SUMMARY
HEALTH EFFECTS STUDY
FINAL REPORT
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SUMMARY

INTRODUCTION

Southern California, like many semi-arid regions of the United States, does not receive sufficient water from local sources to support the considerable population of the area. Almost two-thirds of the water supply is imported 200 to 500 miles from the point of use. The remainder is derived from local groundwater basins. In some areas, the occurrence of overdraft conditions and saltwater intrusion has led to the adjudication of groundwater extractions and/or the implementation of artificial groundwater replenishment. Water sources used for groundwater replenishment include surface runoff, imported river water and, in some cases, treated wastewater (reclaimed water).

There is considerable uncertainty at this time regarding the sufficiency of water supplies for the future water needs of the area. Population growth projections coupled with reductions in imported water deliveries suggest that, by the late 1980s, water needs may exceed available supplies. These water shortage predictions have stimulated regional planning activities aimed at optimizing available water supplies through conservation efforts and developing new local sources of supply through conjunctive groundwater storage and water reclamation. Foremost among these planning efforts is the Orange and Los Angeles Counties Water Reuse Study(1), which has identified the most viable wastewater reclamation projects within the South Coast Region and has developed a financial and institutional scheme for their implementation. Of all the reclamation projects under consideration, groundwater replenishment represents the largest and potentially most economical use of reclaimed water.

Despite this economic incentive, implementation of proposed groundwater replenishment projects is constrained by concerns over the potential health impacts of the indirect use of reclaimed water for potable purposes. Health issues associated with groundwater replenishment include the acute and chronic effects of trace metals, minerals, pathogens and organic compounds which, if present in reclaimed water, may ultimately become part of a potable water supply. Available information on existing groundwater replenishment projects in Southern California has never shown any evidence of impaired water quality or adverse health effects. Yet, it is recognized that this information is insufficient for rigorous evaluation of the possible long-term health implications associated with indirect potable reuse.

The projects in Los Angeles and Orange Counties provided an opportunity to gather data needed to evaluate the health significance of water reuse by groundwater replenishment. A work plan was developed by the Los Angeles County Sanitation Districts which incorporated multidisciplinary research recommendations proposed by a "blue ribbon" panel of experts(2) convened by the California State Water Resources Control Board, the Department of Water

Resources, and the Department of Health Services. The work plan(3) formed the basis for the Health Effects Study, which formally began in November 1978. The focus of the study was the Whittier Narrows groundwater replenishment project, located in the Montebello Forebay area of Los Angeles County, where disinfected filtered secondary effluent, blended with storm runoff and imported river water, has been used for replenishment since 1962. Other work consisted of conducting preliminary background evaluations for proposed replenishment sites in Los Angeles and Orange Counties.

STUDY GOALS AND OBJECTIVES

The primary goal of the Health Effects Study was to develop a data base which would enable health and regulatory authorities to determine whether the use of reclaimed water for groundwater replenishment at the Whittier Narrows project should be maintained at the present level, cut back, or expanded. Two objectives were necessary to meet this goal; first, to determine if the historical level of reuse had impacted either groundwater quality or human health, and second, to assess the relative impacts of the different replenishment sources on groundwater quality. A second goal of the study was to provide information to the California Department of Health Services to use in establishing statewide reclamation criteria for groundwater replenishment.

A wide range of research tasks was undertaken to meet these objectives, including 1) water quality characterizations of groundwater, reclaimed water, and other replenishment water supplies in terms of their microbiological and inorganic chemical quality, 2) toxicological and chemical studies of groundwater, reclaimed water, and other replenishment water supplies to isolate and identify health-significant organic constituents, 3) percolation studies to evaluate the efficacy of soil in attenuating inorganic and organic chemicals in reclaimed water, 4) hydrogeological studies to determine the movement of reclaimed water throughout the groundwater basin and the relative contribution of reclaimed water to municipal water supplies, and 5) epidemiological studies of populations ingesting reclaimed water to determine if their health characteristics differ significantly from a demographically similar control population.

Expenditures for the study amounted to approximately $1.6 million. A total of $1,134,000 was provided by the Orange and Los Angeles Counties Water Reuse Study, of which 87.5 percent was funded by the Environmental Protection Agency and the California State Water Resources Control Board, and the remainder by six local water and wastewater agencies (the Metropolitan Water District of Southern California, Los Angeles Department of Water and Power, City of Los Angeles, Orange County Water District, County Sanitation Districts of Los Angeles County, County Sanitation Districts of Orange County). An additional $500,000 was provided for the epidemiology work by the EPA Health Effects Research Laboratory and the California Department of Water Resources. The majority of study tasks were performed by the Los Angeles County Sanitation Districts. Subcontracted work consisted of the epidemiology study (University of California at Los Angeles, School of Public Health), and portions of the trace organics analyses (Metropolitan Water District of Southern California), hydrogeologic studies (Bookman-Edmonston Engineering, Inc.), and toxicity testing (University of

Southern California Cancer Research Center). Assistance and direction during the course of the study were provided by two technical advisory committees, and the California Department of Health Services.

Specific study findings, conclusions, and recommendations are summarized below in relation to the stated goals and objectives; a detailed study summary is then presented in the remainder of this document.

GOAL

Provide information to health and regulatory authorities to determine whether the use of reclaimed water at the Whittier Narrows groundwater replenishment project should be maintained at its present level, cut back, or expanded.

OBJECTIVES

A. Determine whether the historical level of groundwater replenishment with reclaimed water has had an adverse impact on the quality of the area's groundwater or the health of individuals ingesting the groundwater.

B. Assess the relative impacts of the various replenishment sources on groundwater quality.

FINDINGS

1. Groundwater and reclaimed water complied with all Federally prescribed drinking water regulations for microorganisms, and inorganic and organic chemicals.

2. No viruses were detected in groundwater or chlorinated reclaimed water samples.

3. Analyses for health significant organic compounds not currently regulated by Federally prescribed drinking water standards showed that groundwater and imported water concentrations did not exceed guidelines set by the California Department of Health Services' "action levels" or National Academy of Sciences' "suggested no-adverse-response levels" for chronic ingestion of specific trace organics in drinking water. Concentrations in reclaimed water and storm water were variable and on occasion exceeded levels set by both of these guidelines.

4. Average concentrations of trace organics in groundwater did not exceed the theoretical lifetime risk assessment values calculated in the proposed EPA Water Quality Criteria for priority organics even though average concentrations in reclaimed water, imported water, and storm water did exceed some of the water quality criteria.

5. A 1981 health survey of women residing in the Montebello Forebay study area, which controlled for the potential confounding effects of factors such as smoking, alcohol consumption, bottled water usage, and length of residence, showed no elevated levels of specific illnesses or other measures of general health.

6. Evaluation of health and vital statistics data for the period 1969-80 showed that residents of the area that received reclaimed water experienced no increased rates of infectious diseases, congenital malformations, infant and neonatal mortality, low birth weight, cancer incidence, or deaths due to heart disease, stroke, stomach cancer, rectal cancer, bladder cancer, colon cancer, or all cancers combined, when compared to residents of two control areas that did not receive reclaimed water.

7. Concentrated organic residues derived from all replenishment sources and groundwaters elicited mutagenic responses in bacterial tests related to the presence of a mixture of toxic organic compounds. Chemical and biological assays indicated that low levels of compounds belonging to two classes of organics, the organic halides and epoxides, may have contributed to the mutagenicity. Although there are no drinking water standards or water quality risk assessment data for these two classes of chemicals, members of each group are known to be mutagens and animal carcinogens. Since positive chemical identification of specific mutagens from these two classes could not be made, and since no direct evidence of adverse human health effects was detectable in the epidemiological studies, the biological significance of these materials to humans, at the low levels detected, remains in doubt. Although there was evidence implicating the use of chlorine in industry or in water disinfection as one factor in the occurrence of some of these compounds, other sources may also be important. The presence of such mutagens in groundwater may not be unique to or uniquely aggravated by groundwater replenishment activities. Rather, their presence may reflect the same spectrum of compounds responsible for low-level mutagenesis reported in various drinking water samples nationwide.

CONCLUSIONS

1. Extensive evaluation of the Whittier Narrows groundwater replenishment project did not demonstrate any measurable adverse impacts on the area's groundwater or the health of the population ingesting this water.

2. While the information provided in this report delineates the impact of the existing operation of the Whittier Narrows pro-

project, it does not directly show what impact the increased use of reclaimed water will have on the quality of the groundwater or the health of the individuals consuming the groundwater. It does, however, serve as a baseline study by which impacts of an expansion of the use of reclaimed water can be evaluated.

3. There is a need for continued monitoring and evaluation of the Whittier Narrows project with respect to the trace organic content of the groundwater and replenishment waters. In addition, investigation of the organic compounds responsible for the mutagenicity detected in bacterial tests may be prudent in order to determine whether or not any connection can be made to human health.

RECOMMENDATIONS

1. The existing operation of the Whittier Narrows groundwater replenishment project should continue. Furthermore, because the existing operation has had no adverse impact on either groundwater quality or human health, a closely monitored expansion of the use of reclaimed water should be implemented. The associated monitoring program should be designed to enable early detection of any potential impacts on groundwater quality resulting from the expanded use of reclaimed water for replenishment. Continuation of the expanded program should be conditioned on the finding of no significant degradation of groundwater quality as determined by the monitoring program.

2. The existing monitoring program for percolation source waters and groundwaters should be revised to include some of the organics identified during the course of the study. This program should be reviewed and revised when appropriate as determined from the accumulated data base.

3. Total organic halogen testing should be investigated as a potential surrogate measure for the detection of organic halides in an effort to identify trends that may be associated with groundwater replenishment.

4. Periodic evaluation of the Montebello Forebay population should be conducted in the future in order to examine the possibility that longer periods of exposure to toxic agents, whether of reclaimed water origin or not, might result in an increased incidence of certain diseases. This surveillance is particularly relevant to cancer, since it is widely believed that the induction or latency period between exposure and onset of the clinical disease may be ten to twenty years or more.

5. Restrictions imposed on the volume of reclaimed water percolated should be based on average applications over several

years rather than on annual maximums. Likewise, dilution requirements should be regarded from a long-term standpoint.

GOAL

Provide information to the California Department of Health Services that could be used as a basis for developing statewide reclamation criteria for groundwater replenishment.

FINDINGS

1. There was significant variation in effluent and groundwater quality as well as the hydrogeologic conditions of the different sites evaluated by this study.

2. Results from a pilot soil percolation study and literature review showed that percolation did not consistently remove trace organics from reclaimed water.

3. The combination of biological and chemical analytical methods used in this study proved to be valuable for measuring levels of conventional water quality parameters and focusing attention on components that may have significance with regards to long-term carcinogenic risk.

CONCLUSIONS

1. Percolation cannot, in itself, be relied upon as a treatment process for the removal of specific health-significant compounds.

2. Given the numerous variables involved with groundwater replenishment, implementation of new projects or expansion of existing projects should be evaluated on a case-by-case basis.

3. Results from this study provided a basis for assessing the relative impacts on groundwater from the various Whittier Narrows percolation sources and determining the chemical nature of some unknown materials.

RECOMMENDATIONS

1. Methods and results developed by this study provide a basis for evaluating groundwater replenishment projects outside of the Whittier Narrows region. The implication that the existing replenishment operation has not resulted in a measurable adverse impact on the groundwater of the Montebello Forebay

allows the project to be considered a prototype by which other replenishment projects may be compared. The physical and operational aspects of the project that may be used for comparison include wastewater treatment processes, percolation practices, water quality data, and hydrogeologic conditions.

2. For new groundwater replenishment projects under consideration, it should be recognized that water quality monitoring will be necessary for long-term surveillance purposes. In addition, consideration should be given to initiating epidemiologic studies of vital statistics data for the purpose of establishing baseline data for evaluation of health trends in a population exposed to reclaimed water through groundwater replenishment. The costs of water quality monitoring and epidemiologic studies should be incorporated into the economic analysis of proposed projects.

STUDY SUMMARY

Sampling Sites

Within the South Coast Region, four sites were selected for study on the basis of historical or planned reuse (see Figure 1). The first and most important of these was the Montebello Forebay in Los Angeles County, where groundwater replenishment by surface spreading of reclaimed water has been practiced since 1962. During the twenty years the project has been in operation, over 439,000 acre-feet (AF) of disinfected secondary and tertiary effluent have percolated into the Central Basin groundwater system. On an annual basis, reclaimed water currently constitutes about 26,500 acre-feet per year (AFY) or 16 percent of the total inflow including storm water and imported Colorado River and State Project waters. An arbitrary upper limit for reclaimed water of 32,700 AFY has been established based on historical spreading operations. The marketing evaluation conducted for the OLAC Water Reuse Study, concluded that the current level of reclaimed water use be expanded to 50,000 AFY, or approximately 30 percent of the total inflow.

The second site selected for study was the eastern section of the San Fernando Groundwater Basin in Los Angeles County. Current groundwater replenishment is limited to spreading surface runoff, imported water from the Owens Valley, and base flows of the Los Angeles River which traverses the basin. The OLAC Water Reuse Study proposed that approximately 20,000 AFY of reclaimed water be used to augment the existing replenishment operations. This level of reuse would constitute 20 to 25 percent of the safe yield of the basin.

The third site selected was the Anaheim Forebay in Orange County, which is the principal replenishment area of the Santa Ana Groundwater Basin. Replenishment is accomplished by percolation of storm runoff, imported water, and base flows of the Santa Ana River. Some incidental (unplanned) replenishment has occurred through upstream discharge of treated wastewater into the Santa Ana River. It has been proposed to augment existing replenishment in the

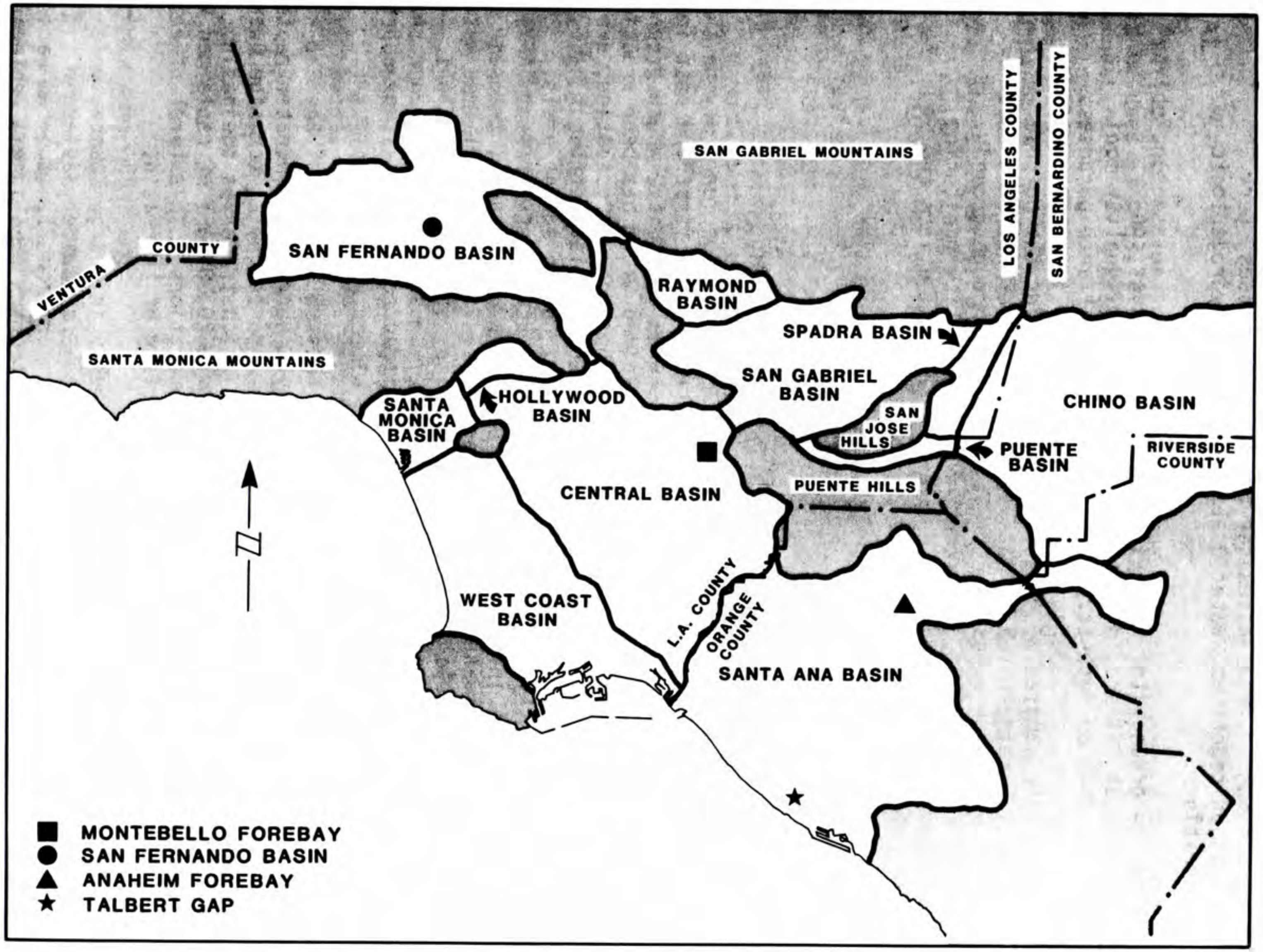

FIGURE 1 HEALTH EFFECTS STUDY SAMPLING SITES

Anaheim Forebay with reclaimed water. The project under consideration would initially provide 12,000 AFY of reclaimed water with an additional 12,000 AFY planned for future expansion. This full scale level of reclaimed water use would represent approximately eight percent of the total input to the groundwater basin.

The final site selected for study was the Talbert Gap, also located in Orange County. It is the site of the Talbert Coastal Barrier Project, which in addition to preventing saltwater intrusion also provides for some groundwater replenishment. The water injected into the intrusion barrier is a blend of native groundwater and advanced treated effluent from Water Factory 21 (activated carbon and reverse osmosis effluents). On an average basis, approximately 11,000 AFY of reclaimed water is injected into the barrier system.

The detailed evaluation of each site differed in terms of emphasis, with the majority of work directed towards the Montebello Forebay. This site had been impacted by groundwater replenishment with reclaimed water for a sufficient period of time to allow for meaningful evaluation of water quality and human health effects. Work conducted for the San Fernando Basin and Anaheim Forebay study sites was designed to provide background information for planned replenishment projects, while work done for the Talbert Gap area was conducted to evaluate the impacts of reclaimed water injection on groundwater quality and to provide data for comparison with other data compiled for the Talbert Barrier Project. Data presented in this summary are specific to the Montebello Forebay project. A complete presentation of data for all study sites can be found in the Health Effects Study Final Report.

Water Quality Characterizations

Water quality characterizations were conducted for each of the four sampling sites. Groundwater, imported water, reclaimed water, storm water, and dry weather runoff were characterized, as available, in each study area. The parameters selected for evaluation comprised the traditionally monitored minerals, nutrients, and metals, many of which are regulated under primary and secondary drinking water standards. In addition, physical parameters such as pH, color, and turbidity, and bacterial indicators such as coliforms, fecal streptococci, and total plate count were measured. Treatment plants and wells in the Montebello Forebay and Anaheim Forebay were characterized for virus in a program separate from the more standard water quality monitoring analyses.

Results obtained from the water quality evaluations demonstrated that the use of reclaimed water for groundwater replenishment in the Montebello Forebay has not adversely impacted the potability of the area's groundwater in terms of inorganic chemical and microbiological contaminants. A summary of these results is presented in Table 1. Reclaimed water from the Los Angeles County Sanitation Districts' San Jose Creek, Whittier Narrows, and Pomona Water Reclamation Plants and imported waters used for replenishment have traditionally met health-related primary drinking water standards and most aesthetics-related secondary standards as has the groundwater impacted by the replenishment operation. Well water concentrations in excess of secondary standards were not attributable to any of the replenishment water supplies; a variable pattern of concentrations above the standards appeared to be a local water quality phenomenon. As for storm water,

TABLE 1

AVERAGED WATER QUALITY DATA FOR MONTEBELLO FOREBAY SAMPLES

Parameter	Drinking Water Standards a/		Reclaimed Water b/			Imported Water			Unchlorinated Well Water			Chlorinated Well Water	
	Primary	Secondary	Cl_2/DeCl_2 3°	Cl_2 2°	UnCl_2 2°	Storm Water	Colorado River	State Project	High c/	Low d/	Control e/	High c/	Low d/
Turbidity, NTU	0.5-5	5	0.8	2.3	1.9	79.2	1.9	2.4	1.7	< 0.2	< 0.5	0.5	0.3
Color, CU	-	15	22.5	28.3	36.7	698.3	< 5	21.7	< 7	< 5	< 5	< 5	< 5
pH	-	-	7.23	7.73	7.52	7.68	8.00	8.07	7.65	7.81	7.90	7.51	7.36
Dissolved Solids, mg/L	-	500-1500	568	588	560	179	664	339	464	478	277	492	713
Total Alkalinity, mg/L $CaCO_3$	-	-	220	276	276	59	127	72	162	201	161	189	258
Chloride, mg/L Cl	-	250-600	133	129	111	19	96	61	62	45	18	105	67
Sulfate, mg/L SO_4	-	250-600	113	102	102	46	308	34	125	123	48	179	200
Nitrate, mg/L N	10.0	-	0.34	0.13	0.19	1.78	0.16	0.60	2.31	1.51	0.93	0.57	3.68
Nitrite, mg/L N	-	-	0.40	0.52	0.50	0.14	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Ammonia, mg/L N	-	-	13.7	20.7	20.5	1.3	< 0.1	< 0.1	< 0.1	< 0.2	< 0.2	< 0.1	< 0.1
Phosphate, mg/L PO_4	-	-	10.6	6.9	7.2	2.4	0.8	0.3	0.6	0.2	< 0.1	< 0.1	0.7
Fluoride, mg/L F	1.4-2.4	-	0.65	0.66	0.60	0.23	0.37	< 0.13	0.43	0.40	0.36	0.51	0.23
Cyanide, mg/L CN	-	-	< 0.01	< 0.01	0.02	0.02	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.02
Total Hardness, mg/L $CaCO_3$	-	-	194	212	211	100	334	93	242	309	255	279	445
Arsenic, mg/L As	0.05	-	0.003	0.004	0.003	0.010	0.003	0.002	0.004	0.003	0.002	0.004	0.002
Barium, mg/L Ba	1.0	-	0.22	0.20	0.23	0.26	0.46	0.16	0.29	0.29	0.29	0.33	0.54
Cadmium, mg/L Cd	0.01	-	< 0.002	0.004	0.004	0.002	0.002	< 0.001	<0.002	0.002	< 0.001	0.002	0.003
Chromium, mg/L Cr	0.05	-	< 0.01	< 0.01	< 0.01	0.02	< 0.01	< 0.01	<0.01	< 0.01	< 0.01	< 0.01	< 0.01
Copper, mg/L Cu	-	1.0	0.008	0.016	0.015	0.046	< 0.006	< 0.010	<0.007	< 0.005	< 0.005	< 0.006	0.014
Iron, mg/L Fe	-	0.3	< 0.06	0.07	0.09	9.13	0.18	0.22	0.40	0.02	< 0.01	0.07	< 0.02
Lead, mg/L Pb	0.05	-	< 0.02	0.02	0.03	0.09	< 0.01	< 0.02	<0.02	< 0.02	< 0.02	< 0.02	< 0.02
Manganese, mg/L Mn	-	0.05	< 0.01	0.02	0.02	0.18	0.01	0.01	<0.05	< 0.05	< 0.01	0.02	< 0.01
Mercury, mg/L Hg	0.002	-	< 0.0001	< 0.0001	0.0001	< 0.0001	< 0.0001	< 0.0001	<0.0001	< 0.0001	< 0.0001	0.0004	< 0.0001
Nickel, mg/L Ni	-	-	0.05	0.07	0.07	0.02	< 0.01	0.01	<0.01	< 0.09	< 0.01	0.01	0.02
Selenium, mg/L Se	0.01	-	< 0.003	0.003	0.003	< 0.003	< 0.003	< 0.002	<0.002	0.002	< 0.001	0.003	0.004
Silver, mg/L Ag	0.05	-	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	<0.001	< 0.001	< 0.002	0.002	0.002
Sodium, mg/L Na	-	-	105	126	116	19	91	45	59	40	19	109	56
Zinc, mg/L Zn	-	5.0	0.03	0.05	0.05	0.10	< 0.01	0.05	0.02	< 0.01	0.09	0.14	0.03
TOC, mg/L C	-	-	11.2	14.1	12.6	16.4	3.2	4.3	0.8	0.6	0.3	2.2	0.7
Bromide, mg/L Br	-	-	< 0.30	0.32	0.31	0.14	0.11	0.22	0.21	0.18	0.05	0.38	0.13
Total Coliform, MPN/100 mL	-	-	8	< 8	$>5.0\times10^{5}$	$>6.2\times10^{4}$	< 2	14	< 2	< 2	< 2	< 2	< 2
Fecal Coliform, MPN/100 mL	-	-	< 2	< 2	$>2.8\times10^{4}$	$>8.7\times10^{3}$	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Fecal Strep, MPN/100 mL	-	-	< 2	< 2	$>8.8\times10^{2}$	$>1.1\times10^{5}$	< 2	< 3	< 2	< 2	< 2	< 2	< 2
Total Plate Count/mL	-	-	194	83	$>2.9\times10^{4}$	7.7×10^{4}	< 1	49	<17	< 1	4	< 1	<10

a/ California Domestic Water Quality and Monitoring Regulations, Articles 4 and 8, Title 22, California Administrative Code, 1977.
b/ Cl_2/De Cl_2 3° = chlorinated/dechlorinated tertiary effluent; Cl_2 2° = batch chlorinated secondary effluent; UnCl_2 2° = unchlorinated secondary effluent.
c/ Wells containing > 5 percent reclaimed water.
d/ Wells containing ≤ 5 percent reclaimed water.
e/ Wells containing no reclaimed water.

concentrations of many trace constituents, particularly lead, have historically exceeded specified limits. No corresponding water quality problems have been observed in the wells, suggesting that dilution and/or soil attenuation have occurred. The only groundwater impact resulting from the replenishment operation has been a fluctuating temporal trend in mineral levels caused by percolation of imported waters.

Virus sampling results indicated that the replenishment operation has not impacted groundwater quality in terms of viral contamination (see Table 2). No viruses were detected in any of the Montebello Forebay groundwater samples or any disinfected tertiary effluents.

Based on these results, it would appear that, in terms of inorganic chemical and microbial constituents, the existing replenishment practice could be expanded without modification. At present, the treatment plants supplying reclaimed water for replenishment routinely produce effluents containing inorganic chemical and microbial constituents at levels that pose no known acute or chronic health threat. There have been concerns expressed over the impacts of plant upsets; i.e., situations in which the treatment facilities are not in full operation and therefore are producing only partially treated water. Contingency procedures have been established for those situations that allow for improperly treated flows to be diverted from the spreading grounds. Moreover, historical records have shown these episodes to be rare; very few plant upsets have occurred during the 20 years that reclaimed water has been used for groundwater replenishment.

As for the San Fernando Basin, results from groundwater sampling have demonstrated that background concentrations of inorganic chemical constituents are in compliance with drinking water standards. Differences were observed between the two well fields monitored in terms of mineral quality. It is speculated that the higher concentrations reported for one of the well fields resulted from the percolation of dry weather runoff in the Los Angeles River which appeared to be high in mineral content.

Reclaimed water sampled for the San Fernando Basin was obtained from the Los Angeles/Glendale Water Reclamation Plant. Effluent from the facility did not typically comply with cadmium requirements for drinking water. This problem, considered to be of industrial origin, may be resolvable through the implementation of more stringent source control measures. Should the reclaimed water to be used for future replenishment in the San Fernando Basin be of similar quality, it will be necessary to determine whether or not it is critical to insure that the heavy metal concentrations in the final effluent routinely comply with maximum contaminant levels prior to replenishment. Experience from the use of storm runoff as a replenishment source in the Montebello Forebay has indicated that no problems have resulted from percolation of a source water that has contained some trace constituents at concentrations above allowable limits. However, it should be recognized that at present there is no control over the quality of storm water entering the basin. The same is not true for reclaimed water. Thus, if the problem can be corrected by source control or operational modifications in existing treatment, then a conservative approach would dictate that the effluent meet standards prior to use.

TABLE 2 - Results of Water Reclamation Plant Virus Sampling

Sample Type	Pomona WRP		San Jose Creek WRP		Whittier Narrows WRP	
	Number of Samples	Concentration pfu/1000 gal	Number of Samples	Median a/ Concentration pfu/1000 gal	Number of Samples	Median a/ Concentration pfu/1000 gal
Unchlorinated Effluent						
Primary	13	2.3×10^5	8	1.6×10^6	8	7.6×10^5
Secondary	12	6.5×10^3	14	5.5×10^2	9	5.6×10^2
Tertiary	12 b/	5.2×10^2	-	-	-	-
Chlorinated Effluent						
Tertiary	33 b/	<2	43 c/	<2	38 c/	<2

a/ Virus concentrations expressed as probability medians, plaque forming units per 1,000 gallons.
b/ Pomona tertiary effluent receives activated carbon filtration.
c/ San Jose Creek and Whittier Narrows tertiary effluents receive dual media filtration.

No data were collected on the virological characteristics of the Los Angeles/Glendale Water Reclamation Plant. In lieu of virus sampling, proper operation of this and similar facilities should insure the production of "essentially virus-free" effluents as verified by the negative virus data obtained for the Montebello Forebay.

Data obtained for the Anaheim Forebay wells were also in compliance with drinking water standards. No viruses were found in any of the chlorinated or unchlorinated well samples. Data obtained for the Orange County advanced waste treatment facility, Water Factory 21, which produces reclaimed water for salt water barrier injection, were in agreement with previously collected data from the facility. Results demonstrated that concentrations of inorganic constituents reliably complied with drinking water standards. No measurable levels of virus were detected in effluent samples. Inorganics data collected for the Talbert Barrier observation wells yielded similar results with no apparent impacts from the injection operation. Production of an effluent similar in quality to that produced by Water Factory 21 (as envisioned for the proposed Anaheim Forebay recharge) should negate any risks for the transmission of harmful agents via surface percolation.

Toxicology and Trace Organics

The complex and largely unknown composition of trace organic chemical residues in wastewater has recently become the major concern related to the use of reclaimed water for groundwater replenishment. Of particular interest is the possible occurrence of long-term or chronic disease (especially cancer and birth defects) in populations ingesting water which might contain organic components having genotoxic effects in humans.

In order to assess possible adverse impacts of reclaimed waters and other percolation source waters on groundwater supplies, an interdisciplinary experimental approach[4] was devised which employed toxicological screening assays[5,6] for mutagens and chemical separation/identification methods[7,8] for isolating and characterizing unknown genotoxic compounds. In conjunction with this, all samples were analyzed for a list of target organics which were considered to be priority health concerns and which were not uniformly amenable to detection by the toxicological methods chosen.

Target organic analyses were conducted on multiple samples from all four study areas, while the more detailed toxicology/trace organics work focused primarily on the Montebello Forebay wells and percolation sources tributary to the Forebay. General comparisons of the molecular complexity and organic content were made for various sample types in all four areas. The data suggest that in order of complexity, the samples could be ranked as follows: surface runoff $\geq$ reclaimed water > imported water > groundwater. The exception to this order was reverse osmosis-treated reclaimed water, which was similar to groundwater in organic content. In addition, it was observed that the general organic complexity of groundwaters appeared to be related to the proximity of the site to industrial operations, i.e., in order of complexity, the groundwater sites could be ranked as follows: San Fernando Basin > Montebello Forebay > Anaheim Forebay $\geq$ Talbert Barrier.

Results of target organic analyses in the Montebello Forebay, shown in Table 3, suggested that influence from all percolation sources could be seen in the refractory organic content of well waters. Storm water contributed tetrachloroethylene, atrazine, chlorinated phenols, phenylacetic acid, and phthalate; reclaimed water contributed methylene chloride, chloroform, trichloroethylene, tetrachloroethylene, chlorinated phenols, and phthalates; imported water from the Colorado River contributed trihalomethanes and phthalates. In addition to input from percolation sources, the impact on trihalomethane (THM) concentrations in well waters was also influenced by chlorination practices at the wells. Other target compounds were detected, but either the incidence was sporadic or the concentrations too low to identify sources or determine the potential impact of these materials.

Although target organics present in different percolation sources could be detected in Montebello Forebay groundwater, the health impact appeared to be insignificant relative to the EPA's maximum contaminant levels[9,10], National Academy of Sciences' "suggested no adverse response levels"[11,12], or State Department of Health Services'[13] "action levels" (see Table 4). Even when viewed in comparison to the very conservative EPA Water Quality Criteria[14] theoretical cancer risk model, where the analytical methodology has sufficient sensitivity, the average groundwater concentrations of solvents and pesticides were below estimated carcinogenic risk levels.

In the San Fernando Basin, the percolation of dry weather surface runoff (incidental drainage and improper industrial waste disposal) appeared to impact groundwater content of methylene chloride, THMs, tetrachloroethylene, trichloroethylene, chlorinated benzenes, phthalate, atrazine, and simazine. California DOHS "action levels" for trichloroethylene and tetrachloroethylene and the proposed EPA criteria for tetrachloroethylene were exceeded in some well samples, although the National Academy of Sciences "suggested no adverse response levels" (SNARLs) were not.

Anaheim Forebay wells showed impacts of surface water percolation and incidental discharge of treated wastewater to the Santa Ana River Basin as evidenced by the quantifiable levels of methylene chloride, trichloroethylene, tetrachloroethylene, phthalate, atrazine, and simazine. As observed for the Montebello Forebay wells, chlorination had a discernible effect on the THM content of Anaheim Forebay groundwater. None of the Anaheim Forebay samples exceeded DOHS "action levels," EPA maximum contaminant levels or NAS SNARLs. Only one well (chlorinated) contained THMs in excess of the EPA proposed criteria.

In the Talbert Barrier observation wells, the probable influence from injection of reclaimed water was detected in terms of methylene chloride, THMs, tetrachloroethylene, toluene, and phthalate. However, none of the observation wells exceeded any of the current contaminant limitations.

In addition to the target organics work, toxicity testing and chemical analyses were performed to isolate and identify other organic compounds of potential health significance which were not included on the target organics list. The approach utilized relied on the Ames test,[5] a short term toxicity test which uses Salmonella bacteria as the test organism to determine the

TABLE 3 - RESULTS OF TARGET ORGANIC ANALYSES IN THE MONTEBELLO FOREBAY a/

Target Compound	Reclaimed Water b/ µg/L	Storm Water µg/L	Imported Water µg/L	Unchlorinated Well Water µg/L	Chlorinated Well Water µg/L
methylene chloride	4.9-56	0.4-0.8	< 0.2-1.7	< 0.2-8.9	< 0.2-1.8
chloroform	5.8-84	< 0.2-0.6	< 0.2-24	< 0.2-2.6	< 0.1-1.6
bromodichloromethane	< 0.1-2.9	< 0.1-0.2	< 0.1-24	< 0.1-0.8	< 0.1-9.1
dibromochloromethane	< 0.1-2.1	< 0.1-0.2	< 0.1-21	< 0.1-0.2	< 0.1-43
bromoform	< 0.1-4.8	< 0.1-1.6	< 0.2-3.6	< 0.1-0.6	< 0.1-50
carbon tetrachloride	< 0.1-12	< 0.1	< 0.1-0.4	< 0.1	< 0.1
1,1-dichloroethane	< 0.1-1.8	< 0.1	< 0.1	< 0.1-2.6	< 0.1-0.4
1,2-dichloroethane	< 0.2-2.2	< 0.2	< 0.2	< 0.2-0.7	< 0.2
1,1,2-trichloroethane	< 0.2-21	< 0.1-0.2	< 0.1	< 0.1-0.2	< 0.2
trichloroethylene	< 0.1-19.4	< 0.2-0.8	< 0.2	< 0.1-2.3	< 0.1-0.2
tetrachloroethylene	< 0.1-17.4	< 0.4-5.7	< 0.1	< 0.2-1.0	< 0.1-0.5
chlorobenzene	< 0.1-1.0	< 0.1-0.1	< 0.1	< 0.1	< 0.1
1,4-dichlorobenzene	0.2-10.2	< 0.1-1.2	< 0.2-0.2	< 0.2-0.4	< 0.2-0.4
1,2-dichlorobenzene	0.2-6.0	< 0.1-1.3	< 0.1-0.1	< 0.1-0.4	< 0.2-0.6
benzene	< 0.2-2.9	< 0.3	< 0.2	< 0.3-0.9	< 0.2-0.3
toluene	< 0.1-1.3	< 0.2-0.2	< 0.2-0.8	< 0.1-0.4	< 0.1-0.2
bis(2-ethylhexyl)phthalate	0.7-13	22-82	< 0.5-170	< 0.5-59	< 0.5-5.7
1,2,4-trichlorobenzene	<0.1	<0.1	<0.1	<0.1	< 0.1
2,4,6-trichlorophenol	< 0.2-0.7	< 0.2-1.9	<0.2	< 0.2-1.5	< 0.2
2,4,5-trichlorophenol	< 0.2-0.9	< 0.2-1.7	<0.2	<0.2	< 0.2
2,3,4-trichlorophenol	<0.4	< 0.4-1.8	<0.4	<0.4	< 0.4
2,3,6-trichlorophenol	<0.2	< 0.2-0.7	<0.2	<0.2	< 0.2
3,4,5-trichlorophenol	<0.9	< 0.9-6.7	<0.9	<0.9	< 0.9
pentachlorophenol	< 1.3-16	< 1.3-6.8	<1.3	<1.3	< 1.3
lindane	< 0.2-1.0	< 0.2-1.4	<0.2	<0.2	< 0.2
2,3',5-trichlorobiphenyl	< 0.1-0.7	<0.1	<0.1	<0.1	< 0.1
2,2',4,4'-tetrachlorobiphenyl	<0.2	<0.2	<0.2	<0.2	< 0.2
aldrin	< 0.2-0.9	<0.2	<0.2	<0.2	< 0.2
phenanthrene	< 0.2-1.7	< 0.2-0.4	<0.2	<0.2	< 0.2
fluoranthene	<0.2	< 0.2-3.3	<0.2	<0.2	< 0.2
DDT	<0.2	<0.2	<0.2	<0.2	< 0.2
dieldrin	<0.4	<0.4	< 0.4-0.4	<0.4	< 0.4
atrazine c/	<0.5	< 0.5-3.9	<0.5	<0.5-0.9	< 0.5-0.9
simazine c/	<1.1	< 1.1-6.6	<1.1	d	< 1.1-1.7
phenylacetic acid c/	<0.7	< 0.7-16	<0.7	<0.7-3.1	d

a/ Concentration ranges for purgeable and non-purgeable target organic compounds.
b/ Chlorinated dual-media filtered effluent.
c/ Compound added to list of target organics for sample Nos. 47-90 as a result of detection in sample Nos. 1-46.
d/ Compound was detected but could not be quantified.

TABLE 4

RISK ASSESSMENT AND DRINKING WATER LIMITS FOR TARGET ORGANICS

Compound	NAS 7-Day SNARL a/ µg/L	NAS Chronic SNARL or 10^{-6} Cancer Risk a/ b/ µg/L	DOHS Action Levels c/ µg/L	EPA MCLs d/ µg/L	EPA Water Quality Criteria e/ µg/L
vinyl chloride	-	1.96 b/	-	1-100 f/	20.0
methylene chloride	5,000	g/	-	-	-
chloroform	3,200	3.12 b/	-	100 h/	1.9 h/
bromodichloromethane	g/	g/	-	100 h/	1.9 h/
dibromochloromethane	g/	g/	-	100 h/	1.9 h/
bromoform	g/	g/	-	100 h/	1.9 h/
carbon tetrachloride	2,000	6.67 b/	5	5-500 f/	4.0
1,1-dichlorethane	-	g/	-	-	-
1,2-dichloroethane	g/	1.42 b/	-	1-100 f/	9.4
1,1,2-trichloroethane	-	-	-	-	6.0
trichloroethylene	15,000	g/	5	5-500 f/	27.0
tetrachloroethylene	24,500	7.14 b/	4	5-500 f/	8.0
chlorobenzene	-	-	-	-	488/20 i/
1,4-dichlorobenzene	-	-	-	-	400 i/
1,2-dichlorobenzene	-	-	-	-	400 j/
benzene	250	k/	-	-	6.6
toluene	35,000	340 a/	-	-	14,300 l/
DDT	-	8.33 x 10-2 b/	-	-	2.4 x 10-4
dieldrin	-	3.84 x 10-3 b/	-	-	7.1 x 10-4
aldrin	-	1.07 x 10-1 b/	-	-	7.4 x 10-4
lindane	500	m/	-	4	1.9 x 10-1
atrazine	-	150 n/	-	-	-
simazine	-	1,505 n/	-	-	-
pentachlorophenol	-	21 n/	-	-	1,010/30 i/
trichlorobiphenyls (as total PCB)	50 o/	m/	-	-	7.9 x 10-4
tetrachlorobiphenyls (as total PCB)	50 o/	m/	-	-	7.9 x 10-4
trichlorobenzene (1,2,4-isomer)	-	-	-	-	-
trichlorophenol (2,4,6-isomer)	2,500	m/	-	-	12
trichlorophenol (2,4,5-isomer)	-	-	-	-	2,600/1.0 i/
bis-(2-ethylhexyl)phthalate	-	4,200 n/	-	-	15,000 l/
phenylacetic acid	-	-	-	-	-
fluoranthene	-	-	-	-	42 l/
phenanthrene	-	-	-	-	-
benzo(a)pyrene	g/	m/	-	-	2.8 x 10-3

a/ National Academy of Sciences, suggested-no-adverse-response-levels for seven day exposure and chronic exposure; References 11,12,15.
b/ National Academy of Sciences, concentration corresponding to 10-6 cancer risk; References 11,12.
c/ California Department of Health Services action levels; Reference 13.
d/ EPA maximum contaminant levels; References 10,16.
e/ EPA Water Quality Criteria for the protection of human health based on exposure by ingestion of water and aquatic products; except where noted as ambient concentrations, these criteria correspond to an excess cancer risk of 10^{-5}; Reference 14.
f/ Proposed maximum contaminant levels; Reference 17.
g/ Concentration not derived due to lack of adequate data.
h/ For total trihalomethanes (chloroform, bromoform, dibromochloromethane, bromodichloromethane).
i/ Ambient water concentrations associated with toxic/organoleptic effects.
j/ Ambient water concentration for combined dichlorobenzenes.
k/ Compound is implicated as a lukemogen, hence no acceptable dose can be determined.
l/ Ambient water concentration.
m/ Compound is implicated as a carcinogen, hence no acceptable dose can be determined.
n/ National Academy of Sciences suggested-no-adverse-response-level assuming 20 percent of the acceptable daily intake is from water.
o/ For total polychlorinated biphenyls.

presence or absence of mutagens in a sample. Although the results of the Ames test have not demonstrated correlation to human health, the test is a useful screening tool for detecting the presence of organics capable of causing damage to genetic material (possible carcinogens) in complex organic mixtures.

In a survey of mutagenic potential in 90 sample residues isolated from all four study areas, the presence of mutagenic organics was detected in at least one sample from each source. The level of mutagenicity, or potency, detected in the different sample types was generally in the order: storm runoff > dry weather runoff > reclaimed water > well water ≥ imported water. In more than half of the cases observed, chlorination appeared to increase mutagenicity. No simple correlation was discernible between estimated percent reclaimed water in wells and the observed mutagenic potency of residues isolated from the wells.

Detailed separations and mass spectral characterizations of residues revealed only four known mutagens (fluoranthene, benzo[a]pyrene, N-nitrosomorpholine, and N-nitrosopiperidine) distributed over five of 33 samples evaluated. In no case was the concentration of any of these sufficient to have contributed to the levels of mutagenicity detected.

Selected residues were then qualitatively evaluated to determine the involvement of major compound classes in the mutagenic responses and to determine appropriate chemical detection methods. This research led to chemical derivatizations[8] using the selective reagents silver nitrate and 4-nitrothiophenol in order to determine the presence of compounds belonging to two organic classes: organohalides and epoxides. Many compounds belonging to these two classes are considered to be potent mutagens and a few of the compounds in these groups are known to be animal carcinogens. The organohalides are of particular concern in the water field because they contain chlorinated, iodinated, and brominated compounds which may result from water chlorination processes used in industrial or other water treatment processes.

Results of the chemical derivatizations suggested that one or both of the subject compound classes contributed to the observed mutagenicity. Several samples had more than 100 reactive components containing chlorine, bromine, or iodine functional groups, as well as several reactive compounds inferred to be epoxides. Work completed failed to provide positive identification of any of the major components detected in these experiments. Nevertheless, several major reactive components in the organohalide class were detected in groundwater and percolation sources and, while specific origins of these compounds could not be determined from the information at hand, water chlorination practices in general were implicated.

The results of the toxicology/trace organics study indicate that in terms of target trace organics compounds, the current groundwater replenishment practices in the Montebello Forebay have shown no evidence of significant impacts resulting from the use of reclaimed water. Other findings for reclaimed water, such as exceeding some of the EPA Water Quality Criteria and the presence of organohalides and epoxides, suggest that additional information is needed before the long-term effects resulting from replenishment with all percolation sources can be fully evaluated. The presence of industrial organics in all samples analyzed indicates the susceptibility of and need for the protection of water supplies from improper handling of chemicals. Areas of emphasis should include the development of more stringent surveillance for the disposal of industrial wastes and evaluations of the effects of and possible alternatives to chlorine disinfection.

The presence of large numbers of apparently mutagenic halogenated organics in well water and surface supplies indicates the prudence of further characterization of the molecular nature and biological effects of these compounds. This work will be a necessary step in order to confirm or refute any implicit health significance posed by these materials.

Percolation Study

A field study was performed in order to determine the water quality changes that occur during the percolation of reclaimed water through soils. A test basin was constructed in the Montebello Forebay with particular care taken not to disturb the original soil profile. Soil conditions at the site were roughly characterized as medium-to-fine brown oxidized sand for the initial eight feet of depth with medium-to-coarse gray sand encountered at depths greater than eight feet. The groundwater table was located at a depth of approximately 8 feet. Samples were collected from permanent samplers installed at different depths: three each at depths of 2, 4, and 6 feet, one at 7 feet, and two at 8 feet.

The source of reclaimed water for the percolation study was the Whittier Narrows Water Reclamation Plant. The basin was operated on a uniform flooding/drying schedule which consisted of five days of flooding followed by 16 days of drying. Samples were drawn from the basin on the third day of flooding.

The percolation basin samples were monitored for eleven parameters, including five inorganic constituents (ammonia, nitrite, nitrate, total dissolved solids, and total hardness), two gross organic parameters (chemical oxygen demand and total organic carbon), and four trace organic compounds (methylene chloride, chloroform, trichloroethylene, and tetrachloroethylene).

The most apparent trend discerned from the development of concentration/depth profiles for the inorganic and gross organic constituents was the elevated activity that occurred between the 4-foot and 6-foot monitoring depths. This activity was particularly evident in the profiles for chemical oxygen demand (COD), total dissolved solids, total hardness, and nitrate-nitrogen.

The rapid reduction in the concentration of COD and total organic carbon, combined with the apparent nitrification of ammonia to nitrate, indicated that aerobic biological activity existed to a depth of greater than four feet. The concentration of both total dissolved solids and total hardness increased substantially between the 4- and 6-foot depths. It was hypothesized that the pH reduction, which would accompany both nitrification and the biodegradation of carbonaceous substances, resulted in the dissolution of soil minerals and subsequent increase in TDS and hardness concentrations.

As shown in Figure 2, methylene chloride displayed the most substantial concentration reduction of the trace organic compounds monitored. The average

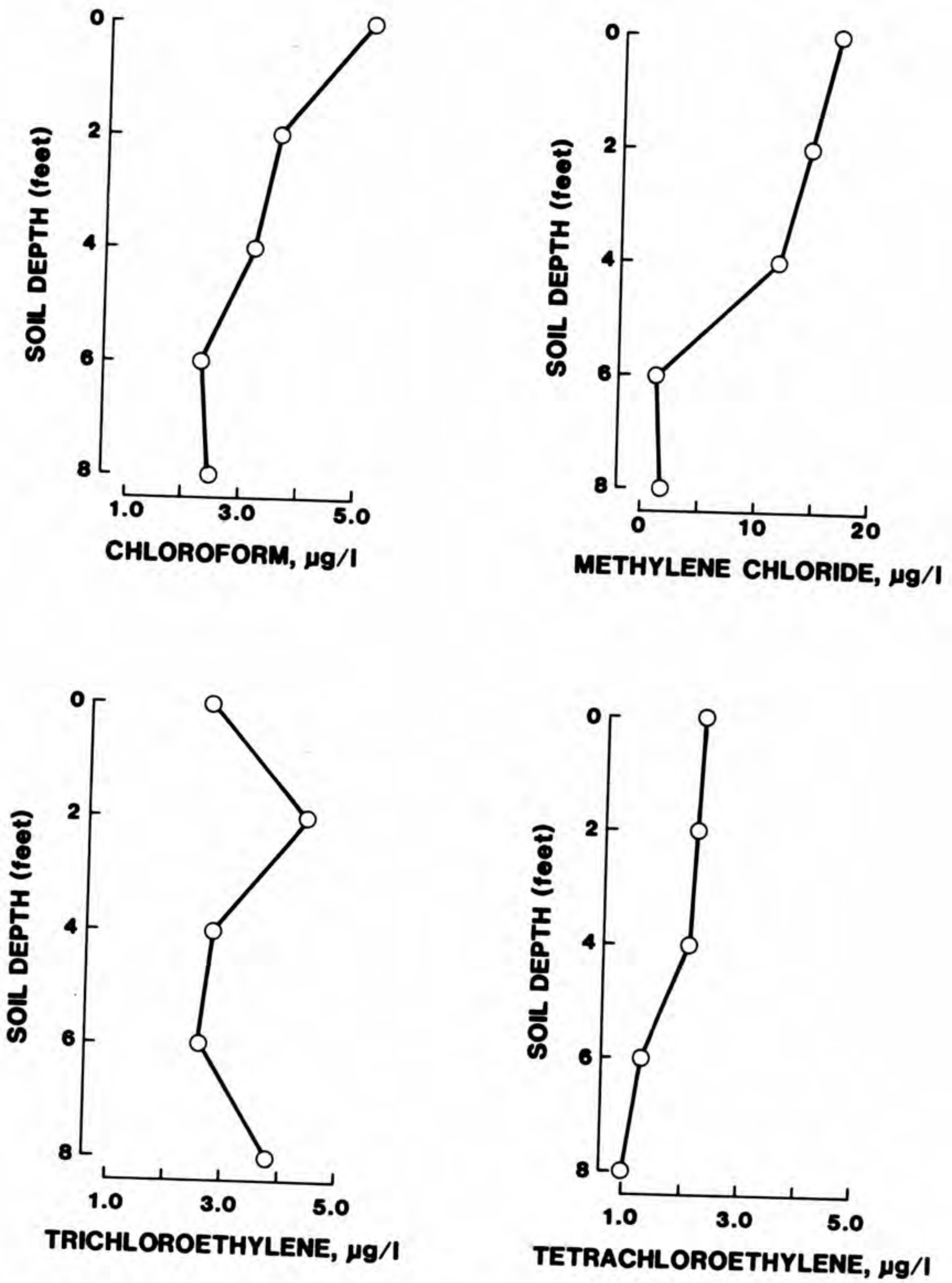

FIGURE 2 CONCENTRATION/DEPTH PROFILES FOR TRACE ORGANIC COMPOUNDS

influent concentration was reduced almost 90 percent to an average of 1.9 µg/L at a depth of eight feet. Chloroform and tetrachloroethylene showed less dramatic but statistically significant removals of 52 percent and 56 percent, respectively. The concentration of trichloroethylene was not reduced during percolation through the first eight feet of soil.

Adsorption, volatilization, and biodegradation were initially identified as potential trace organic removal mechanisms. Each was then examined in an effort to determine the operative treatment mechanism in the percolation basin.

Since the adsorption capacity of a soil is finite, it was necessary to determine whether or not the soil adsorption sites had been saturated during the percolation study. To this end, an empirical equation[18,19] was utilized to estimate the relative retention time of each compound as it traveled through the soil. The empirical equation, which was developed for small concentrations of organic compounds, correlates a compound's octanol/water partition coefficient with its relative adsorptive affinity in a specific soil. Based on this equation, it was estimated that the capacity of the basin to adsorb methylene chloride, chloroform, and trichloroethylene was completely utilized during the basin conditioning process (five spreading cycles) and the capacity to adsorb tetrachloroethylene was exhausted shortly thereafter. Consequently, it was concluded that adsorption alone could not account for the trace organic compound removals detected in the percolation basin.

In a groundwater replenishment operation, volatilization would be expected to occur in the ponded effluent or within the first few inches of soil. Judging from the limited trace organic compound removals detected between the basin influent and the 2-foot depth, volatilization did not appear to be a significant treatment mechanism during effluent percolation.

It was presumptively concluded that biodegradation, perhaps aided by the temporary retention of organics on adsorption sites, was the primary mechanism for the removal of the trace organic compounds. This conclusion was based upon three independent observations. First, there was no removal of trichloroethylene within the top eight feet of the test basin. If adsorption or volatilization was the operative treatment mechanism in the removal of methylene chloride and chloroform, then trichloroethylene should also have been removed from the percolate since it is theoretically of equal or greater susceptibility to these physical treatment mechanisms. Second, the concentration/depth profiles for inorganic compounds and gross organic parameters indicated that the soil environment was suitable for aerobic biodegradation of trace organic compounds. Finally, the literature[20] indicated the occurrence of substantial biodegradation of chloroform and other trihalomethanes, but insignificant biodegradation of trichloroethylene. All three observations implicated biodegradation to be the primary mechanism responsible for the trace organic compound removals detected in this study.

The application of the results of the percolation study to full-scale groundwater replenishment must take into consideration the specific site conditions of the test basin and the proposed spreading grounds. Soil characteristics, replenishment water quality, and basin operation are all critical in determining the effectiveness of soil percolation as a treatment process.

Furthermore, the blending of several source waters could serve to dilute the concentration of critical contaminants in each. The optimum dilution ratio would be based upon the mass contribution of one or more critical constituents to the groundwater system by each replenishment water supply after percolation through the soil strata. Accordingly, the quality of non-reclaimed water supplies is as important as the quality of reclaimed water supplies in determining the impact of groundwater replenishment. Therefore, the development of criteria for the use of reclaimed water for groundwater replenishment must take into consideration the quality and quantity of all source waters to be used in the operation.

Development of Population Exposure Data for Epidemiology Study

In order to effectively assess the impact of groundwater replenishment with reclaimed water, it was necessary to determine the levels of reclaimed water contained in the domestic supplies of the exposed population. The level of exposure depended on 1) the proportion of groundwater making up the total supply and 2) the amount of reclaimed water contained in the groundwater.

The methodology used to estimate the percentage of reclaimed water contained in Montebello Forebay groundwater relied on an empirical model(21) which used sulfate as the tracer of groundwater movement. The model was based on the fact that the sulfate concentration of Colorado River water, a replenishment source since 1954, was substantially greater than the sulfate concentrations of storm water, reclaimed water, and groundwater. Sulfate was considered to be a conservative material not likely to be affected by either vertical or horizontal movement through soil. Observations of the changes in sulfate concentrations in Montebello Forebay wells over time paired with the historical proportions of replenishment waters spread each year allowed for charting the movement of Colorado River water through the groundwater basin. This information was in turn used to simulate the behavior of the reclaimed water based on the premise that the two types of water moved at the same rate. Specifically, calculations were performed to estimate the annual percentages of reclaimed water pumped from individual wells operated by the 32 water purveyors serving the Montebello Forebay area.

Because not all of the purveyors used groundwater as their only source of supply, it was necessary to determine the historical water delivery characteristics of each purveyor, including the delineation of service area boundaries, number of residential service connections, water sources, and production levels. Final results of the investigation provided estimates of the annual percentages of Montebello Forebay groundwater making up the total supply served to each of the water systems. Coordinating this information with estimates of reclaimed water in the groundwater system, exposure data were produced that defined the percentage of reclaimed water contained in each purveyor's total water supply. On an annual basis, these estimates ranged from zero to 23 percent, with a long-term average (1962 through 1977) ranging from zero to 11 percent.

The reclaimed water exposure estimates were used to segregate areas of high and low exposure as the basis of the epidemiological comparisons (see Figure 3). The low reclaimed water exposure area was defined as those water districts that

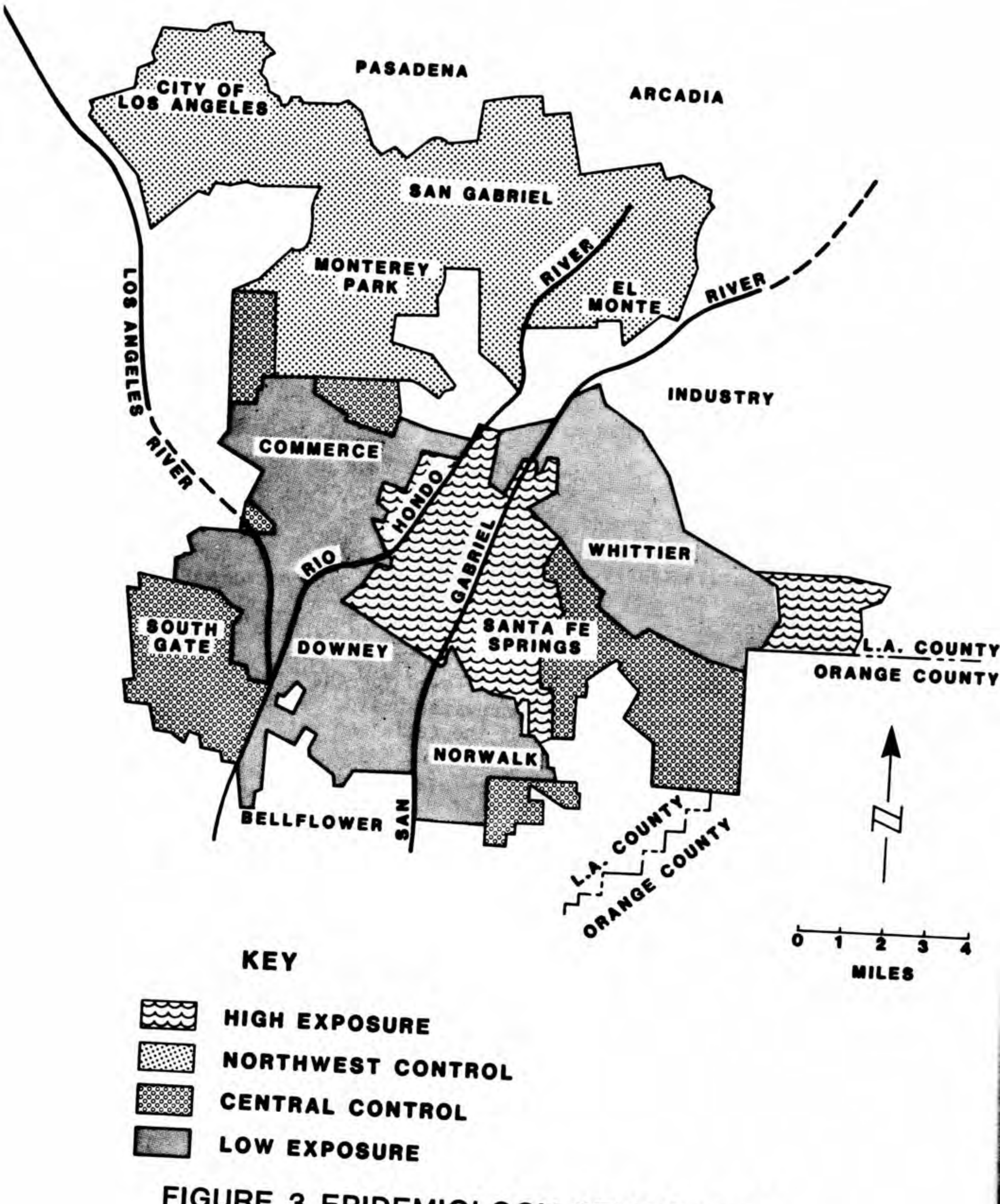

FIGURE 3 EPIDEMIOLOGY STUDY AREA

supplied reclaimed water for at least one year prior to 1970, but in no year prior to 1970 supplied greater than four percent reclaimed water, while the high reclaimed water exposure area was defined as those districts that supplied water containing five percent or more reclaimed water for one or more years prior to 1970. Montebello Forebay communities not exposed to reclaimed water because they did not receive groundwater or the groundwater they received did not contain reclaimed water, were defined as the central control area. A second control area to the northwest of the study area was included to expand the population base studied. This area was chosen because its water supplies did not contain reclaimed water and because the demographic and socioeconomic characteristics of its residents were similar to those of Montebello Forebay residents. At the time of the 1970 U.S. Census, nearly 1.2 million people resided in the overall study area with some 478,000 persons in the high and low exposure areas and 677,000 persons living in the two control areas.

Epidemiology

The University of California at Los Angeles School of Public Health was subcontracted to conduct a multi-stage epidemiologic investigation regarding the health effects of groundwater replenishment in the Montebello Forebay study area[22,23,24]. The epidemiologic monitoring activities were divided over time into three temporal phases: 1969-71, 1972-78, and 1979-80. Health parameters evaluated in these ecologic analyses included mortality patterns (death from all causes, heart disease, stroke, and cancer), cancer incidence, infant and neonatal mortality patterns, birth outcome patterns (low birth weight and congenital malformations), and infectious diseases. Also included in the investigation, was a household survey of women, conducted in 1981, which compared the general health status of women residing in the high reclaimed water area to that of women residing in the central control area and a computer simulation analysis[25] which modeled the theoretical relationship between exposure to contaminants in drinking water and measurable health outcomes based on the characteristics of the study population.

Based on the results from the ecologic analyses, there was no association between the 20 health conditions evaluated and residences in the reclaimed water area. Evidence of a potential association between death due to rectal cancer and exposure to reclaimed water based on the analyses of the 1969-71 and 1972-78 data sets, was not substantiated by the evaluations of the 1979-80 data. In fact, the most sensitive indicator evaluated--the onset of rectal cancer cases nearly two decades after exposure was initiated--shows the trend to be just the opposite, with the highest rate occurring in the control areas and the lowest rates in the reclaimed water areas (see Table 5).

It should be noted that the effects of such confounding variables as age, sex, birth weight, and when possible, race ethnicity were controlled in the ecologic analyses. Unfortunately, it was not possible to control other potential confounders such as smoking behavior, alcohol and drug use, dietary practices, bottled water consumption, mobility, marital status, employment status, or occupation, each of which might affect the inherent risk of the individual. To further clarify the actual level of exposure and the effects of confounding factors and to assess their effect on other more subtle health outcomes, a household survey was conducted among women in the exposed and control areas. Health

TABLE 5

COMPARISON OF CANCER INCIDENCE AMONG RECLAIMED WATER AREAS AND CONTROL AREAS, ADJUSTED FOR AGE AND SEX, 1979-80

Cancer Incidence Category	Control Areas						Reclaimed Water Areas						Significance P DAR c/
	Northwest			Central			Low (< 5%)			High (≥ 5%)			
	Number of Events	SIR a/	DAR b/	Number of Events	SIR a/	DAR b/	Number of Events	SIR a/	DAR b/	Number of Events	SIR a/	DAR b/	
Malignant neoplasm of the stomach	99	1.04	10.12	23	1.06	10.36	58	0.87	8.45	25	1.14	12.11	NS
Malignant neoplasm of the colon	282	0.94	28.01	40	0.61	18.55	202	1.00	29.40	40	0.62	18.08	0.002
Malignant neoplasm of the rectum	99	1.16	10.03	21	1.08	9.29	49	0.82	7.13	12	0.60	6.09	NS
Malignant neoplasm of the bladder	136	1.04	13.72	23	0.78	10.47	88	0.96	12.69	26	0.85	11.64	NS

a/ Standardized incidence ratio; observed cases in 1979-80 divided by expected cases in 1979-80 based on Los Angeles County age- and sex-specific incidence rates (SIR for Los Angeles County = 1.0).

b/ Directly adjusted incidence rate per 100,000 persons per year using 1980 Los Angeles County population as standard (average annual incidence rates for Los Angeles County, 1979-80: 9.72 cases of malignant neoplasm of the stomach per 100,000 population, 29.68 cases of malignant neoplasm of the colon per 100,000 population, 8.69 cases of malignant neoplasm of the rectum per 100,000 population, 13.35 cases of malignant neoplasm of the bladder per 100,000 population).

c/ Level of significant difference among the DARs of the four areas, Mantel-Haenszel nominal test of association; NS = not significant (P ≥ 0.05).

parameters evaluated in the survey included information on adverse reproductive outcomes such as miscarriages and spontaneous abortions and on general indicators of functional impairment such as restricted-activity days, hospital-bed days, and (home) bed disability days.

Simple comparisons between all women in the two study areas demonstrated that there were no significant differences in any of the measured health indices. Other analyses attempted to address the issue of exposure to reclaimed water by comparing women who consumed tap water in the exposed area with women who consumed tap water in the control area (since approximately 22 percent of the women surveyed reported drinking only bottled water). The analyses were further restricted by comparing subgroups of women in the two areas who had lived at their present address for five years or longer. Again, there was no significant difference between the two groups in any of the measured health outcomes. Similar results were obtained when controlling for the confounding effects of age, level of education, employment status, race ethnicity, smoking behavior, and alcohol consumption as well as when limiting the analyses to those women who consumed tap water and who had lived at the same address for at least five years. In general, the level of health observed for the surveyed women tended to be comparable to those reported in other surveys using similar questions lending validity to the accuracy of the survey.

To provide additional insight into the investigations, a computer simulation model was employed to replicate the study population and determine the theoretical effects, based on animal models, of exposure to various contaminants. Outcomes of four diseases were tested in the simulation studies: cancer at all sites, cancer of the rectum, cancer of the liver, and congenital malformations. Four contaminants, dinitrotoluene, heptachlor, polychlorinated biphenyls, and phthalate esters, were assumed to be present in the water of the modeled population. Given the water consumption levels, the migration habits of the people living in the study area and toxicology data for the four compounds, the model estimated the effects these contaminants would individually have on the health status of the exposed population. The results of the simulation study suggested that, in the face of exposure to a particular highly toxic waterborne contaminant of potency similar to the model compounds, a statistically significant increase in the rate of cancer or congenital malformations above the background rate, could not be detected in the reclaimed water community, even up to 24 years following exposure.

Based on the results from all phases of work, available epidemiologic evidence provided no indication that the use of reclaimed water for groundwater replenishment has had a noticeable harmful effect on the population ingesting the water. The completed evaluations of 20 health conditions showed no measurable relationship between exposure to reclaimed water and disease. Furthermore, results of the household survey in 1981 which controlled for such confounding effects as smoking, alcohol consumption, bottled water usage, and length of residence yielded no evidence that exposure to reclaimed water had an effect on levels of adverse reproductive outcomes or on general health indicators. While zero risk can never be insured, based on these findings, it is reasonable to assume that the disease risk attributed to the consumption of water containing reclaimed water has been minimal to non-existent for persons residing in the Montebello Forebay.

REFERENCES

1. Orange and Los Angeles Counties Water Reuse Study Draft Facilities Plan, Vol. I, Los Angeles, California, February 1982.

2. Report of the Consulting Panel on the Health Aspects of Wastewater Reclamation for Groundwater Recharge. State Water Resources Control Board Sacramento, California, February 1976.

3. County Sanitation Districts of Los Angeles County. Health Effects of Groundwater Recharge. Phase I Report. Orange and Los Angeles Counties Water Reuse Study, Los Angeles, California, October 1978.

4. Baird RB, Gute JP, Jacks CA, Jenkins RL, Neisess L, Scheybeler B, Van Sluis R, Yanko WA. Health effects of water reuse: a combination of toxicological and chemical methods for assessment. In Water Chlorination Environmental Impact and Health Effects. Vol. 3. Jolley RL, Brungs WA, Cumming RB, Eds. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1980.

5. Ames BN, McCann J, Yamasaki E. Methods for detecting carcinogens and mutagens with the Salmonella/mammalian microsome mutagenicity test. Mutation Research 31:347, 1975.

6. Mondal S, Brankow DW, Heidelberger C. Two-stage chemical oncogenesis in cultures of $C_3H/10T1/2$ cells. Cancer Res 36:2254, 1976.

7. Baird RB, Jacks CA, Jenkins RL, Gute JP, Neisess L, Scheybeler B. A high performance macroporous resin concentration system for trace organic residues in water. In Chemistry in Water Reuse. Vol. 2. Cooper WD, Ed. Ann Arbor Science, Ann Arbor, Michigan, 1981, p. 149.

8. Cheh AM, Carlson RE. Determination of potentially mutagenic and carcinogenic electrophiles in environmental samples. Anal Chem 53:1001, 1981.

9. National Interim Primary Drinking Water Standards. Jour AWWA 68:57-68, 1976.

10. Federal Register 44:68624, 1979.

11. National Academy of Sciences. Drinking Water and Health. Part II. Chapters 6 & 7. Washington D.C., 1977.

12. National Academy of Sciences. Drinking Water and Health. Vol. 3. National Academy Press, Washington, D.C., 1980.

13. California Department of Health Services. News Release No. 51-80. Sacramento, California, 1980.

14. Federal Register 45:79318, 1980.

15. National Academy of Sciences. Drinking Water and Health. Volume 4. National Academy Press, Washington D.C., 1982.

REFERENCES (Continued)

16. Federal Register. 44:68624, 1979.

17. Federal Register. 47:9356, 1982.

18. Tomson MB, Dauchy J, Hutchins S, Curran C, Cook CJ, Ward CH. Groundwater contamination by trace level organics from a rapid infiltration site. Water Res 15:1109-1116, 1981.

19. McCarty PL, Rittman BE, Reinhard M. Processes affecting the movement and fate of trace organics in the subsurface environment. In Wastewater Reuse for Groundwater Recharge. California State Water Resources Control Board, Office of Water Recycling: 93-117, 1980.

20. Roberts PV, Schreiner J, Hopkins GD. Field study of organic water quality changes during groundwater recharge in the Palo Alto Baylands. In Wastewater Reuse for Groundwater Recharge. California State Water Resources Control Board, Office of Water Recycling: 283-316, 1980.

21. Bookman and Edmonston Consulting Civil Engineers, Inc., Management of Ground Water Quality in the Central and West Basin Water Replenishment District, Central and West Basin Water Replenishment District, Downey, California, 1970.

22. Frerichs RR, Satin KP, Sloss EM. Water Re-Use - Its Epidemiologic Impact, Los Angeles County, 1969-71. Research Monograph, Regents of the University of California, Los Angeles, California, April 1981.

23. Frerichs RR, Sloss EM, Maes E, Satin KP. Water Re-Use, Part II, Its Epidemiological Impact in Los Angeles County. Research monograph, Regents of the University of California, Los Angeles, California, 1982.

24. Frerichs RR, Sloss EM, Maes EF. Water Re-use, Part III, Its Epidemiologic Impact in Los Angeles County. Research Monograph, Regents of the University of California, Los Angeles, California, 1983.

25. Satin KP. An epidemiologic model to assess the health effects related to the consumption of contaminated drinking water. Doctoral dissertation, University of California, Los Angeles, 1981.