Technical Report

CRWR-175

HEALTH EFFECTS OF WATER REUSE BY GROUNDWATER RECHARGE

CENTER FOR RESEARCH IN WATER RESOURCES
BUREAU OF ENGINEERING RESEARCH

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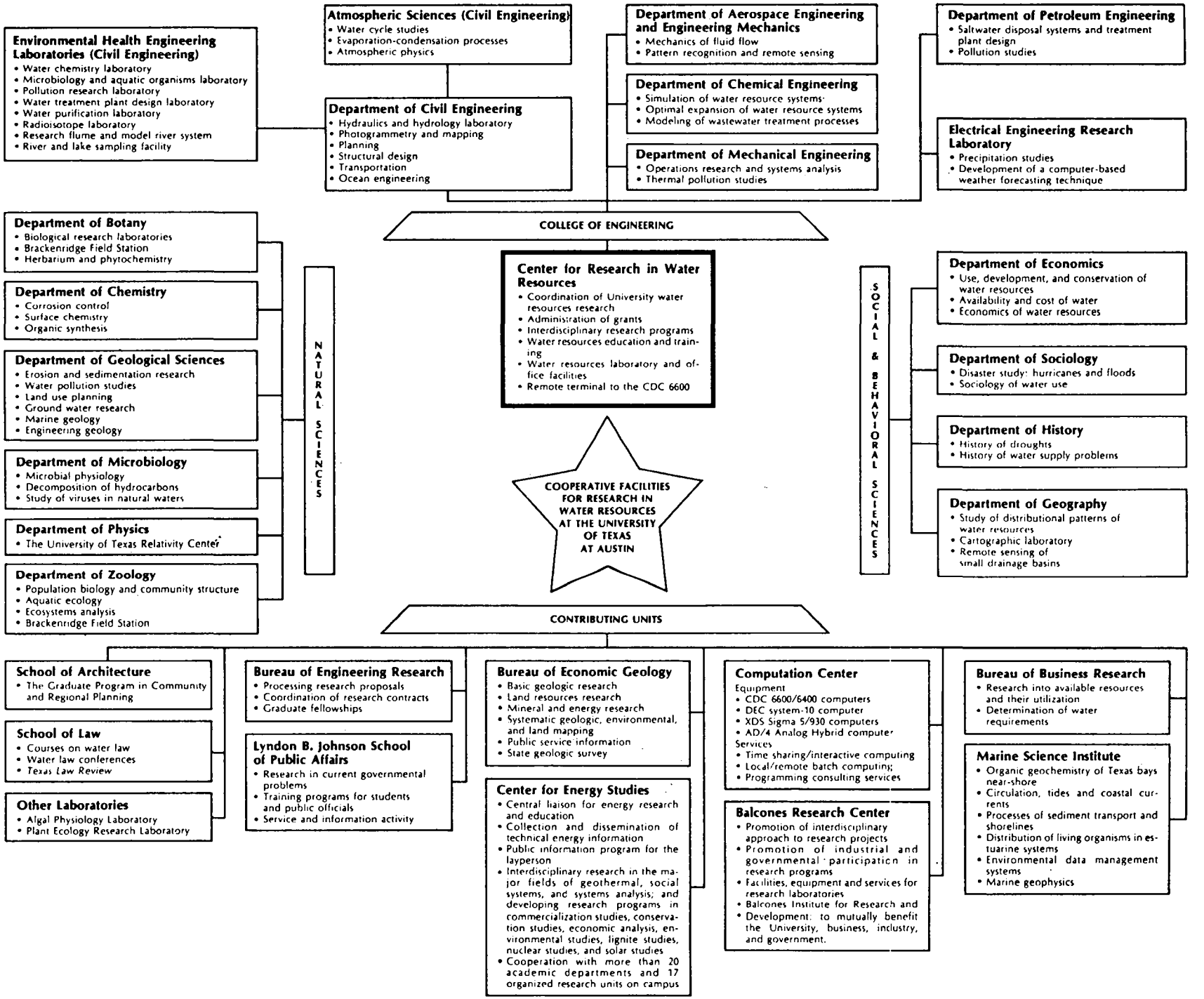
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A Report by

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ABSTRACT

Increasing populations and limited availability of potable water supplies have created an impetus for evaluating the potential of expanded reuse of treated wastewater. Groundwater recharge represents one of the more attractive reuse activities; however, expansion is restricted due to concern over potential health effects associated with consumption of groundwaters replenished in part by reclaimed wastewater. Some of these health issues include the potential effects of trace metals, minerals, microorganisms, and organic compounds that may be present in groundwater supplies influenced by a recharge program. A review of current literature has been performed to ascertain what impacts water reuse via groundwater recharge may have on human health. To accomplish this goal, current groundwater recharge programs were assessed, potential health hazards were reviewed, the types of treatment afforded by soil systems were investigated, and current health effects research was evaluated.

Upon completion of these tasks, it became apparent that little conclusive information existed regarding groundwater recharge and potential health effects. The area of greatest concern and lack of information was the fate of trace organic compounds likely to be present in recharge reclaimed water. Because of this lack of information, it was recommended that existing groundwater recharge projects be carefully monitored and studied to provide sound data for developing operational criteria for safe groundwater recharge systems.

CONCLUSIONS AND RECOMMENDATIONS

Land application of treated wastewater for groundwater recharge is an attractive reuse alternative. Many incentives exist for expansion of ongoing projects and construction of new projects. For wastewater treatment agencies, an incentive exists to help solve disposal problems as well as to possibly defray the operating costs of wastewater treatment by sale of reclaimed water. Furthermore, most agencies feel that as custodian of this water source, they have an obligation to promote its reuse. The user or water purveyor has two basic incentives; namely, that use of reclaimed water for recharge may be a more reliable source of replenishment as compared to using potable water supplies and that reclaimed water may be available at a lower cost than other alternatives. Nevertheless, there is concern that some constituents present in reclaimed water may now be causing or may in the future cause some adverse health effects in a population consuming groundwater replenished in part by reclaimed water.

The objective of this study was to assess the potential hazard of water reuse via groundwater recharge in order to ascertain whether these concerns were justified. The principal findings and conclusions of this assessment are summarized as follows:

1. Most constituents in reclaimed water are substantially reduced during vertical percolation through the unsaturated zone and during horizontal movement in the aquifer. Nonspecific measurements of organics indicate substantial removal during percolation. Notable exceptions are Total Dissolved Solids and hardness which increase with depth of percolation.
2. Bacteriological and virological agents are effectively removed by vertical percolation.
3. Information regarding the behavior of nitrates, heavy metals, and trace organics is inconclusive and/or not available. These constituents are also health significant.
4. By diluting reclaimed water with natural waters prior to spreading or by allowing sufficient time for the percolated effluent to blend with natural groundwaters before pumping, nitrate concentrations in affected groundwaters will meet Drinking Water Standards.
5. Problems associated with metallic elements in reclaimed water can be alleviated by insuring that reclaimed water sources meet the safe levels suggested by the National Academy of Sciences and the Environmental

Protection Agency for drinking water. If reclaimed water sources meet these safe levels, and additional removal of metals occurs in passage through soil via adsorption, ion exchange, precipitation, and other phenomena, then these water sources should provide a factor of safety above no effect levels.

6. The area of greatest concern and lack of information is the chronic ingestion of trace organics which may survive conventional wastewater treatment and soil percolation.
7. The multiple barriers against pathogen transmission provided by treatment, chlorination, and percolation through soil make it unlikely that microorganisms of reclaimed water origin will reach groundwater supplies.
8. There is no definite division between those factors which decelerate or accelerate migration of trace contaminants in soils. This influence depends on the intensity with which all factors are expressed in the soil. The most important factors which relate to contaminant attenuation include pH, oxidation-reduction conditions, particle size distribution, pore size distribution, organic content, concentrations of ions or salts, and climate. This means that treatment afforded by land application of reclaimed water will be site specific.

The lack of specific information regarding the potential health effects of trace organic compounds present in reclaimed water used for groundwater recharge emphasizes the need that extensive research be performed. Well engineered systems which have been in operation for significant periods of time and for which accurate operational and water quality records are available should be rigorously studied. Studies modeled after the Health Effects Study presented in Chapter V which included elements of hydrogeology, water quality characterization, toxicology, and epidemiology should produce sound data for the development of criteria for safe groundwater recharge programs. Unfortunately, because of the equipment and technology involved, this type of study is expensive to perform. Nevertheless, a minimum requirement for any reuse project would be to monitor carefully reclaimed water inputs to the groundwater system and groundwaters impacted by the system for all constituents mandated by Drinking Water Standards as well as a selected list of health significant "indicator" trace organic compounds. Combined with community based health surveillance programs, groundwater recharge projects and the health of the exposed community may be carefully monitored. The capability of a specific recharge site for removal of contaminants will also require careful investigation and it is likely that site

parameters such as soil type and depth to the groundwater table will be regulated through groundwater recharge criteria.

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CHAPTER I

INTRODUCTION

FOREWORD

From the beginning of time, man has used water contaminated by other men, by animals, and by natural processes with varying consequences. In recent times it has become increasingly necessary to reuse water as populations increase and potable supplies become limited. At present, it has been estimated that at least one-third of the population in the United States derives water from sources impacted by wastewater discharges. With the exception of transmission of infectious disease, little attention has been directed towards the disease-producing potential of such contamination. In light of recent evidence which indicates that some forms of cancer are caused or stimulated by environmental contaminants, it is now necessary to review the health effects of water reuse in a more comprehensive fashion.

One area of critical concern is the reuse of wastewater for potable purposes. Land application of treated wastewater provides a means of low cost tertiary treatment, disposal, and groundwater recharge. However, expansion of this planned reuse activity is restricted by unknown health effects associated with consumption of water containing quantities of reclaimed water. Of particular concern are the unknown effects of trace organics, minerals, and heavy metals as well as the transmission of enteric viruses.

OBJECTIVE

The purpose of this study is to delineate the current state-of-the art knowledge pertinent to potential health effects associated with reuse of treated wastewater for groundwater recharge by evaluating the results of research related to health aspects of water reuse. The main thrust of this work is to assess the potential hazards (if any) associated with the introduction of contaminants to potable groundwater supplies.

SCOPE

To accomplish this goal, the following tasks were performed:

- A review of current literature relating to groundwater recharge programs which have evaluated the effects of percolation on reclaimed water quality.

- An investigation of the health literature to determine which components in reclaimed water are of health concern.

- A synopsis of physical, chemical, and biological changes that occur during percolation; specifically, reviewing important removal mechanisms and the effect they will have on reclaimed water quality as it enters the groundwater system.

- An assessment of current health effects research which addresses the health concerns of groundwater recharge using reclaimed water.

CHAPTER II

LITERATURE REVIEW - CHANGES IN WATER QUALITY DURING PERCOLATION

Previous studies have demonstrated that groundwater recharge by infiltration is not only a means of water conservation, but also an important method of purification. Purification of wastewater effluent occurs during vertical percolation through the unsaturated zone and during lateral movement in the saturated zone. Dilution with natural groundwater of higher quality than the percolated effluent also reduces the concentrations of constituents in the reclaimed water. The recharge programs reviewed in this report are located throughout the world and include the Dan Region Sewage Reclamation Project and the Ashkelon Dunes (Tel Aviv, Israel)[1], the Whittier Narrows and San Jose Creek Reclamation Project (Los Angeles County)[2,3], the Flushing Meadows Project (Phoenix, Arizona)[4,5], the Eastern Municipal Water District (Hemet, California) [6,7,8] and the Muskegon Wastewater Management System (Muskegon, Michigan)[9]. Table 1 is a summary of recharge projects reviewed in this report.

Dan Region Sewage Reclamation Project - The scope of experiments conducted during this project was limited to a study of infiltration rate changes and soil quality changes that occur following percolation of secondary and tertiary effluents. Clean sand from the infiltration basins was subjected to chemical analysis prior to the infiltration experiments. Upon conclusion of the experiments, samples were collected from the infiltration basins by means of a hand auger at depth intervals of 0-5 cm (0-2 in.), 5-10 cm (2-4 in.) and 40-50 cm (16-20 in.).

Recharged water could not be sampled below the infiltration basins and removal of constituents could only be estimated by mass balance calculations using the soil sample analyses. Results from the experiments indicate that the bulk of COD was retained in the upper 10 cm (4 in.) of the soil profile. (See Figures 1 and 2). Between 67 and 77 percent of the input COD was retained in the upper 50 cm (20 in.) of soil. The retention of heavy metals in the soil was also evaluated following percolation of tertiary effluent. These data are summarized in Table 2. While some of the metals (lead, chromium, and barium) appear to be retained in the first 50 cm (20 in.) of soil, these results are not conclusive.

TABLE 1

SUMMARY OF RECHARGE PROGRAMS AND EXPERIMENTS

STUDY AND LOCATION	TYPE OF WATER	SOIL TEXTURE	INFILTRATION PATTERN
McMichael & McKee (1965) Whittier Narrows Test Basin, L.A. County	Secondary effluent (high rate activated sludge)	Very fine to medium silty sand	Continuous flooding flooding MWF flooding MTWTHF
LACFCD (1970) Whittier Narrows Test Basin L.A. County	Secondary effluent (high rate activated sludge)	Very fine to medium silty sand	7 days flooding 14 days drying
LACSD (1974) Whittier Narrows Test Basin L.A. County	Secondary effluent (high rate activated sludge) nitrified	Very fine to medium silty sand	7 days flooding 14 days drying
LACFCD (1974) Whittier Narrows Test Basin L.A. County	Secondary effluent (high rate activated sludge) nitrified	Very fine to medium silty sand	7 days flooding 14 days drying
Amramy, et al (1962) Ashkelon dunes	Secondary effluent (anaerobic-aerobic oxidation ponds)	Fine sand dune	Continuous flooding 115 days 5-6 days flooding 10-12 days drying

TABLE 1 (Continued)

STUDY AND LOCATION	TYPE OF WATER	SOIL TEXTURE	INFILTRATION PATTERN
Wachs, et al (1972) Haifa infiltration columns	Tertiary effluent (after high lime treatment and polishing ponds)	Fine sand dune	1 day flooding 2 days drying
Dan Region Pilot Plant (1977) Tel Aviv	Secondary effluent (oxidation pond) and tertiary effluent (polishing pond)	Very fine sand	Continuous flooding and 5 days wet - 10 days dry
Bouwer (1974) Flushing Meadows, Phoenix, Arizona	Secondary effluent (activated sludge)	0.9m (3 ft.) fine loamy sand above 76m (250 ft.) coarse sand and gravel	20 days flooding 10 days drying (summer) 20 days drying (winter)
Eastern Municipal Water District Hemet, California (1971)	Secondary effluent (activated sludge)	Medium and coarse sand	Fill - 1 day Drain - 2 days Dry - 1 day
Muskegon County Wastewater Management System	Aerated lagoon secondary effluent and storage lagoon		Spray irrigation

Ashkelon Dunes

In these experiments, secondary effluent from oxidation ponds was percolated into fine sand dunes and subsequently recovered through observation wells. Results indicate (See Table 3) that 80 percent total nitrogen removal occurs following vertical percolation and lateral groundwater travel of about 61 m (200 ft.). The ammonia in the percolates decreased by approximately 88 percent while nitrate levels did not appreciably change in any of the samples. One explanation for this phenomenon may be volatilization of ammonia caused by high temperatures characteristic of the desert area. The BOD levels in the recharged effluent, although concentrations observed in the well within the recharge basin were much higher (20.6 mg/1). Coliform migration was detected; however, no bacteria were found in samples taken from the furthermost well.

The Flushing Meadows Project

The objective of this project was to study renovation of secondary sewage effluent by groundwater recharge with rapid infiltration basins. The quality improvement of the effluent as it moved through the ground to become renovated water was evaluated by analyzing samples taken from observation wells. A summary of these data are presented in Tables 4 and 5.

Results from these experiments indicate approximately 95-100 percent BOD removal, 67-100 percent TOC removal, 67 percent COD removal and 5 logs of fecal coliform removal following 12m (40 ft.) of horizontal travel. No fecal coliforms were encountered after 92 m (300 ft.) of horizontal travel. Sequences of short, frequent flooding and drying periods of several days each yielded essentially complete conversion of the ammonium to nitrate, but no removal of nitrogen. With flooding and drying periods of two weeks each, ammonium was adsorbed in the soil during flooding and nitrified and partially denitrified during drying. This yielded renovated water with alternating low nitrogen levels and nitrate peaks and a net nitrogen removal of about 30 percent. The results from heavy metal analysis (Table 5) show that concentrations of copper and zinc were reduced by about 80 percent, whereas cadmium and lead levels did not change appreciably as the effluent water moved through the soil. Mercury removal was about 40 percent.

FIGURE 1

INTERMITTENT FLOODING WITH TERTIARY EFFLUENT
RETENTION OF POLLUTANTS BY SOIL
DAN REGION PILOT PLANT 1977

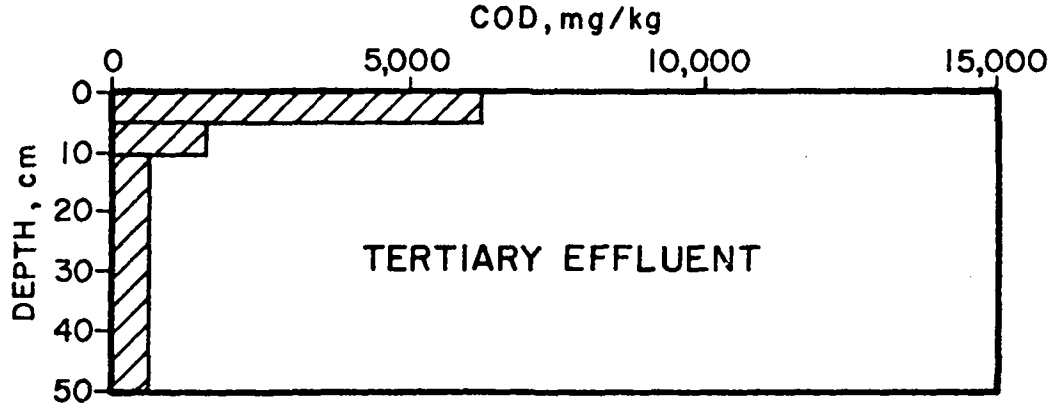
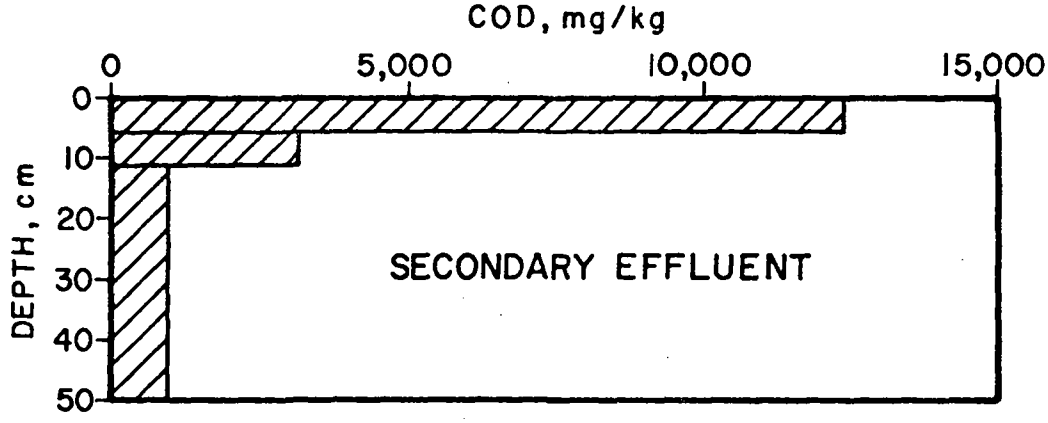


FIGURE 2

INTERMITTENT FLOODING WITH SECONDARY EFFLUENT
RETENTION OF POLLUTANTS BY SOIL
DAN REGION PILOT PLANT 1977



FIGURES TAKEN FROM 1977 TAHAL REPORT
ADVANCED TREATMENT, GROUNDWATER RECHARGE
AND REUSE OF MUNICIPAL WASTEWATER

TABLE 2

HEAVY METAL DISTRIBUTION IN SOIL
BENEATH INFILTRATION BASINS AFTER 40 METER
INFILTRATION OF TERTIARY EFFLUENT

DAN REGION SEWAGE RECLAMATION PROJECT

DEPTH CM	CONCENTRATION IN SOIL (MG/KG)				
	Zn	Ba	Cr	Cd	Pb
0-5	15.25	344	30.25	0.95	22.00
5-10	15.50	238	18.75	0.94	15.75
40-50	13.50	244	23.75	0.96	12.50
	CHEMICAL ANALYSIS OF CLEAN SAND (MG/KG)				
	14.50	350	25.0	0.75	22.5

TABLE 3

EFFECT OF PERCOLATION ON CHEMICAL QUALITY OF EFFLUENT
SAMPLES TAKEN FROM OBSERVATION WELLS

SOURCE	SOIL TYPE	TRAVEL DISTANCE IN THE AQUIFER* M	TOTAL N MG/L	NH_3-N MG/L	NO_3-N MG/L	BOD MG/L	COLIFORMS MPN/100 ML
Ashkelon	Fine	Recharged Effluent	32	26	0.3	2.5	$1.3 \times 10^3 - 7 \times 10^6$
Dunes	Sand	Ψ	24	17	1.0	20.6	$6 \times 10^2 - 2.3 \times 10^3$
Amramy 1962	Dune	8	19	14	0.6	5.8	-
		24[1]	18	12	2.1	2.8	$0 - 2.4 \times 10^2$
		61[2]	6	3	0.3	3.3	-

* Both vertical and horizontal travel
Ψ Wells within the basin
1.Phreatic layer
2.Deep layer

TABLE 4
RESULTS FROM FLUSHING MEADOWS PERCOLATION STUDIES
(East Center Well)

	BOD mg/l	COD mg/l	TOC mg/l	NH_4-N mg/l	NO_3-N mg/l	Fecal Coliforms MPN/100 ml
Recharged Effluent	10-20	30-60	10-30	20-40	0-1	10^6
12m Lateral Travel	0-1	10-20	0-10	3* 4**	24* 0***	0-10

* Short flooding periods, 2 days wet, 4 days dry.
** Long flooding periods, 2-3 weeks wet, 2 weeks dry.
*** For long flooding periods NO_3 level close to zero except for occasional NO_3 peaks.

TABLE 5
HEAVY METAL CONCENTRATIONS FROM FLUSHING MEADOWS PERCOLATION STUDIES

METAL	EFFLUENT µg/l	WELL 1-2* µg/l	EAST CENTER WELL* µg/l	WELL 1** µg/l	WELL 7*** µg/l
Zinc	193	35	108$^{\psi}$	-	37
Copper	123	16	17	-	17
Cadium	7.7	7.2	7.2	-	7.3
Lead	82	66	66	-	66
Mercury	2.1	-	1.3	1.2	1.4

* Well within spreading basin area.
** Well 30m north of basin area.
*** Well 30m south of basin area - more permeable aquifer material.
ψ Higher value may be a result of the galvanized pump used for this well.

The Eastern Municipal Water District

The purpose of this study was to investigate water quality changes that occur in activated sludge effluent as it percolates through sandy soil. Results from these experiments (Table 6) indicate that nitrification occurs in the upper 61 cm (2 ft.) of soil when the operating sequence includes flooding followed by draining and drying to presumably maintain aerobic soil conditions. COD removal occurred mainly in the top 61-122 cm (2-4 ft.) of soil with 60 percent removal at 61 cm (2 ft.) and an additional 6-14 percent removal between 61-122 cm (2 and 4 ft.). Overall COD removal at 244 cm (8 ft.) ranges between 68-75 percent. Coliform migration was evident with 3 log removal occurring in 244 cm (8 ft.) of percolation, but with coliform MPN's of approximately 100/100 ml in the 244-cm (8-foot) percolates. This was probably due to the coarse soil which made up the spreading basin.

The Muskegon Wastewater Management System

The Muskegon System is a land treatment operation in which wastewater is ultimately treated by spray irrigation of 2.2 hectares (5500 acres) of farm land after receiving preliminary treatment in 3.2×10^{-3} hectare (8-acre) aerated lagoons and 0.3 hectare (850-acre) storage lagoons. Samples of raw influent wastewater, aerated lagoon effluent, holding lagoon effluent, and final effluent leaving the site via a drainage tile lying 2-4m (5-12 ft.) below an irrigation area were specifically analyzed for the following toxic pollutants: arsenic, beryllium, cadmium, cyanide, mercury, benzene, chloroform, trichloroethylene, vinyl chloride, benzidene, endrin, toxaphene, and polychlorinated biphenyls. In addition, selected samples were surveyed for other toxic metals, and specific analyses for selected toxic organics were made.

No significant levels of arsenic, beryllium, cadmium, cyanide, or mercury were found in any wastewater sample or drainage tile effluent sample, nor were significant quantities of other toxic metals noted (Table 7 and 8). However, benzene, chloroform, and tricholoroethylene were present in the influent wastewater in concentration ranges of 6-53, 360-2645, and 6-120 g/l, respectively. Concentrations of these compounds were significantly reduced in the treatment sequence, but low levels of chloroform (1-13 g/l and trichloroethylene (2-10 g/l) were present in all drainage tile effluent samples analyzed and benzene (8 g/l) was detected in one sample (Table 9).

Fifty-six additional organic pollutants, including eight on EPA's "List of Dangerous Pollutants" (dichloromethane; 1, 2-dichloroethane; 1,2-dichloroethylene; toluene; dichlorobenzidene; phenol; ethylbenzene; and trichlorobenzene) were identified as

TABLE 6

EFFECTS OF PERCOLATION ON EFFLUENT CHARACTERISTICS

HEMET, CALIFORNIA

	Depth (ft)				
Constituent	0	2	4	6	8
NO_3-N (mg/l)	13	29	28	25	30
COD (mg/l)	50	20	17	17	16
Total hardness (as mg/l $CaCo_3$)	205	280	330	350	340
Coliform, MPN per 100 ml	250,000	1,000	1,000	180	120

TABLE 7

TOC, COD, TSS, AND SPECIFICALLY ANALYZED TOXIC INORGANIC POLLUTANTS IN MUSKEGON SYSTEM WASTEWATER*

Pollutants	Sampling Point (a)	8-8-76 Sun.	8-9-76 Mon.	8-10-76 Tues.	8-11-76 Wed.	8-12-76 Thurs.
Total Organic Carbon (mg/1)	1	160	165	170	150	148
	2	125	110	110	115	124
	3	43	45	56	56	49
	4	9	6	7	5	6
Chemical Oxygen Demand (mg/1)	1	532	758	790	534	438
	2	390	374	373	380	422
	3	127	128	153	160	154
	4	17	16	16	12	17
Total Suspended Solids (mg/1)	1	156	584	205	424	126
	2	250	282	236	214	220
	3	11	14	12	15	21
	4	4	4	2	2	3
Arsenic (µg/1)	1	<10	<10	<10	<10	<10
	2	<10	<10	<10	<10	<10
	3	<10	<10	<10	<10	<10
	4	<10	<10	<10	<10	<10
Beryllium (µg/1)	1	< 2	< 2	< 2	< 2	< 2
	2	< 2	< 2	< 2	< 2	< 2
	3	< 2	< 2	< 2	< 2	< 2
	4	< 2	< 2	< 2	< 2	< 2
Cadmium (µg/1)	1	3	< 2	4	< 2	< 2
	2	< 2	< 2	2	< 2	5
	3	< 2	< 2	3	< 2	< 2
	4	< 2	< 2	< 2	< 2	< 2
Cyanide (µg/1)	1	<10	<10	<10	18	14
	2	14	<10	<10	18	10
	3	20	<10	<10	<10	<10
	4	<10	<10	<10	<10	<10
Mercury (µg/1)	1	< 0.2	< 0.2	< 0.2	< 0.2	0.9
	2	< 0.2	< 0.2	< 0.2	< 0.2	0.2
	3	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
	4	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2

(a) Sampling Point 1 - Influent
Sampling Point 2 - Aerated Lagoon Effluent
Sampling Point 3 - Storage Lagoon Effluent
Sampling Point 4 - Final Effluent

* From Muskegon Wastewater Management System Survey of Toxic Pollutants

TABLE 8

ELEMENTAL ANALYSES OF COMPOSITED SAMPLES OF MUSKEGON WASTEWATER BY PLASMA EMISSION AND NEUTRON ACTIVATION*

	Plasma Emission (ppm)			Neutron Activation (ppm)		
Elements	#1(a)	#3(b)	#4(c)	#1(a)	#3(b)	#4(c)
Al	1.3	1.0×10^{-1}	4.0×10^{-2}	5.9	3.1×10^{-1}	
As	$<5.0\times10^{-2}$	$<5.0\times10^{-2}$	$<5.0\times10^{-2}$			
Au				$<1.0\times10^{-3}$		
B	6.3×10^{-1}	5.2×10^{-1}	3.4×10^{-1}			
Ba	7.1×10^{-2}	4.8×10^{-2}	5.5×10^{-2}	7.4×10^{-2}	5.2×10^{-2}	5.8×10^{-2}
Be	$<1.0\times10^{-3}$	$<1.0\times10^{-3}$	$<1.0\times10^{-3}$			
Br				2.1×10^{-1}	2.7×10^{-1}	1.5×10^{-1}
Ca	5.6×10^{-1}	7.2×10^{1}	5.2×10^{1}	1.2×10^{2}	3.7×10^{1}	3.1×10^{1}
Cd	$<2.0\times10^{-3}$	$<2.0\times10^{-3}$	$<2.0\times10^{-3}$			
Ce				2.0×10^{-3}		1.0×10^{-3}
Cl				1.7×10^{2}	2.0×10^{2}	1.1×10^{2}
Co	4.0×10^{-3}	7.0×10^{-3}	2.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}
Cr	5.9×10^{-2}	5.1×10^{-2}	4.0×10^{-3}	4.7×10^{-2}	2.3×10^{-2}	
Cu	8.0×10^{-3}	4.0×10^{-3}	2.0×10^{-3}			
Eu				$<1.0\times10^{-3}$		$<1.0\times10^{-3}$
Fe	7.3×10^{-1}	7.5×10^{-1}	9.1×10^{-2}	6.6×10^{-1}	4.0×10^{-1}	
Hg	1.2×10^{-2}	1.1×10^{-2}	5.0×10^{-3}	2.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}
K				1.9×10^{1}		
La				1.0×10^{-3}		3.0×10^{-3}
Lu						$<1.0\times10^{-3}$
Mg	1.2×10^{1}	1.4×10^{1}	1.3×10^{1}	1.2×10^{1}	1.4×10^{1}	1.2×10^{1}
Mn	3.1×10^{-1}	2.5×10^{-1}	2.9×10^{-2}	3.4×10^{-1}	2.8×10^{-1}	3.3×10^{-2}
Mo	4.0×10^{-3}	1.3×10^{-2}	1.3×10^{-2}	6.0×10^{-3}	1.1×10^{-2}	
Na				1.4×10^{2}	1.0×10^{2}	5.3×10^{1}
Nd						1.6×10^{-2}
Ni	1.0×10^{-2}	2.3×10^{-2}	6.0×10^{-3}			
Pb	$<5.0\times10^{-2}$	$<5.0\times10^{-2}$	$<5.0\times10^{-2}$			
Rb				1.0×10^{-2}	9.0×10^{-3}	
Sb	$<5.0\times10^{-3}$	$<5.0\times10^{-3}$	$<5.0\times10^{-3}$	4.0×10^{-3}	3.0×10^{-3}	7.0×10^{-3}
Sc				$<1.0\times10^{-3}$	$<1.0\times10^{-3}$	$<1.0\times10^{-3}$
Se	$<5.0\times10^{-2}$	$<5.0\times10^{-2}$	$<5.0\times10^{-2}$			
Sm				1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}
Sn	$<5.0\times10^{-2}$	$<5.0\times10^{-2}$	$<5.0\times10^{-2}$			
Sr	1.4×10^{-1}	1.5×10^{-1}	6.4×10^{-2}			
Th				1.0×10^{-3}		
Ti	2.5×10^{-1}	5.6×10^{-2}	2.0×10^{-3}	1.5		
U				$<1.0\times10^{-3}$		1.0×10^{-3}
V	2.0×10^{-3}	1.0×10^{-3}	2.0×10^{-3}			
Yb						$<1.0\times10^{-3}$
Zn	3.5×10^{-1}	2.1×10^{-1}	1.1×10^{-2}	2.6×10^{-1}	1.8×10^{-1}	8.2×10^{-2}

(a) Sampling Site #1 - Influent
(b) Sampling Site #3 - Storage Lagoon Effluent
(c) Sampling Site #4 - Final Effluent

* From Muskegon Wastewater Management System Survey of Toxic Pollutants

constituents of the influent wastewater. Low levels of only five of these (dichloromethane, acetone, hexadecanoic acid, dodecanol, and tetradecanol) plus trimethylisocyanurate and atrazine were detected in the final effluent. These data are presented in Table 10.

SUMMARY

On the basis of the data generated during these studies, following general conclusions can be made: 1) Most of the constituents are substantially reduced during vertical percolation through the unsaturated zone, as well as during horizontal movement in the aquifer. Non-specific measurements of organic material indicate substantial removal during percolation. Notable exceptions are some heavy metals, TDS, hardness and some trace organics. The occurrence of heavy metal migration is dependent on soil properties such as cation exchange capacity and organic content. Data summarized in this report for experiements with sandy soils represent situations where metal migration would be most likely to occur. Some constituents, such as ammonia, merely undergo chemical changes. 2) Bacteriological and virological agents are effectively removed by vertical percolation. 3) During vertical percolation, most of the pollutants are retained in the upper two feet of soil. These conclusions can only be regarded as very general because they attempt to summarize the findings of studies which varied in application technique and rate, parameters monitored, soil regime, and sampling methodology.

A more detailed discussion of Los Angeles County Recharge activities and experiments conducted at the Whittier Narrows Test Basin follows.

MONTEBELLO FOREBAY RECHARGE PROGRAM

For many years, the Los Angeles County Flood Control District has exercised, as one of its responsibilities, artificial replenishment to augment the replenishment which naturally occurs in the Montebello Forebay. This has occurred in two ways. First, the Flood Control District has constructed surface storage in the mountainous area tributary to the San Gabriel River and the Rio Hondo and has released the flood flows which otherwise would have wasted to the ocean at rates within the percolation capacity. Secondly, the Flood Control District has constructed spreading areas which make possible the percolation of storm flows at rates higher than would take place naturally. This has included both the modification of the channel of the San Gabriel River to increase percolation rates and the construction of offstream spreading basins adjacent to both the Rio Hondo and the San Gabriel River.

TABLE 9 *

BENZENE, CHLOROFORM, AND TRICHLOROETHYLENE
IN MUSKEGON SYSTEM WASTEWATER

Pollutant	Sampling Point (a)	Concentration in µg/1 (b)				
		8-10-76 Tue.	8-11-76 Wed.	8-12-76 Thu.	9-7-76 Tue.	9-8-76 Wed.
Benzene	1	6	53	6	41	32
	2	7	2	< 1	8	5
	3	< 1	< 1	< 1	3	2
	4	< 1	< 1	< 1	< 1	8
Chloroform	1	425	440	480	360	2645
	2	105	61	81	365	610
	3	12	9	4	100	75
	4	3	3	1	13	10
Trichloroethylene	1	13	6	10	110	120
	2	16	3	5	35	33
	3	7	4	1	11	6
	4	6	3	2	10	8

(a) Sampling Point 1 - Influent
Sampling Point 2 - Aerated Lagoon Effluent
Sampling Point 3 - Storage Lagoon Effluent
Sampling Point 4 - Final Effluent

(b) Average for duplicate samples

* From Muskegon Wastewater Management System Survey of Toxic Pollutants

TABLE 10

ADDITIONAL ORGANIC COMPOUNDS IDENTIFIED IN MUSKEGON SYSTEM WASTEWATER*

Pollutant (b)	WASTEWATER SAMPLED (a)			
	Influent	Aerated Lagoon Effluent	Holding Lagoon Effluent	Final Effluent
Dichloromethane (c)	+	+	+	+
1,2-Dichloroethane (c)	+	+	+	-
1,2-Dichloroethylene (c)	+	+	-	-
Toluene	+	+	-	-
Xylene (d)	+	+	-	-
Acetone	+	+	+	+
Dimethyl Sulfide	+	+	+	-
3-Pentanone	+	+	-	-
Dimethyl Disulfide	+	+	-	-
Dichlorobenzidine (c)	+	+	-	-
Phenol (c) (d)	+	-	-	-
Ethylbenzene (c)	+	-	-	-
Trichlorobenzene (c)	+	-	-	-
Diazobenzene	+	+	+	-
Dichlorobenzophenone	+	+	+	-
Aniline (d)	+	+	?	-
N-Ethylaniline	+	-	-	-
N,N-Diethylaniline	+	-	-	-
N,N-Dimethylaniline (d)	+	+	+	-
Chloroaniline (d)	+	+	+	-
Benzothiazole	+	-	-	-
Benzyl Alcohol (d)	+	+	-	-
Cresol (d)	+	-	-	-
Methoxy Phenol (d)	+	-	-	-
Hydroxymethoxyacetophenone	+	+	+	-
Dimethoxyacetophenone	+	+	-	-
Chloropropiophenone	+	-	-	-
Hexanoic Acid (d)	+	-	?	-
Decanoic Acid (d)	+	+	?	-
Dodecanoic Acid	+	+	-	-
Tetradecanoic Acid	+	?	+	-
Hexadecanoic Acid	+	+	+	+
Heptadecanoic Acid	+	+	-	-
Octadecanoic Acid	+	+	+	-
α- Pinene	+	-	-	-
β- Pinene	+	-	-	-
α- Terpineol	+	-	-	-

TABLE 10 - CONTINUED

Pollutant (b)	WASTEWATER SAMPLED (a)			
	Influent	Aerated Lagoon Effluent	Holding Lagoon Effluent	Final Effluent
Trithiapentane (d)	+	+	-	-
Tetrathiahexane (d)	+	+	+	-
2-Ethyl-1-hexanol	+	-	-	-
Isoborneol	+	+	-	-
Decanol	+	-	-	-
Dodecanol	+	+	-	+
Tetradecanol	+	-	-	+
2-(2-(2-ethoxyethoxy) ethoxy)ethanol	+	-	-	-
Tetradecene	-	+	-	-
Trimethylisocyanurate	-	-	+	+
Atrazine	-	-	-	+
Heptanoic Acid (e)	-	(f)	+	-
Octanoic Acid (e)	+	(f)	+	-
Nonanoic Acid (e)	+	(f)	+	-
Pentadecanoic Acid (e)	-	(f)	+	-
O-Phenyl Phenol (e)	+	(f)	-	-
Benzoic Acid (e)	+	(f)	+	-
Phenylacetic Acid (e)	+	(f)	-	-
Salicylic Acid (e)	+	(f)	-	-
Phenylpropionic Acid (e)	+	(f)	-	-
Vanillin (e)	+	(f)	-	-
Acetovanillin (e)	+	(f)	-	-
Homovanillin (e)	+	(f)	-	-
2-(4-Chlorophenoxy)2-Methyl Propionic Acid (e)	+	(f)	+	-

(a) Presence or absence of pollutant in wastewater is indicated by + or -. "?" indicates presence suspected but not confirmed beyond reasonable doubt.

(b) Unless noted otherwise, listed compounds were identified in daily samples at RSKERL.

(c) Compounds appearing on the EPA "List of Dangerous Pollutants."

(d) Identified in both daily samples at RSKERL and composite samples at AERL.

TABLE 10 - CONTINUED

(e) Identified in composite samples at AERL.

(f) Composite samples of aerated lagoon effluent were not obtained.

*From Muskegon Wastewater Management System Survey Study of Toxic Pollutants.

The available percolation capacity of the stream channels and the offstream spreading areas is utilized during only a small portion of the year. During the remainder of the year, this capacity is available for the spreading of water from other sources. Since the early 1950's, this capacity has been utilized to spread imported water supplies purchased from the Metropolitan Water District of Southern California.

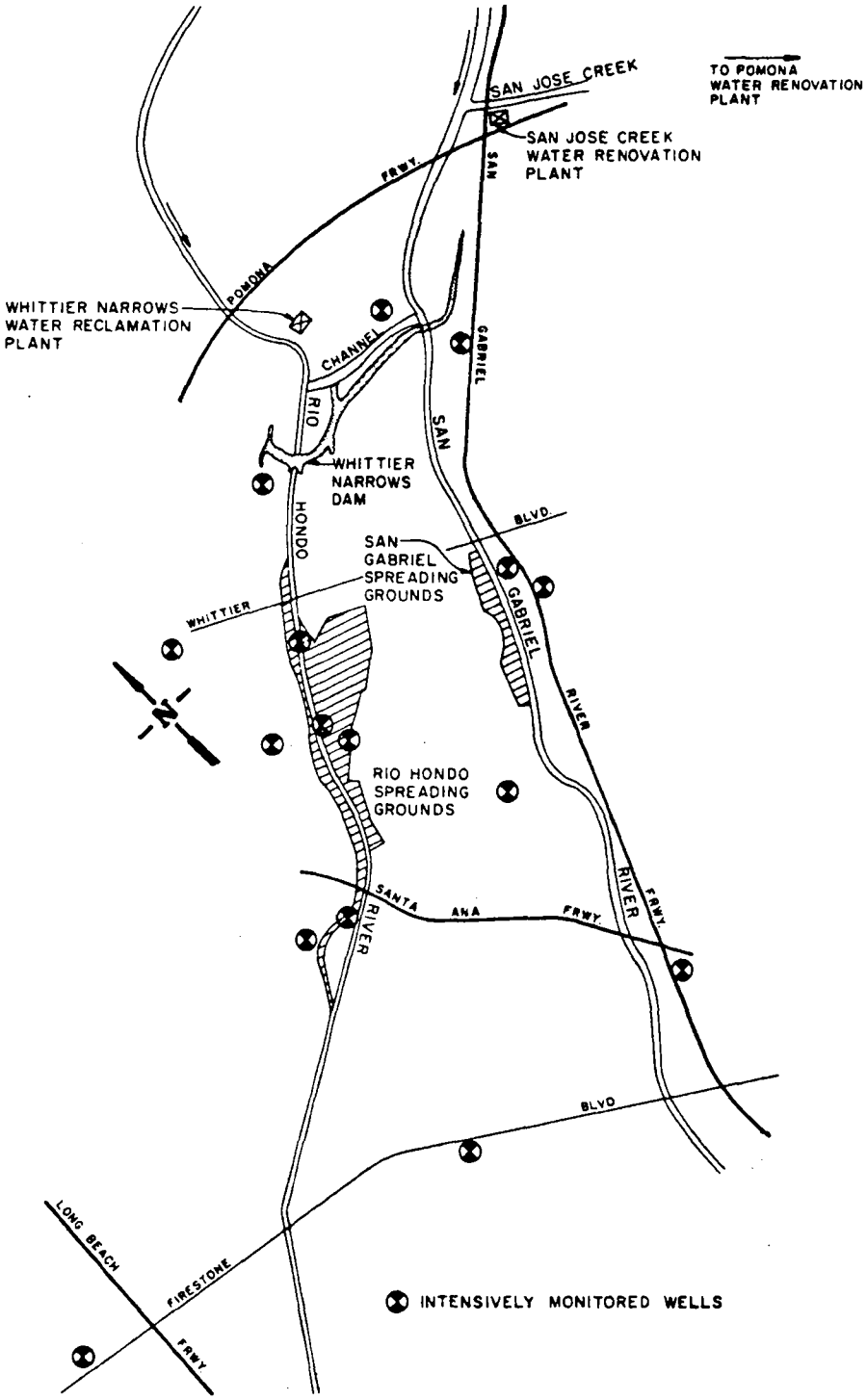
Beginning in 1962, reclaimed water from the LA County Sanitation Districts' Whittier Narrows Water Reclamation Plant became available for spreading. At present three County Sanitation Districts' plants produce reclaimed water used for groundwater recharge. The activated sludge effluent is disinfected by chlorination before discharge to flood control channels which convey the water to the spreading grounds. The locations of the spreading grounds, the treatment plants and the flood control channels are indicated in Figure 3. The Whittier Narrows Water Reclamation Plant produces an average of 2369 cu.m/hr. (15 MGD). The Pomona Water Reclamation Plant and the San Jose Creek Water Reclamation Plant contribute approximately 948 and 2369 cu.m/hr. (6 and 15 MGD), respectively, to the groundwater recharge effort. Filtration systems that will enhance disinfection are presently nearing completion at the Whittier Narrows and San Jose Creek WRP's. The Pomona Plant has employed activated carbon filtration since January, 1977.

The effluent from the Whittier Narrows WRP is conveyed through unlined sections of the Rio Hondo and spread chiefly in the Rio Hondo spreading grounds. Effluent from the San Jose Creek WRP is conveyed through a closed pipeline to a diversion point close to the San Gabriel River spreading grounds where historically it has been spread both in the San Gabriel spreading grounds and the unlined reaches of the San Gabriel River. Current spreading operations allow for most of the San Jose Creek effluent to be spread in the San Gabriel River bed due to an impermeable layer in the San Gabriel River spreading grounds which impedes percolation. The 3158-3948 cu. m/hr. (20-25 MGD) output by San Jose Creek has not been totally used in the past because of limits set by historical spreading proportions and also at times when TDS levels exceeded 700 mg/l. Approximately 15 percent of the reclaimed wastewater from the Pomona WRP is resued for irrigation purposes in the Pomona area. The remaining flow is discharged to the lined section of San Jose Creek in Pomona and conveyed to unlined portions of San Jose Creek and the San Gabriel River where it infiltrates near the Whittier Narrows Dam.

The Rio Hondo and San Gabriel River Spreading grounds, indicated in Figure 3, have total areas available for percolation of 0.2 and 0.04 hectares (455 and 101 acres), respectively. Approximately 0.05 additional hectares (133 acres) are available in the

FIGURE 3

LOCATION MAP
SPREADING GROUNDS AND TREATMENT PLANTS
MONTEBELLO FOREBAY



unlined portion of the San Gabriel River. The spreading grounds are subdivided into numerous individual basins ranging in size from 1.6 to 8.1×10^{-3} hectares (4 to 20 acres). A basin filling cycle has been established that serves several purposes, including maintenance of aerobic conditions in the upper soil strata to prevent sealing of the basins and control of vector insects. Batteries of basins are rotated through a 21 day cycle consisting of filling to a depth of four feet for seven days, draining for seven days, and drying for seven days. On this rotating basis the capacity of the basins for recharge is 31,583 cu. m/hr. (200 MGD). On a short term basis with all basins in operation simultaneously, the capacity for groundwater recharge is 94,750 cu. m/hr. (600 MGD). This latter mode of operation is used in storm periods to maximize conservation of storm water.

WHITTIER NARROWS TEST BASIN

During the first years (1963-1965) of the Whittier Narrows groundwater replenishment program, an investigation was conducted by the California Institute of Technology. The purpose of the study was to characterize the water quality changes that occur in reclaimed water as it percolates through soil. A summary of the study was presented in a report entitled "Research on Wastewater Reclamation at Whittier Narrows" by McMichael and McKee.[2]

A test basin was constructed by the Los Angeles County Flood Control District north of the Whittier Narrows Dam in the dam reservoir area. Site selection was predicated on the area's proximity to the discharge of effluent from Whittier Narrows Water Reclamation Plant. During the study, undiluted effluent was spread at rates varied to maximize the hydraulic loading while maintaining aerobic conditions in the soil. The first spreading schedule consisted of continuous flooding which was subsequently changed to flooding on Mondays, Wednesdays, and Fridays. The final schedule consisted of flooding from Monday through Friday. Grab samples were collected from sampling pans buried at depths of 0.6, 1.2, 1.8, and 2.4 m (2, 4, 6, and 8 ft.) below the ground surface.

Prior to the installation of the test basin, the land was used for farming. Consequently, there was an abundance of organic material in the first few feet of soil. The soil profile at the Whittier Narrows site presented in Table 11 shows the soil to be non-homogeneous with thin, discontinuous layers of silt and micaceous material. The water table was approximately 2.7 m (9 ft.) below the ground surface.

RESULTS FROM THE MCKEE-McMICHAELS STUDY

As indicated by the averages of data presented in Table 12, the sum of organic and ammonia nitrogen was diminished by more than 54 percent in percolation through the upper 0.6 m (2 ft) of soil. Past this depth, the organic and ammonia nitrogen concentration did not change. The most significant changes in nitrate concentrations occurred within the first 0.6m (2 ft.) of percolation. At the 0.6m (2 ft.) level, nitrates increased by a factor of almost three over surface concentrations. Percolates at the 2.4m (8 ft.) level contained nitrate concentrations five times greater than surface concentrations. These increases were slightly less for samples collected during periods of continuous flooding. Total nitrogen decreased slightly (10 percent) over the first 1.8m (6 ft.) of percolation, but increased (18 percent) between the 1.8 and 2.4m (6 and 8 ft.) depths. Figure 4 presents the changes of ammonia plus organic nitrogen and nitrates with depth.

Approximately 53 percent of the COD applied was removed from the percolating water in passage through the first 1.2m (4 ft.) of soil. From 1.2 to 1.8 (4 to 6 ft.), COD concentrations increased to approximately 8 percent over the surface concentrations. Below this level, concentrations decreased to slightly below that of the surface concentration. The increase in COD observed in some of the 1.8m (6 ft.) percolates probably resulted from contamination in the 1.8m (6 ft.) pan.

Test results also demonstrated that total dissolved solids and hardness concentrations increased with depth. TDS concentrations increased by 18 percent while hardness increased by 53 percent. Both increases were attributed to dissolution of minerals by weak nitrous acid formed during the intermediary steps of ammonia to nitrate conversion in the soil.

Contrary to the findings of previous investigators that vertical travel through soil removes coliform organisms, this study demonstrated that well-ripened filtration beds generate coliforms. The median MPN of the applied chlorinated effluent was 190 coliforms per 100 ml, yet the percolates from the four sampling pans produced median MPN concentrations ranging from 1,000 to 20,000 per 100 ml. Further tests revealed that the coliforms in the percolates were of a non-fecal origin, i.e., they were normal soil bacteria that thrived in the environment created by the application of reclaimed water.

Virological analyses performed on the reclaimed water indicated that on the average, enteric virus concentrations were very low (less than 100 PFU per liter). Samples taken during and shortly after the Sabin Oral Sunday Innoculations of February, 1963 showed about 250 PFU of enteric virus per liter in the Whittier Narrows

TABLE 11

Geologic Soil Profile At The Whittier Narrows Test Basin*

Depth Below Surface Feet	Unit Thickness	From	To	At	Description
0-	1 ft. 10 in.	0	1 ft. 10 in.	0	Dark brown very fine to medium silty sand and soil
2-	2 ft. 2 in.	1 ft. 10 in.	4 ft.	1 ft. 10 in.	Light brown to tan fine to medium sand with lenses of gray fine sand. Moist, oxidized, orange fine sand streaks are common in tan portion.
4-	1 ft. 6 in.	4 ft.	5 ft. 6 in.	4 ft.	Wood fragments up to 3 in. long in dark brown to black medium to fine sand. Sand is highly micaceous.
6-	2 ft. 2 in.	5 ft. 6 in.	7 ft. 8 in.	5 ft. 6 in.	Tan fine to medium soft, micaceous sand, with gray fine sand lenses. Tan portions commonly show orange streaks of oxidized fine sand.
8-	4 in.	7 ft. 8 in.	8 ft.	7 ft. 8 in.	Dark brown to black micaceous fine sandy silt stringer.
10-	1 ft. 6 in.	8 ft.	9 ft. 6 in.	8 ft. 8 ft. 6 in.	Gray medium to coarse sand. Gray medium to coarse sand and "pea gravel" with occasional gravels to 3/8 in.

* From 1965 McKee-McMichaels Report - Soil Profile Taken December, 1962.

FIGURE 4

1965 MCKEE - MCMICHAELS STUDY

ORG. + NH_4-N AND NO_3-N VS. DEPTH

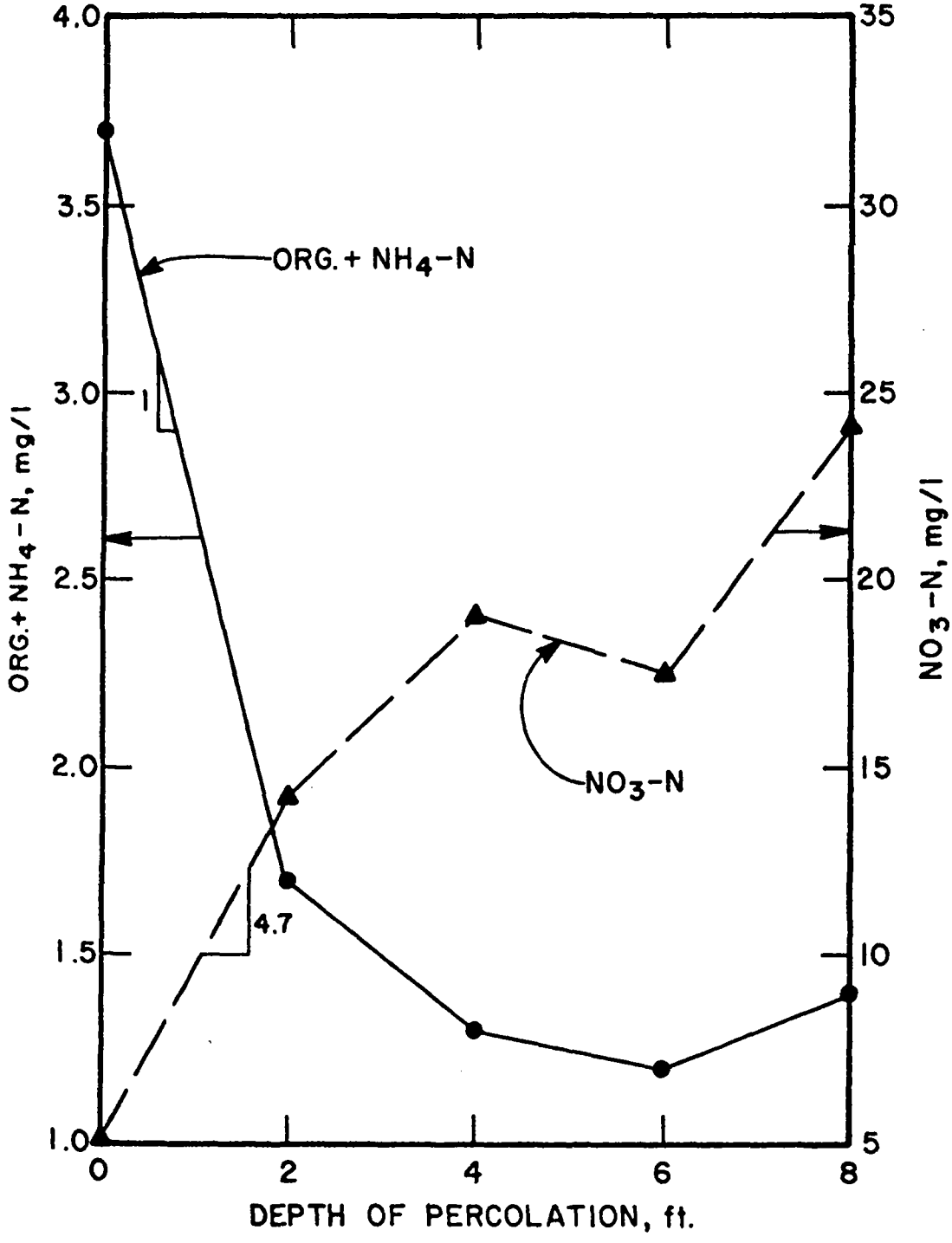


TABLE 12

MCKEE - MCMICHAEL STUDY - SUMMARY OF CHEMICAL DATA AT THE WHITTIER NARROWS TEST BASIN
JANUARY, 1963 - MARCH, 1965
(AVERAGES OF DATA FOR ALL THE SPREADING REGIMES)

Depth of Percolation Ft.	Total N MG/L	Organic+ NH_3-N MG/L	NO_3-N MG/L	COD MG/L	Total Coliforms MPN/100ml	Viruses PFU/L	TDS MG/L	Hardness MG/L
0	21.0	3.7	5.0	37.8	190	None	746	209
2	17.8	1.7	14.4	19.4	15,000	"	734	200
4	20.3	1.3	19.0	17.8	100	"	776	239
6	19.0	1.2	17.6	40.8	1,000	"	880	320
8	24.8	1.4	24.2	29.9	20,000	"	-	-

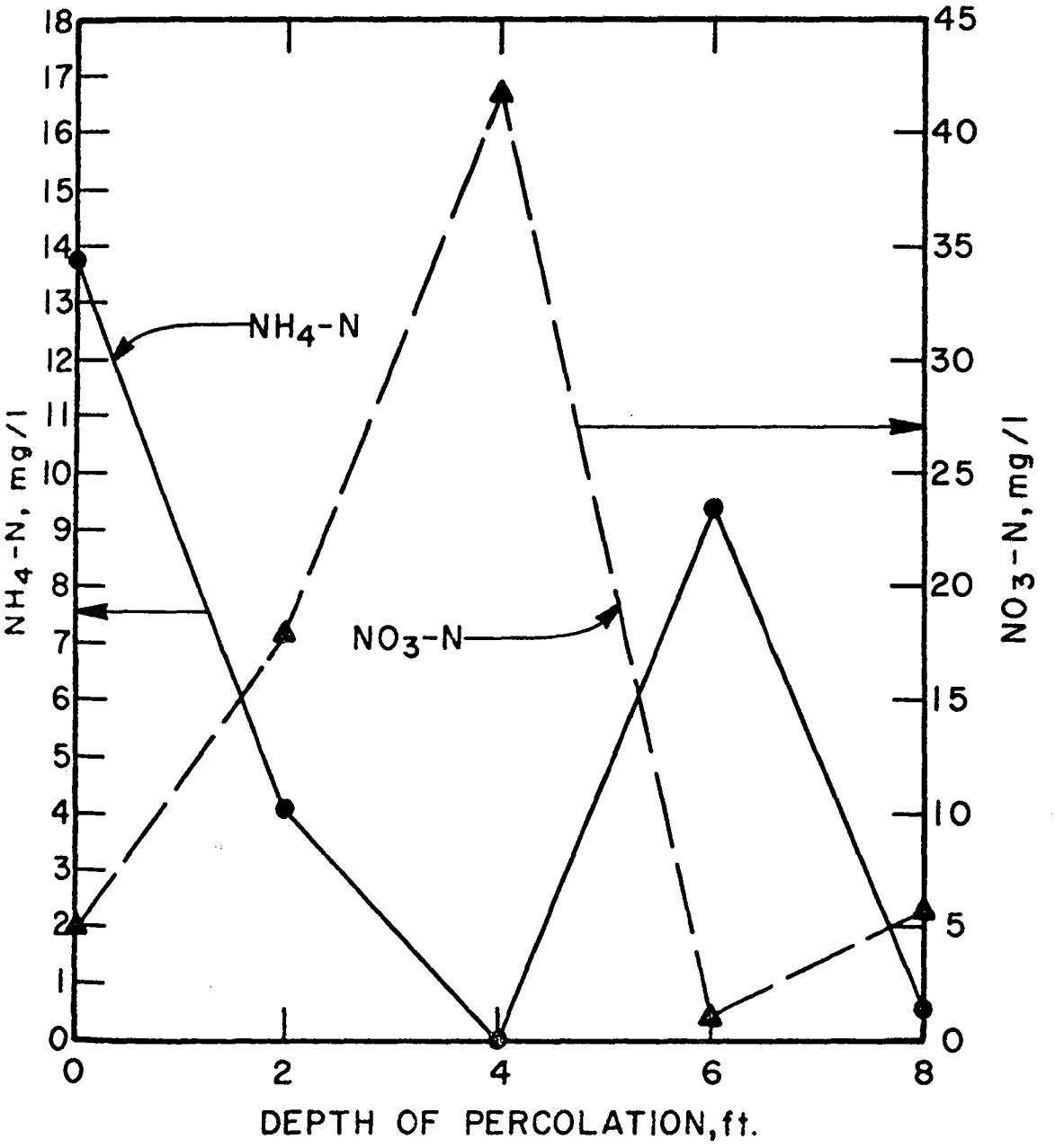
TABLE 13

1970 LACFCD STUDY - SUMMARY OF CHEMICAL DATA AT THE WHITTIER NARROWS TEST BASIN
JUNE, 1970 - FEBRUARY, 1972

Depth of Percolation Ft.	NH_4-N MG/L	NO_3-N MG/L	TDS MG/L	Hardness MG/L	pH
0	13.7	5.0	702	175	7.0
2	4.1	17.8	772	236	6.7
4	0.0	41.8	854	276	6.4
6	9.3	0.8	761	208	6.8
8	0.5	5.7	781	252	6.8

FIGURE 5

1970 LACFCD STUDY
NH_4-N AND NO_3-N VS. DEPTH
(NON-NITRIFIED EFFLUENT)



effluent but not measurable concentration in the percolate from the 0.6m (2 ft.) pan. Further testing with Sabin Type-III vaccine added to the reclaimed water produced no measurable concentrations of viruses in the percolates.

1970 LACFCD STUDY

The Los Angeles County Flood Control District initiated a study in June, 1970 to evaluate the effects of long-term spreading and to investigate further changes in reclaimed water quality during percolation. During the study, the test basin was flooded for seven consecutive days and then allowed to dry at least 14 consecutive days, which resembles the schedule for the Rio Hondo and San Gabriel spreading grounds. Undiluted Whittier Narrows Water Reclamation plant effluent was spread. Grab samples of reclaimed water and percolates were taken in a similar manner to the previous study. During this investigation, measurements of COD, coliforms and viruses were not made. Results are presented in Table 13.

At the 1.2m (4 ft.) level, the ammonium concentration was essentially zero, while the nitrate concentration had increased by a factor of eight from the surface concentration. One unexplained phenomenon occurred at the 1.8m (6 ft.) level where percolate samples showed a sharp increase in ammonium and a decrease in nitrate (see Fig. 5). This led to further uncertainty over validity of results from the 1.8m (6 ft.) pan. Following 2.4m (8 ft.) of percolation, the ammonium concentration was essentially zero and the nitrate concentration returned to its initial concentration.

As in the study by McKee and McMichaels, total dissolved solids and hardness both increased with depth. In this case, TDS concentrations increased by approximately 11 percent and hardness by 31 percent following 2.4m (8 ft.) of percolation.

LACFCD-LACSD STUDY

In March, 1973, the Los Angles County Flood Control District and the Los Angeles County Sanitation Districts began a joint investigation of the effects of spreading nitrified secondary effluent. Each agency collected data for a period of approximately one year. Spreading and sampling methods corresponded to those used in the 1970 study. Results from this study are presented in Table 14. The main thrust of these experiments was to evaluate the interrelationship of nitrification and TDS increase.

LACSD data indicated that the average COD removal as a result of percolation through 2.4m (8 ft.) of soil was 51 percent. This removal closely approximates the removal found by the Flood Control District of 57 percent. In both cases, the greatest

TABLE 14

LACSD-LACFCD Study Summary of Chemical Data at the Whittier Narrows Test Basin March, 1971-June, 1974

DEPTH OF PERCOLATION FT.	NH_4-N MG/L		NO_3-N MG/L		COD MG/L		TDS MG/L		HARDNESS MG/L	
	LACSD	LACFCD	LACSD	LACFCD	LACSD	LACFCD	LACSD	LACFCD	LACSD	LACFCD
0	0.31	0.90	14.3	14.4	31.4	36.9	593	645	170	170
2	0.18	0.00	14.3	16.5	21.2	18.7	635	743	193	215
4	0.07	0.00	15.2	20.3	17.8	15.2	630	726	191	199
6	0.07	0.20	14.4	19.6	17.5	13.7	652	772	211	236
8	0.12	0.00	14.9	14.0	15.5	15.8	707	840	259	277

FIGURE 6
1973 LACSD - LACFCD AND
1965 MCKEE - MCMICHAELS STUDIES

COD VS. DEPTH

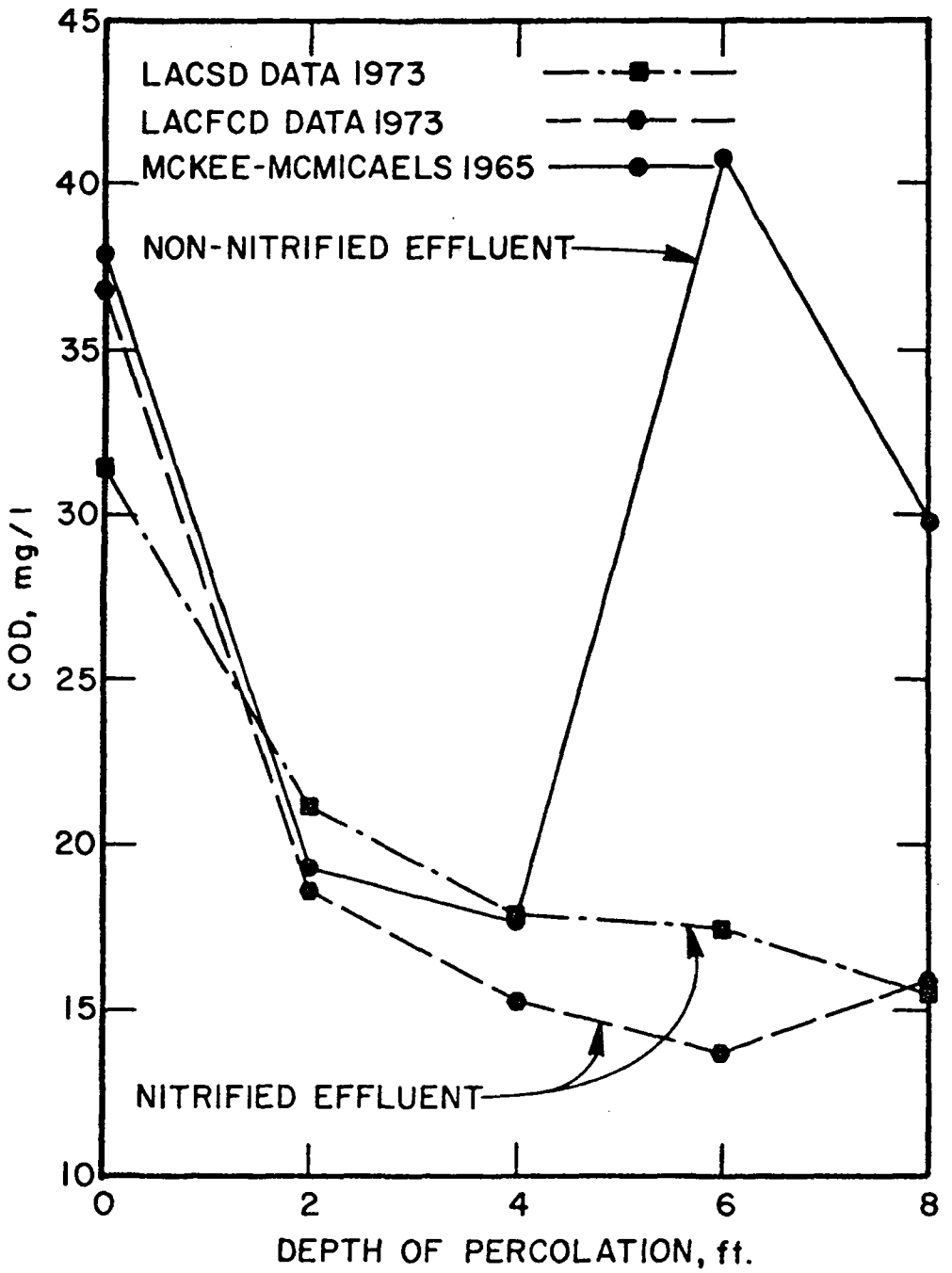
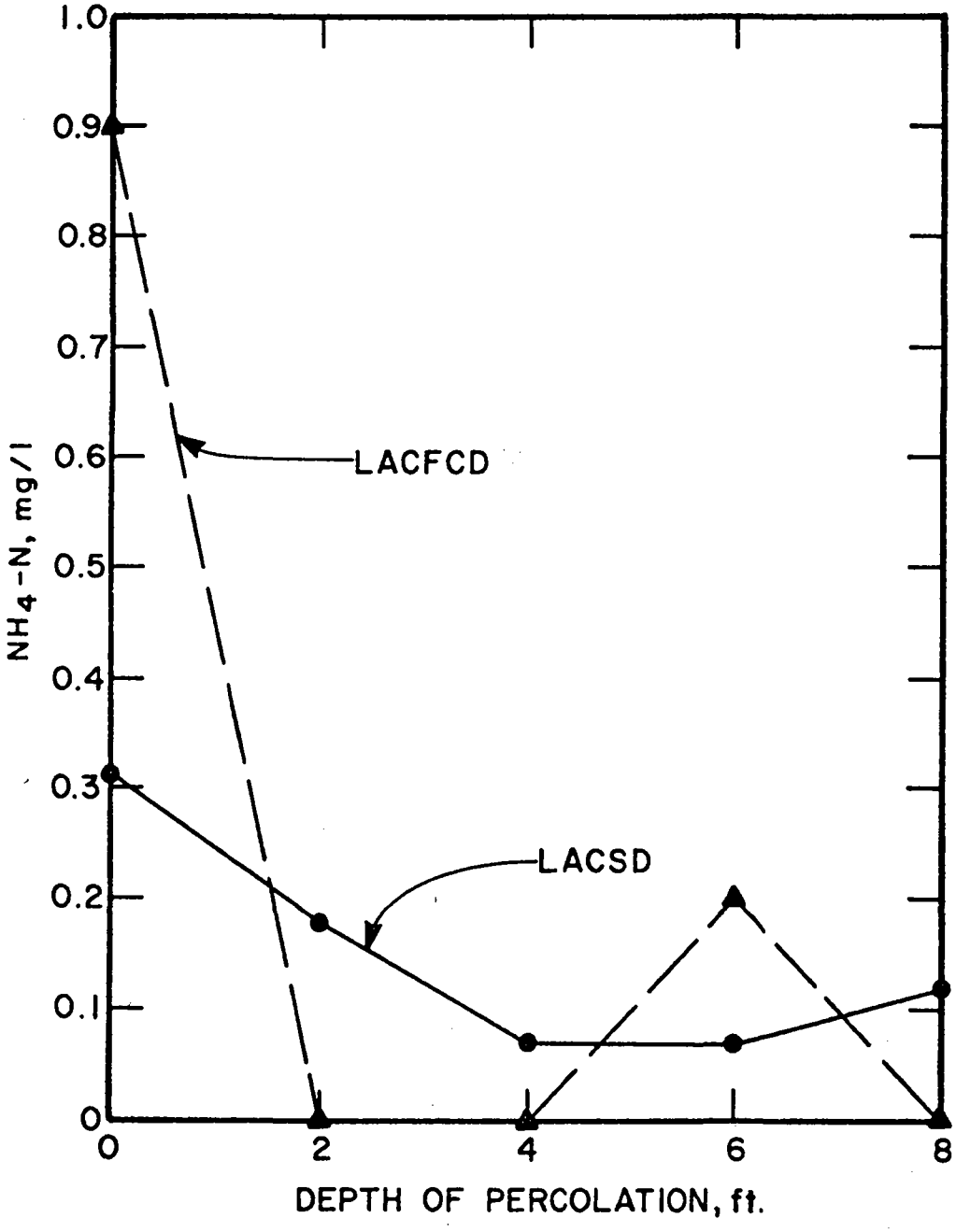


FIGURE 7

1973 LACSD AND LACFCD STUDY
NH_4-N VS. DEPTH
(NITRIFIED EFFLUENT)



change occurred within the first 1.2m (4 ft.) of percolation. These data along with data from the McKee-McMichaels Study are plotted in Figure 6.

Results also indicated that little if any further nitrification occurred as a result of percolation since nitrate and ammonium concentrations remained constant with depth. Nitrate levels in the applied water and percolates exceeded the recommended drinking water standards of 10 mg/l. Ammonia data are summarized in Fgiure 7.

According to LACSD data, total dissolved solids increased 19 percent over surface concentrations. This increase was approximately 30 prcent for LACFCD data. These results combined with data from the two previous studies which used non-nitrified effluent demonstrate that some differences did exist for nitrified and non-nitrified percolated effluents in terms of TDS increase; however, these differences were felt to be insignificant. Hardness concentrations also increased with depth. The average increase, according to LACSD data, was 52 percent which approximates the increase found by the LACFCD of 63 percent. TDS and hardness data are plotted in Figures 8 and 9.

SUMMARY

Combining data from all Whittier Narrows Test Basin Studies, the following conclusions can be made regarding the water quality changes that occurred:

1. An 80 percent decrease in ammonium following 2.4m (8 ft.) of percolation (See Figure 7). This value represents changes that occur when nitrified effluent is applied and is not typical of what would normally occur with non-nitrified effluent.
2. A 54 percent decrease in COD following 2.4m (8 ft.) of percolation (See Figure 6). This average value did not include data from the McKee-McMichaels Study because that data did not fit the pattern of the more recent studies.
3. Approximately 20 percent increase in TDS following 2.4m (8 ft.) of percolation (See Figure 8). This average includes data from all three studies.
4. A 50 percent increase in hardness following 2.4m (8 ft.) of percolation (See Figure 9). This average includes data from all three studies. Nitrate behavior varied from study to study and also varied between effluent type. On the basis of one study, both viruses and fecal coliforms were shown to be effectively removed.

FIGURE 8

1973 LACSD & LACFCD, 1970 LACFCD,
1965 MCKEE-MCMICHAELS STUDIES
TDS VS. DEPTH

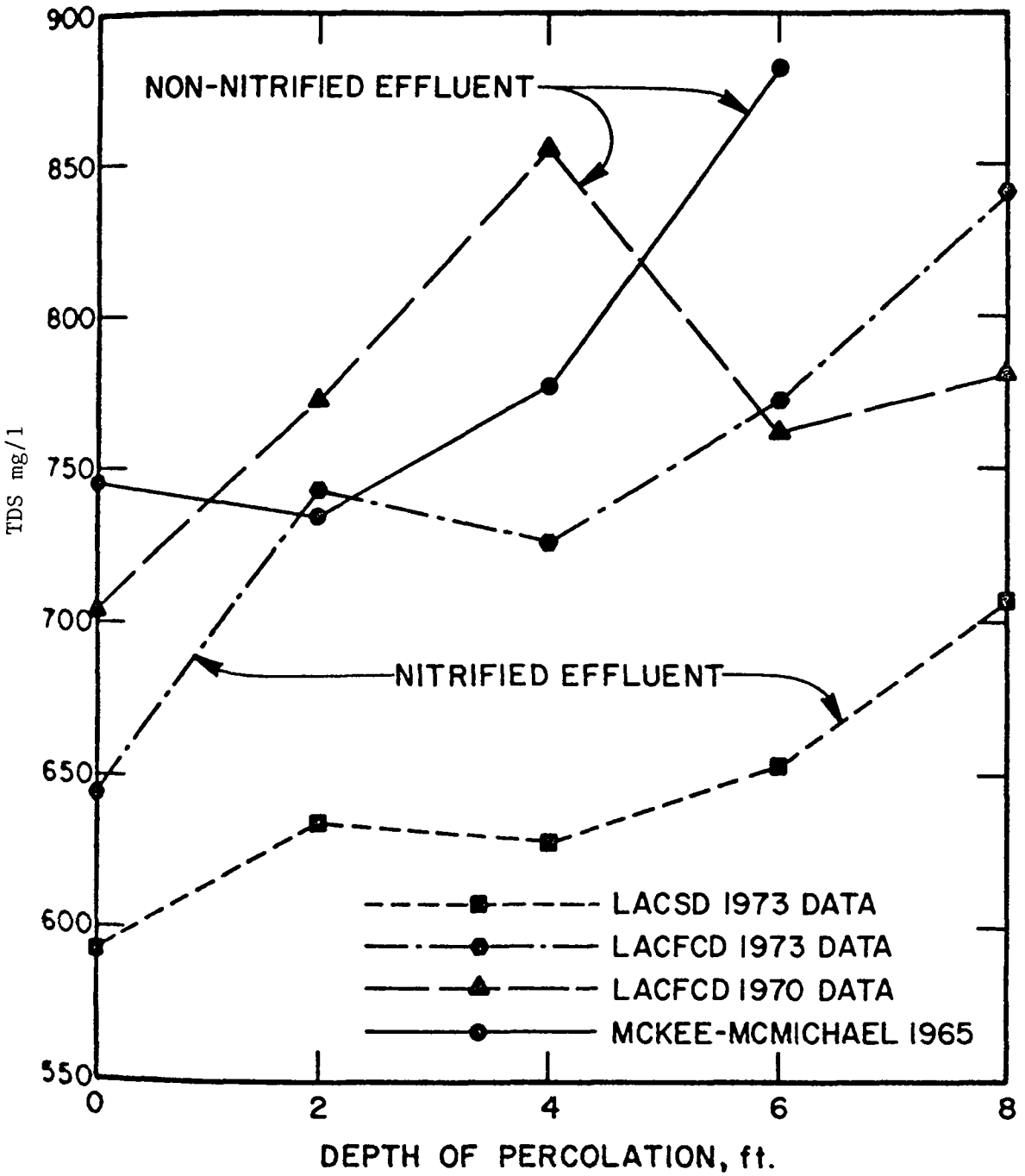
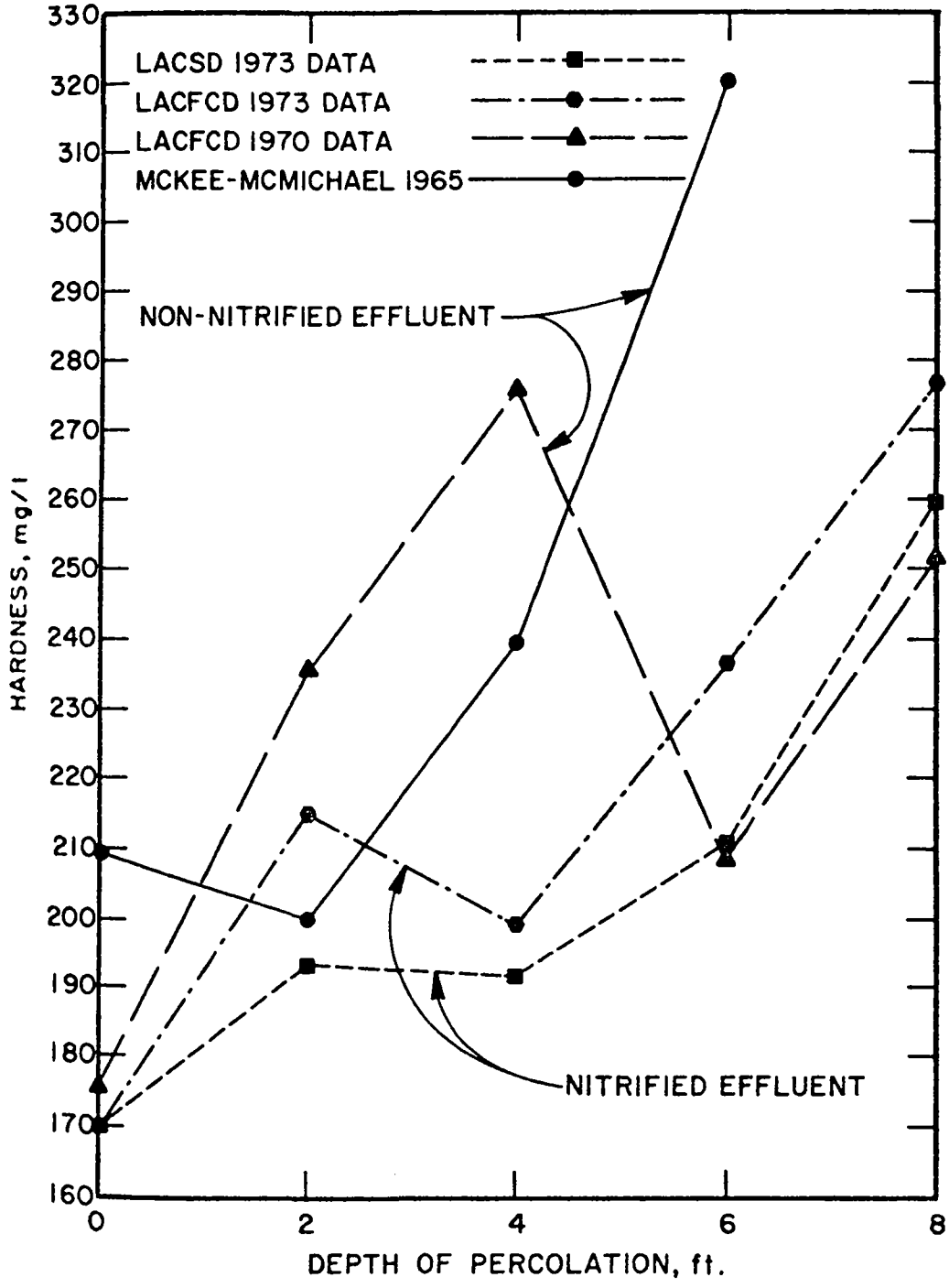


FIGURE 9

1973 LACSD & LACFCD, 1970 LACFCD,
1965 MCKEE-MCMICHAELS STUDIES
HARDNESS VS. DEPTH



CHAPTER III

THE HEALTH EFFECTS OF RECLAIMED WATER FOR GROUNDWATER RECHARGE

Reclaimed water constituents of potential health significance can generally be classified as chemical or biological. Chemical agents include dissolved minerals (i.e., hardness, total dissolved solids), nitrates, trace metals, and organic material. Biological agents which may be present in reclaimed water include parasites, bacteria and viruses. The direct influence of most of these materials is unknown due to lack of data and the subtle effects which are experted by these materials. The purpose of this section is to discuss known health effects and probable concerns caused by these agents with respect to the health of communities exposed to water systems impacted by reclaimed water.

MINERALS

Correlations have been observed between mineral content of water (hardness) and cardiovascular disease.[10] Although this relationship is not entirely clear, populations consuming waters of higher mineral content exhibit lower rates of cardiovascular disease. An example of the effect of reclaimed water is the Montebello Forebay area of Los Angeles County in which pumped groundwaters exhibit moderately high levels of total dissolved solids (TDS) with concentrations ranging from 200 mg/l to 100 mg/l. The high TDS level in these groundwaters is predominantly influenced by percolation of higher volumes of Colorado River water (TDS 750 mg/l) rather than reclaimed water (TDS 500 mg/l). For this recharge situation, replacement of reclaimed water with lower mineral content water would only cause a long term TDS reduction of approximately 5 percent.

Nitrates

The standard for nitrates in drinking water was established based on epidemiologic studies which investigated cases of infant methemoglobinemia.[11] These studies indicated that no cases of methemoglobinemia occurred in areas with less than 10 mg/l of NO_3-N in the water. Since this standard was established, there has been considerable controversy on the subject. Some European researchers have reported increased methemoglobin levels in "normal" infants in areas where clinical cases of the

disease have been observed. Clinical disease was also reported among infants exposed to water containing less than 10 mg/l NO_3-N.[11] As a result of these studies, suggestions have been made to the effect that stricter nitrate standards should be enforced.

On the other hand, areas in the United States with waters containing nitrate levels about the Standard have reported little or no clinical cases of methemoglobinemia.[11] Shearer reported that nearly all reported cases of methemoglobinemia resulted from rural household water supplies of questionable sanitary construction.[12] Goldsmith noted that infants in the Delano, California area ingested NO_3-N concentrations greater than 80 mg/l without ill effects.[13] The high ntirate levels reported were caused by boiling the drinking water for purification.

Although the presence of high concentrations of nitrate is the principal factor for the occurrence of methemoglobinemia, research has demonstrated other important factors in the pathogenesis of the disease. Some of the factors are age,[11,12,14] presence of bacteria,[13,15] gastric acidity,[10,17] gastro-intestinal disturbances,[15] type of powdered milk product used,[11] high fluid intake,[11] nutrition,[18] fetal hemoglobin,[11] and methemoglobin reduction.[19]

Current studies have reported that nitrates and nitrites may be more toxic than generally considered.[11] Several reports have described the different phenomena caused by nitrates and nitrites on the central nervous system.[20,21,22] Information is also available, which demonstrates that standards should not be relaxed, particularly in areas where infants consume significant amounts of tap water in the form of powdered milk.[11] There is also some evidence that ingestion of nitrite treated foods may be related to stomach cancer.[22,23]

Percolation studies have demonstrated that the nitrate concentration in percolates from undiluted effluent exceeded the recommended limit of the USPHS Drinking Water Standards by a factor of two to three. This problem can be alleviated by diluting effluents with natural waters prior to spreading or by allowing sufficient time for the percolated effluent to blend with natural groundwaters before pumping.

Trace Metals

Metallic elements in water supplies have been suspected to cause specific organ failure and possibly cancer.[25] Certain elements tend to concentrate in target organs causing malfunction when accumulated quantities exceed safe levels. One example is renal cortex failure observed when cadmium exceeds 200 mg/Kg in the kidney.[26] A complete review of metal toxicity is presented in the recent National Academy of Sciences Report.[25]

Safe levels of trace metals suggested by the NAS and EPA incorporate factors of safety relative to no effect levels. If reclaimed water sources meet in these safe levels, and additional removal of metals occurs in passage through soil via adsorption, ion-exchange, precipitation, and other phenomena, then these water sources should provide a factor of safety above no effect levels.

TRACE ORGANICS

The area of greatest health concern and lack of information is the chronic ingestion of trace organics which may survive conventional wastewater treatment and soil percolation. This concern is not limited to planned water reuse as demonstrated by current proposed drinking water regulations.[27,28] Additionally, the chlorination process produces chlorinated compounds which may be of greater health significance than the precursor organic material.[29,30]

Many experiments have demonstrated the formation of halogenated compounds during chlorination of treated water and wastewater.[31] The quantity of halogenated compounds formed in wastewater has been related to the form of chlorine used for disinfection.[32] Free chlorine ($HOCl^-$ and OCl^-) which is present when wastewater containing low ammonium concentration (0.1 mg/l - N) is chlorinated has a high propensity to form halogenated compounds (i.e., chloroform). On the other hand, chlorination of wastewater containing higher amounts of ammonia reduces chloroform production by one to two orders of magnitude.[32] The difference in chloroform production may be explained by the higher reactivity of free chlorine compared to chlorine which has combined with ammonia (chloramines).

Evidence of the carcinogenicity of chloroform in animals has been confirmed by several studies.[25] Data on the tumor producing effect of other trihalomethanes are limited, but several of these compounds are currently being tested by the National Cancer Institute Bioassay Screening Program. Toxicologic experiments testing brominated trihalomethanes have demonstrated that these compounds may be more active than chlorinated compounds.[28]

Epidemiological evidence relating trihalomethane concentrations and cancer morbidity/mortality is not conclusive, but suggestive of a health risk. A recent epidemiologic study funded by the EPA indicated that chlorinated water supplies in New York seem to increase the risk of certain types of cancer.[33] Research conducted in New Orleans in 1974 indicated that white males consuming chlorinated Mississippi River water exhibited higher rates of urinary tract and gastrointestinal cancer than did white males consuming chlorinated groundwaters.[34] Although the adequacy of

the statistical methods employed and the validity of the human health interpretations drawn from this study were challenged,[35,36] continued investigations established that the chlorination process can result in the formation of a variety of chlorinated organic compounds, some of which are known or suspected carcinogens.[37,38]

Statistical assessments of risk from ingestion of chloroform have been attempted using several mathematical models.[28] Results from these studies indicate that the excess risk for lifetime exposure at EPA proposed trihalomethane levels of 0.10 mg/l would be on the order of 10^{-4} to 10^{-5} (i.e., an excess 70 year lifetime cancer risk in the range of 1 in one hundred thousand). Those risk estimates were based on the presence of chloroform alone and does not consider the direct or synergistic effects that may result from the presence of other organic compounds.

Public health officials have expressed concern about how this type of reuse will impact groundwater supplies, specifically in terms of the addition of organic materials.[39] Consequently, the potential health effects of trace organic components in reclaimed water used for groundwater recharge is one area which demands further investigation.

MICROORGANISMS

Bacteria, viruses and parasites are the remaining constituents of potential health concern in reclaimed water used for groundwater recharge. Because of the multiple barriers against pathogen transmission provided by treatment, chlorination, and percolation through soil, it is unlikely that microorganisms of reclaimed water origin will reach groundwater supplies. This section is intended to provide information on pathogens which are associated with reclaimed water.

Parasites - There are myriad diseases of protozoan and metazoan etiology which are transmitted in fecal material and thereby associated with wastewater. Amoebic dysentery appears to be the most important parasitic disease associated with wastewater.[40] The etiology of this disease is Entamoeba histolytica, a protozoan which can infect the colon causing erosion of mucous membranes. As with most parasitic diseases, the symptomatology produced by this type of pathogenic intestinal protozoa is too nonspecific for accurate clinical diagnosis. Outbreaks of giardiasis, caused by Giardia lamblia, a flagellated protozoan of the small intestine, have also been reported.[40,41,42] In most cases, these outbreaks resulted from consumption of water supplies contaminated by untreated waste or untreated surface water supplies. Other helminthic parasites which may be present in municipal wastewater include ova from the giant roundworm Ascaris lumbricoides, the whipworm Trichuris trichuria, and the tapeworm Taenia saginata.

Bacteria - A wide variety of pathogenic species belong to the genus Salmonella. Water and food as well as personal contact are the main routes for disease transmission. There are three distinct forms of salmonellosis in man; namely, enteric fevers, septicemias, and acute gastroenteritis.[10] Typhoid fever caused by Salmonella typhosa is the most severe enteric fever form of salmonellosis, and man is the only host. At this time, water is not a significant vehicle for transmission of typhoid fever.[44,45] The Salmonella septicemias are relatively rare and are charcterized by bactermia and a high remittent fever.[10] The third form of salmonellosis, acute gastroenteritis, is the most commonly encountered form of Salmonella. Although incidence of waterborne salmonellosis is low, there are a large number of occurrences, suspected and verified, in which large numbers of persons were infected by this route. One example is the outbreak in Riverside, California, in 1965, in which 18,000 people were infected with S. typhimurium.[57] Evidence indicated that this water supply had been contaminated by an unknown source.

Bacteria of the genus Shigella produce an intestinal disease known as bacillary dysentery. In one instance approximately 1200 cases of acute gastrointestinal illness were reported during a two month period in Richmond Heights, Florida. The outbreak was caused by a malfunction in the local chlorination system which allowed for distribution of insufficiently chlorinated water from a contaminated well.[46] Most instances of Shigella-induced illness reported have involved either small wells, temporary breakdowns of water supply chlorination systems, or swimming in waters contaminated by sewage.[40]

Other bacteria considered to be of less importance in domestic wastewater due to the relatively few number of disease reports would include Vibrio cholerae, the etiologic agent of cholera, the tubercle bacillus, Leptospira, and "non-pathogenic" bacteria.[10]

There are numerous cases of waterborne gastroenteritis of unknown etiology in which bacterial agents are suspected. In 1971, a gastroenteritis outbreak was reported in Pico Rivera, California, in which 11,000 residents became ill with diarrhea and abdominal cramps.[40] No pathogens were isolated from any of these cases. It was later determined that contaminated well water was the source of the outbreak, resulting from a malfunction in the chlorination system. One other major outbreak of gastroenteritis resulting from sewage contaminated water was reported at Crater Lake National Park in 1975.[47]

There has been some speculation that coliforms exhibiting R factor resistance to antimicrobial agents are present in wastewater and may be of public health signifi-

cance.[58] Ingestion of coliforms containing the R factor may result in transfer of this factor to intestinal flora, thereby creating a reservoir of resistance. This resistance may, in turn, be transferred to pathogens the most may encounter. Evidence of this phenomenon is illustrated by the world occurrence of the R factor antibiotic resistant Salmonella typhosa.[59]

Viruses - Many types of viruses are discharged in the feces of infected persons and are disseminated in water via sewage or other sources of fecal contamination. Overt instances of recognized waterborne viral disease transmission have been relatively uncommon.[10] However, improved technology for concentration and detection of viruses has resulted in reports describing widespread occurrence of viruses in sewage and surface waters.

Infectious hepatitis (hepatitis A) is the enteric virus disease of major concern associated with wastewater. Many outbreaks of the disease have been attributed to contaminated water supplies based on epidemiologic evidence.[60] It has also been suggested that many unrecognized infectious hepatitis epidemics occur.[61] The infectious agent responsible for infectious hepatitis is still unknown, although recent studies have demonstrated the presence of virus-like particles in infected stools using immune electron microscopy.[63]

Other outbreaks of viral infections have been attributed to swimming in contaminated lakes or swimming pools.[64-67] Many outbreaks of gastroenteritis and diarrhea occur with no specific associated agent, but with the cause often listed as "viral" in nature. Low level transmission or endemic occurrence of waterborne virus diseases are difficult to assess for several reasons: a) present virus detection methods for detecting low levels of naturally occurring viruses are still developmental, b) enteric virus infections are inapparent, thus making it difficult to establish endemicity, and c) person to person contact is the major mode of enteric virus transmission, thereby obscuring the role of water transmission.

In terms of water reuse, some studies have demonstrated that enteric viruses survive even a well operated conventional wastewater treatment system and are released at low levels in effluents applied to land.[48] Although percolation of virus contaminated water has not been directly associated with disease outbreaks, several cases of viral disease have been attributed to groundwater contamination.[49] Previous studies have indicated that enteric viruses can survive for extended periods in soil environments.[50] Although most investigations have demonstrated limited movement of viruses through soils during percolation,[51,52] recent reports have demonstrated that in

some soil systems viruses can be recovered at considerable distances from the input sources.[53,54]

Other studies have demonstrated the effectiveness of wastewater treatment processes for removal of viruses. During a two year study performed by the Los Angeles County Sanitation Districts, results demonstrated that five logs (99.9994 percent) of seeded virus removal could be obtained by an inert media filtration system, followed by adequate chlorination to achieve a coliform MPN count of 2.2/100 ml.[55] Results from an intensive well monitoring program (including virus analysis) conducted in a portion of Los Angeles County impacted by groundwater recharge with reclaimed water demonstrated that no viruses were detected in these water supply wells.[56] The discrepancy between the Los Angeles experience and the observations previously discussed may be attributed to variations in soil type and type of treatment used. Nevertheless, viral contamination is still a problem of great concern.

CHAPTER IV

MECHANISMS FOR REMOVAL OF CONTAMINANTS FROM WASTEWATER VIA PERCOLATION THROUGH SOIL

INTRODUCTION

The planned application of treated wastewaters to lands for groundwater recharge is a relatively new concept. The rationale behind this type of reuse is that objectionable components in wastewaters will be removed by soils and/or vegetation before these waters mix with potable groundwaters. Although much experimental work has been performed with regard to disposal of water to soils, major attention was directed toward getting the water into the ground as rapidly as possible while only limited consideration has been given to the impact of such practice on the quality of existing supplies. Accordingly, the objective of this section is to present information on the removal of biological and chemical contaminants by soil systems during the recharge process.

GENERAL SOIL PROPERTIES RELATED TO RECHARGE

The ideal soil for percolation of reclaimed water should meet the following criteria: 1) have rapid rates of infiltration and transmission of water, 2) be underlain by soil materials that have no clay layers or other layers that restrict movement of water, 3) have no expanding-contracting clays that create cracks which allow the reclaimed water to bypass the soil during infiltration, 4) have sufficient clay content to adsorb trace elements, microorganisms, and heavy metals as well as to provide surfaces on which microorganisms decompose organic material, and 5) have an available supply of carbon that would favor denitrification during flooding periods and decomposition of organics.[61] Thus, an ideal system would provide rapid rates of infiltration and transmission of water and at the same time provide soil surfaces and contact time for chemical and microbiological reactions. Unfortunately, the ideal system does not exist because these two features are mutually exclusive.

Rates of infiltration and transmission are dependent on pore size distribution in soils.[68] Those soils with the largest fractions of large pores have the highest rates of transmission while those with the lowest fractions of large pores have the lowest rates of transmission. Pore size distribution is a function of texture; specifically, percent sand, silt, and clay.[68] Generally, the percentage of large pores decreases as silt and

clay content increases. The arrangement of soil particles into aggregates and the stability of these aggregates also effects pore size distribution.[69] For example, sandy loams have lower rates of transmission because of an absence of aggregates whereas some clay soils have rapid rates of transmission if they are highly aggregated.[10] However, soils with high infiltration and transmission rates in which water passes through large pores, provide minimum contact time for chemical and biological reactions and thus provide minimum treatment per distance of infiltration.

Sandy gravelly soils of stream beds which comprise recharge areas in Arizona and California have small clay and organic contents, and large fractions of larger pore spaces.[2,4] Consequently, large volumes of water can be recharged per unit wetted area, but treatment is minimal. On the other hand, adsorption of trace elements would be enhanced by using a soil with more clay and organic content and a lower intake rate.

Despite treatment restrictions, high infiltration rates have the advantage of minimizing the effect of evaporation on the total dissolved solids content of the recharged water.[10] High infiltration rates also minimize the wetted area needed for recharge operations. To compensate for lack of treatment provided by high infiltration rates, reclaimed waters may be diluted with higher quality waters prior to recharge.

Some compromise between the two extreme situations, i.e., high infiltration rates with minimum treatment versus low infiltration rates with maximum treatment is desirable. One alternative may be to prepare a soil mix that can be incorporated with river bed materials to reduce infiltration and transmission rates.[10] Another possibility might be to install a soil treatment system that would precede land spreading.[10]

REMOVAL OF BIOLOGICAL CONTAMINANTS BY SOIL SYSTEMS

During groundwater recharge, the movement of microorganisms in soils is governed by soil and hydraulic parameters as well as environmental conditions. As particulate matter suspended in water, bacteria and pathogens do not move through porous media at the same rate as water.[70] Large particles such as ova and cysts are rapidly filtered out, while other microorganisms such as bacteria and viruses are small enough to pass through soil pores with the percolating water, but are somewhat mitigated by adsorption to soil particles. Studies have demonstrated that once bacteria are introduced into soils, their movement can vary from several hundred feet in one day to only a few feet over a long period of time, depending on soil texture.[70]

Laboratory studies have also indicated that soils, in general, are effective in

TABLE 15

SURVIVAL OF PATHOGENS IN SOILS[75,76]

ORGANISM	SURVIVAL TIME
Ascaris lumbricoides ova	2.5 - 7 years
Endamoeba histolytica cysts	8 days
Salmonella species	6 hrs - 77 days
Coliform organisms	133-147 days
Q-fever organisms	148 days
Brucilla abortus	30-100 days
Tuberculosis bacteria	6 months
Enteroviruses	12 days

immobilizing viruses.[71,72] Unlike bacteria, the outer layer of viruses consists of proteins which display amphoteric behavior. Removal of viruses, therefore, is an adsorption phenomenon rather than a filtering action. Ionic strength and pH are two factors which influence the ability of soils to remove viruses.[73] When the pH of soil solutions is increased, ionization of amino groups of virus particles decreases while ionization of carboxyl groups of virus particles increases.[73] This results in a situation where negatively charged virus particles repel negatively charged soil particles. Consequently, maintenance of pH 7 or less promotes virus adsorption to soils.[10]

Cations present in water have a profound effect on neutralizing or reducing the repulsive potential of soil and virus particles.[73] At the same time, divalent and trivalent cations in solution effectively remove viruses from suspension.[73] When the ionic strength of percolating water is sufficiently decreased, desorption of viruses may occur. This has been demonstrated by studies which show when virus adsorbed clay particles were washed with distilled water, complete desorbtion and reactivation occurred.[70]

The clay and organic content of soil also influences virus adsorption capabilities. In general, soils with higher clay and/or organic content have higher adsorptive capacities.[74]

Survival of Pathogens in Soils. - Since soil is a natural habitat for microorganisms, the existence of pathogenic organisms in soil is well documented.[10] When introduced into soils via recharge, pathogens do not compete well with normal soil organisms and are subject to attack from some antagonistic species. The time involved for their ultimate destruction varies with type of species and environmental conditions.[75,76] Table 15 presents a summary of pathogen survival data. The most persistent pathogens in soil are ova, cysts, and spore-forming bacteria. Although not thoroughly studied, viruses are expected to survive in soils for a considerable period of time once outside their host.

REMOVAL OF CHEMICAL CONTAMINANTS BY SOIL SYSTEMS

The chemical composition of percolates entering the groundwater system will depend not only upon the chemical composition of the water spread, but also upon the biological, chemical and physical properties of the soil.

Soil microorganisms exert a significant effect on the attenuation of trace contaminants by initiating or performing the following processes: 1) degradation of carbonaeous materials, 2) nitrification-denitrification, 3) oxidation-reduction, 4) min-

TABLE 16 Some Microbial Transformations of Inorganic Substances[77]

Element	Microorganisms	Reactions
As	F. *ferrooxidans*	As_2S_3 oxidized to AsO_3^{3-}; AsO_4^{3-}; SO_4^{2-}
	Heterotrophic bacteria *Achromobacter* *Pseudomonas* *Xanthomonas*	AsO_3^{3-} oxidized to AsO_4^{3-}
	M. *lactilyticus*	AsO_4^{3-} reduced to AsO_3^{3-}
Cd	*Desulfovibrio*	$CdCO_3 + SO_4^{2-} + 8H^+ + 8e^- = CsS + 4H_2O + CO_3^{2-}$
Cu	T. *ferrooxidans*	$Cu_2S + 4H_2O = 2Cu^{2+} + 6H^+ + H_2SO_4 + 10e^-$
	F. *ferrooxidans*	$CuS + 4H_2O = Cu^{2+} + 6H^+ + H_2SO_4 + 8e^-$
	Desulfovibrio, C. *nigrificans*	Cu^{2+} and SO_4^{2-} reduced to CuS; $Cu_{10}S_9$; Cu_2S
	M. *lactilyticus*	$Cu(OH)_2 + H^+ + e^- = CuOH + H_2O$
Fe	T. *ferrooxidans* *Ferrobacillus* *Gallionella*	$Fe^{2+} = Fe^{3+} + e^-$
	M. *lactilyticus* B. *circulans* B. *polymyxa*	$Fe^{3+} + e^- = Fe^{2+}$
	Desulfovibrio C. *nigrificans*	$Fe^{3+} + SO_4^{2-} + 8H^+ + 9e^- = FeS + 4H_2O$
Ni	T. *ferrooxidans*	$NiS + 4H_2O = Ni^{2+} + 8H^+ + SO_4^{2-} + 8e^-$
	Desulfovibrio	$NiCO_3 + SO_4^{2-} + 8H^+ + 8e^- = NiS + 4H_2O + CO_3^{2-}$ $Ni(OH)_2 + SO_4^{2-} + 10H^+ + 8e = NiS + 6H_2O$
S	Thiobacteriaceae Thiorhodaceae Chlorobacteriaceae Beggiatoaceae	$H_2S = S^0 + 2H^+ + 2e^-$
	S. *natans* *Achromatium* Leucothrix	$H_2S + H_2O = SO_4^{2-} + 10H^+ + 8e^-$

Element	Microorganism	Reactions
Se	M. *selenicus*	$H_2Se + 4H_2O = SeO_4^{2-} + 10H^+ + 8e^-$
	M. *lactilyticus*	$Se^o + 2e^- + H^+ = SeH^-$
	C. *pasteurianum* D. *desulfuricans* *Neurospora* C. *albicans* Baker's yeast	$HSeO_3^- + 4e^- + 5H^+ = Se^o + 3H_2O$
V	M. *lactilyticus* D. *desulfuricans* C. *pasteurianum*	$H_2VO_4 + 2e^- + 2H^+ = VO(OH) + H_2O$
Zn	T. *ferrooxidans*	$ZnS + 4H_2O = Zn^{2+} + SO_4^{2-} + 8H^+ + 8e^-$
	Desulfovibrio	$\frac{1}{5}\left[2ZnCO_3 \cdot 2Zn(OH)_2\right] + SO_4^{2-} + 9\frac{1}{5} H^+ + 8e^-$ $= 5\frac{1}{5} H_2O + \frac{2}{5} CO_3^{2-} + ZnS$

eralization-immobilization, and 5) production of organic complexes which may react with trace contaminants.[68] Of these processes, oxidation-reduction, mineralization-immobilization, and production of organic complexes are probably the most important biological mechanisms for migration and attenuation of trace contaminants. Most trace contaminants can be oxidized or reduced by at least one type of microorganism depending on the availability and lack of oxygen and other susbstances in the habitat.[77] Table 16 presents a summary of oxidation-reduction reactions of certain inorganic substances.

Because some potentially hazardous constituents enter groundwater systems as part of plants, animals, and soil microorganisms, mineralization and immobilization have a significant effect on attenuation and migration of these hazardous materials. The incorporation of trace and heavy metals into microbial tissues limits the mobility of these constituents until the tissues die and decay.[68] These processes are also an important facet of nutrient cycling.[78]

Organic complexes in soils which result from microbial synthesis as well as degradation of organic material have a great propensity to combine with trace contaminants, particularly heavy metals.[68] These complexes immobilize trace contaminants by various chemical mechanisms including ion-exchange, surface adsorption, chelation, and precipitation.[79] One other important chemical mechanism not directly related to organic complexing includes a wide variety of chemical oxidation-reduction reactions.

Physical and chemical attenuation mechanisms are in most cases so closely related that it is difficult to separate the two effects. One example is adsorption which is highly dependent on the type of clay present, the quantity of clay mineral present, and the pH of the soil. More obvious physical parameters which effect trace contaminant attenuation include particle size distribution, pore size distribution, moisture conditions, and temperature.

Chemical contaminants in treated wastewaters amenable to removal by soil systems during recharge of groundwaters include organic substances, nitrogen, soluble salts, trace elements and heavy metals.

ORGANIC SUBSTANCES - Adsorption and microbial degradation are the processes primarily responsible for removal of organic substances from water which percolates through the soil profile.[80-83] Although vast numbers of organic pesticides have been used since early 1940, there is no evidence that pesticides moving with percolating waters have contaminated groundwater supplies. Soil studies have demonstrated that most pesticides remain in surface soils, while more mobile pesticides are usually subject to rapid microbial degradation.[83]

Nitrogen - For removal of nitrogen, an ideal recharge system would provide a cycle of aerobic and anaerobic conditions either in time or in depth of soil profile. Aerobic conditions are needed for microorganisms to convert NH_4^+ to NO_3^- while anerobic conditions are needed to convert NO_3^- to nitrogen gas (N_2). Because anerobic conditions favor the production of soluble organic compounds, a second aerobic period in the cycle would be desirable.[10] Alternate flooding and drying periods provide a compromise between complete denitrification and maintenance of low concentration of organic substances. In general, secondary effluents have a deficiency of available carbon for denitrification, such that other sources of carbon must be supplied to insure complete denitrification.[10]

Soluble Salts - The dissolution of carbonates and/or cation-exchange reactions associated with the acidification that results from nitrification can produce an increase in total dissolved soilids (TDS) during percolation of reclaimed waters. This is particularly of concern in cases where soils contain residual salts from agricultural irrigation or from natural geologic processes. The increase in TDS in a soil system depends on the amount of acid generated by nitrification and other chemical reactions which reacts with soluble HCO_3^- in the water and the amount of acid which reacts with soil solids.[10] If the reaction is with HCO_3^-, then the NO_3^- anion replaces the HCO_3^- anion with no net increase in TDS. However, if the reaction is with $CACO_3$, an increase in TDS results. This increase is a result of increases in soluble Ca and Mg with proportionate increases in hardness.

Trace Elements and Heavy Metals - In general, elements which occur in solution as anions or neutral molecules pass through solids more readily than elements that occur as cations.[10] The elements As, Se, and F in an inorganic form occur as anions or neutral molecules. Depending upon the system, Cd, Cu, Cr, Pb, Hg, Ag, and Zn most commonly occur in inorganic form as cations. Research conducted at the University of Arizona investigated the attenuation in Soils of 10 selectd elements (As, Be, Cd, Cr, Cu, Fe, Hg, Pb, Se, Zn) plus asbestos and cyanide.[68] These constituents were grouped with respect to mobility in soils under aerobic conditions. These results are summarized in Table 17.

Summary

The purpose of this section is to list broad or general trends which affect attenuation and migration of trace contaminants. However, before these factors are reviewed, two important conditions should be mentioned. The first is that soils themselves contribute to trace materials that move through soils. Insoluble or slowly

TABLE 17

RELATIVE MOBILITY OF TRACE CONTAMINANTS IN SOILS[68]

MOBILITY CLASS	ELEMENT	COMMENTS
I. RELATIVELY MOBILE	Cyanide-CN^-	Not strongly retained by the soil
	Selenium-$HeSO_4^-$ -SeO_3^{2-}	Not strongly retained by the soil at normal pH levels
II. MODERATELY MOBILE	IRON ZINC LEAD COPPER	Absorbed more strongly by the soil in order of Cu^{2+}> Pb^{2+}>Zn^{2+}>Fe^{2+}. Stability for complexes of any given type should be increasing in the order of Fe>Zn>Pb>Cu
	BERYLLIUM - Be^{++}	Chemistry in soils should be similar to aluminum
III. SLOWLY MOBILE	ARSENIC - $H_2AsO_4^-$	Mobility similar to phosphorus
	CADMIUM - Cd^{2+}	Forms insoluble precipitates under oxidizing conditions
	CHROMIUM - Cr^{3+} OR Cr^{6+}	Forms insoluble precipitates under oxidizing conditions
	MERCURY - Hg^{2+}	Retained in the surface layer of most aerated soils.
	ASBESTOS - <2μ	Particles <2μ retained in surface layer of clay soils.
IV. IMMOBILE	ASBESTOS ->2μ	Particles >2μ are retained on the surface.

soluble compounds in soils may be re-released by man's activities or rainfall. The second important condition to recognize is that the soil contaminant relationship is dynmaic and time dependent. For example, ions are not permanently attached to cation exchange postions on clay minerals. As the concentration of the ion in solution decreases or the concentration of a competing ion increases, ions will be exchanged and free to migrate. Additionally, low concentrations of contaminants may accumulate in soils only to be released in significant quantities at a later time. Thus, as the applied wastewater or soil environment changes, attenuation becomes time dependent.

There is no definite division between those factors which decelerate or accelerate migration of trace contaminants. This influence depends on the intensity which all factors are expressed in the soil. A factor which may attenuate a constiuent in one soil may have no effect or an opposite effect in another type of soil. Additionally, a factor which may inhibit the movement of one element may have no influence on the movement of another element.

The most important factors which relate to contaminant attenuation include the following:

1. pH - Except for a few trace constituents attenuation may be expected to be greater in soils of neutral to alkaline pH values.
2. Oxidation - Reduction - Reducing (anoxic) conditions favor accelerated migration of heavy metals as compared with oxidative (oxic) conditions.
3. Particle Size Distribution - Because of the greater surface area per unit weight available for physical and chemical reactions, finer soil materials (silts, clays, and colloids) have greater attenuatingcharacteristics than coarser materials (sand and gravels).
4. Pore Size Distribution - Soils with small diameter pores will restrict the migration of trace contaminants by slowing the rate of movement of water through soil which, in turn, allows more time for the contaminants to react physically, chemically, or biologically.
5. Organic Material - Organic material in soils generally has a decelerating influence on trace contaminant mobility. However, complexes formed by organics are susceptible to microbial attact which can release the element to the soil environment or result in mcrobial incorporation.
6. Concentrations of Ions and Salts - Concentrations of ions or salts may either increase or decrease attenuation depending on the types and concentrations of ions present in the soil solution, the concentration of the trace contaminant in the soil solution, and pH. Each case must be analyzed separately.

7. Climate - Climate expressed as rainfall and temperature influences attenuation. In general, wetting and drying in soil which are controlled by climate, decreases the mobility of trace contaminants, particularly if they occur during short time intervals.

CHAPTER V
HEALTH EFFECTS RESEARCH

INTRODUCTION

The record drought years of 1976 and 1977 created an impetus in California to analyze the potential for expanded reuse of treated wastewater. A Policy and Action Plan[84] for Water Reclamation was adopted by the California State Water Resources Control Board in January, 1977. The Plan required that regional studies be organized to identify potential reuse projects and placed increased funding emphasis on wastewater reclamation. A regional study within the Orange and Los Angeles County area has been formed to define the reuse potential in Southern California, to analyze the technical and institutional barriers to expanded reuse, and to evaluate the necessary conditions for expanded reuse.

Groundwater recharge with reclaimed water is an attractive planned reuse activity, but expansion is restricted due to unknown health effects related to water reuse. Each day, approximately 189,500 cu. m/hr. (1.2 billion gallons) of wastewater are generated in the coastal Los Angeles/Orange County Metropolitan area. At least half of this wastewater is suitable for reuse because of mineral content or proximity to reuse sites. At this time, only six percent, or approximately 6,317 cu. m/hr. (40 MGD), of the reclaimable flow is being deliberately reused. The majority of reuse, approximately 5,527 cu. m/hr. (35 MGD), occurs by percolation of reclaimed water into the Montebello Forebay area of Los Angeles County. Percolation of treated wastewater from Riverside and San Bernadina Counties occurs along the Santa Ana River in Orange County.

As part of the Orange and Los Angeles Counties regional study, the County Sanitation Districts of Los Angeles County have proposed a study[85] of health effects related to water reuse via groundwater recharge. The proposed Health Effects Study has attempted to implement research recommendations made by the Consulting Panel on Health Aspects of Wastewater Reclamation for Groundwater Recharge.[86] This panel was convened by the California State Water Resources Control Board in 1976 to discuss the health aspects of water reuse and consisted of experts in public health, engineering, and representatives of the public. The research areas singled out by the panel are as follows: (1) Characterization of contaminants in reclaimed wastewater applied to land and subsequently affected groundwaters, (2) Study of treatment processes for the removal of potentially harmful organics, (3) Study of disinfection

techniques and viruses, (4) Study of the behavior of pollutants in soils, (5) Assessment of toxicologic risk, (6) Epidemiologic studies of exposed populations, and (7) Research and application of monitoring techniques and strategy.

The overall objective of the Health Effects Study is to produce data upon which a rational decision can be made regarding expansion or curtailment of water reuse by groundwater recharge in Southern California. At this time little information on health effects associated with water reuse is available for making operational or regulatory decisions. The purpose of this study is to produce data that will allow control authorities to make decisions regarding continuation or expansion of existing projects and, in addition, to provide information upon which other recharge projects could be established.

Four interrelated areas of research have been identified to address the problems of health effects of groundwater recharge with reclaimed water. The four research areas include:

1. Determining the influence of reclaimed water on potable groundwater supplies
2. Water quality characterization
3. Toxicology
4. Epidemiology

It should be noted that these four areas are so closely intertwined that it is difficult to clearly separate some of the functions into four areas.

INFLUENCES OF RECLAIMED WATER ON POTABLE SUPPLIES

A key element in evaluating the health aspects of groundwater recharge with reclaimed water is quantifying the effect of reclaimed water on potable water supplies. Following spreading, three factors govern the effect of reclaimed water on groundwater quality: a) Movement of the recharged water away from the site of percolation, b) Changes in water quality during percolation through soil, and c) Mixing of reclaimed water with high quality, natural groundwater.

The main thrust of work to be conducted for this section of the Health Effects Study will be to quantify the percentage of potable water in Montebello Forebay wells that was once reclaimed water. This provides essential exposure data for epidemiologic studies. The most promising approach to this problem involves use of a previously developed water movement model for the Montebello Forebay based on sulfate in Colorado River water acting as a tracer.

Assessment of population exposure to percolated reclaimed water is an important input to the epidemiology task; however, many of the reclaimed water agents of suspected health significance may be mitigated during the percolation process. Because little information is available on changes in heavy metals, trace organics, and viruses during percolation, test basin and soil column studies will be performed. Additional tasks will define water delivery practices in the Montebello Forebay to estimate the yearly proportion of reclaimed water in water delivered to domestic consumers and will summarize existing water quality data from these wells to provide historical data on exposure of the population to various water constituents.

WATER QUALITY CHARACTERIZATION

The objective of this task is to produce detailed water quality characterizations of well water, reclaimed water, and other water used for recharge (i.e., storm water, Colorado River water, Owens Valley water) in order to develop a water quality data base to be used in assessing health risk. These data will supply significant information to epidemiologic studies in terms of exposure of populations to health significant compounds.

The list of constituents to be analyzed includes inorganic, organic, and biologic agents. The list was formulated based on regulations for potable water and upon current literature on water related health effects. Inorganic constituent sampling will consist of traditionally monitored minerals nutrients, and heavy metals. Sampling for organic material will involve concentration of the organic fraction from water samples onto macroreticular resin, followed by elution and then analysis using gas chromatography/mass spectrometry/computer methods (GC/MS/COMP). A list of approximately 40 trace organic compounds has been developed which represent several classes of man-made potentially hazardous organics which seem suitable for tracing possible impact of organic mattter in reclaimed water on groundwater supplies. In addition to analysis for specific organic compounds, gross organic content will be determined by Total Organic Carbon (TOC) analysis. Microorganism sampling will include viruses and bacteria. Special efforts have been made to develop a portable virus concentrator capable of sampling up to 3.8 cu. m (1,000 gallons) of tap water and 1.9 cu. m (500 gallons) of reclaimed water within a two hour period.

The water quality characterization program has been designed to be flexible. Adjustments in sampling frequency or location will be made as dictated by the following criteria: a) If constituent concentrations approaching health significant levels are detected, sampling for these constituents would be increased in frequency;

b) If concentration gradients in time or position are detected, sampling would be increased to better define the gradient and its cause; c) If epidemiologic results indicate diseases related to water constituents, then the frequency of sampling for these constituents would be increased, and d) If constituents are infrequently detected or detected at a very low concentrations, the sampling frequency for these constituents would be decreased. Adjustments will be made as data are collected and reviewed.

Toxicology

The impact of the trace organic content of reclaimed and other recharge waters on groundwater quality can be assessed in three ways. First, potable supply wells, reclaimed and other recharge water can be surveyed for the presence of specific organics and classes of health significant compounds. Second, short-term toxicity tests can be used to isolate classes of compounds or individual compounds which may be health significant. Third, the relative toxicity of wellwater versus reclaimed waters versus "pristine" water sources can be assessed using short-term toxicity tests. Items two and three form the basis for toxicologic experiments to be conducted during the Health Effects Study.

Both the Ames test and the Mammalian Cell Transformation test have been selcted as the short-term toxicity tests to be used during the study. The Ames test was chosen because it has been demonstrated to be the single best available tool for assessing the relative mutagenic strength of organics in water. The Mammalian Cell Transformation test will be used to verify Ames test results. These short-term toxicity tests are more cost and time effective than conventional animal toxicity tests.

In general, the toxicology screening involves the following steps:

1. The organic fraction of a sample will be concentrated onto resin, eluted, and applied to Ames and mammalian cell cultures.
2. If a mutagenic response is elicited, the organic concentrate will be fractionated using high pressure liquid chromatography and the fractions then separately applied to the cell cultures.
3. Any fraction(s) yielding mutagenic results will be further fractionated until the fraction or set of fractions yielding mutagenic response is found.
4. These positive fractions will then be characterized using GC/MS/COMP methods.

Interaction of the toxicology experiments with the water quality characterization task is critical. The list of target trace organic compounds will be modified based on isolation of mutagenic materials.

Epidemiology

The objective of conducting epidemiologic studies in the Montebello Forebay is to determine whether a population which has been exposed to reclaimed water for approximately 15 years exhibits unusual health characteristics relative to an unexposd population. Results from these studies would be used to aid in making regulatory and operational decisions regarding existing or future recharge activities. During these studies, major emphasis will be placed on the use of existing and available health information such as mortality records, infant and fetal deaths, cancer registry data, and hospital discharge records. The need for gathering new data through surveys, examinations, case-comparison group studies, and studies of body burdens of known toxins through analysis of surgical or autopsy specimens will also be investigated. Additionally, a data acquisition framework for a long term health surveillance program will be developed.

Overview of Health Effects Study

Even though the proposed Health Effects Study is the most comprehensive, costly and challenging project of its type attempted to date, there are some limiting factors in being able to demonstrate a causal relationship between constituents of reclaimed water origin and human health. It is probable that if such health effects have occurred, they are subtle and long term because by this time acute health problems of great consequence would be evident. The greatest problem is that not enough is known about those diseases which have a long lag period between exposure and clinical illness and about those diseases which are not serious enough to make people seek medical attention. These problems are compounded by the difficulty in being able to separate out all the other environmental factors such as air pollution, occupation, socio-economic status, and diet, all of which have some effect on human health.

Most of the research proposed by the Health Effects Study is developmental, namely, the short-term toxicity tests, the organic concentration techniques, the virus concentration procedures, and the groundwater modeling. Nevertheless, these research techniques represent the state-of-the-art in each respective field and therefore represent the best attempt to evaluate what impact reclaimed water used for

groundwater recharge has on human health. The Montebello Forebay Recharge project is unique because it is the oldest and best engineered program of its type and therefore represents the best opportunity to study the effects of reclaimed water. It is hoped that results from this study will conclusively demonstrate that the current practice of recharge is safe or that additional treatment of wastewater used for recharge (i.e., carbon treatment) will provide an adequate health safety factor. However, due to the developmental nature of much of the study, it is likely that results will be inconclusive. Under these circumstances, the Health Effects Study will at least provide a solid background for future studies.

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