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National Water Research Institute

Report of the Scientific Advisory Panel

ORANGE COUNTY WATER DISTRICT'S

Santa Ana River Water Quality and Health Study

August 2004

In Memory of
LANGDON 'DON' OWEN

This report is dedicated to the memory of Langdon "Don" Owen, a pioneer of the Southern California water industry, who passed away April 24, 2003. Mr. Owen began his career 50 years ago as an engineer with the California Department of Water Resources, where he supervised planning for the proposed Peripheral Canal around the Sacramento-San Joaquin Delta during construction of the State Water Project. In 1963, he joined the Orange County Water District in Fountain Valley, California, as District Engineer, and eventually rose to the post of General Manager. Mr. Owen left the Orange County Water District in 1973 to form his own consulting firm in Newport Beach, California. He later served from 1980 to 1998 as an elected Board Member of the District. He also represented Orange County on the Metropolitan Water District of Southern California's Board of Directors since 1996.

During the decade he managed the Orange County Water District, he devised and oversaw construction of Water Factory 21, an internationally known water treatment and groundwater recharge plant in Fountain Valley, California. The facility, developed in the mid-1960s, was designed to protect groundwater from seawater intrusion through injections of highly treated reclaimed water mixed with deep-well water. It has helped to reduce the region's dependence on the State Water Project and Colorado River supplies, and has attracted more than 1,000 visitors a year from 30 countries.

The Scientific Advisory Panel for the Santa Ana River Water Quality and Health Study agrees with Virginia Grebbien, current General Manager of the Orange County Water District, that: "Mr. Owen was an icon in the water industry and a visionary leader who was light-years ahead of his time." The Orange County Water District benefited immensely from his visionary leadership during the years he served on the District's Board of Directors. Without his vision and leadership, there may not have been a Santa Ana River Water Quality and Health Study or a Groundwater Replenishment System, both of which will serve the Orange County Water District well in the years ahead. This report, in which the conclusions of the Scientific Advisory Panel for the Santa Ana River Water Quality and Health Study are presented, is dedicated to his memory.

Acknowledgments

The Scientific Advisory Panel (Panel) of the Santa Ana River Water Quality and Health (SARWQH) Study is grateful for the financial support provided by the Orange County Water District (OCWD), and for the overall support of William R. Mills, Jr., and Virginia Grebbien, former and current General Managers of OCWD, respectively, throughout the course of the SARWQH Study. The Panel is also deeply appreciative of the OCWD staff (Michael Wehner, Greg Woodside, Nira Yamachika, Katherine O'Connor-Patel, Roy Herndon, and Susan Bradford), who exhibited a high degree of responsiveness to the Panel's suggestions, alerted us to potential new problems encountered in the District operations, and provided finely-tuned management of the overall project. In addition, we thank them for the valuable technical support they provided. The Panel is also indebted to numerous other individuals in the following departments at OCWD: Hydrogeology, Water Quality, and Laboratories. Without the support of these individuals, who collected and analyzed thousands of water samples, designed and supervised the drilling and casing of monitoring wells, and performed other tasks too numerous to mention, the SARWQH Study could not have been completed.

The Panel is grateful to the many distinguished researchers who participated in the SARWQH Study and is deeply appreciative of their scientific contributions and support. The Panel is particularly grateful to M. Lee Davisson (Lawrence Livermore National Laboratory) and William Yanko, Ph.D. (Consulting Microbiologist and former Chief of the Microbiology Laboratory at the County Sanitation Districts of Los Angeles County) for analyzing and summarizing specific research studies (e.g., tracer studies to determine flow paths and residence times of recharged water [Davisson] and microbiological studies [Yanko]).

The Panel also acknowledges the contributions made by its *ex officio* members: Richard H. Sakaji, Ph.D., P.E. (California Department of Health Services); Larry Honeyborne, REHS (Orange County Health Care Agency); and Hope Smythe (California Regional Water Quality Control Board, Santa Ana Region [VIII]). The Panel is also grateful to Robert Hultquist, P.E. (California Department of Health Services) for his technical assistance and for keeping us informed of pending changes in the regulations governing reclaimed water.

Finally, the Panel is deeply appreciative of the support provided by the National Water Research Institute (NWRI) and its Executive Director, Ronald B. Linsky. The Panel is also appreciative of NWRI's Gina Melin for editing this report. The Panel was formed under the auspices of NWRI in 1996 and received the whole-hearted support of Mr. Linsky throughout the duration of the SARWQH Study. The Panel is, and will remain, deeply grateful to NWRI and Mr. Linsky for this support.

Contents

FIGURES

ACRONYMS

AF	Acre feet (1 acre foot = 43,560 cubic feet)
AFY	Acre feet per year
CPE	Cytopathic enterovirus *or* cytopathic effect
DHS	California Department of Health Services
DOC	Dissolved organic carbon
EDTA	Ethylenediamine tetraacetic acid
EPA	United States Environmental Protection Agency
GWR System	Groundwater Replenishment System
ICR	Information Collection Rule
IFA	Immune fluorescence assay
LAS	Linear alkylbenzene sulfonate
MBAS	Methylene blue active substance
mgd	Million gallons per day
MTBE	Methyl tertiary butyl ether
NCEA	National Center for Environmental Assessment
NDMA	N-nitrosodimethylamine
NHEERL	National Health and Environmental Effects Laboratory
NTA	Nitrilotriacetic acid
Non-CPE	Non-cytopathic enterovirus *or* non-cytopathic effect
NWRI	National Water Research Institute
OC	Orange County
OCSD	Orange County Sanitation District
OCWD	Orange County Water District
PCR	Polymerase chain reaction
QA/QC	Quality assurance/quality control
SAR	Santa Ana River
SARWQH	Santa Ana River Water Quality and Health Study
SUVA	Specific ultraviolet absorbance
TDS	Total dissolved solids
TOC	Total organic carbon
TOX	Total organic halide
WERF	Water Environment Research Foundation

Executive Summary

The Santa Ana River Water Quality and Health (SARWQH) Study was initiated by the Orange County Water District (OCWD) in 1994 to address questions about the use of Santa Ana River (SAR) water for recharging the Orange County (OC) groundwater basin because of the high percentage of treated wastewater in the river's baseflow. The study was designed to provide scientific information to help address concerns frequently expressed by the California Department of Health Services (DHS) regarding the use of reclaimed water to recharge groundwaters subsequently withdrawn for potable use. Researchers from several universities, research institutions, and government agencies participated in the study. A list of the papers and reports that were produced, as well as research institutions and government agencies that participated in the study, is presented in the Appendix.

At the request of OCWD, the National Water Research Institute (NWRI) formed the Scientific Advisory Panel (Panel) in the spring of 1996 to provide independent review and guidance to the SARWQH Study. Panel membership includes nationally recognized experts in various fields related to public health, such as environmental chemistry, environmental engineering, environmental microbiology, environmental epidemiology, groundwater recharge, hydrology, toxicology, and water quality. Panel members generally met once per year as a full Panel to provide a comprehensive review of the research findings and to provide overall direction regarding various research elements. Additionally, members of the Panel serving on various subcommittees met on an as-needed basis. The subcommittees were:

- Hydrogeology.
- Microbiology.
- Organics and Water Chemistry.
- Toxicology.
- Health Effects.

The first meeting of the Panel was held on June 3-5, 1996, and the final meeting was held on April 27-30, 2003. The findings, conclusions, and recommendations of the Panel are summarized in this report. The overall conclusions and recommendations of the Panel are presented in Chapter 5 of this report.

The Study Setting

The SAR is the primary source of water for recharging the OC groundwater basin, which provides over 2-million OC residents with about two-thirds of their water supply. As with many densely populated metropolitan areas in the western United States, OC has a limited natural local water supply that does not meet its water demands. The region's arid climate is characterized by dry summers and mild winters, with an average rainfall of about 13 inches per year. OC uses almost twice the amount of water that is currently available in the SAR watershed, and the local supply must be supplemented by the purchase of imported water from the Colorado River and from Northern California. Population growth projections indicate that the importance of maximizing local groundwater supplies is clear, especially since adequate supplies of imported water may not be available in the future. Thus, groundwater recharge with SAR water is critical for replenishing OC's groundwater supply.

During the summer months, much of the SAR baseflow is tertiary treated wastewater from upstream treatment facilities in San Bernardino and Riverside Counties. Tertiary treatment, or advanced wastewater treatment, refers to a tertiary water treatment process (e.g., filtration, beyond primary [physical] and secondary [biological] treatment). The treated wastewater discharges, which currently total approximately 161-million gallons per day (mgd) (~180,000 acre-feet per year [AFY]), comprise more than 90 percent of the baseflow of the river. Total SAR baseflow has increased significantly over the past two decades due to population growth in the tributary watershed upstream of Prado Dam and to increases in treated wastewater discharges into the river from these rapidly urbanizing areas in the watershed. These upstream discharges will continue to increase as the population grows in the upper watershed. OC's dependence on the groundwater basin will also increase with time.

Hydrogeology

The hydrogeologic studies conducted as a part of SARWQH investigations were important in defining how, where, and when water leaving a recharge basin reaches a given well, and what changes occur to its quality during passage underground. These studies were possible only because of the construction of multi-depth monitoring wells by OCWD. Analyses undertaken during the years of the SARWQH Study consisted of age dating, injection and subsequent monitoring of xenon and sulfur hexafluoride groundwater tracers, and the study of porous media flow near the outer surface of a recharge basin. Based on these studies, it was found that:

- Recharge water migration was complex and rapid.
- Groundwater originating from the three recharge areas studied (Anaheim Lake, Kraemer Basin, and the SAR) maintained individual flow paths, and the mixing of groundwater from the three recharge areas was not observed.
- Groundwater may have traveled at different rates over the distance downstream from the recharge source, and flow rates varied with each recharge location.
- The horizontal distance from a well to a recharge basin was not a good predictor of the travel time of recharge water to the well (horizontal groundwater flow velocities ranged from approximately 4 to 25 feet per day, but so little vertical movement was observed that deep wells adjacent to the recharge basins may not be receiving water from the basin).

Microbiology

The SARWQH Study included a significant and intensive microbiology component. Over the last 7 years, the study's microbiological monitoring program was directed toward evaluating the sanitary quality of SAR water and the recharge monitoring wells within the study area. Samples of water were assayed for indicator bacteria, protozoan cysts, culturable enteric viruses, and somatic and male-specific bacterial coliphage. A major focus was on assessing the potential vulnerability of the groundwater system to viruses, because they are more resistant to treatment than bacteria (which are usually removed easily by subsequent disinfection) and protozoa (which typically are removed by the natural filtering capacity of the aquifer and other mitigating factors).

Testing was conducted for coliphage and *Salmonella* phage, both of which are bacterial viruses. These organisms are considered indicators of fecal contamination and are not human pathogens. Phage were detected in 13 percent of the samples collected from the wells in the study area. There was a spatial randomness to the positive samples, and most of them occurred during or shortly after periods of heavy rainfall. Furthermore, based on the age of the groundwater, phage detection did not appear to be associated with the SAR or recharge activities of OCWD. Bacterial indicators were detected in 3 percent of the groundwater samples; however, no human enteric viruses were detected in 200 groundwater samples. Only one (a river water sample below Prado Dam) out of 100 SAR samples was positive for enteric virus.

Although 40 groundwater samples from monitoring wells were analyzed for protozoa, only one was positive for *Giardia* and two were positive for *Cryptosporidium*. The protozoan cysts detected in groundwater contained no internal structures and were considered nonviable. Protozoan pathogens were detected in eight out of 105 samples of SAR water, none of which were considered viable.

The Panel concluded, based on the microbial studies, that:

- The SAR does not represent a significant source of human pathogens in the recharge aquifer and, concomitantly, the health risk associated with groundwater recharge using SAR water is small.
- The groundwater in the SARWQH Study area is vulnerable to microbial contamination, as indicated by the occasional presence of coliphage.
- The source of the coliphage in groundwater samples is unknown.
- The coliphage were likely of fecal bacterial origin and could be from sources such as leaking sewers rather than from the SAR or associated recharge activities.

To minimize any risks that might be associated with the vulnerability of the groundwater to fecal contamination, the Panel recommends disinfection of all production wells in the study area found positive for somatic or male-specific coliphage.

The Panel spent an appreciable amount of time discussing the need for continued monitoring of the groundwater and OCWD's recharge activities. The Panel recommends:

- Water samples from wells in the groundwater basin should be tested routinely for somatic and male-specific coliphage and *E. Coli* (consistent with the applicable United States Environmental Protection Agency [EPA] Groundwater Rule) to determine to what degree the basin may be vulnerable to fecal contamination from any source that may be inferred from their presence.
- If two or more positive samples are detected in any well, then sampling for culturable enteric viruses and bacterial indicators of fecal contamination should be conducted.
- An appropriate number of monitoring wells should be constructed around the Santiago Pits, a recharge area that was not included in the SARWQH Study. Subsequently, the groundwater flow characteristics around the Santiago Pits should be determined, and water samples from the Santiago Pits and from the monitoring wells should be analyzed for specific indicator and pathogenic organisms.

Organics and Water Chemistry

The origins and composition of organic carbon in surface waters subject to wastewater discharge have been of particular concern in all previous evaluations of the public health safety of groundwater recharge. It has been noted that approximately 90 percent of the total organic carbon (TOC) entering groundwater was unidentified.[1]

In the SARWQH Study, OCWD employed carefully planned analytical and monitoring approaches to identify unknown dissolved organic carbon (DOC), as well as previously identified synthetic organic chemicals known to be found in wastewater. OCWD obtained the requisite research expertise from uniquely qualified scientists

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[1] State of California (1987). *Report of the Scientific Advisory Panel on Groundwater Recharge with Reclaimed Water*. Prepared for the State of California, State Water Resources Control Board, Department of Water Resources, and Department of Health Services.

at Stanford University, the United States Geological Survey, and Lawrence Livermore National Laboratory. Their efforts resulted in the classification of a substantial majority of organic matter in the SAR and recharge system, perhaps greater than 90 percent. In addition, the isolation and classification schemes provided information on the relationship of compound classes to their probable origins. The Panel concluded that this research was groundbreaking and of exceptional quality, and will be widely assimilated in future recharge studies and in the broader field of aquatic geochemistry.

The Panel concluded that most of the organic carbon in the SAR, recharge basins, and groundwater near the recharge basins is of natural origin. Radiocarbon and chemical classification studies determined that an approximate upper limit of 20 to 25 percent of the DOC entering the Anaheim Lake recharge basin, after significant pretreatment, is of anthropogenic origin and consists mostly of metabolites of linear alkylbenzene sulfonate (LAS) detergents and surfactants. The Panel also concluded that the remainder of the organic carbon is derived from contact with the terrestrial biosphere. Metabolites of LAS and other specific wastewater indicators (also of detergent origin) were found in lower concentrations in the SAR than in treatment plant effluents, with further decreases occurring after passage through the recharge basin sediments and subsequent groundwater transit.

Based on the research conducted on wastewater indicator compounds, it can be concluded that some waste-related organic materials do reach the Forebay groundwaters and, therefore, serve as markers of the incursion of wastewater; however, no chemicals of wastewater origin were identified at concentrations that are of public health concern in the SAR, in water in the infiltration basins, or in nearby groundwaters. These studies also show that the groundwater transit of recharged SAR water produces a quality and composition of DOC in production water that is comparable to other sources of drinking water, such as the Colorado River. The facilities and mechanisms currently employed for recharge by OCWD have proved effective for removing a significant percentage of organic material in recharge water. For example, the TOC in SAR water is reduced by approximately 50 percent during infiltration and 1 month of subsurface flow time.

Toxicology

The toxicology efforts largely focused on the extent to which the chemical and biomonitoring data derived from the SARWQH Study provided evidence that water from SAR recharge activity could impact human health when consumed upon withdrawal for potable purposes. The Panel recognized that considerable assurance is provided that the water is safe when analyzing water for contaminants identified in:

- Standards.
- Lists of priority pollutants.
- Measures of unregulated chemicals identified in municipal wastewater (e.g., pharmaceutically active compounds).
- General measurements of water quality.

However, there remains the possibility of chemicals that may not have been detected, even with the most modern analytical methods. As a result, there can be no guarantee of safety; therefore, continuing emphasis needs to be placed on using appropriate treatment technology and on implementing an ongoing monitoring effort that focuses on the potential for new or emerging contaminants introduced into the water and carried to the consumer at levels of potential public health concern.

At the beginning of the SARWQH Study, considerable uncertainty remained about the identity of most of the organic chemicals in drinking water, especially the undefined DOC of predominately natural or non-industrial chemical origin that may account for up to 95 percent of the organic material in processed water. The Panel encouraged OCWD to characterize organic chemicals in wastewater more thoroughly and to consider biomonitoring approaches (e.g., fish bioassays) to provide additional assurance that chemicals of potential health importance that were not included in the analytical scheme would not go undetected.

Health Effects

The long-term health (e.g., carcinogenic) consequences of exposure to trace chemicals in drinking water derived from groundwater recharged with reclaimed water is of concern to DHS. Because of the high percentage of treated wastewater in the baseflow of the SAR, as well as the long-standing concerns of DHS regarding the use of reclaimed water to recharge groundwaters that are withdrawn for potable use, OCWD contracted with researchers from the University of California, Irvine, to explore the feasibility of a health effects study examining cancer rates as part of the SARWQH Study. Working with these researchers and consultants, OCWD attempted to quantify exposure with respect to the ingestion of water derived from local groundwater supplies. The assessment of past exposure is a critical component of all epidemiologic studies, because it shows associations (or suggests the absence of associations) between adverse health outcomes and exposure to environmental or other contaminants. An effort was undertaken to determine whether an accurate picture of exposure to recharged water was possible given present-day knowledge of aquifer flows and the distribution of water to OC residents for domestic water supply purposes. It was concluded that there was no reliable scientific basis for estimating exposures of communities or individuals to recharged SAR water within the county.

Estimates of exposure are especially challenging in studies of chronic disease, such as cancer. The latent period – that is, the period between first exposure to a carcinogenic agent and diagnosis of cancer – is at least 15 to 20 years. When the levels of exposure are low, as is typical with exposures to contaminants in the environment, the latent period can extend to 40 or 50 years. This characteristic of cancer induction must be accommodated when designing epidemiologic studies of cancer, especially when considering the exposure assessment aspect of such studies. It is a requirement in such studies to develop defensible estimates of exposure that go back an absolute minimum of 20 years and, preferably, 40 or 50 years.

An accurate description of potential adverse health outcomes was not at issue in the epidemiologic studies contemplated as part of the SARWQH Study; however, there were several factors limiting the ability to assess historical exposures. The Panel concluded there are at least four factors that, together, severely limit the ability to assess long-term exposure to recharged water in the SARWQH setting:

- Insufficient understanding of hydrogeologic water flows, timing, and mixing to predict the relative levels of recharged water reaching production wells used by water utilities to serve the population of the basin.
- Inability to reconstruct past histories of the water utilities that serve OC's population.
- A population with elevated geographic mobility, including a high level of in-migration to the study area.
- Mixing of groundwater and water from other sources in the distribution systems and a lack of data to define the mixing.

In addition, based upon what has been learned about the composition of the water, if there were any incremental risk, it would likely be extremely small and difficult to differentiate from normal background risk. The problems with the estimates of exposure to recharged drinking water compromised the scientific validity of a preliminary study that had been attempted and led to the early termination of a proposed case-control study.

Based on the scientific data collected during the SARWQH Study, the Panel found that:

- The SAR met all water-quality standards and guidelines that have been published for inorganic and organic contaminants in drinking water.
- No chemicals of wastewater origin were identified at concentrations that are of public health concern in the SAR, in water in the infiltration basins, or in nearby groundwaters.

The constituents that were considered included non-regulated chemicals (e.g., pharmaceutically active chemicals) and contaminants of concern that arose during the course of the SARWQH study (e.g., N-nitrosodimethylamine [NDMA]).

The unprecedented classification of the major components of DOC and the transformations that occur within these chemical classes as water moves downstream and into the aquifer provided significant new evidence to support the conclusion that the product water is suitable for potable consumption and is also becoming comparable to other sources of drinking water, such as the Colorado River, in its organic profile.

Panel Conclusions

The general conclusions and recommendations of the Panel, derived from an integrated review of the findings of the individual subcommittees, are presented in Chapter 5 of this report.

Chapter 1:
Introduction

OCWD was created as a special district by state law (*California Statutes, 1933, chapter 924, page 2400, as amended, "The District Act,"*) in 1933 for the protection and preservation of the OC groundwater basin. The District Act authorizes OCWD to "transport, reclaim, purify, treat, inject, extract, or otherwise manage and control water" for its beneficial use and to improve and protect the quality of groundwater supplies within the district. The mandate of the special district is to ensure adequate water supplies for the producers, while also protecting the integrity of the basin's groundwater quality and quantity. To this end, OCWD conducts annual investigations of basin conditions, sets goals for recharge, and establishes limits on the pumping of groundwater to control overdraft of the basin. OCWD does not sell or distribute water to consumers, but levies "replenishment assessments," which are fees paid to OCWD by the groundwater producers for the continued management of the groundwater basin. Replenishment activities, such as the diversion and percolation of SAR water or the purchase of import water for groundwater recharge, are consistent with the District Act for the "protection of the water supplies for users within the district that are necessary for the public health, welfare and safety of the people of this state."

1.1 The OC Groundwater Basin

Groundwater production occurs from approximately 500 active wells within the district with approximately 200 large-capacity wells operated by 20 water retail agencies. These large-capacity wells account for an estimated 96 percent of the total production from the groundwater basin and provide water for over 20 cities and agencies (Figure 1-1). Producers are responsible for pumping and maintaining their respective, individually metered production wells. Monthly well production is documented by OCWD. Because OCWD does not sell or distribute water directly to consumers, once the water is extracted from the groundwater basin, the producers have full responsibility for ensuring that the water served to consumers complies with all drinking-water standards.

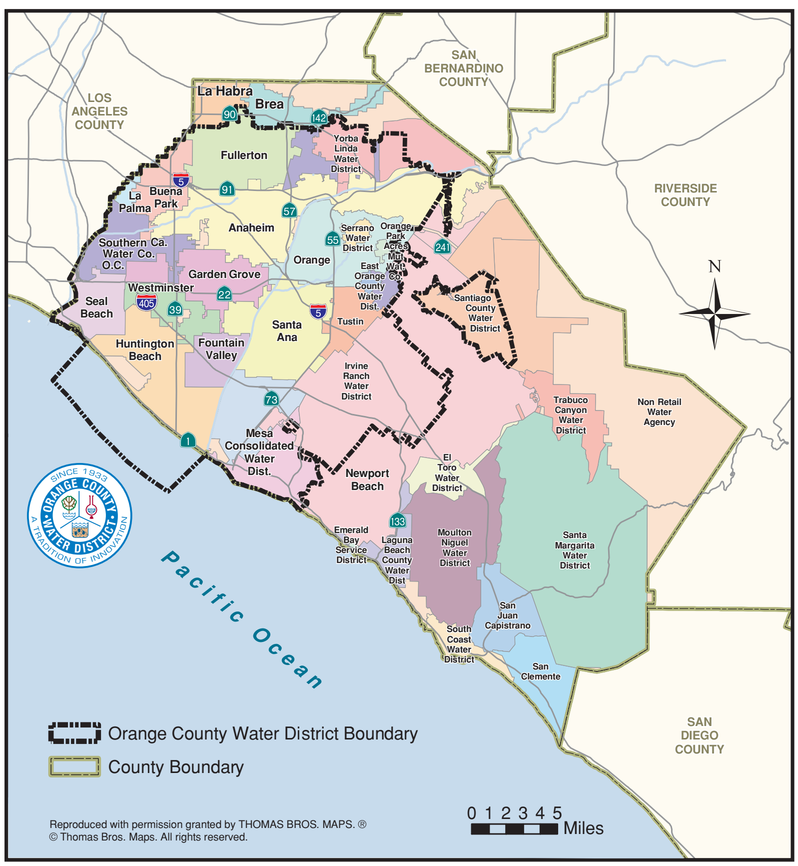

Figure 1-1. Retail water agencies in Orange County.

The SAR is the primary source of water for replenishing the groundwater basin. In addition to capturing and recharging water from the SAR, OCWD also purchases and recharges imported water from the Colorado River and Northern California. In the past, OCWD was able to purchase large volumes of imported water for recharge in the spreading basins in the OC Forebay; however, the accessible quantity of groundwater is threatened by overdraft during periods of drought and by the reduction in the availability of imported water for recharge. Long-term planning of water resources management at OCWD includes new projects, particularly the Groundwater Replenishment (GWR) System, to maximize groundwater yield by increasing groundwater recharge with purified reclaimed water.

1.2 OCWD's Mission

The mission of OCWD is to provide local water retailers with a reliable quantity of high-quality groundwater, supplied at the lowest reasonable cost in an environmentally responsible manner.

1.3 Rationale for the SARWQH Study

During the summer months, much of the SAR baseflow is tertiary treated wastewater from upstream treatment facilities in San Bernardino and Riverside Counties. The wastewater discharges, which currently total approximately 161 mgd (~180,000 AFY), comprise the bulk of the baseflow. These discharges are expected to increase with population growth in the upper watershed. OC's dependence on water extracted from the groundwater basin will increase as well.

The comprehensive, multidisciplinary SARWQH Study was initiated by OCWD in 1994 to:

- Examine the use of SAR water for recharging the groundwater basin because of the high percentage of treated wastewater in the baseflow of the river.
- Provide scientific information to help address concerns expressed by DHS regarding the use of reclaimed water to recharge groundwaters that are subsequently withdrawn for potable use.

The broad goals of the SARWQH Study were to characterize the quality of SAR water and the quality of the groundwater basin it recharges. The specific objectives of the SARWQH Study were to:

- Ensure the continued safety of the drinking-water supply in OC and of OCWD's groundwater recharge program.
- Characterize the quality of SAR water and evaluate the impact of recharge on groundwater quality and public health.
- Provide information to help the regulatory community refine groundwater recharge criteria.
- Facilitate the future expansion of groundwater recharge activities.
- Compare the study findings with DHS's proposed regulations on groundwater recharge.
- Ensure the safety of future drinking-water supplies in OC.

DHS is continuing to update the state's criteria for groundwater recharge, which will govern planned indirect potable reuse projects that are intended to augment groundwater used as a drinking-water source. Due to the source waters of SAR baseflows, these criteria could affect the use of river water for recharging OC's groundwater basin. Specific research elements in the SARWQH Study were designed to address issues raised in DHS' draft groundwater recharge criteria.

Research findings from the SARWQH Study have provided valuable information necessary for the planning and permitting of future projects, such as the GWR System currently under construction at OCWD. In addition, many of the SARWQH Study findings discussed in this report have been helpful in refining DHS' proposed criteria as they continue to evolve.

1.4 Scientific Advisory Panel of the SARWQH Study

At the request of OCWD, NWRI formed the Scientific Advisory Panel in the spring of 1996 to provide independent review and guidance to the SARWQH Study. The Panel initially included 14 nationally recognized experts in various fields relating to public health, environmental chemistry, environmental engineering, environmental microbiology, environmental epidemiology, groundwater recharge, hydrology, toxicology, and water quality. An additional toxicologist, Dr. F. Bernard Daniel, was added to the Panel in October 1996. In the spring of 1997, Dr. Jennifer Clancy, who had been unable to participate in Panel deliberations, resigned from the Panel and a physician-epidemiologist, Dr. Herschel E. Griffin, was added. Current and past members of the Panel are identified in Appendix A. Biographical sketches of the Panel members are presented in Appendix B.

The first meeting of the Panel was on held June 3-5, 1996, and the final meeting was held on April, 27-30, 2003. Nearly all of the original members remained on the Panel, actively participated in meetings and deliberations, and worked diligently in completing assignments. The only changes in Panel membership, other than those discussed above, were that Drs. Herschel Griffin and Talbot Page left the Panel in 1999 due to downsizing of the Panel after discontinuing the Health Effects Studies.

1.5 Organization and Approach to the SARWQH Study

The various research elements of the SARWQH Study were organized into the following areas:

- Hydrogeology.
- Microbiology.
- Organics and Water Chemistry.
- Toxicology.
- Health Effects.

Specific Panel members were assigned to subcommittees to oversee and guide research studies that came under these specific areas. Members of these subcommittees are identified in Appendix A. Findings, recommendations, and conclusions of the Panel for each of these study elements are presented in Chapter 3. The reader is referred to the *Santa Ana River Water Quality and Health Study: Final Report*, published by OCWD in 2004, for more detailed information regarding each study element and the interconnections therewith.

Panel members generally met once per year as a full Panel to provide a comprehensive review of the research findings and to provide overall direction regarding various research elements. Additionally, members of the Panel serving on various subcommittees met on an as-needed basis. A subcommittee report was prepared after each subcommittee meeting. The findings and recommendations of each subcommittee were then presented at the next meeting of the full Panel.

Researchers from several universities, research institutions, and government agencies participated in the study. A list of these organizations, as well as the papers and reports that were produced, is presented in Appendix C.

From 1996 through 2003, the Panel provided expert oversight of the research conducted for the SARWQH Study and made recommendations for additional studies. The Panel also participated in discussions of important research findings with OCWD staff, individual researchers, and regulatory agencies. The final conclusions and recommendations of the Panel, based on research findings of the SARWQH Study, are presented in this report.

1.6 Additional Related Activities of OCWD: The GWR System

Currently, the total water demand within the OCWD service area is approximately 500,000 AFY, of which 60 to 70 percent is derived from the groundwater basin. The total projected water demand for the year 2025 is approximately 602,000 AFY. Because of increasing water demands, the inevitability of droughts, and the potential for shortages of imported water, OCWD concluded that additional supplies of recharge water were needed to maintain the seawater intrusion barrier and to recharge the basin. Based on these factors, OCWD and the Orange County Sanitation District (OCSD) developed an innovative proposal, called the GWR System, to produce a new source of high-quality water from urban wastewater.

The largest project of its kind in the country, the GWR System will start with secondary-treated wastewater now discharged to the ocean and subject it to advanced treatment processes to produce water that will comply with, and surpass, all drinking-water standards. The advanced water treatment processes include microfiltration, reverse osmosis, and ultraviolet light for the disinfection and destruction of organic compounds. Some of the highly treated water will be piped to spreading basins to recharge the groundwater basin, thereby making up the difference between supply and demand for water in OC. The remainder of the water will be used for protecting the groundwater basin from seawater intrusion, which will also augment the potable groundwater supply.

Phase 1 of the GWR System will provide 72,000 AFY of new water. The GWR System will:

- Make OCWD less dependent on more expensive, less reliable imported water.
- Free up water that can be used by agriculture and the environment.
- Produce “drought-proof” water, easing the hardships of the next drought.
- Improve the overall quality of the groundwater.

OCWD and OCSD are joint sponsors of the project. Phase 1, which will cost about $450 million (2004 dollars), is expected to begin supplying about 20 percent of the water needed for groundwater recharge in 2007.

The Panel was not charged with reviewing the GWR System; however, because the GWR System will provide a valuable new source of high-quality water and, as mentioned, will improve the overall quality of the groundwater basin, the Panel included a brief description of the GWR System in this report.

1.7 Sponsorship

The Panel, as mentioned earlier, was formed under the auspices of NWRI. All Panel expenses were paid by NWRI under a grant provided by OCWD to NWRI for those expenses. NWRI also provided direct assistance to Panel members by arranging for travel and lodging, and by providing overall advice and direction. Furthermore, NWRI provided financial support for some of the research elements of the SARWQH Study (e.g., a biomonitoring demonstration project).

Chapter 2:
STUDY AREA

The SAR watershed, encompassing parts of Riverside, San Bernardino, and Orange Counties (Figure 2-1), is the largest watershed in coastal Southern California, with a drainage area of approximately 2,800 square miles. The watershed has a population of more than 4.5 million. Currently, this population is dependent on imported water for more than a third of its water supply. Because the SAR is the principal source of water for replenishing the groundwater basin, OCWD conducts extensive monitoring of the quality of the river and its tributaries. OCWD has successfully managed the groundwater recharge of SAR water for over half a century, and it continues to expand the recharge capacity of the basin. Approximately 190,000 AFY of SAR water is recharged on an average basis, representing more than half of the total recharge. This 190,000 AFY is valued at approximately $50 million annually, which corresponds to the amount that imported water would cost if SAR water was not available for recharge.

2.1. Characteristics of the SAR and Groundwater Basin

During the summer months, much of the SAR baseflow is tertiary treated wastewater from upstream treatment facilities in San Bernardino and Riverside Counties. The treated wastewater discharges, which currently total approximately 161 mgd (yielding 180,000 AFY) comprise more than 90 percent of the baseflow of the SAR (Figure 2-2). Total SAR baseflow has increased significantly over the past two decades due to population

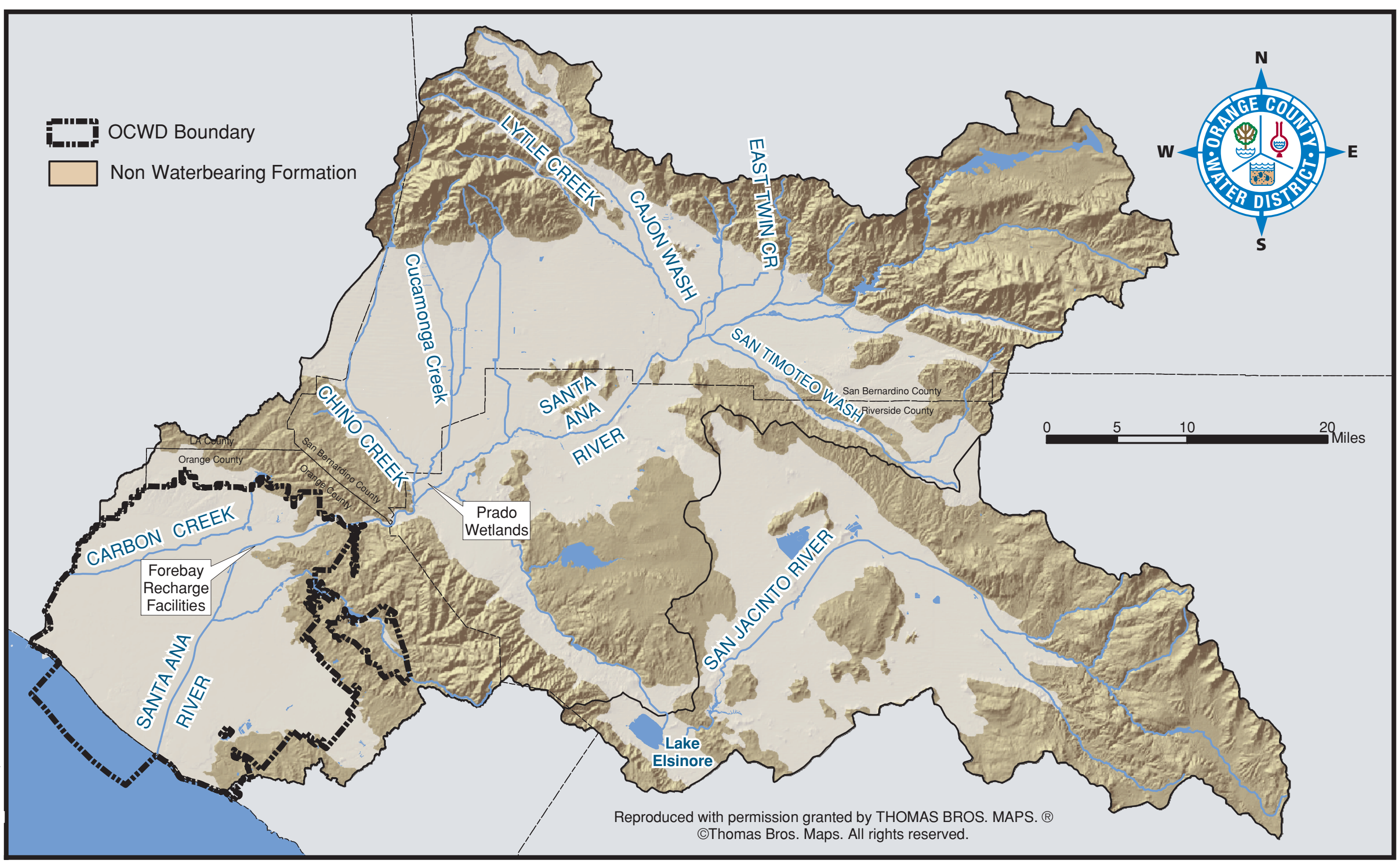

Figure 2-1. Santa Ana River watershed.

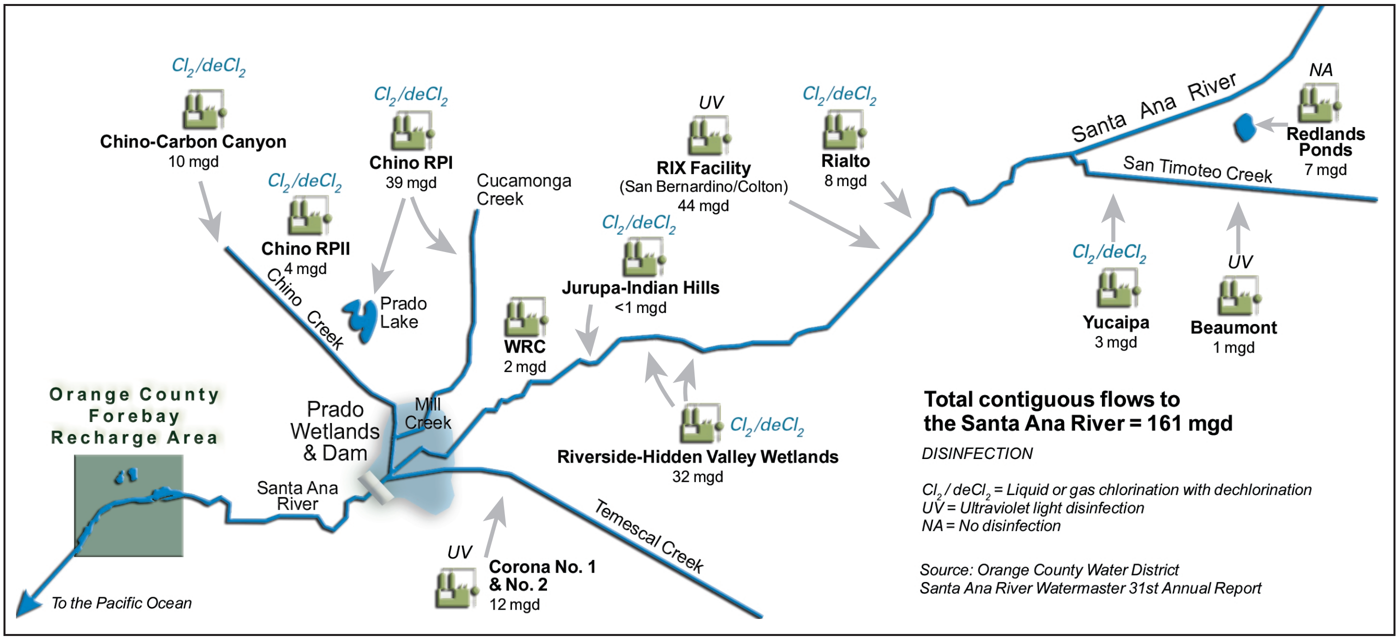

Figure 2-2. Year 2001 wastewater discharges to the Santa Ana River.

growth upstream of Prado Dam and to increases in wastewater discharges into the river from these rapidly urbanizing areas in the watershed. These upstream discharges will continue to increase as the population grows in the upper watershed. OC's dependence on the groundwater basin will also increase with time.

The level of treatment provided for wastewater discharged to the SAR is based on the beneficial uses of the river (in particular, body contact recreation). The level of treatment is sufficient to provide water that is adequately oxidized, coagulated, clarified, filtered, and disinfected (tertiary treated wastewater). The degree of treatment is capable of reducing concentrations of viruses in the water by approximately 5 orders of magnitude (100,000 times less), resulting in "essentially virus-free water" in accord with California Water Recycling Criteria (Title 22, Division 4, Chapter 3, California Administrative Code).[2]

The groundwater basin underlies the northern half of OC beneath broad lowlands known as the Tustin and Downey Plains. The basin covers an area of approximately 350 square miles, bordered by the Coyote and Chino Hills to the north, Santa Ana Mountains to the northeast, Pacific Ocean to the southwest, and county line to the northwest, where its aquifer systems continue into the Central Basin of Los Angeles County (Figure 2-3). Groundwater flow is unrestricted across the county line. The Newport-Inglewood fault zone forms the southwestern boundary of all but the shallow aquifers in the basin.

The aquifers comprising the basin extend over 2,000 feet deep and form a complex series of interconnected sand and gravel deposits. In coastal and central portions of the basin, these deposits are separated by extensive lower-permeability clay and silt deposits that form aquitards, which limit the vertical movement of water between aquifers. In the inland area, generally northeast of Interstate 5, the clay and silt deposits become thinner and more discontinuous, allowing larger quantities of groundwater to flow more easily between shallow and deep aquifers.

By means of the extensive groundwater monitoring-well network developed by OCWD, data are available on the aquifers to depths of 2,000 feet in many areas of the basin. The monitoring wells are used to obtain

[2] State of California (1978). *Wastewater Reclamation Criteria, California Administrative Code, Title 22, Division 4, Chapter 3*. California Department of Health Services, Sanitary Engineering Branch, Berkeley, California

detailed, depth-specific water level and water-quality data from individual aquifer zones. Data from these wells were used to delineate the depth of the "principal" aquifer system, within which most of the groundwater production occurs. Deeper aquifers exist below the principal aquifer system, but these zones contain colored water or are too deep to economically construct production wells. With the exception of OCWD monitoring wells and four colored water production wells constructed by Mesa Consolidated Water District and Irvine Ranch Water District, few wells penetrate the deep aquifer system.

2.2 Growing Water Demands and Sources of Recharge Water

Over 2-million OC residents and commercial and industrial users depend upon the groundwater basin for about two-thirds of their water supply and rely on imported water to meet the remainder of the demand. Since the early 1970s, the water supply in the OCWD service area has been made up of about 60- to 75-percent groundwater and 25- to 40-percent imported water. Total demand was approximately 483,000 acre feet (AF) from July 1, 2002, to June 30, 2003. Total water demand is projected to increase to 602,000 AFY by the year 2025.

Like many densely populated metropolitan areas in the western United States, OC has a limited natural local water supply that does not meet its water demands. The region's arid climate is characterized by dry summers and mild winters, with an average rainfall of about 13 inches per year. If the average annual rainfall of 13 inches were uniform over the 350 square miles area of the groundwater basin and infiltrated completely into the basin, it would provide 240,000 AFY of water.

OC uses almost twice the amount of water that is currently available in the SAR watershed and, as pointed out, the local supply must be supplemented by the purchase of imported water from the Colorado River and Northern California. Population growth projections show the importance of maximizing local groundwater supplies, especially because adequate supplies of imported water may not be available in the future. Thus, groundwater recharge with SAR water is critical for replenishing OC's groundwater supply. The OCWD facilities for recharging SAR and imported water are illustrated in Figure 2-4.

To determine the hydrologic budget, OCWD staff measures key inflow and outflow components in the watershed, including baseflow,

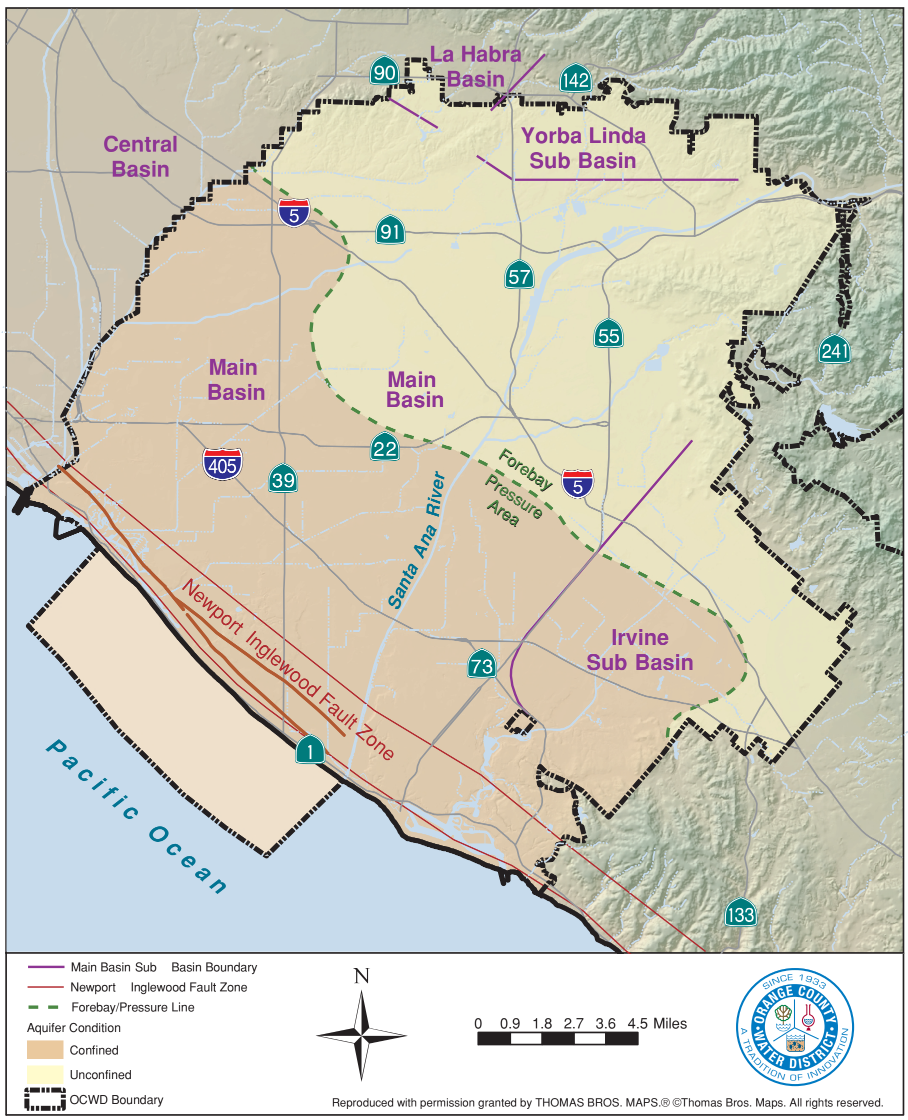

Figure 2-3. Orange County groundwater basin.

stormflow, imported water, and inflow to the major recharge systems. This hydrologic budget, or "water balance," is used to evaluate basin production capacity in the watershed and to estimate the percentage of stormflow and baseflow in the recharge water. Since 1992, the average amount of SAR stormflow recharged into the basin was approximately 50,000 AFY. The largest amount of stormflow recharged in 1 year was 117,000 AF, and the lowest amount was approximately 16,000 AF. The range of flows and discharges into the river from 1987 to 1996 is illustrated in Figure 2-5.

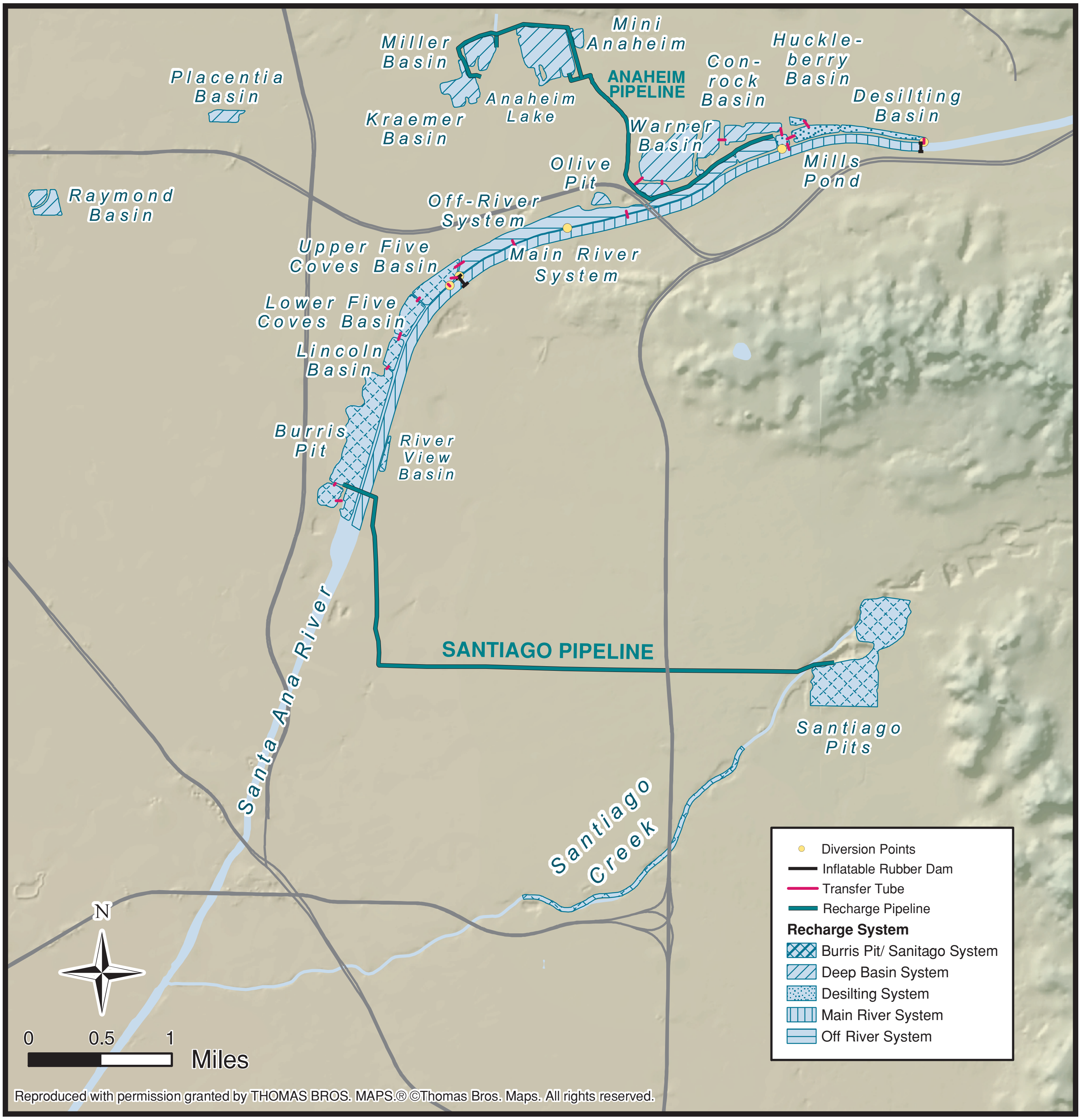

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Figure 2-4. OCWD recharge facilities.

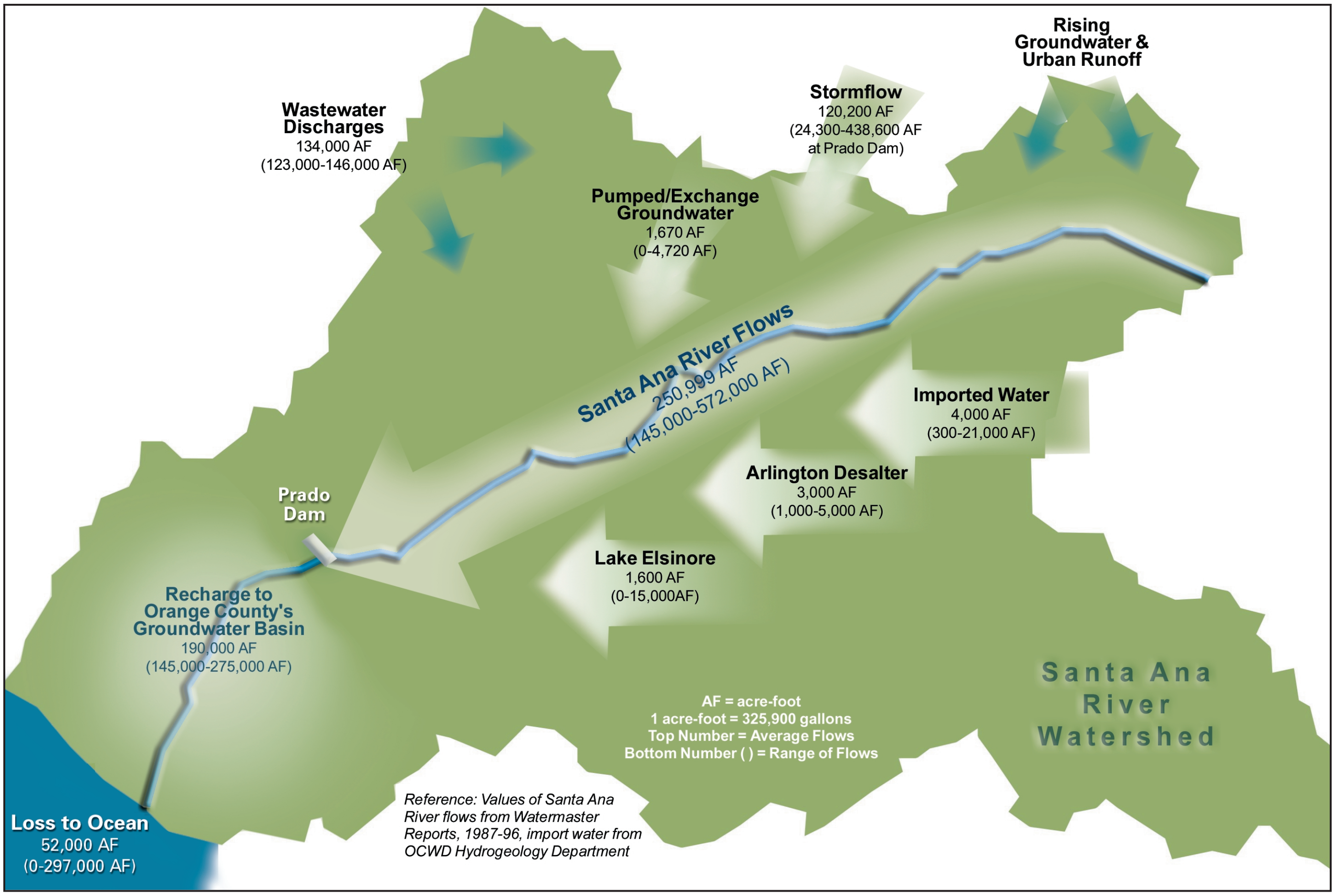

Figure 2-5. Sources of Santa Ana River flow (1987-1996).

Chapter 3:
FINDINGS, RECOMMENDATIONS, AND CONCLUSIONS BY TOPIC AREA

Observations, findings, recommendations, and (where appropriate) conclusions by topic area corresponding to the subcommittees of the full Panel are presented in this chapter. Panel recommendations for future monitoring are presented in Chapter 4. The overall Panel conclusions and recommendations are presented in Chapter 5. The material presented in this chapter has been organized into the following topic areas:

- Forebay Hydrogeology.
- Microbial Water Quality.
- Organic and Chemical Water Quality.
- Toxicology.
- Health Effects Study.

3.1 Forebay Hydrogeology

The hydrogeologic studies conducted as a part of SARWQH investigations were important in defining how, where, and when water leaving a recharge basin reaches a given well and what changes occur to its quality during passage underground. These studies would not have been possible without OCWD's construction of multi-depth monitoring wells. Analyses undertaken during the years of the SARWQH study consisted of age dating, injection and subsequent monitoring of xenon and sulfur hexafluoride groundwater tracers, and the study of porous media flow near the outer surface of a recharge basin.

3.1.1 Importance of Hydrogeological Studies

Shortly after the start of the SARWQH Study, the Panel came to the conclusion that the findings from hydrogeological studies were of fundamental importance to all of the other study elements. That is, flow paths and travel times of recharged water had to be defined before researchers could address the fate and transport of microbes, organic and inorganic chemicals, disinfection byproducts, and other constituents that might be of health concern. Flow paths and travel times are also central to an accurate exposure assessment for the conduct of epidemiological studies. Furthermore, DHS' proposed regulations governing groundwater recharge with reclaimed water require a specified travel time and dilution by the time the recharged water is extracted for potable use. The hydrogeological studies conducted during the SARWQH Study were used to define flow paths and subsurface velocities that allowed residence times to be calculated. Age dating of subsurface waters, as well as various tracer studies, helped define travel times and dilution in the Forebay and nearby groundwaters.

Information on the flow paths and velocities of recharged water in the Forebay and nearby groundwaters allowed researchers to sample "paired" water samples. That is, recharge water in the spreading basins was sampled at the start of a sampling run (considered to be time 0), followed by samples collected from specific monitoring or production wells after flow time "t" along a defined flow path. In this way, the groundwater sampling regime could be used to monitor at least a portion of the recharged water that was sampled at time 0.

This sampling approach allowed a snapshot of any constituent of interest (e.g., microbial, inorganic, organic, etc.) and the fate and transport of that constituent to be determined. It would not have been possible to conduct the transport and fate studies without having an understanding of the hydrogeology of the basin.

3.1.2 Hydrogeological Studies

Groundwater flow, in contrast to surface water flow, generally follows pathways that tend to disperse horizontally and vertically with distance depending on the geologic structure of the aquifer. The only way to quantify flow directions, flow velocities, and any modifications in water quality over time and distance is by subsurface investigation. Typically, groundwater tracing involves injection of a tracer into the water at an upstream point (in this situation, a recharge facility, followed by collection of water samples from a series of downstream monitoring wells). This methodology is essential from a public health standpoint if groundwater is the water supply source because the movement of contaminants, such as bacteria and viruses, can be traced and a determination can be made as to their persistence underground. Furthermore, this type of information is essential in identifying the source(s) of contaminants. For example, the SAR and OCWD's various recharge basins are not the only pathways by which contaminants of concern can enter OC groundwater (e.g., leaking sewers and interbasin subsurface transport).

During the SARWQH Study, groundwater tracer studies were carried out successfully by personnel at the Lawrence Livermore National Laboratory and University of California, Santa Barbara, using advanced sampling and analytic techniques in the vicinity of Anaheim Lake, Kraemer Basin, and the SAR. To facilitate these studies, three multi-depth monitoring wells were constructed by OCWD to evaluate vertical hydraulic gradients and to obtain water samples at various depths below ground surface.

3.1.3 Findings and Conclusions

The principal findings and conclusions of the SARWQH hydrogeologic studies are:

1. From the tracer studies conducted near the SAR, it was found that recharge water migration was complex, flow away from the recharge facilities was rapid, and multiple tracer arrivals over times were observed at the sampling wells.
2. Groundwater originating from the three recharge areas (Anaheim Lake, Kraemer Basin, and the SAR riverbed) maintained unique flow paths and velocities, and the mixing of groundwater from the three recharge areas was not observed.
3. Based on results from the monitoring wells, it was found that groundwater may travel at different rates over the distance downstream from a recharge source, and flow rates vary with each recharge location. Groundwater flow rates ranged from approximately 4 to 25 feet per day or more.
4. Data on groundwater flow derived from the study can be used to develop an early-warning groundwater monitoring system that could be useful in the hypothetical event of a toxic spill reaching groundwater and, potentially, nearby municipal wells.
5. Tritium-helium monitoring was used to provide information on groundwater ages that helped define the general pattern of groundwater flow near the recharge basins and aided in identifying a fast-flow path from the Anaheim Lake/Kraemer Basin area. The results of this study helped in the design of the monitoring program for the recharge tracer studies.

6. The 1996 and 1998 noble gas recharge tracer studies at Anaheim Lake and Kraemer Basin provided data that allowed the calculation of groundwater velocities, including data to estimate the mean groundwater velocity and the "peak" velocity based on the first arrival of the tracer.
7. The 1996 and 1998 noble gas recharge tracer studies at Anaheim Lake and Kraemer Basin provided data on the amount of recharge water reaching monitoring locations. The magnitude of dilution of recharge water occurring at various monitoring locations was estimated based on these data.
8. The SAR recharge water tracer test with sulfur hexafluoride provided mean and "peak" groundwater velocity data for water recharged from the unlined channel of the SAR.
9. The noble gas and sulfur hexafluoride tracer test data were of sufficient resolution to define the 6-month and 1-year travel time areas for all three of the recharge facilities.
10. The recharge tracer test data provided key information to design the monitoring program that was implemented to evaluate water-quality changes between recharge water and groundwater with known travel times and dilution.
11. Based on the recharge tracer test data, it was found that the horizontal distance from a well to a recharge basin is not a good predictor of the travel time of recharge water to the well (some wells adjacent to the recharge facilities did not produce water from the recharge facilities due to the depths of the screened intervals and the direction of recharge water movement away from the recharge basin).

3.14 Recommendations

The principal recommendations derived from the hydrogeological studies are:

1. The sulfur hexafluoride monitoring program has continued to provide useful information on the travel of water from the SAR for several years and, therefore, should be continued as long as meaningful data are being generated.
2. With development of the Santiago Pits for recharge purposes, a hydrogeologic characterization of the surrounding area should be undertaken as a basis for understanding how recharged water will travel.
3. A series of monitoring wells should be placed near the Santiago Pits and in the vicinity of any future recharge facilities.
4. In the interest of assuring public health protection, OCWD's groundwater monitoring efforts have proven to be extremely beneficial and should be continued as an early warning system to detect any contaminants that could possibly adversely affect public water supplies.

3.2 Microbial Water Quality

The SARWQH Study included a significant and intensive microbiology component. Over the last 7 years, the microbiological monitoring program of the study was directed toward evaluating the sanitary quality of SAR water and groundwater from monitoring wells within the study area.

3.2.1 Microbial Monitoring Program

Samples of water were assayed for indicator bacteria, protozoan cysts, culturable enteric viruses, and somatic and male-specific coliphage. A major focus was on assessing the potential vulnerability of the groundwater system to virus contamination. Although bacteria are easily removed by subsequent disinfection and protozoa typically are removed by the natural filtering capacity of the aquifer, viruses can be transported with the groundwater.

Microbiological Assays

Microbiological assays were performed in the laboratories of recognized national experts. In addition, coliphage were used as surrogates for human enteric viruses in assessing the vulnerability of groundwater to virus contamination. Immunoassays of coliphage isolates were made in an attempt to identify their animal or human origin. Testing the SAR for the presence of the protozoan parasites *Cryptosporidium* and *Giardia* was also an important aspect of the monitoring program.

Virus Testing

An extensive study was undertaken to detect enteroviruses in the OC groundwater basin and in the SAR. The water samples were analyzed by the Metropolitan Water District of Southern California laboratory. Virus testing included the application of molecular biological methods for the detection and characterization of any animal enteric virus. Combining conventional cell culture and molecular methods allows for greater detection of infectious viruses, including those that give typical results in tissue culture and those that do not (cytopathic enteroviruses [CPE] and non-cytopathic enteroviruses [non-CPE]).

The Panel concluded that rigorous quality assurance/quality control (QA/QC) protocols are essential to avoid misinterpreting results (false positives) when using molecular methods for detections such as polymerase chain reaction (PCR), an analytical method that is used to amplify target gene sequences in the laboratory. Because of the sensitivity of PCR, even small amounts of genetic material from positive controls can cross-contaminate samples and show up as false positives.

3.2.2 Findings

The key findings from the microbiological assays of the SARWQH Study include:

1. The phage, including coliphage and *Salmonella* phage, were detected in 13 percent of the samples from all of the wells sampled in the study area. There was a spatial randomness to the positive results, and most of them occurred during or shortly after periods of heavy rainfall.
2. Bacterial indicators were detected in 3 percent of the groundwater samples.
3. No human enteric viruses were detected in 200 groundwater samples. Culturable viruses were detected in only one of the 100 surface water samples analyzed for enteric virus (a reovirus).
4. Out of the 40 samples collected from monitoring wells and analyzed for protozoan pathogens, one was positive for *Giardia* and two were positive for *Cryptosporidium*. These determinations were made using immune fluorescence assay (IFA). These protozoan cysts appeared to be nonviable as there was no evidence of internal structures. These organisms were not found in production wells.
5. Protozoan pathogens were detected in 8 of the 105 samples of SAR water, but appeared to be nonviable.
6. Flow through the Prado wetlands did not result in any appreciable changes in concentrations of enteric indicator organisms.
7. Natural attenuation of the indicator bacteria and coliphage was observed in the study transect from Prado Dam to Anaheim Lake and Kraemer Basin. Further mixing and dilution of these upstream sources occur, particularly when imported water (Colorado River and State Project Water) is added to the system. Limited data were collected to address microbial removals during river flow and storage in the recharge basins.

8. Cross-contamination of viral samples was noted during this study, even with careful field and laboratory protocols. The observed cross-contamination resulted from the use of spiked blind positive controls.

3.2.3 Conclusions

Based on recommendations of the Microbiology Subcommittee, the Panel reached the following conclusions from microbiological assays of the SARWQH Study:

1. Based on bacterial indicator and phage data, groundwater in the SARWQH study area is vulnerable to microbial contamination. The data are not sufficient to determine the level of human health risk from direct consumption of the water without disinfection. Groundwater vulnerability may be greater during wet periods of the year, and varies from year to year. Based on the groundwater age study, phage detection was not associated with the SAR or managed recharge; however, the study was not designed to evaluate transport (e.g., specific microbiological tracer studies or specific higher intensity temporal sampling). Although the source of the phage is unknown, the Panel concluded that the phage were likely of fecal bacterial origin and could be coming from sources other than the SAR or recharge basins (e.g., leaky sewer lines).
2. Based on pathogen monitoring, particularly the intensive virus testing that found no positive samples for enteric viruses in groundwater and only one positive sample in SAR surface water, the health risk associated with consuming undisinfected groundwater recharged with SAR water is considered quite small. The risk could not be quantified, but it is likely less than 1/10,000, the tentative goal mentioned by the EPA for consumption of tap water (that is, the annual risk of a person contacting an illness from consuming treated drinking water should be less than 1/10,000).
3. Based on the pathogen monitoring data, the SAR does not appear to be a significant source of human pathogens to the recharged aquifer. Effective and reliable wastewater treatment, including filtration and disinfection, of the upstream wastewater discharges must be continued to ensure that the microbiological quality (i.e., essentially virus-free, based on 5-log virus removal through tertiary treatment) of SAR water is not compromised.
4. Because the Prado wetlands are a biologically active system supporting a diverse community of both animal and bird populations, the Panel concluded that these animals and birds contribute significant quantities of indicator organisms to the system; however, flow through the Prado wetlands did not result in any appreciable changes in concentrations of enteric indicator organisms.
5. Protozoan cysts and oocysts, as well as viruses, were not detected often enough in the wetlands inflow and outflow to assess any effect of the wetlands on their survival or removal. Only one surface water sample out of the 100 samples analyzed was positive for enteric virus during the entire study.

3.2.4 Recommendations

The principal recommendations derived from the microbiological studies are:

1. To minimize any risks that might be associated with the vulnerability of groundwater seen during this study, the Panel recommends disinfecting of all production wells in the study area if they are found to be positive for somatic or male-specific coliphage.

2. The QA/QC plan for microbial studies that employ molecular techniques should at least include genetic sequencing to resolve any suspect analyses that may be due to cross-contamination in the laboratory.
3. Finally, the use of performance evaluation samples is preferred over the use of blind positive controls for testing laboratory proficiency and to avoid cross-contamination problems.

3.3 Organics and Chemical Water Quality

The origins and composition of organic carbon in surface waters subject to wastewater discharges have been of particular concern in all previous evaluations of the public health safety of groundwater recharge. In an earlier study (State of California, 1987),[3] it was noted that approximately 90 percent of the TOC entering groundwater was unidentified.

3.3.1 Characterization of DOC

In the SARWQH Study, OCWD employed carefully planned analytical and monitoring approaches for measurable synthetic organics and a chemical classification approach to the problem of unknown DOC. OCWD obtained the requisite research expertise from uniquely qualified scientists at Stanford University, the United States Geological Survey, and Lawrence Livermore National Laboratory. Their efforts resulted in the classification of a substantial majority of the DOC in the SAR and recharge system, perhaps greater than 90 percent. In addition, the isolation and classification schemes provided information on the relationship of classes of compounds and their probable origins. The Panel concluded that this research was groundbreaking and of exceptional quality, and will be widely assimilated in future recharge studies and in the broader field of aquatic geochemistry.

Most of the organic carbon in the SAR and recharge system is of natural origin. Radiocarbon and chemical classification studies determined that an approximate upper limit of 20 to 25 percent of the DOC entering the Anaheim Lake recharge basin, after significant pretreatment, is of anthropogenic origin and consists mostly of metabolic derivatives of LAS detergents and surfactants. Other specific wastewater indicators, also of detergent origin, were found in the SAR at concentrations lower than in treatment plant effluents, with further decreases occurring after passage through the recharge basin sediments and subsequent groundwater transit. Collectively, from the research on wastewater indicator compounds, it was concluded that although some waste-related organic materials do reach Forebay groundwaters, their concentrations are not of human health concern, except as markers of the incursion of wastewaters. The end result of these studies is that groundwater transit of recharged SAR water produces a quality and composition of DOC in production water that is comparable to other sources of drinking water, such as the Colorado River.

The Panel notes that the SARWQH Study, as with any scientific investigation, could not prove absolutely that the recharge practices are devoid of any possible health concern for the following reasons:

- Samples were necessarily limited in time and space.
- Difficulties remain in anticipating the occurrence of trace quantities of unknown organic chemicals.
- Discharges to the SAR may change in the future.
- A negative is impossible to prove.

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[3] State of California (1978). *Wastewater Reclamation Criteria, California Administrative Code, Title 22, Division 4, Chapter 3*. California Department of Health Services, Sanitary Engineering Branch, Berkeley, California

3.3.2 Findings

The Panel found that most of the organic carbon in the SAR, recharge basins, and groundwater near the recharge basins is of natural origin. Furthermore, natural transformation processes during river flow and passage through recharge basin sediment significantly reduce the concentration of natural organic carbon and render these materials less reactive to subsequent chlorination or other disinfection processes upon withdrawal from the aquifer. An exception to the above is that the concentration of organic carbon increased during passage through the Prado Wetlands. It subsequently decreased with river flow and during recharge and subsurface flow.

3.3.3 Conclusions

The principal conclusions derived from the studies regarding organics and chemical water quality are:

1. Organic carbon in SAR water is derived primarily from contact with the terrestrial biosphere.
2. The facilities and mechanisms currently employed for recharge by OCWD have proven to be effective for the removal of a significant portion of TOC (approximately 50 percent during infiltration and 1 month of subsurface flow).
3. Groundwater transit of recharged SAR water produces a quality and composition of DOC in production water that is comparable to other sources of drinking water, such as the Colorado River.
4. Prudence requires continued monitoring for organic chemicals of wastewater, industrial, and agricultural origin.

3.3.4 Recommendations

1. The possibility of the intrusion of anthropogenic chemicals into groundwater should be monitored through the continued testing of recharge water for regulated or indicator compounds. Monitoring frequency should be quarterly, at minimum, with modifications to account for variations in the source of recharge water. Monitoring should be conducted at selected SAR sites, recharge basins, and key subsurface locations.
2. OCWD and all health and environmental agencies should continue to be alert to any activity on the watershed that would adversely affect the SAR and the quality of OC's drinking water.
3. Enhanced source control efforts for compounds of concern in drinking water should be considered for wastewater treatment collection systems that discharge into the SAR.
4. OCWD should remain alert to new findings regarding specific anthropogenic chemicals that are found in other locations and are of potential health significance.
5. The possibility of using selected chemicals and chemical classes of compounds as sentinel indicators of continued efficient operation of the recharge basins should be evaluated. From an analysis of present monitoring data, information on the following constituents would be useful:
    a. Total organic halogens (TOX) and chlorate for levels of chlorinated discharges.
    b. Pesticides from agricultural application in the drainage basin.
    c. DOC and specific ultraviolet absorbance (SUVA) for evaluation of the characteristics and flux of organic carbon from the surface to the groundwater.
    d. Data on selected organic chemicals, such as NDMA and 1,4-dioxane.

e. Other selected compounds, including:
    - Chelating agents, ethylenediamine tetraacetic acid (EDTA), and nitrilotriacetic acid (NTA).
    - Methylene blue active substances (MBAS).
    - Perchlorate.
    - Benzene, methyl tertiary butyl ether (MTBE), xylenes, and toluene from petroleum contamination.

6. Budgetary exigencies prevented a complete analysis of organic water-quality variations within the watershed, particularly with respect to stormwater flow. OCWD should pursue research support from appropriate agencies for application of the United States Geological Survey organic classification method to characterize the organic components of stormwater samples that might percolate into the groundwater.

3.4 Toxicology

Toxicology efforts were focused largely on the extent to which the chemical and biomonitoring findings derived from the SARWQH study might provide quantifiable evidence that water from the SAR recharge activity could impact human health when consumed upon withdrawal for potable purposes. The Panel recognized that analyses of water for contaminants identified in standards, lists of priority pollutants, measures of unregulated chemicals identified in municipal wastewater (e.g., pharmaceutically active compounds), and general measurements of water quality provide considerable assurance that any water is safe, but cannot guarantee safety.

At the beginning of the SARWQH Study, there was considerable uncertainty about the identity of most of the organic chemicals in drinking water, especially the undefined DOC of predominately natural or non-industrial chemical origin that may account for up to 95 percent of the organic material in the processed water. The Panel encouraged OCWD to characterize organic chemicals in wastewater more thoroughly and to consider the utility of employing biomonitoring approaches to provide additional assurance that chemicals of major health importance not included in the analytical scheme would not go undetected.

3.4.1 Findings

With respect to the toxicology of the analytical chemistry results, the key findings include:

1. Based on routine monitoring, it was found that the SAR met all regulatory standards and guideline levels for inorganic and organic contaminants.
2. No chemicals of wastewater origin have been identified at concentrations that are of public health concern in the SAR, in water in the infiltration basins, or in nearby groundwaters. Non-regulated chemicals (e.g., pharmaceutically active chemicals) and contaminants of concern that arose during the course of the SARWQH Study (e.g., NDMA) were included in this assessment.
3. As part of the SARWQH Study, an unprecedented classification of the major components of DOC was prepared. The organic profile of SAR water was found to be comparable to other sources of drinking water, such as the Colorado River, which supplies a third of OC's current drinking water.

With respect to biomonitoring, the key findings include:

1. Rapid screening tests were employed early in the SARWQH Study. These tests included Microtox, measures of the induction of enzymes involved in metabolism of xenobiotics, and estrogenic responses in rat pituitary cell lines. These tests proved to be of limited value because of:

    - Their lack of specificity and the difficulty of relating any results to adverse health effects in intact animals and humans, and
    - Their lack of sensitivity at the concentration levels of interest.
2. The SARWQH study sought and obtained external support for assessing the use of *Medaka* fish as an experimental model for detecting carcinogens in water that is to be percolated into the aquifer.
3. The planned location of the intake water for the fish studies (below the bank that separates water intended for the infiltration basins from the SAR) is appropriate for providing water to the fish that would be both representative of the water being introduced into the aquifer and for ensuring that there would be no interruptions in the supply of the water to the fish tanks.
4. Maintaining contact and coordinating efforts to develop these systems with federal agencies that are investing in the validation of these biomonitoring assays is essential. Substantial supplemental testing and validation is required to characterize the sensitivity and applicability of the fish model and its possible appropriate role in future applications.

3.4.2 Conclusions

1. The Panel concluded that SAR water is suitable for groundwater recharge for potable water supply based on:
    - The measured quality of the SAR water.
    - The observed transformations within chemical classes during river transit.
    - Treatment that occurred during groundwater recharge and underground transport.
2. Although it was beyond the scope of the SARWQH study, the Panel encouraged OCWD to carefully evaluate the potential mobilization of materials adsorbed in the bottom of Kraemer Basin and in the downgradient aquifer following the planned introduction of water from the GWR System into the basin. The new water will be of a very high quality, but potentially could be aggressive in mobilizing organic and inorganic chemicals in the natural geology or in the deposits that may have accumulated in the overlay from years of infiltrating water that has had much higher levels of total dissolved solids (TDS) or other constituents.
3. Growing demand for water could eventually require that stormwater runoff, which is currently being lost to the ocean, be captured for infiltration into the aquifer.

3.4.3 Recommendations

1. To maintain confidence in the safety of the water, an ongoing monitoring effort should be undertaken that focuses on the potential for new or emerging contaminants being introduced into the water and carried through to the consumer at levels of potential public health concern.
2. The Panel remains concerned that stormwater may be considerably impaired in quality and that the characterization of this water was not as complete as that of the baseflow in the SAR. Stormwater should be further characterized to ensure that additional stormwater captured for groundwater recharge will not degrade groundwater quality.

3.5 Health Effects Study

Health monitoring of populations served with recharged water from the SAR could provide direct information about the potential for risk associated with consuming these waters. If risks linked to consuming recharged water are low or non-existent, as appears likely after evaluating a wide variety of water-quality parameters, such health monitoring could serve to reassure the public of the relative safety of the water supply. If certain types of health threats are present, careful monitoring of health endpoints with relatively brief incubation periods, such as enteric infections, might detect elevations in risk, if the surveillance is thoughtfully and carefully designed; however, epidemiologic studies of various types of cancer or other diseases with very long latent or incubation periods pose many challenges in this setting.

In many other settings where epidemiologic studies of drinking-water contaminants have been conducted, the detection of high levels of known or suspected carcinogens provided the major motivation. For example:

- Disinfection byproducts (the mixture of byproducts includes mutagens and animal carcinogens).
- Nitrates (endogenous production of carcinogenic N-nitroso compounds in the stomach has been demonstrated).
- Arsenic (many lines of evidence for carcinogenicity in humans).

The motivation for conducting epidemiologic studies of cancer and exposure to recharged drinking water, where studies have been attempted, does not meet a similar test of elevated suspicion of carcinogenicity. In the SARWQH Study, for example, levels of a wide range of contaminants in the source water used for recharge are below detection or found at levels lower than many other waters used for drinking water.

3.5.1 Assessment of Past Exposure

An accurate assessment of past exposure is a critical component of all epidemiologic studies. To show associations (or the absence of associations) between adverse health outcomes and exposure to environmental or other contaminants, accurate information on both outcome and exposure is a necessary prerequisite.

Accurate descriptions of potential adverse health outcomes were not at issue in the epidemiologic studies contemplated as part of the SARWQH Study. The preliminary studies were conducted at the University of California, Irvine, facility that is also responsible for maintaining the cancer registry for OC and other counties. This cancer registry has a superb history of recording close to 100 percent of all diagnosed cancer cases in the county; therefore, the ascertainment of cases would occur through the cancer registry.

3.5.2 Termination of the Epidemiologic Study

There were several major issues with the methods used to estimate current and historical exposure to recharged drinking water. The inability to define exposure compromised the scientific validity of a preliminary ecologic study and led to the termination of the proposed case-control study. The history of these activities within the SARWQH Study is presented in detail in Chapter 8 of the *Santa Ana River Water Quality and Health Study: Final Report*, published by OCWD in 2004. Estimates of exposure are especially challenging in studies of chronic disease, such as cancer. The latent period — that is, the period between first exposure to a carcinogenic agent and diagnosis — is, at minimum, 15 to 20 years. When the levels of exposure are very low, as is typical with exposures to contaminants in the ambient environment, the latent period can extend to 40 or 50 years. Thus, differentiating the outcomes from normal background is difficult, if not impossible. This characteristic of cancer induction must be accommodated when designing epidemiologic studies of cancer, especially when considering the exposure assessment aspect of such studies. Defensible estimates of exposure that go back 20 years and, preferably, 40 or 50 years, are a minimum requirement.

3.5.3 Findings and Conclusions

1. There are at least four factors that, taken together, severely limit the ability to assess long-term exposure to recharged SAR water in the SARWQH setting. They are:
   - Insufficient understanding of hydrogeologic water flows, timing, and mixing to predict the relative levels of recharged water reaching production wells used by distribution systems that serve the population of the basin.
   - Inability to reconstruct past histories of the water utilities (purveyors) that serve OC's population.
   - A population with elevated geographic mobility, including a high level of in-migration to the study area.
   - Mixing of groundwater and water from other sources in the distribution systems and a lack of data to define the mixing.

   For a more complete discussion of these factors, please consult the *Santa Ana River Water Quality and Health Study: Final Report*, published by OCWD in 2004.
2. A critical issue in deciding whether to pursue further epidemiologic studies of exposure to recharged water is the adequate framing of the study rationale. The motivation for past studies (e.g., Montebello Forebay in Los Angeles and Windhoek in South Africa) and for work completed in the current SARWQH Study was that exposure to recharged water, per se, may possibly result in elevated cancer risk, and that this elevation was large enough to be detected in epidemiologic investigations.
3. In some situations, health surveillance studies to reassure the public exposed to recharged water could be helpful. If such studies are conducted, the health endpoints should be evaluated carefully before study implementation. Endpoints with much shorter latency than cancer could be studied with more confidence, as they require estimating exposure over periods where data are likely to be available. Such endpoints might include reproductive outcomes or gastrointestinal effects. An important element in demonstrating the feasibility of conducting such studies is prior determination of the extent to which exposure to recharged water can be defined for the study population during the period most relevant to the health endpoint(s) under consideration.

Chapter 4:
Panel Recommendations For Future Monitoring

Water-quality monitoring for chemical and microbial contaminants and indicators will continue to be a part of any large water project. New indicators and analytical methods have been developed or are on the horizon, and these offer water providers and the community with continued assurance that the best effort is being made to maintain, protect, and improve water resources.

4.1 Monitoring

1. The suggested future monitoring program should be designed to determine the sanitary quality of the waters involved and then, if necessary, to determine the fate and transport of the various microbes.
2. OCWD should be vigilant of contaminated groundwater plumes arising from various sources (e.g., hazardous waste sites and past industrial waste disposal to land or sewers), as the groundwater plumes may reach OCWD's groundwater basin or the SAR (for example, in recent years, the detection of perchlorate in groundwater has resulted in the closure of several drinking-water supply wells in both Northern and Southern California).
3. Chlorate, which may be related to chlorine disinfection and/or to the application of chlorate as an herbicide, persists in groundwater samples, even in some older groundwater. OCWD should monitor studies currently in progress with the EPA and the National Toxicology Program on the human health significance of chlorate.

4.2 Santiago Pits Monitoring

1. The Santiago Pits recharge area was not included in the SARWQH Study. Future monitoring around these pits, similar to that done during the SARWQH Study in the Forebay area, should be done. Indicator bacteria, protozoan cysts, enteroviruses, and somatic and male-specific coliphage should be monitored.
2. Monitoring wells should be constructed as appropriate, and flow characteristics from the recharge pits to the well field should be determined.
3. Using the monitoring wells and other wells as needed, a transect should be set up for sampling, as dictated by the flow data to include at least four downgradient sampling stations.
4. At the downgradient monitoring wells, samples should be collected and analyzed for:
    - Fecal coliforms and *E. coli*.
    - *Giardia* and *Cryptosporidium* using EPA method (1623).
    - Total culturable viruses (EPA Information Collection Rule [ICR] method).
    - Somatic and male-specific coliphage (EPA 1601/1602 method or modification of the same).

   If culturable enteric viruses are found, they should be characterized to determine whether they are of animal or human origin.

5. Sampling frequency and duration:
   a. The duration of sampling should be at least 1 year to cover the four seasons.
   b. Samples should be collected from surface water that directly influences the recharge water at least once per month and analyzed for protozoan cysts.
   c. Samples should be collected from wells receiving recharge water with the shortest travel times on a biweekly (two times per month) schedule (weekly during and immediately after very wet weather) and analyzed for somatic and male-specific coliphage. Samples from the other downgradient wells should be collected monthly, except during wet weather (when they should be collected biweekly).
   d. Samples should be collected from wells that are positive for somatic or male-specific coliphage as soon as practical after phage presence is determined and analyzed for total culturable viruses.
   e. Samples should be collected at the same sites and frequency as the coliphage samples and analyzed for fecal coliform and *E.coli*.
   f. In all cases, the sample collection frequency should be consistent with the applicable EPA Groundwater Rule.

4.3 OCWD Groundwater Basin Microbiological Monitoring

1. Initial monitoring for microbiological quality of the groundwater basin should be limited to somatic and male-specific coliphage. Testing of wells in the groundwater basin should be carried out at least monthly to determine to what degree the entire basin may be vulnerable to fecal contamination.
2. Samples should be collected from existing monitoring wells that best define the flow characteristics of the basin.
3. EPA Analytical Method 1601, or an acceptable modification, should be used for analyzing the presence of somatic and male-specific coliphage. A sample volume of at least 1 liter should be assayed for the presence or absence of coliphage.
4. Sampling frequency and duration:
   - The sampling period should encompass at least 1 year.
   - Somatic and male-specific coliphage samples should be collected from each well on a biweekly schedule and weekly during and immediately after very wet weather.
   - If two or more coliphage positive samples are detected in any well, then sampling for culturable enteric viruses and bacterial indicators of fecal contamination should be instituted.

Chapter 5:
Overall Conclusions and Recommendations of the Panel

The overall conclusions and recommendations of the Panel were based on the synthesis and integration of the findings and conclusions derived from each of the individual subcommittees. A complete list of conclusions and recommendations by topic area may be found in Chapter 3. Detailed recommendations for future monitoring are given in Chapter 4.

5.1 Conclusions

1. Based on the results of the SARWQH Study, the recharge of SAR water to the groundwater basin does not currently threaten water quality or public health.
2. Water quality in the SAR will continue to change, and these changes may influence OCWD recharge operations.
3. Emerging chemical and microbiological constituents of concern (non-regulated and previously unidentified) will require continued surveillance.
4. OCWD should continue to monitor the quality of SAR water and groundwater for chemical and biological constituents of public health concern.
5. Groundwater in the SARWQH Study area is vulnerable to microbial contamination, as indicated by the occasional presence of phage in some water samples.
6. Utilities using recharged groundwater supplies from vulnerable sources must do more than rely on drinking-water standards and guidelines to ensure safety.
7. To minimize any risks that might be associated with the vulnerability of groundwater to fecal contamination, the Panel recommends disinfecting all production wells in the study area that are found positive for phage.

5.2 Recommendations

1. In cooperation with DHS and other interested regulatory agencies, OCWD should continue its efforts to characterize and monitor contaminants in wastewater.
2. OCWD should systematically pursue questions related to the potential occurrence of emerging contaminants in wastewater and, especially, in underground water that serves as the drinking-water supply source. The form of such an effort might include an initial scoping study, followed by inclusion in the routine monitoring program if a contaminant appeared to be troublesome (i.e., occurs at levels approaching those that might be considered harmful to health) and is not removed in subsequent steps.
3. The validation and standardization of biomonitoring tools is beyond the capability of OCWD. In part, this is because of the resources needed, but also because, ultimately, regulatory agencies will need to accept any interpretations that are made of the results. Some of the key agencies with which

contact should be maintained include the National Toxicology Program, National Center for Environmental Assessment (NCEA), and National Health and Environmental Effects Laboratory (NHEERL) of the EPA. Activities that OCWD should track include the completion of the large-scale effort using *Medaka* to characterize the low dose-response curve produced by N-diethyl-N-nitrosamine-induced cancer, as well as efforts to utilize the *Medaka* system as an alternative species for evaluating carcinogenic responses.

4. The Panel recommends continuing the exploration of fish biomonitoring for now, until a clear role is determined for it in the water-quality evaluations. An expansion or reduction of this effort may become warranted by data developed on-site, as well as by the background data that will be generated by federal agencies.
5. If a biomonitoring approach is found to provide additional assurance of the quality of water, in respect to the nonpresence of carcinogens and endocrine disrupting compounds, OCWD should consider a deliberate and systematic expansion of this effort to include other health endpoints; however, biomonitoring should not be implemented until clear guidelines are developed for taking actions in the interest of public health based on the results of such monitoring.
6. A research effort should be initiated to more fully characterize the quality of stormwater in anticipation of a need to develop monitoring parameters to ensure that such water does not degrade water quality in the aquifer. Biomonitoring could play a role in this effort, but endpoints need to be developed that are shorter in term than those being used in the current pilot study funded by the Water Environment Research Foundation (WERF) for this to be a useful approach.
7. OCWD should develop a study plan to assess the extent to which chemicals, particularly metals and metalloids from soil and rock, can be extracted by GWR System water introduced into the Kraemer Basin. Simulations can be studied immediately using soil samples from the aquifer. The initial work should focus on the bottom of Kraemer Basin and in the downstream monitoring wells nearest the basin. If substantial extraction or movement of these materials underground is found in this initial study, a long-term study may be needed to determine the extent to which GWR System water may have to be conditioned to avoid the possibility that metals may be selectively mobilized into the aquifer and eventually affect drinking-water quality.

Appendix A

Scientific Advisory Panel Members: (top row, from left) George Tchobanoglous, Joseph Cotruvo, Daniel Okun, Robert Cooper, Harvey Collins, Kenneth Cantor, and James Crook; (*bottom row, from left*) Russell Christman, Joan Rose, Jack Skinner, David Todd, Richard Bull, and F. Bernard Daniel.

Members and Subcommittees of the SARWQH Study Scientific Advisory Panel (1996-2004)

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[1] Health Effects [2] Hydrogeological [3] Microbiological
[4] Organics and Water Chemistry [5] Toxicological

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Talbot Page, Ph.D.
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Ex Officio Panel Members

Larry Honeybourne
Program Chief, Environmental Health Water Quality Section
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Richard H. Sakaji, Ph.D., P.E.
Senior Sanitary Engineer, Drinking Water Program
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Hope Smythe
Senior Environmental Specialist and Chief, Inland Waters Planning Section
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APPENDIX B

Biographical Sketches of Panel Members

Richard J. Bull, Ph.D.
Consulting Toxicologist
MoBull Consulting

Since 2000, Richard Bull has been a Consulting Toxicologist with MoBull Consulting, where he provides expert advice on regulating chemicals in water and conducts studies on chemical problems for water utilities and for federal, state, and local governments. In addition to his work with MoBull Consulting, he also teaches at Washington State University, where he is an Adjunct Professor in the Department of Environmental Science, as well as an Adjunct Professor on the College of Pharmacy. Currently, Bull serves as a Councilor and Committee Member for the Society of Toxicology and as a Member on Toxicology and Perchlorate Subcommittees for the National Research Council. He is also on the editorial boards of several journals, including *Toxicology* and the *Journal of Toxicology and Environmental Health*. 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.

Kenneth P. Cantor, Ph.D., MPH
Senior Investigator, Division of Cancer Epidemiology and Genetics
National Cancer Institute

Ken Cantor is an Environmental Epidemiologist with 30-years research experience in cancer epidemiology. He has directed numerous investigations into the relationship between the risk of human cancer and exposure to a variety of drinking-water contaminants, including disinfection byproducts, nitrate, and arsenic. He is also interested in the carcinogenic effects of pesticides, especially in occupational settings, as well as other occupational and environmental factors. Cantor has served as advisor to several national and international organizations, including the National Research Council, Public Health Service, Environmental Protection Agency, Pan American Health Organization, and International Agency for Research on Cancer. The author or coauthor of over 150 research papers, review articles, and book chapters, he is an Associate Editor of the *American Journal of Epidemiology* and has served as an Officer of the International Society for Environmental Epidemiology and other professional societies. Cantor received a Masters degree from the School of Public Health at Harvard University and a Ph.D. in Biophysics from the University of California, Berkeley.

Russell F. Christman, Ph.D.
Professor, Environmental Sciences and Engineering
University of North Carolina at Chapel Hill

Russell Christman is a Professor of Environmental Chemistry at the University of North Carolina at Chapel Hill whose work focuses on the analytical identification of toxic byproducts of the reaction of natural aquatic organic matter with chlorine during water disinfection. Throughout his 40-year career, Christman served as Editor of *Environmental Science and Technology* for 13 years and has chaired major research conferences in the United States and abroad, holding distinguished lectureships in Geochemistry in the United States, Germany, and Japan. In 1989, as Visiting Scientist at the Norwegian Institute of Public Health, he extended his work on disinfection byproduct identification to non-trihalomethane carbonyl compounds of low molecular weight. He is also a Past-President of the International Humic Substance Society, where he was awarded honorary life membership, and a recipient of the A.P. Black Award of the American Water Works Association for outstanding research in the chemistry of water supply. Christman received a Ph.D. in Chemistry at the University of Florida.

Harvey F. Collins, Ph.D., P.E.
Environmental Engineer Consultant

Harvey Collins has over 30 years of experience in California state government, working in all fields of sanitary/environmental engineering and environmental health. He served as Deputy Director of Public Health at the California Department of Health Services and was Chief of the Division of Drinking Water and Environmental Management when he retired in 1995. Since then, he has consulted on various water and wastewater engineering projects, and has served on several blue ribbon panels and on the Research Advisory Board for the National Water Research Institute. He also has received numerous awards, including a Rudolf Hering Medal of the American Society of Civil Engineers, Walter F. Synder Award from the National Environmental Health Association and NSF International, and Special Recognition Award from the California Department of Health Services. Collins received a B.S. in Civil Engineering from Oregon State University, an M.S. in Sanitary Engineering from the University of Missouri, Columbia, and a Ph.D. in Sanitary Engineering from the University of California, Berkeley.

Robert C. Cooper, Ph.D.

Vice President, BioVir Laboratories, Inc.

Professor Emeritus, School of Public Health, University of California, Berkeley

Robert Cooper is Professor Emeritus of the School of Public Health at the University of California, Berkeley, where he served as Director of the University's Sanitary Engineering and Environmental Health Research Laboratory from 1980-1991. He also served in the United States Army Medical Corps and retired from the United States Public Health Service reserve. Cooper has over 45 years of experience in the field of water quality, infectious disease, and public health, and has published more than 70 papers on water quality and infectious disease. In addition, he has served on Federal, state, and local government panels and committees dealing with these and related issues. At present, he is Vice President of BioVir Laboratories, Inc., a laboratory devoted to environmental microbiology. Cooper received a B.S. in Public Health from the University of California, Berkeley, and both an M.S. and Ph.D. in Microbiology from Michigan State University.

Joseph A. Cotruvo, Ph.D.

President

Joseph Cotruvo & Associates, L.L.C.

Joe Cotruvo is President of Joseph Cotruvo Associates, an environmental and public health consulting firm, and is as 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 United States 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 under the Safe Drinking Water Act. He was also Director of the Risk Assessment Division of the EPA's Office of Pollution Prevention and Toxics, and former Vice President for Environmental Health Sciences at NSF International. At present, Cotruvo is a member of the WHO Drinking Water Guidelines development committees and serves on the National Water Research Institute and WateReuse Foundation Research Advisory Boards. He is also the manager of WHO's Desalination Guidance project and is engaged in several studies on antiterrorism and water supplies through the American Water Works Association Research Foundation. Cotruvo received a B.S. in Chemistry from the University of Toledo and a Ph.D. in Physical Organic Chemistry from Ohio State University.

James Crook, Ph.D., P.E.

Water Reuse Consultant

Jim Crook is an Environmental Engineer with more than 30 years of experience in state government and consulting engineering arenas, serving public and private sectors in the United States and abroad. He has authored more than 100 publications and is an internationally recognized expert in water reclamation and reuse. Previously, he spent 15 years directing the California Department of Health Services' water reuse program and developed California's first comprehensive water reuse criteria. He was the principal author of the *Guidelines for Water Reuse*, published by the United States Environmental Protection Agency and United States Agency for International Development. He also spent 15 years with consulting firms overseeing water reuse activities and is now an independent consultant specializing in water reuse. Recently, he served on the National Research Council's Water Science and Technology Board, the Water Environment Research Foundation's Research Council, and the WateReuse Association's Board of Directors. Among his honors, he was selected as the American Academy of Environmental Engineers' 2002 Kappe Lecturer. 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.

F. Bernard Daniel, Ph.D.

Environmental Toxicologist

United States Environmental Protection Agency, National Exposure Research Laboratory

Bernie Daniel has been a Senior Environment Scientist with the United States Environmental Protection Agency for the last 28 years. As Director of the Microbiology and Toxicology Division (and its successor organizations), he was charged with assessing the toxicologic potentials of drinking-water disinfectant byproducts, and the results of many of these studies are now used to support drinking-water contaminant standards. He and his colleagues were among the first to describe the carcinogenicity of the halogenated acetic acids, halogenated acetaldehydes, and chloral hydrate in rodents. In addition, they were the first to establish the genotoxic effects of the chlorinated furanones (MX) in the rodent gastrointestinal tract (*in vivo*). Daniel has received several awards for research excellence from the Agency's Office of Research and Development. Currently, his research is focused on the use of remotely sensed information to evaluate the interactive impacts of land use and geological features on stream water quality and biological integrity. Daniel received a B.S. in Biology and Chemistry from St. Mary's University and a Ph.D. in Biochemistry from Ohio State University.

Daniel A. Okun, Sc.D., P.E.

Kenan Professor of Environmental Engineering, Emeritus

University of North Carolina at Chapel Hill

Dan Okun has been a Consulting Engineer throughout his 56-year career, serving consulting firms, cities, states, industry, the Federal government, and international agencies. He began teaching at the University of North Carolina at Chapel Hill in 1952, and was Chair of the Department of Environmental Sciences and Engineering for 18 years. He also served as Chair of the Water Science and

Technology Board of the National Research Council from 1991 to 1994. Okun's early research involved the first use of pure oxygen in wastewater treatment, for which he received the Eddy Award. He was also the first engineer elected to the National Academy of Engineering and one of the few engineers elected to the Institute of Medicine. In 1999, the *Engineering News-Record*, in celebration of 125 years of publishing, honored him as one of the "top" 125 Engineers in that period who, "singularly and collectively helped shape this nation and the world." His current interests are in wastewater reclamation. Okun received degrees from The Cooper Union, California Institute of Technology, and Harvard University.

Joan B. Rose, Ph.D.

Homer Nowlin Endowed Chair for Water Research
Michigan State University

Joan Rose, the Homer Nowlin Endowed Chair for Water Research at the Michigan State University, has made groundbreaking advances in understanding water quality and protecting public health for more than 20 years. She is widely regarded as the world's foremost authority on the microorganism *Cryptosporidium* and was the first person to present a method for detecting this pathogen in water supplies. Among her honors, Rose was named as one of the 21 most influential people in water in the twenty-first century by *Water Technology Magazine* (2000) and received the 2001 Clarke Prize from the National Water Research Institute for her advances in microbial water-quality issues. Currently, she is one of only a handful of scientists around the world who are examining the relationship between climate, water quality, and public health. Rose received a B.S. in Microbiology from the University of Arizona, an M.S. in Microbiology from the University of Wyoming, and a Ph.D. in Microbiology from the University of Arizona.

Jack Skinner, M.D.

Diplomate, American Board of Internal Medicine
Public Representative, Scientific Advisory Panel

Jack Skinner, a medical doctor, has been interested in water-quality issues for 20 years. He has become an outspoken advocate for clean water, alerting the public, governmental agencies, and dischargers of the human health effects that result from recreational water contaminated with human waste. Having practiced internal medicine for 30 years, he has cared for patients with complications from human enteric viruses, including hepatitis, viral meningitis, and myocarditis. As a result, he has a continuing interest in the treatment train for reclaimed water used for recharge purposes to ensure the removal of pathogens, toxic organics, and pharmaceutical products of concern. In this respect, he has served on a number of committees reviewing these water-quality issues and has testified at the request of the United States Environmental Protection Agency and Justice Department. His medical experience includes serving as Assistant Clinical Professor of Medicine at the University of California, Irvine, Medical School and later as Director of Continuing Medical Education at Hoag Memorial Hospital in Newport Beach. Jack Skinner received his undergraduate and medical training from Stanford University.

George Tchobanoglous, Ph.D., P.E.

Professor Emeritus, Department of Civil and Environmental Engineering
University of California, Davis

For over 30 years, wastewater expert George Tchobanoglous 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 12 textbooks and three reference books that have been used in more than 225 colleges and universities in the United States and worldwide. 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 the National Water Research Institute in 2003. 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.

David K. Todd, Ph.D., P.E.

Professor Emeritus, Civil Engineering
University of California, Berkeley

David Todd has served as teacher, researcher, author, and consultant in the field of groundwater resources. As a Professor at the University of California, Berkeley, he established and led the graduate program in Water Resources Engineering. His research papers are numerous, and several of his former graduate students are internationally recognized in the groundwater field. His textbook, *Groundwater Hydrology*, has been used as a leading reference for many years and has been translated into six foreign languages. Todd has served as a consultant to several Federal and United Nations agencies and to industries throughout the world. In addition, his consulting firm, Todd Engineers, which specializes in the planning, development, management, and protection of groundwater resources, has established a leading reputation in the Western United States. Todd received a B.S. in Civil Engineering from Purdue University, an M.S. in Meteorology from New York University, and a Ph.D. in Civil Engineering from the University of California, Berkeley.

Biographical Sketches of *Ex Officio* Panel Members

Larry Honeybourne

Program Chief, Environmental Health Water Quality Section
County of Orange Health Care Agency

Larry Honeybourne has been Program Chief of the Environmental Health Water Quality Section for the County of Orange Health Care Agency since 1991. In this position, he oversees the management of a variety of water-quality regulatory programs related to the protection of public health. These programs include ocean recreational water protection, drinking-water supply oversight for state small water systems, the construction and destruction of all types of wells, cross connection control, recycled water, and wastewater. Honeybourne is a State of California Department of Health Services Registered Environmental Health Specialist, Water Treatment Operator, and American Water Works Association Cross Connection Control Specialist. He is also a part-time Instructor at Santiago Canyon College. Honeybourne received both a B.S. in Biological Sciences and an M.S. in Environmental Studies from California State University, Fullerton.

Richard H. Sakaji, Ph.D., P.E.

Senior Sanitary Engineer, Drinking Water Program
California Department of Health Services

Rick Sakaji's background in Marine Biological Sciences and Environmental Engineering gives him a unique technical background and public health policy perspective in his role as Senior Sanity Engineer in the Drinking Water Program for the California Department of Health Services (DHS). Throughout his career, Sakaji has brought a public health perspective to all the advisory committees and workgroups of which he was a member. These committees have been assembled to discuss public health, water quality, and water treatment issues surrounding drinking water and wastewater reclamation. At present, he serves on several project advisory committees for the American Water Works Association Research Foundation and Water Environment Research Foundation, and is a member of the Research Advisory Board for the National Water Research Institute. In addition to articles on drinking-water treatment, Sakaji has coauthored articles on analytical methods, microbial risk assessment, water treatment, and wastewater reclamation. Sakaji received an A.B. in Marine Biological Sciences and an M.S. and Ph.D. in Environmental Engineering from the University of California, Berkeley.

Hope Smythe

Senior Environmental Specialist and Chief, Inland Waters Planning Section
California Regional Water Quality Control Board, Santa Ana Region

Hope Smythe is a Senior Environmental Specialist and Chief of the Inland Waters Planning Section at the California Regional Water Quality Control Board, Santa Ana Region, which she joined in 1987. In her role as Chief of Planning, Smythe supervises several programs, including Water Quality Assessment, Clean Water Act-Section 303(d) List of Impaired Waters update, and Total Maximum Daily Load (TMDL) development for a number of impaired waterbodies (Big Bear Lake, Lake Elsinore, and the Santa Ana River). Prior to addressing waterbodies in the inland areas, she oversaw the development, adoption, and implementation of several TMDLs for the Newport Bay Watershed. She is also overseeing a major update of the Region's Basin Plan to include revised groundwater basins boundaries and a revised Nitrogen/Total Dissolved Solids Management Plan. Smythe received a B.S. in Chemistry from the University of California, Irvine, and an M.S. in Environmental Sciences from California State University, Fullerton.

Former Panel Members

Herschel E. Griffin, M.D.

Professor Emeritus, Epidemiology
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San Diego State University
(Member 1997-1999)

Talbot Page, Ph.D.

Professor of Economics
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(Member 1996-1997)

Appendix C

Papers, Reports, and Research Organizations

Burton, C.A., et al., *Water-Quality Trends in the Santa Ana River at MWD Crossing and Below Prado Dam, Riverside County, California,* U.S. Geological Survey, Water-Resources Investigations Report 97-4173, 1997.

Clark, J.F, et al., "Geochemical Imaging of Flow Near an Artificial Recharge Facility, Orange County, California," *Ground Water*, 2004, Vol. 42, No. 2, 167-174.

Davisson, M.L., et al., *Final Report on Isotope Tracer Investigations in the Forebay of the Orange County Groundwater Basin*, Lawrence Livermore National Laboratory, 2004UCRL-TR-201735.

——— *Report on Isotope Tracer Investigations in the Forebay of the Orange County Groundwater Basin: Fiscal years 1996 and 1997,* Lawrence Livermore National Laboratory, 1999, UCRL-ID-133531.

——— *Tracing Waste-Water in River and Ground Water of Orange County Using Boron Isotopes and General Geochemistry,* Lawrence Livermore National Laboratory, 1999, UCRL-ID-133529.

——— I*sotope Tracers of Organic Carbon During Artificial Recharge,* Lawrence Livermore National Laboratory, 1998, UCRL-ID-129785.

——— "Isotope Tracer Approaches for Characterizing Artificial Recharge and Demonstrating Regulatory Compliance," Annual UC Water Reuse Res. Conference, Monterey, CA, June 4-5, 1998.

——— *Report on the Feasibility of Using Isotopes to Source and Age-Date Groundwater in the Orange County Water District's Forebay Region, Orange County, CA,* Lawrence Livermore National Laboratory, 1996, UCRL-ID-123953, 31 pp.

Ding, W.D., et al., "Occurrence and Behavior of Wastewater Indicators in the Santa Ana River and the Underlying Aquifers," *Chemosphere,* 1999, 39(11), 1781-1794.

———- "Identification of Organic Residues in Tertiary Effluents by GC/EI-MS, GC/CI-MS and GC/TSQ-MS," *Fresenius' J. Analysis Chem.,* 1996, 354, 48-55.

Fujita, Y., et al., *Tracking the Movement of Recharge Water After Infiltration,* Lawrence Livermore National Laboratory, 1998, UCRL-ID-130194.

——— "Tracking the Movement of Recharge Water After Infiltration." *Proceedings of the Third International Symposium on Artificial Recharge of groundwater,* Amsterdam, A. A. Balkema Publishers, September 21-25, 1998.

———- *Occurrence and Fate of Organic Wastewater Indicators in Groundwater Recharged with Reclaimed Wastewater,* Ph.D. Thesis, Stanford University, 1997.

——— "Identification of Metabolites from the Biological Transformation of the Nonionic Surfactant Residue Octylphenoxyacetic acid and its Brominated Analog," *Environmental Science & Technology*, 1997, 31(5): 1518-1524.

———- "Identification of Wastewater DOC Characteristics in Reclaimed Wastewater and Recharged Groundwater," *Water Environment Research,* 1996, 68, 867-876.

Gamlin, J.D., et al., "Large-Scale Tracing of Ground Water With Sulfur Hexafluoride," *Journal of Environmental Engineering,* 2001, 127(2):171-174.

Gray, K.A., et al., *Evaluation of Organic Quality in Prado Wetlands and Santa Ana River by Pyrolysis-GC-MS,* 1996.

Gross, B., Montgomery-Brown, J., Naumann, A., and Reinhard, M., 2004, "Occurrence and Fate of Pharmaceuticals and Alkylphenol Ethoxylate Metabolites in an Effluent-Dominated River and Wetland, Environmental Toxicology and Chemistry" (Accepted for Publication).

Izbicki, J.A., et al., *Stormflow Water Chemistry in the Santa Ana River below Prado Dam and at the Diversion Downstream from Imperial Highway, Southern California, 1995-98,* U.S. Geological Survey Water-Resources Investigations Report, 2000, 00-4127.

Leenheer, J.A., Nanny, M.A. and McIntyre, C., 2003, "Terpenoids as Major Precursors of Dissolved Organic Matter in Landfill Leachates, Surface Water, and Groundwater," *Environmental Science and Technology* (Accepted for publication).

Leenheer, J.A., Aiken, G.R., Woodside, G., and O'Connor-Patel, K. "Assessment of DOM in Recharge Waters, Santa Ana River Basin," to be submitted to the *Journal of the American Water Works Associations* (first draft written and under author review).

Leenheer, J.A., Noyes, T.I, Rostad, C.E., and Davisson, M. L. "Characterization and origin of polar dissolved organic matter from the Great Salt Lake" (submitted to *Biogeochemistry*).

Leenheer, J.A., *Comprehensive Characterization of Dissolved and Colloidal Organic Matter in Waters Associated with Groundwater Recharge at the Orange County Water District,* 2004.

Lin, A.Y.C., et al., "Comparison of Rhodamine WT and Bromide in the Determination of Hydraulic Characteristics of Constructed Wetlands," *Ecological Engineering*, 2003, 20(1), 75-88.

Maloney, W., *Biodegradable Dissolved Organic Carbon Analysis of Prado Wetlands,* Report for the Orange County Water District, 1995.

Orner, G.A. and J.M. Spitsbergen, *Feasibility of using fish for the toxicological component of the Santa Ana River Water Quality and Health Study (SARWQH),* March 1999.

Reinhard, M., et al., *Organic Contaminant Behavior During Groundwater Recharge With Santa Ana River Water,* Stanford University, Department of Civil and Environmental Engineering Technical Report No. 323, 2000.

——— "New and Emerging Analytical Techniques for the Detection of Organic Compounds in Water," in *Identifying Future Drinking Water Contaminants,* National Academy Press, Washington, D.C., 1999.

——— Technical Report No. 322, *Behavior and Fate of Organic Contaminants During Groundwater Recharge with Reclaimed Wastewater and Santa Ana River Water — A Field and Laboratory Investigation,* 1996.

Toussaint, M. and G. Woodside, *Biomonitoring Demonstration Project Final Report*, Prepared by Geo-Centers Inc. and Orange County Water District, 2001.

Wild, D. and M. Reinhard, "Biodegradation Residual of 4-Octylphenoxyacetic Acid in Laboratory Columns Under Ground Water Recharge Conditions," *Environmental Science & Technology,* 1999, 33(24), 4422-4426.

Woodside, G.D., O'Connor-Patel, K., and Wehner, M.P. (2004). *Santa Ana River Water Quality and Health Study: Final Report,* Orange County Water District, Fountain Valley, California, 2004.

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- GeoCenters, Inc./United States Army [5]
- Lawrence Livermore National Laboratory [2, 4]
- Metropolitan Water District of Southern California [3, 4]
- Northwestern University [4]
- Oregon State University [5]
- Stanford University [4]
- United States Geological Society [2, 3, 4]
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  - Berkeley [4]
  - Irvine [1, 3]
  - Riverside [3]
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[2] Hydrogeological
[3] Microbiological
[4] Organics and Water Chemistry
[5] Toxicological

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