***ND***	***ND***[g]
Benzo(G,H,I)perylene	µg/L	ppb	none		***na***	***ND***	***ND***	***ND***[g]
Benzo(b)fluoroanthene	µg/L	ppb	none		***na***	***ND***	***ND***	***ND***[g]
Benzo(K)fluoroanthene	µg/L	ppb	none		***na***	***ND***	***ND***	***ND***[g]
Butyl benzyl phthalate[12]	µg/L	ppb	none		***na***	***ND***	***ND***	***ND***[g]

Appendix D: Water Quality Comparison of Source Waters to San Diego - Colorado River (CR), State Project Water (SPW), City of San Diego (SD)

Constituent	***Metric Units***	***Units***	***Maximum Contaminant Level (MCL)***	***Colorado River Yearly Average[2]***	***State Water Project Yearly Average[2]***	***San Diego Source Water Yearly Average[5A]***	***NCWRP Tertiary Effluent Average[5B]***	***NCWRP UV + Peroxide Average[6]***
Miscellaneous (Continued)								
Chrysene	µg/L	ppb	none		***na***	***ND***	***ND***	***ND[g]***
Fluorene	µg/L	ppb	none		***na***	***ND***	***ND***	***ND[g]***
Geosmin	µg/L	ppb	none		***na***	***6.25***	***na***	***na***
Indeno(1,2,3-CD)pyrene	µg/L	ppb	none		***na***	***ND***	***ND***	***ND[g]***
N-nitroso dimethylamine (NDMA)	ng/L	ppt	10[d]		***na***	***ND*****	***na***	***ND[h, l]***
Ortho Phosphates	mg/L	ppm	none		***na***	***ND[l]***	***5.34***	***ND[g]***
Phenanthrene	µg/L	ppb	none		***na***	***ND***	***ND***	***ND[g]***
Pyrene	µg/L	ppb	none		***na***	***ND***	***ND***	***ND[g]***
Paraquat	µg/L	ppb	none		***na***	***ND*****	***ND***	***ND***
Unregulated Contaminant Monitoring Rule (UCMR)-List 1								
DCPA mono and di-acid degradate	µg/L	ppb	none		***ND***	***ND*****	***na***	***ND[h]***
MTBE	µg/L	ppb	5[a]		***na***	***ND***	***na***	***ND[h]***
Nitrobenzene[14]	µg/L	ppb	none		***na***	***na***	***na***	***na***
2,4-dinitrotoluene	µg/L	ppb	none		***ND***	***na***	***na***	***na***
2,6-dinitrotoluene	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Acetochlor[12]	µg/L	ppb	none		***ND***	***na***	***na***	***na***
EPTC	µg/L	ppb	none		***ND***	***na***	***na***	***na***
DDE[12]	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Molinate	µg/L	ppb	20		***ND***	***ND***	***ND***	***ND[h]***
Terbacil	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Perchlorate	µg/L	ppb	6[d]		***na***	***ND***	***na***	***ND[h]***
UCMR-List 2								
1,2-Diphenylhydrazine	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Diazinon	µg/L	ppb	6[d]		***ND***	***na***	***na***	***na***
Disulfoton	µg/L	ppb	none		***ND***	***na***	***na***	***na***

Appendix D: Water Quality Comparison of Source Waters to San Diego - Colorado River (CR), State Project Water (SPW), City of San Diego (SD)

Constituent	*Metric Units*	*Units*	*Maximum Contaminant Level (MCL)*	*Colorado River Yearly Average*[2]	*State Water Project Yearly Average*[2]	*San Diego Source Water Yearly Average*[5A]	*NCWRP Tertiary Effluent Average*[5B]	*NCWRP UV + Peroxide Average*[6]
UCMR-List 2 (Continued)								
Fonofos	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Nitrobenzene[14]	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Prometon	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Terbufos	µg/L	ppb	none		***ND***	***na***	***na***	***na***
2,4,6-Trichlorophenol	µg/L	ppb	none		***ND***	***na***	***na***	***na***
2,4-Dichlorophenol	µg/L	ppb	none		***ND***	***na***	***na***	***na***
2,4-Dinitrophenol	µg/L	ppb	none		***ND***	***na***	***na***	***na***
2-Methyl-phenol	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Alachlor ESA[15]	TBD		none		***na***	***na***	***na***	***na***
RDX[15]	µg/L	ppb	0.3[d]		***na***	***na***	***na***	***na***
Diuron	µg/L	ppb	none		***ND***	***na***	***na***	***na***
Linuron[12]	µg/L	ppb	none		***ND***	***na***	***na***	***na***
UCMR-List 3								
Lead-210	TBD		none		***na***	***na***	***na***	***na***
Polonium-210	TBD		none		***na***	***na***	***na***	***na***
Endocrine Disrupting Compounds (EDCs), Pharmaceuticals and Personal Care Products (PPCPs)								
Hydrocodone	ng/L	ppt	none			***<1.0***	***84***	***<1.0***
Trimethoprim	ng/L	ppt	none			***<1.0***	***365***	***<1.0***
Acetaminophen	ng/L	ppt	none			***<1.0***	***<1.0***[n]	***<1.0***
Caffeine	ng/L	ppt	none			***<10***	***<10***	***<10***
Erythromycin-H_2O	ng/L	ppt	none			***<1.0***	***323***	***<1.0***
Sulfamethoxazole	ng/L	ppt	none			***3.0***	***788***	***<1.0***
Fluoxetine	ng/L	ppt	none			***<1.0***	***41***	***<1.0***
Pentoxifylline	ng/L	ppt	none			***<1.0***	***<1.0***	***<1.0***

Appendix D: Water Quality Comparison of Source Waters to San Diego - Colorado River (CR), State Project Water (SPW), City of San Diego (SD)

Constituent	*Metric Units*	*Units*	*Maximum Contaminant Level (MCL)*	*Colorado River Yearly Average*[2]	*State Water Project Yearly Average*[2]	*San Diego Source Water Yearly Average*[5A]	*NCWRP Tertiary Effluent Average*[5B]	*NCWRP UV + Peroxide Average*[6]
Endocrine Disrupting Compounds (EDCs), Pharmaceuticals and Personal Care Products (PPCPs) (Continued)								
Meprobamate	ng/L	ppt	none			***4***	***262***	***<1.0***
Dilantin	ng/L	ppt	none			***<1.0[n]***	***125***	***<1.0***
TCEP	ng/L	ppt	none			***<10***	***289***	***<10***
Carbamazepine	ng/L	ppt	none			***<1.0[n]***	***275***	***<1.0***
DEET	ng/L	ppt	none			***6.8***	***270***	***<1.0[l]***
Atrazine	ng/L	ppt	1			***2.0***	***1***	***<1.0***
Diazepam	ng/L	ppt	none			***<1.0***	***2.9***	***<1.0***
Oxybenzone	ng/L	ppt	none			***<1.0***	***<1.0[n]***	***<1.0[l]***
Estriol[11]	ng/L	ppt	none			***<5.0***	***<5.0***	***<5.0***
Ethynylestradiol[11]	ng/L	ppt	none			***<1.0***	***<1.0***	***<1.0***
Estrone[11]	ng/L	ppt	none			***<1.0***	***12***	***<1.0***
Estradiol[11]	ng/L	ppt	none			***<1.0***	***<1.0***	***<1.0***
Progesterone[11]	ng/L	ppt	none			***<1.0***	***<1.0***	***<1.0***
Testosterone	ng/L	ppt	none			***<1.0***	***<1.0***	***<1.0***
Androstenedione	ng/L	ppt	none			***<1.0***	***4.7***	***<1.0***
Iopromide	ng/L	ppt	none			***<1.0[n]***	***543***	***<1.0***
naproxen	ng/L	ppt	none			***<1.0***	***36***	***<1.0***
Ibuprofen	ng/L	ppt	none			***1.3***	***26***	***<1.0***
Diclofenac	ng/L	ppt	none			***<1.0***	***62***	***<1.0***
Triclosan	ng/L	ppt	none			***na[7]***	***na[7]***	***<1.0[m]***
Gemfibrozil	ng/L	ppt	none			***<1.0***	***184***	***<1.0***

Appendix D: Water Quality Comparison of Source Waters to San Diego - Colorado River (CR), State Project Water (SPW), City of San Diego (SD)

End Notes

na = Not Analyzed or Not Available.
ND = Not Detected.
LE = Laboratory Error.
TBD = To Be Determined.
MFL = million fibers per liter.
mg/L = milligrams per liter.
μg/L = micrograms per liter.
ng/L = nanograms per liter.
μmho/cm = micromhos per centimeter.
NTU = nephelometric turbidity unit.
CU = color unit.
pCi/L = picocuries per liter.
ppm = parts per million.
ppb = parts per trillion.
ppt = parts per trillion.

1 = Primary drinking water standards; lowest standard is used from the United States Environmental Protection Agency (EPA) or California Department of Health Services (DHS).
2 = CR and SPW general mineral, physical analysis and trace metals data provided by Metropolitan Water District of Southern California (MWD); all data reported are annual arithmetic
averages based on analysis of samples collected during fiscal year 2004-2005.
3 = Sample data provided by Montgomery Watson Harza Laboratory (MWH) or their contract laboratory.
4 = Average yearly data for calendar year 2005 provided by the City of San Diego Water Quality Laboratory (WQL) or their contract laboratory.
5A = Average yearly data for calendar year 2005 provided by the WQL or their contract laboratory, except where noted;
5B = WQL average data of three samples collected 3/25/2005, 4/13/2005 and between 7/14/2005 - 7/19/2005.
7 = No data available due to contaminated samples.
6 = Average of data obtained by the WQL and MWH for three sample dates, unless otherwise noted.
8 = MWD radiological samples collected during the four quarters of fiscal year 2002-2003.
9 = One radiological sample each from Lake Murray and Lake Miramar analyzed by MWH; sample date 4/13/2005.
10A = MWD: VOC data are averages for first three quarters of 2005 (fourth quarter data ***na*** at this time) of all source and treated water;
10B = MWD: pesticide, herbicide, SVOC and UCMR data are averages from source and treated water samples collected in August, 2004; 2005 data ***na*** at time of this comparison.
11 = Estrogens
12 = Compound/element in red is a suspected endocrine disruptor;
13 = DHS unregulated VOCs (April 11, 2005)
14 = Nitrobenzene is on List 1 and 2 Federal UCMR Contaminants with two different reporting levels and analytical method requirements.
15 = Monitoring will be required when List 3 requirements are finalized.
16 = Average of data provided by the Southern Nevada Water Authority Laboratory (SNWA) from analysis on samples collected on 3/25/05 and 04/13/2005.
17 = Average of data provided by the SNWA from analysis of samples collected on 4/13/2005 from Lake Murray and Lake Miramar.
18 = Average of data provided by the SNWA from analysis of samples collected on 4/13/2005 and 12/30/2005.

Appendix D: Water Quality Comparison of Source Waters to San Diego - Colorado River (CR), State Project Water (SPW), City of San Diego (SD)

End Notes (Continued)

A = Secondary drinking water standard.

b = MCL for xylene is either for a single isomer or for the sum of the three isomers.

c = MCL for 1,3-dichloropropene is either for a single isomer or for the sum of the cis & trans isomers.

d = Notification level. NOTE: action levels became notification levels in 2005 and some action levels have been archived but may be used by agencies per DHS.

e = Effective date of January 1, 1993 has been postponed, Federal Register, May 27, 1992, pending revised MCL.

f = MCL is for radium-226 & -228 combined.

g = WQL data only, based on analysis of one sample, sample date 4/13/2005.

h = MWH data only, based on average of two samples dated 4/13/2005 and 12/30/2005.

j = While data is greater than the San Diego Source Water Average, this analyte does not have a notification level or MCL.

k = Analyte not required analysis for source water.

l = Analyte detected in one or more samples, however, the average of the data is below the method detection limit and thus ***ND*** per state reporting protocols.

m = Data based on one sample, sample date 12/30/2005.

n = Analyte detected in one or more samples, however, the average of the data is below the method detection limit and thus ***<1*** per state reporting protocols.

p = While data is greater than the San Diego Source Water Average, it is below the MCL considered a human health concern.

** = No City of San Diego data available, average value taken from MWH's analysis of two samples, one each from Lake Murray and Lake Miramar, sample date 4/13/2005.

1 = Primary drinking water standards; lowest standard is used from the United States Environmental Protection Agency (EPA) or California Department of Health Services (DHS).

2 = CR and SPW general mineral, physical analysis and trace metals data provided by Metropolitan Water District of Southern California (MWD); all data reported are annual arithmetic

averages based on analysis of samples collected during fiscal year 2004-2005.

3 = Sample data provided by Montgomery Watson Harza Laboratory (MWH) or their contract laboratory.

4 = Average yearly data for calendar year 2005 provided by the City of San Diego Water Quality Laboratory (WQL) or their contract laboratory.

5A = Average yearly data for calendar year 2005 provided by the WQL or their contract laboratory, except where noted;

5B = WQL average data of three samples collected 3/25/2005, 4/13/2005 and between 7/14/2005 - 7/19/2005.

7 = No data available due to contaminated samples.

6 = Average of data obtained by the WQL and MWH for three sample dates, unless otherwise noted.

8 = MWD radiological samples collected during the four quarters of fiscal year 2002-2003.

Appendix E: Information from the Independent Advisory Panel for West Basin Municipal Water District's Seawater Barrier Water Conservation Project

Appendix E provides an excerpt from the 2008 report of the Independent Advisory Panel for West Basin Municipal Water District's Seawater Barrier Water Conservation Project. This excerpt comes from Appendix A of the 2008 Panel report.

Appendix A[1]

ORGANIC COMPOUNDS RECOMMENDED FOR MONITORING IN WATER INJECTED INTO THE SEAWATER BARRIER

The following list of chemicals is recommended for monitoring for the primary purpose of evaluating treatment performance for the West Basin plant. Inclusion of a chemical on this list does not necessarily imply that its presence in reclaimed water poses any health risk. Rather, this list of chemicals was carefully selected to include those that are relatively likely to occur at detectable levels in secondary wastewater and that can be used to evaluate the success of one or more of the advanced water treatment processes applied at the West Basin plant, specifically microfiltration/reverse osmosis (MF/RO) followed by advanced oxidation by UV/hydrogen peroxide.

Because these chemicals were selected as sets of complimentary contaminants for the purpose of assessing the performance of the treatment train used by West Basin, the entire list of chemicals should be monitored, at least initially. In some cases, more than one chemical was selected as an indicator of the performance of a single treatment process to provide some level of redundancy. Because these chemicals generally occur only at trace levels, it is possible that one of these indicators might not be detected in the secondary effluent, rendering it useless as an indicator of treatment performance. Also, because of the low detection limits required to detect these contaminants and the widespread occurrence of some of them in the environment, blank contamination can sometimes result in questionable data for a single indicator. Thus, using sets of chemicals rather than individual indicators is a more robust approach. It is recommended that routine monitoring take place quarterly for the list of indicator compounds in order to track system performance and reliability. However, in the case of a membrane system breach (i.e., conductivity spike), it is recommended that the indicator suite be analyzed to determine system integrity.

The criteria used to select these chemicals are described below. These criteria may be used as guidelines for selection of additional or alternative chemicals. For example, if one of the suggested indicator chemicals is not detected in the majority of the secondary wastewater samples collected, it will not be particularly useful for monitoring treatment performance. In that case, one or more alternate chemicals that meet the same criteria might be selected for monitoring instead. This list should not be construed as a recommended list for monitoring the performance of any other type of treatment train and should be reconsidered if West Basin makes any changes to their treatment methods. The criteria below provide additional information on the selection process.

SELECTION CRITERIA

Criterion 1: Molecular Weight

Generally, chemicals with molecular weight greater than 1000 g/mol are removed by granular filtration, while smaller chemical compounds require other types of treatment (Taylor and Wiesner

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[1] This excerpt comes from Appendix A of the 2008 report of the Independent Advisory Panel for West Basin Municipal Water District's Seawater Barrier Water Conservation Project.

2003). MF membranes remove particulate matter primarily by size exclusion (0.05 to 1.0 microns) (Wong 2003). MF generally does not remove dissolved substances without chemical pretreatment but can removed dissolved organic matter when operated in direct filtration mode (Wong 2003). RO membranes remove all particulates and typically remove chemical contaminants with a molecular weight cut off of less than 200 Daltons (Wong 2003). According to EPHC (2007), RO rejects monovalent ions and organics of molecular weight greater than approximately 50 Daltons (membrane pore sizes are less than 0.002 μm). For these reasons, chemicals with a range of molecular weights less than 1000 g/mol were selected.

Criterion 2: Water Solubility

Chemicals that are more water soluble generally are more likely to occur in water at relatively higher levels and are more resistant to conventional water treatment processes. Thus, chemicals with very low water solubility were excluded, and chemicals with a range of solubility values ≥ 0.01 mg/mL were selected.

Criterion 3: Hydrophobicity/Ionogenicity

Water treatment processes used to remove organic compounds rely primarily on sorption (e.g., to activated sludge or activated carbon), oxidation (e.g., by UV light, ozonation, chlorination, or other oxidants, alone or combined), physical separation (RO/NF), and biodegradation (e.g., in a membrane bioreactor) (Wells 2006). Treatment efficiency is dependent on the structure and properties of the target chemical, water quality, and the operational conditions of the treatment process employed. The pH of the water affects the ionization state of organic chemicals, which in turn impacts contaminant removal.

The octanol-water partition coefficient (K_{OW}, or P or P_{OW}) or log K_{OW} (or log P or log P_{OW}) is a measure of the degree of a chemical's solubility in octanol (a nonpolar solvent) versus water (a polar solvent). The K_{OW} or log K_{OW} of a chemical is used as a measure of hydrophobicity. Hydrophobic chemicals are more likely to be bound to particulate matter and thus to be removed by microfiltration along with the particulates to which they are bound.

The acid dissociation constant (K_a) describes a compound's tendency to be charged or neutral at a given pH. Taking the negative logarithm of this constant (designated as pK_a) allows for simpler comparison to pH. For organic acids, the concentrations of the ionized and neutral forms are equal when $pK_a = pH$, and pH values higher than the pK_a result in a greater proportion of the charged species. For a base, pH values lower than the pK_a produce a greater proportion of charged species. Knowledge of the pK_a is important because charged species are typically much more water soluble, and in comparison with the ionized form, the neutral form of an organic acid is expected to sorb to particulate matter to a greater extent. Moreover, RO/NF membranes tend of exhibit greater rejection of charged species as compared to neutral species. The actual rejection characteristics based on charge potential will be a function of the membrane properties (particularly zeta potential) and degree of membrane fouling.

For organic chemicals, the hydrophobicity-ionogenicity profile can be investigated to estimate the ratio of unionized to ionized chemical forms present in the pH range most commonly observed in wastewater and water treatment (i.e., pH 7-8).

Many wastewater derived contaminants are thought to occur in surface water because they are strongly hydrophilic in the pH range relevant to water treatment (i.e., characterized by log $D_{OW} < 1$ in the pH range 7-8) (Wells 2006). Another group of wastewater-derived contaminants, the hydrophobic ionogenic organic chemicals (HIOCs), are believed to occur in surface water despite their hydrophobic nature because they are ionized within the pH range commonly found in water and wastewater (Wells 2006).

Criterion 4: Occurrence in Secondary Wastewater

Lipophilic compounds like organochlorine pesticides and polychlorinated biphenyls (PCBs) adhere to solid particles and may be found in large amounts in suspended solids and sewage sludge but are relatively easy to remove during water treatment processes (GWRC 2003). However, even if a chemical is efficiently removed, significant amounts might still remain in reclaimed water or drinking water if the influent or source water concentrations are particularly large.

Analytical data and experimental treatment data are more reliable than predicted occurrence or removal but might represent site-specific conditions that are not applicable at other locations. Thus, the most robust approach to developing a list of chemicals for monitoring will involve consideration of analytical occurrence data and experimental removal data in conjunction with predicted removal based on physicochemical properties.

There are numerous sources of occurrence and treatment data for unregulated (or “emerging”) contaminants. For example, the United States Geological Survey (USGS) Toxic Substances Hydrology Program has arguably conducted the largest and most comprehensive emerging contaminant monitoring program in the world. The USGS published a national reconnaissance study on organic contaminants in “susceptible” surface waters in March 2002 (Kolpin et al. 2002). The Southern Nevada Water Authority (SNWA) conducts research on treatment of emerging contaminants in wastewater and drinking water and has recently published a report for the American Water Works Association Research Foundation (AwwaRF) entitled “*Removal of EDCs and Pharmaceuticals in Drinking and Reuse Treatment Processes*” (Snyder et al. 2007). This project evaluated nearly all commonly employed water treatment processes for their ability to remove emerging contaminants. A portion of this project sought to evaluate U.S. raw and finished drinking water for these contaminants.

Criterion 5: Removal by Microfiltration

Size and steric exclusion, electrostatic repulsion, adsorption, and diffusion mechanisms have been identified as key factors involved in removal of organic contaminants by membranes, including MF and RO membranes (Snyder et al. 2007). Interactions between organic contaminants and membranes are influenced by physicochemical properties of the target contaminant, membrane properties, solution chemistry, influent water quality (e.g., pH, presence of natural organic matter), and operating conditions (Snyder et al. 2007).

Microfiltration is generally not effective for removal of organics (Wong 2003), with the exception of contaminants with higher K_{OW} values, which might bind to and be removed along with particulate matter (Snyder et al. 2007). This holds true for the organic contaminants recommended for monitoring (Snyder et al. 2007).

Criterion 6: Removal by Reverse Osmosis

RO is an extremely effective barrier for many organic and inorganic contaminants, with the exception of small molecular weight, uncharged chemicals. Removal is dependent on the target chemical, membrane type, feed water quality (particularly pH), and operating conditions (Snyder et al. 2007). Reverse osmosis rejects contaminants based on steric characteristics (molecular and pore size) and through electrostatic repulsion (zeta potential and molecular charge). Adsorption and diffusion mechanisms also are key factors controlling organic contaminant transport through membranes.

RO membranes can generally be expected to remove chemicals that exceed a nominal molecular weight cut off in the range of 200 Daltons, as well as particulate matter to which chemicals might be bound (Wong 2003). However, in some cases, chemicals with molecular weights greater than the molecular weight cut off can permeate RO, possibly as a result of contaminant diffusion into and through the membrane, short-circuiting of the membrane, membrane damage, or support media failure (Snyder et al. 2007). An important considering in the evaluation of performance indicators is that the rejection of many trace organics will be similar to the rejection of common ions such as chloride. In other words, one should not expect higher rejection of trace organics than would be observed for chloride. On the other hand, certain organic contaminants, such as NDMA, are able to pass through RO membranes and result in significantly poorer rejection as compared to chloride. The fact remains that all membrane systems have some degree of "leakage" through fractured glue-lines, o-ring failures, or other physical limitations. For this reason, it is suggested that conductivity rejection will be an excellent surrogate for many of the emerging compounds of interest, while understanding that some low molecular weight neutral compounds will exhibit less rejection.

RO membranes typically achieve excellent removal (>90%) of pesticides, industrial chemicals, and steroid hormones; good removal of metals (70-90%); good to excellent removal of organometallics; and poor to low (<20% or 20-40%, respectively) removal of some inorganics (Snyder et al. 2003). There are a few contaminants that are known to breach many RO systems; these include boron, N-nitrosodimethylamine (NDMA), and 1,4-dioxane. While bromide rejection is generally quite good through RO, rejection is highly dependent on incoming bromide concentrations and on the chloride rejection capability of the specific membrane. RO has been shown to be highly effective in the rejection of PFOA, bromate, chlorate, and perchlorate, but NDMA rejection is generally less than 50%.

Criterion 7: Removal by UV/Hydrogen Peroxide

As early as the 1970s, UV light-based processes were identified as promising alternatives to conventional treatment technologies for organic pollutant removal from contaminated waters. In addition to the effectiveness of UV as a disinfectant, the energy carried by the UV-C radiations (200-280 nm) is often sufficient to break chemical bonds in organic compounds that absorb those radiations. This process is called direct UV photolysis, and its efficiency is strongly dependent on both the contaminant under consideration and water quality. At a typical disinfection dose of 40 mJ/cm^2, oxidation of organic contaminants is extremely limited. At significantly higher doses (i.e. greater than 400 mJ/cm^2, UV reacts with constituents in water to form highly reactive intermediates, with the formation of hydroxyl radicals (HO•) being the most important in water treatment for oxidation of organic compounds. Hydroxyl radicals are highly reactive, non-selective oxidants that can react with organic compounds.

UV irradiation is sometimes combined with hydrogen peroxide to form an advanced oxidation process (AOP) to achieve increased HO• yield and greater organic contaminant removal efficacy. UV doses >200 mJ/cm^2 may be effective for photolysis of NDMA and, if combined with hydrogen peroxide, achieve some reduction of other recalcitrant chemicals such as perfluorooctanoic acid (PFOA).

Criterion 8: Availability of Analytical Methods

Contaminants that were selected for monitoring were limited to (1) those that can be analyzed by contract labs or (2) those for which analytical methods have been developed and for which standards are readily available. One possible exception is meprobamate, which is a DEA Controlled Substance; however, forensic standards may be available for analytical calibration standards.

JUSTIFICATION FOR SELECTION OF CONTAMINANTS

The follow section provides specific information of the indicator contaminants selected for West Basin. Additional information is provided in Table A.1. Where guidelines for concentrations are available these are cited, but the focus of these analyses are primarily for performance evaluation rather than compliance monitoring.

Atrazine

Atrazine is known to known to occur in drinking water in the U.S., and its concentration in drinking water is regulated with a maximum contaminant level (MCL) of 0.003 mg/L (U.S. EPA 2006). Use of recently developed methods with lower detection limits has revealed that atrazine occurs ubiquitously at ng/L levels in reclaimed water, surface water, groundwater, and drinking water. Atrazine is difficult to remove with conventional water treatment processes and is detected at much greater concentrations than most of the pharmaceuticals and steroid hormones (Snyder et al. 2007). Consequently, it can serve as an indicator, with increased removal of atrazine suggesting efficient removal of steroid hormones and pharmaceuticals (Snyder et al. 2007).

Boron

Boron is a metalloid that occurs in various, mainly inorganic forms (e.g., as borax, boric acid, boron oxide, etc.) in sediments and sedimentary rocks. Weathering of boron-containing minerals found in rocks is thought to be the major source of boron to water, though volcanic activity and volatilization of boric acid from seawater are other major natural sources (U.S. EPA-OW 2006). Elemental boron is insoluble in water and occurs rarely in the environment. Most boron compounds found in the environment are soluble in water and hydrolyze to form a boric acid-borate ion equilibrium that is dependent on pH. Borate ion ($H_3BO_2^-$) predominates at pH > 9.3 (U.S. EPA-OW 2006). Because it is a weak acid with a pK_a of 9.2, undissociated boric acid (H_3BO_3) is the primary form that exists at pH levels found in natural water and drinking water.

Although boron is considered to be ubiquitous in the environment, it has been suggested to be useful as a conservative tracer of municipal wastewater (Schreiber & Mitch 2006). However, it should be noted that municipal wastewater is only one of several potential anthropogenic inputs to water (U.S. EPA-OW 2006).

Conventional water treatment processes (i.e. coagulation, sedimentation, filtration) do not significantly remove boron. Boron also is not easily removed by RO from water at pH levels common in surface water or drinking water (see Dydo et al. 2005 (landfill leachate treatment) and Taniguchi et al. 2001, 2004 (seawater desalination).

Carbamazepine

Carbamazepine (trade name Tegretol) is an anticonvulsant pharmaceutical used to treat epilepsy and bipolar disorder. It was listed among the top 300 (208th) most prescribed pharmaceuticals in the U.S. in 2005 (RxList 2008). Following excretion, it resists conventional sewage treatment and is persistent in the environment (Snyder et al. 2007). In several studies in Europe and the U.S., carbamazepine was reported to resist degradation and detected in wastewater (Glassmeyer et al. 2005, Gross et al. 2004). The California Department of Public Health included carbamazepine among compounds that might be considered for monitoring under the Groundwater Recharge Reuse Draft Regulation (CDPH 2007).

In a recent study evaluating 20 U.S. drinking waters (Snyder et al. 2007), carbamazepine was detected in 55% of the samples with a maximum concentration of 5.7 ng/L. If carbamazepine is detected, it is likely that other pharmaceuticals also are present (e.g., meprobamate and phenytoin).

Vogna et al. (2004) reported that UV/peroxide treatment was effective for degradation of carbamazepine. However, others indicated that UV/peroxide provides little removal of carbamazepine under typical water treatment conditions (Snyder et al. 2007 – see Table 13.4). Thus, degradation of this compound by UV/peroxide might be useful in assessing the effectiveness of this treatment where removal by the RO membrane system is not complete.

N,N-Diethyl-*m*-toluamide

N,N-Diethyl-*m*-toluamide (DEET) is used as an insect and tick repellant (ATSDR 2004). It is reported to be a widespread contaminant of wastewater effluents and streams in the U.S. (Glassmeyer et al. 2005, Sandstrom et al. 2005) as well as source waters for drinking water treatment plants (Snyder et al. 2007). The California Department of Public Health included DEET among compounds that might be considered for monitoring under the Groundwater Recharge

Reuse Draft Regulation (CDPH 2007). DEET is resistant to conventional water treatment processes and has been recommended as an indicator compound for oxidation process evaluation, with removal of DEET indicating that more readily oxidized substances will be subject to even greater removal.

1,4-Dioxane

1,4-Dioxane (or *p*-dioxane) is an synthetic compound primarily used as an industrial solvent or solvent stabilizer that prevents the breakdown of chlorinated solvents during manufacturing processes. Industrial solvents are used in degreasing, electronics, metal finishing, fabric cleaning, pharmaceutical production, herbicide and pesticide formulations, antifreeze, paper manufacturing, and many other applications. It is also present in ordinary household products, e.g., personal care products (shampoos, baby lotion, hair lotions, bath foam), cosmetic products, and dishwashing detergents and liquids.

1,4-Dioxane is stable in water and does not break down (ATSDR 2007). It has been reported to occur at concentrations of 1 µg/L or less (or reported to occur without concentration or detection limit information) in WWTP effluents in North America and the United Kingdom (ATSDR 2007). 1,4-dioxane was reported to occur at equal or greater concentrations in combined collection treatments of apartment houses and river basin sewage systems in Japan (ATSDR 2007). Little information is available to judge current levels of 1,4-dioxane in the environment. Historical data (1980s or earlier) suggest that 1,4-dioxane occurred at ambient levels of 1 µg/L in water, but higher concentrations were found in ground water (ATSDR 2007). It also has been detected in drinking water (ATSDR 2007, U.S. EPA 1987). The Environmental Working Group (2005) reported that 1,4-dioxane is a contaminant of drinking water provided in several systems in California.

It is relatively difficult to remove 1,4-dioxane during water treatment. Biological and physical methods are not effective for removal of 1,4-dioxane from water. Small amounts of 1,4-dioxane may be diluted with and discharged to WWTPs (ATSDR 2007, citing United Nations 1985), but because it is not amenable to biodegradation in WWTPs, much of the 1,4-dioxane disposed in this fashion will be discharged into the environment. ATSDR (2007) reported estimated release of 1,4-dioxane to the environment including releases to publicly owned water treatment works, so it is possible that detectable levels might be found in the secondary effluent treated by West Basin. Chemical treatment can be highly effective for removal of 1,4-dioxane from water, e.g., treatment with hydrogen peroxide in combination with a ferrous salt and treatment by chlorination. Treatment with chlorine and hypochlorous acid are highly effective for oxidation of 1,4-dioxane in water.

Certain advanced oxidation technology firms use 1,4-dioxane as a benchmark when sizing UV-AOP systems, and some full-scale treatment systems employ UV/peroxide treatment for the purpose of removing recalcitrant contaminants including 1,4-dioxane (Snyder et al. 2007). Degradation of 1,4-dioxane indicates that other less easily oxidized contaminants also are likely degraded. If it is found at elevated levels in secondary effluent subjected to further treatment by West Basin, it can serve as a useful indicator.

Estrone

Estrone is an estrogenic steroid hormone excreted by humans and other animals. It is one of the three natural endogenous estrogens, along with 17ß-estradiol and estriol. When all three phenolic steroid estrogen hormones are analyzed in wastewater treatment plant (WWTP) effluents, estrone is generally present in the greatest concentration (Snyder et al. 2007). Likewise, ethynylestradiol (a synthetic pharmaceutical estrogen used in oral contraceptive medications) is often found in municipal wastewater effluent, but at smaller concentrations than estrone. Estrone in tertiary treated effluent generally ranges from 1-15 ng/L, whereas estradiol and ethynylestradiol (a synthetic pharmaceutical estrogen used in oral contraceptive medications) generally occur at concentrations < 2 ng/L. Estrone has been reported to occur in source/raw water and rarely in finished drinking water (Kuch and Ballschmiter 2001, Snyder et al. 2007).

Estrone can be expected to occur in detectable concentrations in undiluted municipal wastewater and sometimes in surface water including wastewater-impacted source water for drinking water treatment plants, but it is easily removed during drinking water treatment. It has been recommended as an indicator compound for phenolic steroid estrogen hormones because it occurs at a greater concentration than the other phenolic steroids and is similarly susceptible to UV/peroxide treatment (Snyder et al. 2007).

Gemfibrozil

Gemfibrozil (trade name Lopid) is a blood lipid lowering drug. It has been reported to occur in effluents of conventional WWTPs at concentrations relatively higher than several other pharmaceutically active compounds (Gross et al. 2004, Sedlak et al. 2005). Gemfibrozil has also been found in surface water and finished drinking water in the U.S. (Snyder et al. 2007). The California Department of Public Health included gemfibrozil among compounds that might be considered for monitoring under the Groundwater Recharge Reuse Draft Regulation (CDPH 2007). MF does not remove gemfibrozil, but MF followed by RO can be expected to remove it very well (Sedlak et al. 2005, Snyder et al. 2007). Gemfibrozil appears to be resistant to UV/peroxide treatment (Snyder et al. 2007).

Iopromide

Iopromide is used in medical diagnostic x-ray contrast media. Iopromide and tris(2-chloroethyl) phosphate have been suggested as indicator compounds due to their widespread occurrence and resistance to oxidation (Snyder et al. 2007). Iopromide is a large molecular weight compound that is likely to be easily removed by RO. The California Department of Public Health included iodinated contrast media among compounds that might be considered for monitoring under the Groundwater Recharge Reuse Draft Regulation (CDPH 2007).

Meprobamate

Meprobamate is a pharmaceutical used to treat anxiety disorders. It is detected relatively frequently in USGS and SNWA monitoring programs. Although analytical methods are available for meprobamate in water, analytical standards can be difficult to obtain. Still, meprobamate (along with ibuprofen and sulfamethoxazole) has been recommended as an indicator compound in monitoring programs due to its frequent occurrence in the water cycle and variable removal during water treatment (Snyder et al. 2007). Meprobamate also appears to be resistant to many water treatment processes including some advanced processes (Snyder et al. 2007 – see Table 13.4). The California Department of Public Health included meprobamate among compounds that might be considered for monitoring under the Groundwater Recharge Reuse Draft Regulation (CDPH 2007).

Phenytoin

Phenytoin (trade name Dilantin) is an antiepileptic drug. It is detected relatively frequently in USGS and SNWA monitoring programs. In a nationwide survey (Snyder et al. 2007), phenytoin was noted to be among the most commonly detected pharmaceuticals in raw and finished drinking water. The California Department of Public Health included phenytoin among compounds that might be considered for monitoring under the Groundwater Recharge Reuse Draft Regulation (CDPH 2007). Phenytoin is only moderately removed by UV/peroxide treatment under typical conditions (Snyder et al. 2007), but RO can be expected to remove it very effectively.

Sulfamethoxazole

Sulfamethoxazole is an antibiotic medication. It has been reported to occur frequently in effluents of WWTPs and at relatively higher concentrations than several other pharmaceutically-active compounds (Glassmeyer et al. 2005, Sedlak et al. 2005). It is detected relatively frequently in USGS and SNWA monitoring programs and has been reported to occur in surface water, ground water, and finished drinking water in the U.S. (Snyder et al. 2007). Sulfamethoxazole (along with ibuprofen and meprobamate) has been recommended as an indicator compound in monitoring programs due to its frequent occurrence in the water cycle and variable removal during water treatment (Snyder et al. 2007). The California Department of Public Health included sulfamethoxazole among compounds that might be considered for monitoring under the Groundwater Recharge Reuse Draft Regulation (CDPH 2007). MF does not remove sulfamethoxazole, but MF followed by RO can be expected to remove it very well (Sedlak et al. 2005). Sulfamethoxazole appears to be degraded by UV/peroxide to a much greater extent than meprobamate, so removal of the antibiotic could serve as an indicator of the performance of the UV/peroxide process used by West Basin.

Tris(2-chloroethyl) phosphate

Tris(2-chloroethyl) phosphate (TCEP) was used historically in polyurethane foams, mainly for rigid foam, with some minor use in flexible polyurethane. Currently, it is mainly used to produce liquid polyester resins and used less often in back-coating formulations for textiles, PVC compounds, cellulose ester compounds, and coatings. Although it is commonly listed as a flame retardant, TCEP is not currently recommended for use as an additive to textiles or in block polyurethane foams because of its tendency to decompose. (World Health Organization 1998b)

TCEP has been detected at trace levels in sewage sludge, industrial and municipal wastewater effluents, landfill leachates, sediment, surface water, and drinking water (Lee et al. 2004). The

California Department of Public Health included TCEP among examples of compounds that might be considered for monitoring under the Groundwater Recharge Reuse Draft Regulation (CDPH 2007). Along with iopromide, TCEP has been suggested as an indicator compound due to its widespread occurrence and resistance to oxidation (Snyder et al. 2007).

IMPORTANCE OF ANALYTICAL DETECTION LIMITS

Selection of analytical methods with appropriate detection limits is extremely important for monitoring any of the above-listed compounds. If detection limits are too high, the contaminants of interest might not be detected even in the secondary effluent. Conversely, use of methods with very low detection limits might allow detection of contaminants even after treatment with MF/RO and UV/peroxide. This does not necessarily mean that the treatment train is not functioning effectively because some of these contaminants are commonly found in blanks due to ubiquitous occurrence in the environment (Snyder et al. 2007). A rigorous QA/QC program with the sampling events should include field blanks, lab blanks, and some duplicates (spiked duplicates should also be considered).

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Table A.1. Organic Compounds Recommended for Monitoring in Water Injected into the Seawater Barrier by West Basin Municipal Water District

Chemical	CAS No.	Mol. Weight	Mol. Volume ($Å^2$)**	Log K_{OW}	pK_a	Log D at pH 7§	Water Solubility (mg/mL)†	Relatively Likely to Occur in Secondary WWTP Effluent	Removal by Microfiltration	Removal by Reverse Osmosis	Removal by UV/Peroxide	Analytical Feasibility	Drinking Water Standards	Additional Reasons for Selection
Atrazine	1912-24-9	215.69	760.9	2.00-2.80 (Mackay et al. 2006, DOE 2007)	1.6-1.7 (Mackay et al. 2006, DOE 2007)	2.63	0.02-0.07 (24-70 mg/L) (Mackay et al. 2006, DOE 2007)	Yes; Found ubiquitously at ng/L in effluents	Poor	Excellent	Moderate to high (50-80%) (Snyder et al. 2007)*	Commonly analyzed by contract labs	Yes; MCL of 0.003 mg/L	Ubiquitous occurrence, Resistant to oxidation
Boron and compounds†	7440-42-8	61.83‡	NA 71.5 $Å^3$ (Dordas et al. 2000)	0.175‡	9.24‡		50 (50,000 mg/L)‡	Yes; Has been used as a conservative tracer of wastewater effluents (Schreiber & Mitch 2006)	Poor	Poor to moderate, depending on pH	Poor	Commonly analyzed by contract labs	Yes; U.S. EPA lifetime health advisory at 1 mg/L; 10-day health advisory at 0.9 mg/L for a 10-kg child (U.S. EPA 2006), health reference level at 1.4 mg/L (U.S. EPA-OW 2006)	Has been used as a conservative tracer of wastewater effluents (Schreiber & Mitch 2006)
Carbamazepine	298-46-4	236.27	774.6	2.45	13.9	2.67 (= log K_{OW})	0.02 (18 mg/L)	Yes	Poor (< 20%) (Snyder et al. 2007)	Excellent (> 80%) (Snyder et al. 2007)	Excellent (> 80%) (Snyder et al. 2007)*	Common analyte for pharmaceutical analyses	No; Draft Australian recommended drinking water guideline of 1,000 µg/L (EPHC 2007)	Very common marker for WWTP effluent – occurs in relatively high concentration
N,N-diethyl-*m*-toluamide (DEET)	134-62-3	191.27	758.5	2.02 2.18 (Snyder et al. 2007)	-0.67 (est.) (Snyder et al. 2007)	1.96 (= log K_{OW})	> 1 (> 1,000 mg/L at room temperature)	Yes (Drewes et al. 2007a,b)	Poor (< 20%) (Snyder et al. 2007)	Excellent (> 80%) (Snyder et al. 2007)	Moderate to good (50-80%) (Snyder et al. 2007)*	Standards readily available; Common in PPCP analytical suites	No; Draft Australian recommended drinking water guideline of 2.5 mg/L (EPHC 2007)	Detected in 90% of US drinking waters (Snyder et al. 2007)

Chemical	CAS No.	Mol. Weight	Mol. Volume (Å^2)**	Log K_{OW}	pK_a	Log D at pH 7§	Water Solubility (mg/mL)†	Relatively Likely to Occur in Secondary WWTP Effluent	Removal by Microfiltration	Removal by Reverse Osmosis	Removal by UV/Peroxide	Analytical Feasibility	Drinking Water Standards	Additional Reasons for Selection
Dioxane, 1,4-	123-91-1	88.10	NA	-0.27 (DOE 2007)	NA	-0.27 (= log K_{OW})	1000 (1,000,000 mg/L (DOE 2007); Miscible)	Detected in sewage / wastewater effluents (Hazardous Substances Data Bank 2008)	Poor	Poor	Moderate to Excellent depending on UV and peroxide doses	Relatively common analyte for contract laboratories	U.S. EPA 10-day health advisory at 0.4 mg/L and one-day health advisory at 4 mg/L for a 10-kg child; California advisory level of 3 µg/L. Michigan, Maine, and Vermont have set advisory or safety levels at 85, 70, and 50 µg/L, respectively. ; WHO guidance level of 50 µg/L.	Moderately common detection – poor rejection by UF-RO
Estrone	53-16-7	270.37	903.4	3.13	10.3	3.69 (-2.24 for glucuronide conjugate, 0.01 for sulfate conjugate) (Wells 2006)	0.03 (0.003 g/100 mL)	Moderately common at ng/L concentrations	Poor (< 20%) (Snyder et al. 2007)	Excellent (> 80%) (Snyder et al. 2007)	Excellent (> 80%) (Snyder et al. 2007)*	Common in EDC-Steroid analyses	No; Draft Australian recommended drinking water guideline of 0.3 µg/L (EPHC 2007)	Surrogate for other phenolic steroids (estrogen hormones)
Gemfibrozil	25812-30-0	250.34	945.1	4.77	4.42 (est.) (Snyder et al. 2007)	2.15 (0.03 for glucuronide conjugate) (Wells 2006)	0.01 (10.9 mg/L)	Commonly occurs at ng/L concentrations	Poor (< 20%) (Snyder et al. 2007)	Excellent (> 80%) (Snyder et al. 2007)	Excellent (> 80%) (Snyder et al. 2007)*	Moderately common in pharmaceutical analyses	No; Draft Australian recommended drinking water guideline of 6,000 µg/L (EPHC 2007)	High degree of occurrence and ideal surrogate for acidic pharmaceuticals
Iopromide	73334-07-3	791.12	1,461.6	-2.05	10.24 (est.) (Snyder et al. 2007)	-2.95	0.02 (23.8 mg/L)	Yes; ubiquitous at ng/L concentrations	Poor (< 20%) (Snyder et al. 2007)	Excellent (> 80%) (Snyder et al. 2007)	Moderate to good (50-80%) (Snyder et al. 2007)*	Less commonly analyzed, but standards are available	No; Draft Australian recommended drinking water guideline of 7,500 µg/L (EPHC 2007)	X-ray contrast media surrogate - large molecular weight

Chemical	CAS No.	Mol. Weight	Mol. Volume (Å^2)**	Log K_{OW}	pK_a	Log D at pH 7§	Water Solubility (mg/mL)†	Relatively Likely to Occur in Secondary WWTP Effluent	Removal by Microfiltration	Removal by Reverse Osmosis	Removal by UV/Peroxide	Analytical Feasibility	Drinking Water Standards	Additional Reasons for Selection
Meprobamate	57-53-4	218.25	781.0	0.70	9.2	0.7 (= log K_{OW})	4.7 (4,700 mg/L)	Yes; ubiquitous at ng/L concentrations	Poor (< 20%) (Snyder et al. 2007)	Excellent (> 80%) (Snyder et al. 2007)	Fair to moderate removal (20-50%) (Snyder et al. 2007)*	Less commonly analyzed; Difficult to obtain standards	No	Detected in nearly 80% of US drinking waters (Snyder et al. 2007)
Phenytoin	57-41-0	252.3	781.6	2.47	8.3	2.5 (pH 7) 2.36 (pH 8)	0.03 (32 mg/L)	Yes; commonly detected at ng/L concentrations	Poor (< 20%) (Snyder et al. 2007)	Excellent (> 80%) (Snyder et al. 2007)	Excellent (> 80%) (Snyder et al. 2007)*	Relatively common in pharmaceutical analyses	No	Detected in 74% of US drinking waters surrogate pharmaceutical
Sulfamethoxazole	723-46-6	253.3	769.4	0.89	6.0 (HSDB) 8.88 (Snyder et. al 2007)	-0.27 (pH 7) -0.90 (pH 8)	0.61 (610 mg/L, at 37 °C)	Yes; ubiquitous at ng/L concentrations	Poor (< 20%) (Snyder et al. 2007)	Excellent (> 80%) (Snyder et al. 2007)	Excellent (> 80%) (Snyder et al. 2007)*	Common in pharmaceutical analyses	No; Draft Australian recommended drinking water guideline of 350 µg/L (EPHC 2007)	Detected in 89% of US source waters – surrogate antibiotic
Tris (2-chloroethyl) phosphate (TCEP)	115-96-8	285.5		1.44 (DOE 2007), 1.7 (World Health Organization 1998)	NA	0.48 (= log K_{OW})	7.0 (7,000 mg/L)	Yes; ubiquitous at ng/L concentrations	Poor (< 20%) (Snyder et al. 2007)	Excellent (> 80%) (Snyder et al. 2007)	Poor (< 20%) (Snyder et al. 2007)*	Less commonly analyzed, but standards are readily available	No	Detected in 53% of US source waters – flame retardant surrogate

K_{OW} – octanol-water partition coefficient, MCL – maximum contaminant level (U.S. EPA primary drinking water regulation under the Safe Drinking Water Act); Mol. Volume – molecular volume, Mol. Weight – molecular weight, pK_a – acid dissociation constant, PPCPs – pharmaceuticals and personal care products, WWTP – municipal wastewater treatment plant

Unless otherwise noted, physicochemical properties data were taken from one or more of the following sources:

- Hazardous Substances Data Bank (HSDB) or ChemIDplus; available at TOXNET - Toxicology Data Network. Bethesda, Maryland: National Library of Medicine. http://toxnet.nlm.nih.gov/
- DrugBank - Wishart, D.S., C. Knox, A.C. Guo, S. Shrivastava, M. Hassanali, P. Stothard, Z. Chang, and J. Woolsey. 2006. DrugBank: a comprehensive resource for in silico drug discovery and exploration. *Nucleic Acids Research* 1(34 (Database issue)) January: D668-D672. http://www.drugbank.ca/
- Syracuse Research Corporation's Interactive PhysProp Database Demo [Online database]. Syracuse, New York: Syracuse Research Corporation. http://www.syrres.com/esc/physdemo.htm

*UV dosage of approximately 400 mJ/cm^2 with H_2O_2 dose of 5 mg/L.

†Water solubility at 25 °C unless otherwise noted.
‡Boron occurs in water mainly as boric acid (CAS no. 11113-50-1). Physicochemical properties are presented for boric acid (H_3BO_3): MW (U.S. EPA-OW 2006), log K_{OW} (World Health Organization 1998a, as cited by Hazardous Substances Data Bank 2008), pK_a (Hazardous Substances Data Bank 2008), water solubility (Hazardous Substances Data Bank 2008, U.S. EPA-OW 2006).
§Log D is the log of the pH-dependent *n*-octanol:water distribution ratio. Recorded data are predicted values taken from the ACS SciFinder databasexxx unless otherwise noted.
**Molecular volume was obtained by Snyder et al. (2007) using QikProp, version 2.2 (2005), Schrodinger, LLC, New York, New York.

APPENDIX F: Flow Science Scope of Work

A large number of simulations have been proposed in the scope of work for Flow Science (a total of 19 or more). In considering the issues at hand, the Panel has attempted to identify specific simulation scenarios and the variables and properties to evaluate in this essential study (Table F-1). Additional details and rationale follow.

Table F-1. Proposed Simulation Study Design

Simulation Series	Model Run	Purpose	Reservoir	AWT	Output
1	1.1	Calibrate ELCOM/CAEDYM (2006)	Existing	No	Physics, water quality
	1.2	Validate ELCOM/CAEDYM (2007)	Existing	No	Physics, water quality
	1.3	Verify tracer studies (1995)	Existing	No	Physics
2	2.1	Test enlarged model grid	Enlarged	No	Compare w/ 1.2
3	3.1	Optimize AWT – test site #1	Enlarged	Yes	Physics, % AWT, t_d
	3.2	Optimize AWT – test site #2	Enlarged	Yes	Physics, % AWT, t_d
	3.3	Optimize AWT – test site #3	Enlarged	Yes	Physics, % AWT, t_d
4*	4.1	Evaluate hypolimnetic oxygenation	Enlarged	No	Compare w/ 2.1
	4.2	**Evaluate hypolimnetic oxygenation + AWT**	**Enlarged**	**Yes**	**Compare w/ 4.1**
5*	5.1	Evaluate flow effects – low import	Enlarged	Yes	Compare w/ 4.2
	5.2	Evaluate flow effects – high import	Enlarged	Yes	Compare w/ 4.2, 5.1
6*	6.1	Evaluate AWT effects – low concentrations	Enlarged	Yes	Compare w/ 4.2
	6.2	Evaluate AWT effects – high concentrations	Enlarged	Yes	Compare w/ 4.2, 6.1
	6.3	Evaluate AWT effects - failure	Enlarged	Yes	Compare w/ 4.2
Total Model Runs	14				

*Simulations in Series 4, 5, and 6 should be at least 3 years to reduce effects of initial conditions and allow some approach to a steady-state condition, although with theoretical detention times of what appears will be 12-19 months, it may be necessary to run for longer period of time, perhaps 4 or more years.

Simulation Series 1: Calibrate/Validate the Model.

Series 1 is focused on calibrating and validating both the physics (ELCOM) and water quality/ecology (CAEDYM) modules to field measurements in the existing reservoir (e.g., 2006, 2007 data). The calibrated model should then be validated against a second dataset (e.g., 2007 data). Validation is a critical step, since the findings and conclusions drawn from all subsequent simulations are based upon this calibration and validation. Because the model will be used to provide key information about both the physics and the water quality in San Vicente Reservoir with advanced treated recycled water inputs, all modeled variables should be calibrated as necessary and validated:

- Temperature.
- Nutrients.
- DO.
- Chlorophyll a.
- Algal speciation (three groups are probably sufficient: diatoms, greens and blue-greens).

Zooplankton will probably also need to be simulated, since grazing can limit phytoplankton levels. The performance of the model for each of the variables should be rigorously quantified using appropriate statistics, and the criteria used to define an acceptable fit should be described. Also, as proposed in the scope of work, the third simulation should independently verify the calibrated-validated model's ability to reproduce the lanthanum tracer studies conducted in 1995.

Simulation Series 2: Test Enlarged Model Grid.
This series develop and tests the expanded model grid for the enlarged reservoir. No AWT inputs are included (Table F-1), so this simulation allows one to meaningfully compare the effects of increased storage volume on the physics and water quality of the reservoir. This simulation represents baseline conditions (no recycled inputs) for the enlarged San Vicente Reservoir.

Simulation Series 3: Optimize AWT.
The goal of Series 3 is to optimize the location of the AWT inlet so as to minimize the amount of short-circuiting and maximize retention and reaction in the reservoir. The Panel presumes that "typical" operational flows as defined by the City (e.g., 140,000 AF imported water; 7,000 AF local runoff; and 15,000 AF advanced treated recycled water as provided in presentation or other) will be used. Staying with the three simulations proposed in the original scope, the Panel presumes three different sites reflecting engineering or other constraints will be evaluated. These simulations should be used to quantify over time the transport processes in the reservoir, and include the percentage of advanced treated recycled water reaching outlet, transit times, and storage/detention times. Results should be presented using cumulative distribution functions (cdfs), probability density functions (pdfs), or other statistical representations.

Simulation Series 4: Evaluate Hypolimnetic Oxygenation.
This series uses the optimized AWT inlet location from Simulation Series 3 to compare physics and water quality in the reservoir under nominal flow conditions with and without hypolimnetic oxygenation (Model Runs 4.2 and 4.1, respectively). This effort is important because it quantifies the water quality gains provided by the hypolimnetic oxygenation system, and should also help in the design and operation of the system, including the length and siting of the oxygenation lines. Moreover, the second simulation (i.e., Model Run 4.2, with hypolimnetic oxygenation and AWT inflows) serves as the reference condition for all subsequent simulations (hence, the bold font in Table F-1). It is recommended that these and subsequent model runs be conducted for a 3-year simulation time to minimize the effects of initial conditions on predicted outcomes, especially in light of the relatively long theoretical detention time.

Simulation Series 5: Evaluate Flow Effects.

The volume of water imported into San Vicente Reservoir affects the hydrologic balance, relative proportion of added advanced treated recycled water, and potentially affects the physics and water quality in the reservoir. The effects of different imported water flow rates or runoff will be explored in this proposed series and compared with the reference case (i.e., Model Run 4.2: Nominal flow, hypolimnetic oxygenation and AWT inputs). The fraction of advanced treated recycled water in the reservoir and outflow, transit and relative storage times, and water quality should all be evaluated to identify the sensitivity of the system to variations in imported water flows.

Simulation Series 6: Evaluate AWT Effects.

The water quality in the reservoir will be dependent upon nutrient loading from all sources, including the advanced treated recycled water, if any. The simulations in Model Runs 4.1 and 4.2 will quantify the incremental change in predicted water quality associated with AWT inflows under “nominal” flow and effluent concentration conditions. The purpose of the simulations here are to evaluate predicted changes in reservoir water quality from long-term improved treatment efficiencies (Model Run 6.1), poorer treatment efficiencies (Model Run 6.2), and (in the case of the final simulation) the effect of a treatment plant failure. This latter simulation should be used to illustrate the capacity of the reservoir to serve as an environmental barrier, dilute and assimilate the waste load, provide lag time, and potentially remove some fraction of the waste load through in-lake processes. It is in this simulation that the capacity of the reservoir to remove contaminants through inactivation, photolysis, hydrolysis, and other microbiological and chemical processes can be demonstrated.

APPENDIX G: Survival (Inactivation/Die-Off) of *Cryptosporidium* as a Function of Water Temperature

Cryptosporidia are resistant to chlorination and are a challenge to filtration processes. The data below provide a basis for establishing maximum *Cryptosporidia* concentrations in advanced treated recycled water that could be related to reservoir concentrations and die-off rates based on water temperature and retention time minimum requirements. Additional removal is provided by sedimentation, solar UV, and metabolism by larger organisms.

The King et al., 2005 study[1] and others contain a detailed quantitative investigation of the temperature-dependent inactivation (loss of infectivity) of *C. parvum* and demonstrate that the rates of inactivation increase rapidly as the water temperature rises from 15°Celcius (C) to 37°C, and especially as temperatures exceed 20°C. Inactivation at 15°C or lower was not significant over 10 weeks, whereas 4 logs of inactivation were achieved in 70 to 80 hours (approximately 3 days) at 37°C (Table G-1).

Table G-1. *Cryptosporidium* Inactivation Results by Time (Days) and Water Temperature

Temperature	1 log	2 log	3 log	4 log
15°C	-	-	-	-
20°C	56	70	-	-
25°C	28	35	49	56
30°C	4	7	10-15	15-20
37°C	<2	~2.5	<3	-

Source: King et al., 2005.

These data are very consistent with earlier work conducted in both filter-sterilized and non-filter-sterilized river water samples. The numbers of infective oocysts stored at 21 to 23°C decreased by 3.3 and 2.6 logs, over 12 weeks, and no infective foci were detected in 14 weeks (Pokorny, 2002).[2]

The reservoir has a large assimilative capacity, and the retention time for treated water added to the reservoir is expected to exceed 1 year. The preference is that residual organic components in the advanced treated recycled water would be biodegradable, and that any potentially harmful microorganisms in the water would be removed by die off, sedimentation, and other natural purification processes in the reservoir. It is recognized that, in any case, the reservoir water will undergo subsequent complete conventional drinking water treatment when it is abstracted for public water supply use.

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[1] King, B.J., A.R. Keegan, P.T. Monis, and C.P. Saint (2005). "Environmental Temperature Controls/Cryptosporidium/Oocyst Metabolic Rate and Associated Retention of Infectivity." *Applied and Environmental Microbiology*, 71 (7), 3848-3857.

[2] Pokorny, N.J., S.C. Weir, R.A. Carreno, J.T. Trevors, and H. Lee (2002). "Influence of Temperature on *Cryptosporidium* Parvum/Oocyst Infectivity in River Water Samples as Detected by Tissue Culture Assay." *Journal of Parasitology*, 88:3, 641-643.

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18700 Ward Street
P.O. Box 8096
Fountain Valley, CA 2728-8096
(714) 378-3278
(714) 378-3375 (fax)
www.NWRI-USA.org