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Water Factory 21: Reclaimed Water, Volatile Organics, Virus, and Treatment Performance

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WATER FACTORY 21: RECLAIMED WATER, VOLATILE ORGANICS, VIRUS, AND TREATMENT PERFORMANCE

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report describes the performance of Water Factory 21, a 0.66 m^3/s advanced wastewater treatment plant designed to treat municipal wastewater so that it can be used to recharge a groundwater system. Through this project groundwater supplies are being replenished, saltwater-endangered aquifers are being protected, and water is being reclaimed for future use.

Francis T. Mayo, Director
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ABSTRACT

Water Factory 21 is a 0.66 m^3/s (15 mgd) advanced wastewater treatment plant designed to improve the quality of biologically treated municipal wastewater so that it can be used to provide the injection water for a seawater barrier system. Processes included are lime treatment, ammonia stripping, breakpoint chlorination, filtration, activated-carbon adsorption, reverse osmosis, and final chlorination. Because of interest in the use of reclaimed water to augment the domestic water supply, this study was initiated to evaluate the effluent quality and efficiency of treatment for inorganic, organic, and biological contaminants. This report covers the first one and one-half years of plant operation.

Chemical clarification with lime at pH greater than 11.3 removed 60 percent of the influent COD, 99 percent of the phosphates, and greater than 50 percent of the barium, cadmium, chromium, copper, iron, lead, manganese, silver, and zinc. Removal of mercury, selenium, and arsenic were minimal. Ammonia stripping with two towers in series removed an average 82 percent of the influent ammonia, and was highly effective in reducing the concentrations of a wide range of low molecular weight and non-polar organics such as one- and two-carbon halogenated organics, chlorinated benzenes, and hydrocarbons. These in general were not removed efficiently by other processes.

Activated-carbon adsorption was effective not only for general COD removal, but also for the removal of a wide range of specific organic compounds such as chlorinated benzenes and aromatic hydrocarbons, many of which are of toxicological significance. This process in combination with the others resulted in an overall COD removal of 90 percent, producing an effluent with a mean COD of 15 mg/l.

Breakpoint chlorination (9:1 weight ratio of Cl_2 to NH_3-N) is effective in reducing ammonia nitrogen to 1 mg/l; however, it results in the production of relatively high concentrations of chlorinated organics, particularly the haloforms, if carried out before carbon adsorption, and depresses pH if practiced following carbon adsorption. The latter point of application is probably best for breakpoint chlorination as it minimizes effluent organics and pH control is technically feasible. Pilot studies with reverse osmosis indicated removals of 95 percent for general inorganics and 93 percent for COD. However, haloforms, chlorinated benzenes, and other low molecular weight organics were not removed.

Most influent samples taken were positive for virus and the presence of over 25 different viruses was verified. However, of 77 effluent samples analyzed, only one was positive for virus, and contained one plaque of Polio Type 2. This single incidence appears to have been associated with an occasional problem of activated-carbon fines in the effluent.

This report is a progress report submitted in partial fulfillment of Research Grant No. EPA-S-803873 by the Orange County Water District under sponsorship of the U.S. Environmental Protection Agency. This report covers the period of January 1, 1976, to July 31, 1977, and was completed January 1, 1978.

CONTENTS

Foreword iii
Abstract iv
Figures viii
Tables ix
Acknowledgments x

1. Introduction 1

2. Conclusions 2

3. Recommendations 4

4. Water Factory 21 5

General Description 5
Process Description 8

5. Sampling and Analytical Procedures 10

Sampling 10
General Inorganics and Heavy Metals 10
Organics 10
Viruses 15

6. Results 18

Characteristics of Influent Water 18
Treatment Plant Performance 19
General Inorganics and Heavy Metals 19
Organics 28
Virus 48

7. Discussion 55

Background 55
General Inorganics 55
Heavy Metals 56
Organics 57
Virus 60
Plant Reliability 60

References 64

Appendices

A. Major Design Criteria, OCWD 0.66 m^3/s Advanced Wastewater Treatment Plant 66
B. Summary Analyses for General Constituents, Trace Inorganics, Radioactivity and Pesticides 71

FIGURES

Number		Page
1	Processes and sampling locations at Water Factory 21	6
2	Variation in flow rate at Water Factory 21 during the two periods of this study	7
3	Haloform concentrations after October 1976 when breakpoint chlorination was initiated; upper: filtration effluent (Q6); lower: plant effluent (Q9)	33
4	Chromatograms of CLS extracts with simultaneous flame ionization and electron capture detection. A: Q2 taken 6/12-13/1977; B: Q9 taken 6/12-13/1977 (numbers refer to Table 25)	40
5	ECD-chromatogram (setting $337/2^4$) of Q1 extract, internal standard 2.34 μg/l. 1: diethylphthalate; 4: dioctylphthalate; 3: retention time as lindane; 2: unknown . . .	41
6A	Pesticide standard (ECD setting $337/2^5$). 1: BHC isomers 260 pg; 2: lindane 260 pg; 3: heptachlor 160 pg; 5: aldrin 160 pg; 7: dieldrin 160 pg; 8: DDE 194 pg; 9: endrin 170 pg; 10: TDE 500 pg; 11: DDT 240 pg; i.s.: internal standard, 1170 pg; 4, 6: impurities	42
6B	PCB arochlor 1242 standard, 2.66 ng; internal standard, 0.464 ng. Detector $337/2^4$	42
7	Typical total ion chromatogram (computer reconstructed) of a CLS extract from Q2. Lower graph is independently normalized. Numbers refer to substances in Table 25 . . .	47
8	Probability plot of virus assay levels	50
9	Seasonal variation in natural viruses in Water Factory 21 influent	52
A-1	Reverse osmosis plant flow diagram	70

TABLES

Number		Page
1	Water Factory Sampling Schedule, January 1976 through June 1976	11
2	Water Factory Sampling Schedule, October 1976 through June 30, 1977	12
3	General Analytical Procedures	13
4	Summary of Virus Concentration Methods	16
5	Mean Characteristics of Secondary Effluent Treated at Water Factory 21	18
6	Mean Characteristics of Treated Water and Regulatory Requirements, January 1976 through June 1976	20
7	Changes in General Parameters by Chemical Clarification, January through June 1976 (Monthly Mean Values)	21
8	Chemical Clarification. Heavy Metals Removal, January through June 1976	21
9	Ammonia Removal by Stripping, January through June 1976	22
10	Heavy Metals Removal by Carbon Adsorption, January through June 1976	23
11	Mean Characteristics of Treated Water and Regulatory Requirements, October 1976 through June 1977	24
12	Changes in General Parameters by Chemical Clarification, October 1976 through June 1977 (Monthly Mean Values)	26
13	Effect of Chemical Treatment on Heavy Metals, October 1976 through June 1977	27
14	Effectiveness of Ammonia Stripping Process, October 1976 through June 1977	27
15	Filter Performance for Turbidity Reduction, October 1976 through June 1977	28

TABLES (continued)

Number		Page
16	Heavy Metals Removal by Activated Carbon, October 1976 through June 1977	29
17	COD Removal by Water Factory 21	30
18	TOC Removal by Water Factory 21	30
19	Haloform Concentrations Prior to Breakpoint Chlorination, January 1976 through June 1976	31
20	Haloform Concentrations during Second Period, October 1976 through June 1977	32
21	Concentrations of Highly Volatile Constituents Other than Haloforms (μg/l), October 1976 through June 1977	35
22	Closed-Loop Stripping Analyses for Selected Organics, October 1976 through June 1977	36
23	Efficiency of Ammonia Stripping and Carbon Adsorption for Removal of Selected Trace Organics Based upon Paired Samples	38
24	PCBs and Phthalate Concentrations at Various Sampling Points, April 1977 through June 1977	43
25	Compounds in WF-21 Samples Analyzed by CLSA and Their TIC Peak Heights Relative to the Internal Standard, 1-Cl-C8	45
26	Substances Tentatively Identified in Hexane Extracts	46
27	Virus Concentration in Influent (Q1)	49
28	Viruses Identified in Water Factory 21 Influent (Q1)	51
29	Virus Concentration in Chemical Clarifier Effluent (Q2), November 1975 through June 1976	53
30	Variability of Inorganic Constituents in Water Factory 21 Effluent	61
31	Variability of Organic Constituents in Water Factory 21 Effluent	62

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SECTION 1

INTRODUCTION

The Orange County Water District (OCWD) has constructed Water Factory 21 and a series of injection wells near the Pacific Coast in order to reduce seawater intrusion into the groundwater supply by recharge of reclaimed wastewater (9). Water Factory 21 is a 0.66 m^3/s (15 mgd) advanced wastewater treatment plant which was designed to improve the quality of biologically treated municipal wastewater so that it could be used to provide the injection water needed for the seawater barrier system. Processes included in this facility are lime treatment for suspended solids and heavy metal removal, ammonia stripping and breakpoint chlorination for nitrogen removal, filtration and activated-carbon adsorption for organics and additional suspended solids removal, reverse osmosis for demineralization, and final chlorination for disinfection.

Because of the high quality of water reclaimed by Water Factory 21, interest has increased in the potential of using the reclaimed and injected wastewater to augment the domestic water supply. However, inadequate knowledge of inorganic, organic and biological constituents remaining after advanced wastewater treatment has caused concern among health agencies responsible for protecting the safety of groundwater supplies. Because of such concern, this study was undertaken to: (1) characterize the quality of Water Factory 21 effluent, (2) assess the reliability of treatment plant operation for removal of trace contaminants, and (3) evaluate the effectiveness of the individual processes and processes in combination for removing materials of public health concern.

This report is a summary of the results of inorganic and organic analyses, viral assays, and an evaluation of the performance for the first one and one-half years of operation of Water Factory 21.

SECTION 2

CONCLUSIONS

The results of the first one and one-half years of operation of Water Factory 21 have indicated that the advanced wastewater treatment plant is capable of removing a variety of inorganic, organic, and biological contaminants present in trickling filter treated municipal wastewater.

Chemical clarification with lime at a pH greater than 11.3 resulted in more than 50 percent reduction in the concentration of trace heavy metals such as barium, cadmium, chromium, copper, iron, lead, manganese, silver, and zinc. Mercury, selenium, and arsenic were not removed significantly by this process. The lime process also removed 60 percent of the influent COD, only a portion of which was in suspended form, and 99 percent of the influent phosphates.

Following lime clarification ammonia stripping with two towers operated in series removed an average of 82 percent of the influent ammonia. In earlier studies with the towers operated in parallel, removal was only 56 percent. In addition, ammonia stripping resulted in a high degree of removal of a variety of low molecular weight organic compounds, many of which were not efficiently removed by the other processes in the treatment system, such as activated-carbon adsorption and reverse osmosis. Included in the compounds removed were several chlorinated organics. This indicates that air stripping can be an important complementary process for removal of trace organic materials.

Activated-carbon adsorption was effective not only for general COD removal but also for the removal of a wide range of specific organic compounds, many of which are of toxicological significance. This process in combination with the others resulted in an overall COD removal of 90 percent, producing an effluent with a mean COD of 15 mg/l.

Breakpoint chlorination at a weight ratio of 9 parts chlorine to 1 part ammonia nitrogen was effective for reducing the ammonia nitrogen concentration to 1 mg/l. However, this process also caused the production of high concentrations of chlorinated organics such as the haloforms, created problems in pH control, and adversely affected the effectiveness of activated-carbon adsorption. These problems except pH control are minimized if breakpoint chlorination is practiced after rather than before activated carbon.

Virus were present in most samples of secondary treated wastewater received at Water Factory 21. The advanced wastewater treatment was effective in removal of the virus as only one was found in the 77 samples of final

effluent analyzed. The appearance of this single virus appears to have been related to an operational problem which resulted in the escape of activated-carbon fines in the effluent.

Pilot plant studies indicated that reverse osmosis was effective in removing about 95 percent of the total dissolved solids in advanced treated effluent. It also removed 93 percent of the organics as measured by the COD test, although many trace organics with low molecular weight such as the haloforms were not removed by this process.

The combined advanced wastewater treatment processes employed at Water Factory 21 are capable of meeting the regulatory requirements for injection water as needed for the seawater barrier system. They also show promise for producing a water which may satisfy public health concerns associated with mixing of the injected water with groundwater in an aquifer used for general municipal purposes.

SECTION 3

RECOMMENDATIONS

This study has provided extensive data which can be used to evaluate the effectiveness of advanced wastewater treatment for removing inorganic, organic, and biological materials of public health concern. Problems which require further evaluation are indicated in the following.

The effect of breakpoint chlorination or a free chlorine residual on the capacity of activated carbon, and its potential for release of specific organic materials from activated carbon needs further study.

Breakpoint chlorination results in the formation of high concentrations of several chlorinated organics of public health concern. The low nitrogen requirement which necessitated the use of breakpoint chlorination should be reevaluated. The potential benefits from the required ammonia nitrogen concentrations of 1 mg/l in the injection water are offset by a high cost for breakpoint chlorination, increased concentrations of chlorinated organics, and reduced treatment plant reliability. Also, operational procedures which will minimize chlorinated organic formation need to be developed.

Activated-carbon fines cause problems when present in effluents from advanced wastewater treatment systems including clogging of reverse osmosis membranes and well injection systems, as well as increasing the potential for pathogen passage through the system. Methods for reducing activated-carbon fines need to be explored.

The program for measuring trace organics needs to be modified to allow more frequent and precise quantification for those specific organics which are of health concern. For these materials, the individual treatment processes should be more closely evaluated to determine the effect of operational variables on the efficiency of removal. Because of time and expense, this may necessitate modification of the routine monitoring program.

Many organics are not measureable by currently available analytical techniques. In order to gain some idea of the health risks associated with such materials, some method of biological testing of the organics, such as bacterial mutagenicity should be instigated and the results should be compared with those from alternative supplies.

SECTION 4

WATER FACTORY 21

GENERAL DESCRIPTION

The wastewater reclamation plant was designed to treat 0.66 m^3/s (15 mgd) of municipal trickling filter effluent by the processes indicated in Figure 1. These include lime clarification with sludge recalcining, ammonia stripping, recarbonation, breakpoint chlorination, mixed-media filtration, activated-carbon adsorption and carbon regeneration, post-chlorination, and reverse osmosis (RO) demineralization.

The plant operation covered in this report has been divided into two distinct periods. Plant operation began in January of 1976 and was maintained continuously through June, 1976. During this period the water being treated was not injected, the plant was operated for the specific purpose of gathering data to determine treatment capability. Following a plant shutdown which occurred during July, August and September of 1976 for routine maintenance and modifications, operations were restarted in October and were maintained continuously for the duration of the study period. Figure 2 illustrates the variation in flow rate through the plant during these two periods of operation. Generally, plant flows were maintained in the 0.22 to 0.26 m^3/s range.

Water Factory 21 is composed of dual unit processes which allow the individual units to be operated near design capacity even when the total system was operated at reduced flow. Typical flow rates for the various processes are as follows:

Process	Normal Percent of Design Flow Rate	
	Prior to October 1976	After October 1976
Lime Clarification	100	80
Ammonia Stripping	100	40
Recarbonation	50	80
Filtration	100	100
Carbon Adsorption	100	100
Final Chlorination	20	40

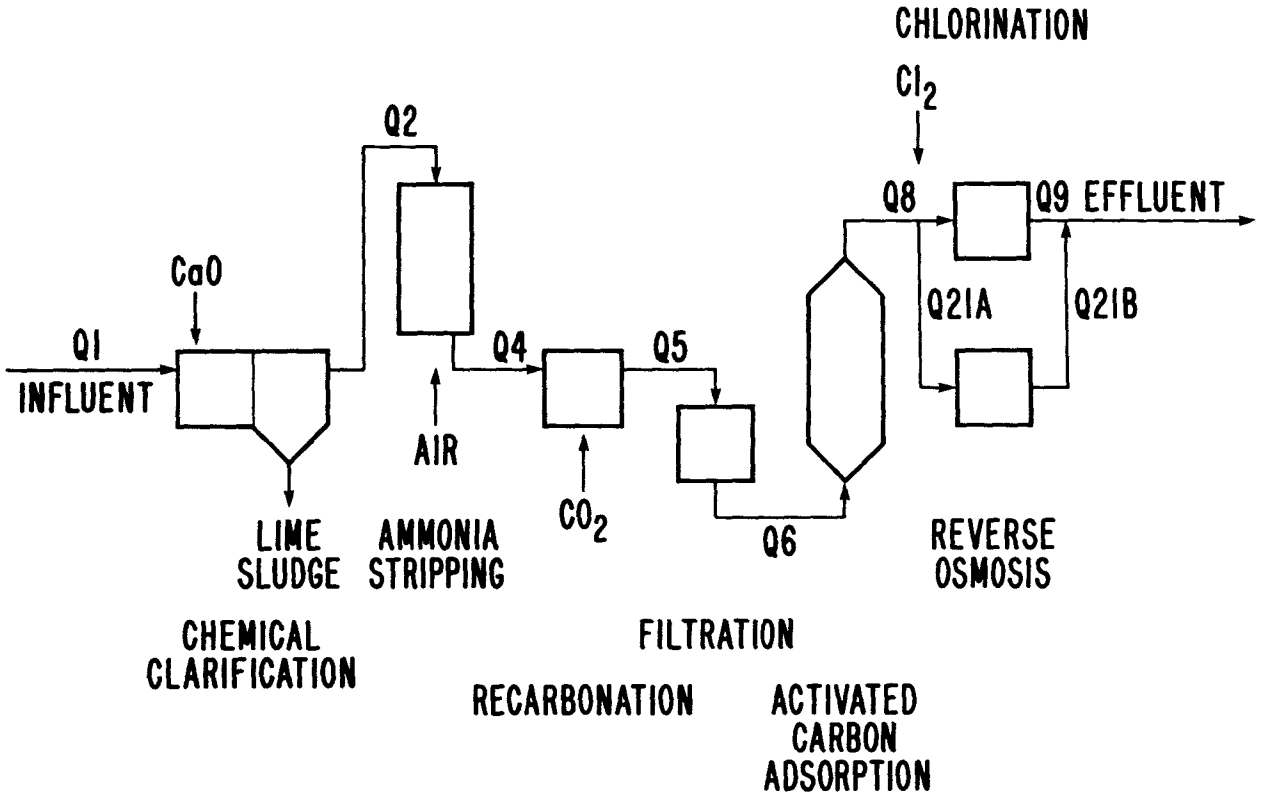


Figure 1. Processes and sampling locations at Water Factory 21.

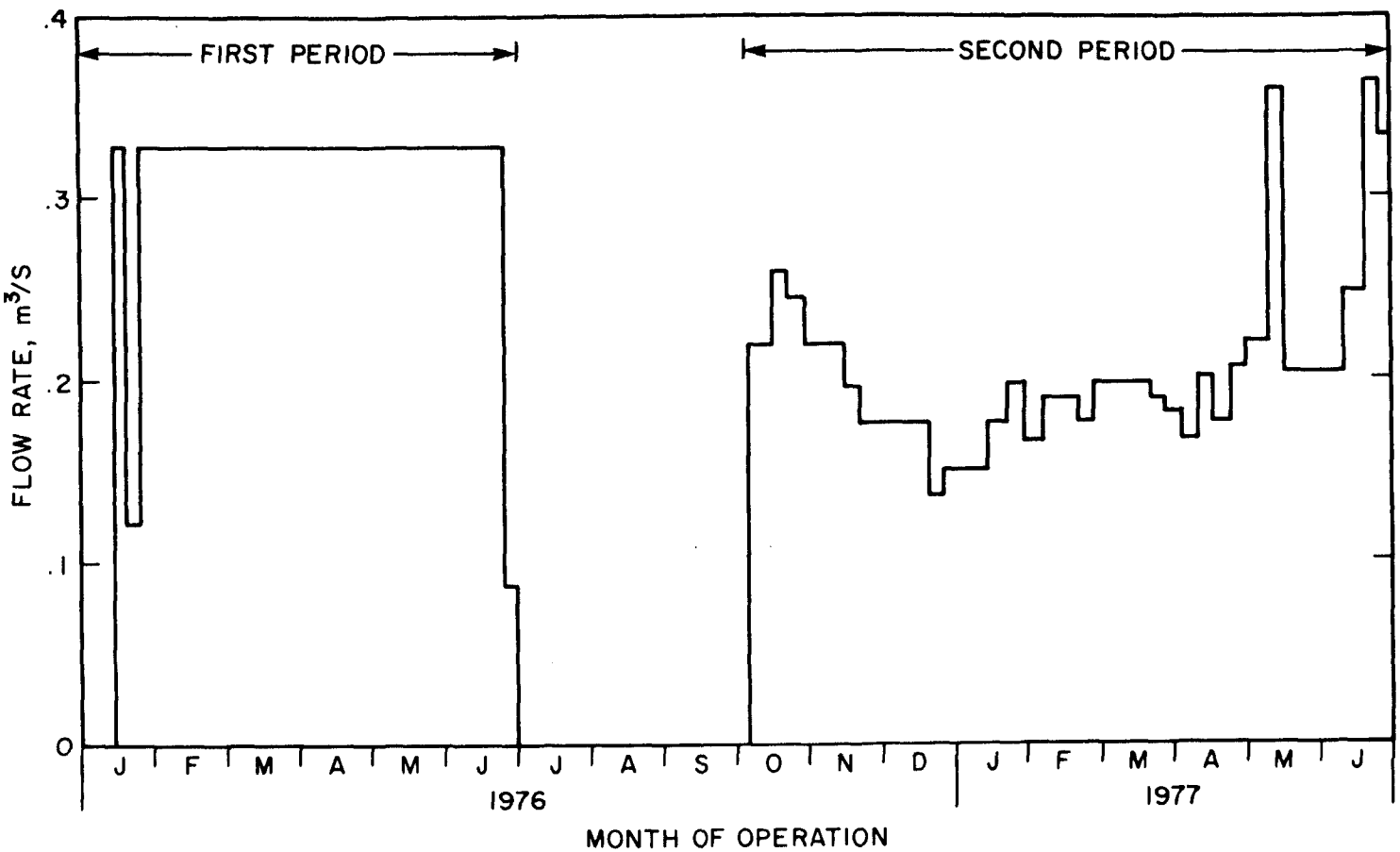


Figure 2. Variation in flow rate at Water Factory 21 during the two periods of this study.

PROCESS DESCRIPTION

The individual processes at Water Factory 21 are illustrated in Figure 1. The major design criteria for each process are listed in detail in Appendix A. A general description of each process is given in the following.

Chemical clarification is accomplished in separate rapid mix flocculation and sedimentation basins. Lime is used as a primary coagulant and is added in slurry form to the rapid mix basin. Lime feed is automatically controlled to achieve an optimum pH of 11.3. A lime dose of 350 to 400 mg/l as calcium oxide is sufficient to maintain this pH. The three-stage flocculation basins are operated with G values of 100, 25, and 20 s^{-1} in the first, second, and third flocculation basins, respectively. Detention time in the flocculation basin is approximately ten minutes in each compartment. An anionic polymer, Dow A 23, is used as a settling aid in the third-stage basin. A polymer dose of 0.1 mg/l is usually added as a settling aid to improve clarification. The water flows from the bottom of the third flocculation basin into a settling basin. The settling basin is also equipped with inclined settling tubes to improve clarification. This process has been found effective for reducing turbidity, phosphates and suspended solids.

Following settling, ammonia stripping is accomplished in a countercurrent induced draft tower at an air to water ratio of 3000 m^3/m^3. The depth of the polypropylene splash bar packing is 7.6 m. Each tower was originally designed to operate independently; however, due to poor initial ammonia removals, the towers were modified to operate in series. Performance prior to modification had indicated ammonia removals of 50-65 percent. Following the tower modification, removals have been increased to 80-85 percent.

Breakpoint chlorination has been practiced since October, 1976, for nitrogen control. It was found that a chlorine to ammonia nitrogen weight ratio of 9 or greater was required to decrease ammonia nitrogen levels to 1 mg/l or less. Three different locations for breakpoint chlorination were evaluated: just after ammonia stripping, while pH is high; between first and second stage recarbonation; and in conjunction with final chlorination. Each location was found to have relative advantages and disadvantages.

In the recarbonation process, carbon dioxide is added to lower pH to approximately 7.5. The recarbonation basin also served as a chlorine contact chamber during some portions of this study to allow detention time for breakpoint chlorination reactions to occur.

Following the recarbonation basin, the effluent passes through open gravity mixed-media filter beds designed for a hydraulic loading rate of 0.2 m^3/m^2-min. The filter media is 0.76 m deep and consists of layers of coarse coal, silica sand, and garnet. It is supported by a layer of silica and garnet gravel with a Leopold underdrain. Alum (11 mg/l) and polymer (0.05 mg/l) are added to improve clarification.

The water is then pumped through packed-bed, upflow pressure contactors filled with Calgon Filtersorb 300 granular activated carbon. There are 17

contactors each operating in parallel and with an empty bed contact time of 30 minutes. The hydraulic loading rate for each column is 0.2 m^3/m^2-min.

Following activated-carbon treatment the effluent flows to the final chlorination basin for post-chlorination, followed by 30 minutes of contact time at the design flow of 0.66 m^3/s.

A 0.22 m^3/s reverse osmosis plant will treat a portion of the reclaimed water following activated-carbon treatment, so that when blended with the remaining portion, an adequate reduction in total dissolved solids can be obtained. During this study the full-scale reverse osmosis plant was under construction, but effluent was available for evaluation from a 0.9 m^3/h pilot plant using spiral-wound membrane elements. The pilot RO plant was operated on either activated-carbon effluent or mixed-media filter effluent. A flow diagram of the full-scale reverse osmosis plant is shown in Appendix A Figure A-1. The plant incorporates feeding sodium hexametaphosphate as a scale precipitation inhibitor, 25 μ cartridge filtration, prechlorination and pH control with sulfuric acid.

SECTION 5

SAMPLING AND ANALYTICAL PROCEDURES

SAMPLING

Analyses for chemical oxygen demand (COD), total organic carbon (TOC), inorganic constituents, and heavy metals were conducted by the Water Factory 21 analytical laboratory. Viral analyses were conducted by James Montgomery Engineers, Pasadena, California. Specific organic constituents were analyzed in the Stanford Water Quality Control Research Laboratory. Grab and composite samples were stored under refrigeration prior to organic analysis. Composite samples were prepared by mixing equal volumes of nine grab samples taken at three-hour intervals over a 24-hour period. Samples analyzed at Stanford were shipped by air in insulated containers, and arrived on the same day. Specific methods used in sample preservation prior to analysis are given under the specific analytical procedures which follow. Sampling locations are designated by numbers preceded by the letter Q in Figure 1.

GENERAL INORGANICS AND HEAVY METALS

The sampling and analytical procedures for general inorganics and heavy metals are described for two distinct periods. First is the period prior to injection and encompasses January, 1976, through June 1976. The other period coincides with the start of injection, from October 1976, through June, 1977. Table 1 indicates the sampling schedule and frequency for all inorganic and heavy metals analyses prior to October, 1976, and Table 2 for the period after October, 1976. The major difference between the two schedules is a decrease in heavy metals sampling frequency from daily composites during the first period to weekly composites for the second period. Also, additional samples from the pilot RO unit were taken during the second period. All analyses were conducted in accordance with Standard Methods (1). Table 3 summarizes the particular procedures from Standard Methods used for each parameter.

ORGANICS

COD and MBAS were determined on composite samples using the standard procedures listed in Table 3. TOC was determined on composite samples using a Beckman 915A TOC analyzer. The characterization of trace organic substances in water was performed for a number of selected substances on a routine basis. A broad and detailed characterization was attempted with some of the samples. In the following, the three basic procedures for the routine analysis of organics are described: VOA (volatile organic analysis), CLSA (closed-loop

TABLE 1. WATER FACTORY 21 SAMPLING SCHEDULE
January 1976 through June 1976

Parameter	Sample Points: Plant Influent Q1	Clarifier Effluent Q2	Ammonia Tower #1 Effluent Q3	Ammonia Tower #2 Effluent Q4	Recarb. Intermed. Settling Q5A	Recarb. Basin Effluent Q5	Filter Effluent Q6	Carbon Effluent Q8	Chlorine Contact Basin Effluent Q9
Temperature[1]		2G	2G	2G					
pH	2G	2G			2G	2G		2G	2G
EC	2G	2G			2G	2G			(2G)
Turbidity	2G	2G					2G		(2G)
NH_3-N		2G	2G	2G				2G	2G
Total & Free Chlorine Res.									2G
TOC							DC	DC[2]	
COD	*DC*	*DC*					*DC*	*DC*[2]	
MBAS							*DC*	*DC*[2]	
Phenol									(*DC*)
Cyanide									(*DC*)
Trace Elements[3]	*DC*	*DC*					*DC*	*DC*	
Alkalinity	*DC*	*DC*			*DG*	*DG*			(*DC*)
Calcium	*DC*	*DC*			*DG*	*DG*			(*DC*)
Mg	*DC*	*DC*							
Total Hardness									(*DC*)
Sodium	*DC*								(*DC*)
Sulfate	*DC*								(*DC*)
Chloride	*DC*								(*DC*)
PO_4-P	*DC*	*DC*							
TKN			*DG*	*DG*					(*DC*)
ORG-N	*DC*	*DC*							(*DC*)
F									(*DC*)
B									(*DC*)
Coliform	*DG*	*DG*					*DG*		(*DG*)
Virus[4]	G	G							G
Color									

DC - Daily composite (1 grab every 4 hr. 500 ml sample)
G - Grab sample
DG - Daily grab sample
2G - One grab every 2 hr. (day shift only)
GM - Once per month grab

LEGEND: Test by operations lab
Test by lab

[1] Air and water in and out.

[2] Each carbon column

[3] Trace elements include: arsenic, chromium (VI), barium, copper, mercury, selenium, cadmium, silver, lead, zinc, Fe, Mn.

[4] Sampling and concentration on-site by B. Martin, analysis by Montgomery Engineers

TABLE 2. WATER FACTORY 21 SAMPLING SCHEDULE
October 1976 through June 30, 1977

Parameter	Sample Points: Plant Influent Q1	Clarifier Effluent Q2	Ammonia Tower #1 Effluent Q3	Ammonia Tower #2 Effluent Q4	Recarb. Intermed. Settling Q5A	Recarb. Basin Effluent Q5	Filter Effluent Q6	Carbon Effluent Q8	Chlorine Contact Basin Effluent Q9	RO Plant Influent Q21A	RO Plant Effluent Q21B
pH	DC	2G			2G				DC		
EC	DC	DC			DC					DG	DG
Turbidity	CA	CA				2G	CA				
NH_3-N	DC	2G	2G	2G		2G			2G		
Total & Free Chlorine Res.						2G			2G		
TOC							DC	WC			
COD	DC	DC					DC	SC		DG	DG
MBAS							WC	WC			
Phenol							WC	WC			
Cyanide									WC		
Trace Elements	WC	WC					WC	WC			
Alkalinity						2G					
Calcium	WC					2G					
Mg	WC	WC									
Total Hardness									WC		
Sodium	WC								WC	DG	DG
Sulfate										DG	DG
Chloride	WC									DG	DG
PO_4-P	DC	DC									
TKN	DC	DC							DC		
ORG-N	DC	DC							DC		
F									WC		
B	WC	WC									
Coliform	WG	WG							WG		
Virus[1]	DG								DG		
Color									WG		

DC - Daily composite (1 grab every 4 hr. 500 ml sample)
G - Grab sample
DG - Daily grab sample
2G - One grab every 2 hr. (day shift only)
GM - Once per month grab
WC - 24 hr composite taken once per week
CA - Control panel value - online instrument average
WG - Grab sample once per week

Trace elements include: arsenic, chromium (VI), barium, copper, mercury, selenium, cadmium, silver, lead, zinc, Fe, Mn.

[1]Sampling and concentration on-site by B. Martin, analysis by Montgomery Engineers.

TABLE 3. GENERAL ANALYTICAL PROCEDURES

Parameter	Method	Page Number from Standard Methods (1), 14th Edition
conductivity @ 25°C	direct, specific conductance meter	71
pH	direct, pH meter	460
total dissolved solids (TDS)	glass fiber filtration, water bath (100°C) and oven drying (180°C)	92
calcium	titration with EDTA	189
magnesium	atomic absorption, flame	148
sodium	atomic absorption, flame	250
potassium	atomic absorption, flame	234
aluminum	atomic absorption, graphite furnace	148
iron	atomic absorption, graphite furnace	148
manganese	atomic absorption, graphite furnace	148
silver	atomic absorption, graphite furnace	148
arsenic	atomic absorption, graphite furnace	148
barium	atomic absorption, graphite furnace	148
cadmium	atomic absorption, graphite furnace	148
chromium	atomic absorption, graphite furnace	148
copper	atomic absorption, graphite furnace	148
lead	atomic absorption, graphite furnace	148
selenium	atomic absorption, graphite furnace	148
zinc	atomic absorption, graphite furnace	148
mercury	flameless atomic absorption	156
alkalinity	as $CaCO_3$, titration with H_2SO_4	278
chloride	titration with $Hg(NO_3)_2$	304
fluoride	specific ion electrode	391
sulfate	turbidimetric	496
phosphate	ascorbic acid	481
nitrate-nitrogen	brucine sulfate	427
ammonia-nitrogen	1. Kjeldahl method	438
	2. phenate method	416
organic-nitrogen	Kjeldahl	437
boron	curcumin	287
methylene blue active substance (MBAS)	methylene blue	600
chemical oxygen demand (COD)	dichromate digestion	550
silica	molybdosilicate	487
hardness, total	EDTA	202
phenol	colorimetric (AAP)	582
dissolved oxygen	iodometric, azide modification	443
dissolved sulfide	methylene blue	503
coliform	membrane filter	928
fecal coliform	membrane filter	937
color	visual comparison	64
cyanide	distillation and colorimetric	361

Table 3 continued

Table 3 continued

Parameter	Method	Page Number from Standard Methods (1),14th Edition
residual chlorine	1. amperometric	322
	2. DPD	332
odor	threshold procedure	*
radioactivity		
gross alpha	internal proportional count.	648
gross beta	internal proportional count.	648

*"Methods for Chemical Analysis of Water and Wastes," page 287, EPA-625-6-74-003 (1974).

stripping analysis), and SEA (solvent extraction analysis). The procedures and findings of the detailed characterization are given in Section 6.

VOA

Organics with high volatility were determined by stripping, concentration on a porous polymer trap, and gas chromatography (Tracor MT-220) using a Hall electrolytic conductivity detector as described by Bellar and Lichtenberg (2), but as modified by Symons et al. (3). One ml of 0.1N sodium thiosulfate was added to 50-ml vials at the time of grab sample collection to reduce residual chlorine. Organics measured include most haloforms, and various other chlorinated one- and two-carbon organics. Concentrations measured were 0.1 μg/l and higher.

CLSA

Closed-loop stripping by the Grob procedure (12) allows analysis for a broad range of volatile organics present in the ng/l range and above, such as solvents, petroleum products, and chlorobenzenes. However, it is not very effective in quantitatively analyzing for haloforms in the μg/l range. Organics in 200 to 500 ml of composite sample were removed by recirculation for two hours of a small volume of air through the sample and over an activated charcoal filter. The filter was extracted with 20 μl of CS_2, approximately 10 μl of which could be recovered. An aliquot of 2 μl was used for high resolution gas chromatographic (GC) analysis (Finnigan 9610), using a glass capillary column (25 m UCON HB, Jaeggi Laboratory for GC, Trogen, Switzerland) and flame ionization detection (FID). The gas chromatograph was equipped with a Grob type injector (Brechbühler AG, Urdorf, Switzerland). In May, an effluent stream splitter was introduced for simultaneous flame ionization and electron capture detection. For mass spectrometric (MS) identification (Finnigan 4000), a 3-μl aliquot was used. Monochlorinated normal alkanes (1-Cl-C8, 1-Cl-C12, 1-Cl-C16) were added to samples for internal standards. The method was calibrated with tetrachlorethylene, chlorobenzenes, and aromatic hydrocarbons, recoveries from 40 to 80 percent were measured.

SEA

Solvent extraction analysis was used for pesticides (including PCB's) and non-volatile organics. Initially, GC with a packed column was used, following procedures outlined by the EPA (5). This permitted detection of pesticides in concentrations of 10 to 100 ng/l and above. From the beginning of October 1976 analyses were conducted with a GC system (same as above) with a glass capillary column (20 m SE 54, Jaeggi Laboratory), and equipped with a wide-range electron capture detector (ECD, Analog Technology Model 140). The specially designed interface consists of a temperature-stabilized heating block for preheating Argon/methane (95/5) pure gas and capillary column inlet. One-liter composite samples were extracted with 25 ml of hexane, dried with sodium sulfate, concentrated to 2 ml, and cleaned on a florisil column (15). Two µl were injected splitless onto the 90°C column, and after solvent elution, the oven temperature was increased at a rate of 4°C/min from 90°C to 230°C. This procedure allowed an improved peak separation. An internal standard, 1,4-bis-(trichloromethyl)-benzene (Aldrich Chemical Co.), was added for quantification of halogenated compounds.

VIRUSES

Virus monitoring was conducted by James M. Montgomery, Consulting Engineers, Inc., Pasadena, California (JMM). The concentration methods used are summarized in Table 4, which includes a brief description of each method, the amount and type of chemical added, the sample volume usually tested, methods of elution, detection limits, the location where the method was used, and the corresponding dates. These methods were developed from a pooling of the information gathered by the San Diego County Health Department; Baylor University; the Los Angeles County Sanitation Districts; the University of California, Berkeley; the University of North Carolina, Chapel Hill; and James M. Montgomery. The various methods were employed in an effort to improve virus recovery and to reduce manpower requirements.

The concentration of enteric viruses in the final concentrated eluate was determined by the plaque assay method employing either a Buffalo Green Monkey kidney continuous cell line (BGM) maintained at JMM or a Primary African Green Monkey kidney (PAG) cell line purchased commercially. The general method consisted of adding Earle's Balanced Salts, Fetal Calf Serum (FCS), and antibiotics to the sample, incubating at 37°C for 90 min, diluting with 0.05M Tris Buffer, inoculating a 30- or 60-ml prescription bottle containing the attached cell line, incubating for 90 min at 37°C (absorption), washing the cells with Phosphate Buffered Saline (PBS), overlaying them with agar, and incubating at 37°C. Plaques were counted on days 2 through 7.

During the course of this study it was found that many of the apparent plaques were not caused by animal viruses, and hence confirmation of plaques was required in order to obtain a time count. For confirmation, cellular debris from all suspected plaques were passed to tubes containing a monolayer of BGM cells and maintenance media, placed on a roller apparatus, and incubated for 7 to 8 days. A small sample was then passed to a new tube of the same kind and these tubes were examined for cytopathic effects during 2 to 7

TABLE 4. SUMMARY OF VIRUS CONCENTRATION METHODS

Sampling Meth.	Description	Chemicals Added	Amount	Sample Volume gal	Elution	Eluant Volume ml	Reconcentration Method	Final Eluant Volume ml	Detection Limit PFU/m^3	Location Sampled	Period Used
A.	Adsorption on K-27 filter	Al(III) Acid	0.0005M pH 3.5	50	glycine pH 11.5	4000	Flocced, centrifuged, eluted up glycine, 3 times, last pellet dissolved and used to plaque.	80	2×10^2	Q1	11/25/75 - 7/28/76
B.	Direct flocculation	Al(III)	0.003M	1	glycine pH 11.5	200	Same as A.	80	10^4	Q1	10/8/76-11/23/76
		Al(III)		2		200	Same as A.		5×10^3	Q1	12/3/76-6/2/77
C.	Direct flocculation	Al(III)		2	Nutrient Broth pH 9.0	500	Flocced, centrifuged, eluted twice with nutrient broth, pH 9.0, flocced at pH 4.3, dissolved at pH 9.0 and plaqued.	80	5×10^3	Q1	6/20/77-7/21/77
D.	Adsorption on K-27 filter	Al(III) Acid	0.0005M pH 3.5	1100	glycine	8000	Same as A.	80	2	Q2	12/1/75-6/9/76
										Q3	6/15/76-7/16/76
										Q4	7/20/76-7/29/76
E.	Adsorption on K-27 and Cox Filter	Al(III) Acid	0.005M pH 3.5	50	glycine pH 11.5	1500	Same as A.	80	2×10^2	Q9	10/8/76-6/2/77
F.	Adsorption on K-27 and Cox Filter	Al(III) Acid	0.0005M pH 3.5	50	Nutrient Broth pH 9.0	1500	Same as C.	80	2×10^2	Q9	6/20/77-7/21/77

days incubation. The positives were then recorded as confirmed plaques. Tubes determined as positive were then frozen at -70°C. All Q9 positives were identified as were a small percentage of the positive Q1 samples by JMM. In addition, identifications were made by the California Department of Public Health.

Virus identifications by JMM were accomplished using the Lim-Belnish-Melnick cross-secting antisera. A microtiter system using a cytopathic effect (CPE) as a positive response was employed in some identifications and a plaque reduction method was employed for others. After an initial titering of the isolated virus, it is appropriately diluted to 100 $TCID_{50}$/0.1 ml mixed with the cross-secting antisera, incubated one hour at room temperature, and inoculated into microtiter dishes or plaquing bottles. Neutralization of the CPE from a plus four to a plus one or an 80% reduction of plaques is the criteria used for identification.

SECTION 6

RESULTS

CHARACTERISTICS OF INFLUENT WATER

Water Factory 21 reclaims treated municipal wastewater obtained from the Orange County Sanitation District. This wastewater has received primary and secondary treatment by trickling filtration. The effluent characteristics as determined from this study are given in Table 5 for the two separate periods of operation of Water Factory 21.

TABLE 5. MEAN CHARACTERISTICS OF SECONDARY EFFLUENT TREATED AT WATER FACTORY 21

Parameter	First Period - Jan. 1976 through June 1976	Second Period - Oct. 1976 through June 1977	Entire Period - Jan. 1976 through June 1977
General, mg/l			
Na	209	218	212
Ca	102	110	104
Mg	25	24	25
Cl	231	258	239
SO_4	284	-	-
Alkalinity ($CaCO_3$)	306	-	-
Hardness ($CaCO_3$)	358	374	363
NH_3-N*	43	37	39
Org-N	1.6	8.3	5.9
PO_4-P	5.2	5.6	5.5
B	-	1.0	-
TDS	-	1020	-
COD	108	142	131
Other			
pH	7.6	7.5	7.5
EC (μS/cm)	1870	1850	1860
Turbidity (TU)	24	42	36

*Values at Q2

TREATMENT PLANT PERFORMANCE

Results of analysis for general inorganic and heavy metals, organics, and viruses are given in the following paragraphs together with an evaluation of the effectiveness of individual and combinations of processes in removing constituents of interest. In general, the results are divided into the two main periods of plant operation, that prior to October 1976 before injection was started, and that period after October 1976 when injection was initiated.

GENERAL INORGANICS AND HEAVY METALS

Detailed summaries of data obtained for general inorganics and heavy metals are tabulated in Appendix B for the period before October 1976, the period after October 1976, and the total period. These tables contain mean values, standard deviations (which assume normal distribution), ranges, and numbers of samples analyzed. The following comparisons are made primarily with mean values.

January 1976 through June 1976

A comparison of the influent, effluent and regulatory requirements for inorganics and heavy metals for this period is given in Table 6. The results illustrate that inorganics and heavy metals are sufficiently removed by the advanced wastewater treatment processes to meet regulatory requirements. The mineral quality including ammonia in general exceeded regulatory limits. Since this was during a testing period of operation and prior to injection, no blending, demineralization, or breakpoint chlorination for ammonia removal was provided.

Chemical Clarification--

Lime is used as the primary coagulant in the chemical clarification process. Lime is slaked and added as a slurry to the rapid mix basin, the water is then flocculated in three separate individual flocculation basins, where an anionic polymer is added to improve clarification. Lime addition is controlled automatically to achieve a treatment pH of 11.3, which corresponds to a dose of approximately 350-400 mg/l as calcium oxide. The flocculated water is settled in the sedimentation basins, which are equipped with settling tubes. Chemical clarification is effective in reducing turbidity, COD and phosphate concentrations. Operation of the chemical clarifier at pH of 11.3 or greater provides good removal efficiency. A monthly and period summary for some of the parameters monitored on a continuous basis is given in Table 7. Chemical clarification was also effective in reducing many of the heavy metals remaining in the secondary effluent. Lime treatment reduced arsenic, barium, cadmium, Cr(VI), copper, iron, lead, manganese, silver, and zinc concentrations. The percentage removal for each metal is summarized in Table 8. Those metals which were not reduced by chemical treatment were mercury and selenium.

Ammonia Stripping--

The effluent from the chemical clarifier had an average pH of 11.4 and was pumped to the top of the ammonia stripping towers. Tower No. 1 was operated until May 1, 1976, at full design capacity of 2.7 m^3/m^2-h of packing

TABLE 6. MEAN CHARACTERISTICS OF TREATED WATER AND REGULATORY REQUIREMENTS
January 1976 through June 1976

Parameter	Units	Plant Infl. Q1	Clarif. Efflu. Q2	Ammonia Tower Effl. Q4	Filter Effl. Q6	Carbon Effl. Q8	Chlorine Contact Basin Effl. Q9	Overall Reduction Percent	Regulatory Requirement for Blended Injection Water
Alk	mg/l	306	328	-	-	-	137	55	-
NH_3-N	mg/l	-	43	19	-	-	17	60	1.0
TKN	mg/l	-	44	-	0.5	-	0.9	96	1.0
B	mg/l	-	-	-	-	-	0.63	-	0.5
Ca	mg/l	102	142	-	-	-	107	-	-
Cl	mg/l	231	-	-	-	-	246	-	120
EC	µS/cm	1870	-	-	-	-	1470	21	900
F	mg/l	-	-	-	-	-	0.64	-	0.8
Mg	mg/l	25	1.0	-	-	-	-	96	-
pH		7.6	11.4	-	-	-	6.7	-	6.5-8.0
PO_4-P	mg/l	5.2	0.09	-	-	-	-	98	-
Na	mg/l	209	-	-	-	-	205	-	110
SO_4	mg/l	284	-	-	-	-	312	-	125
TH	mg/l	358	359	-	-	-	271	-	220
Turb.	TU	24	1.9	-	0.5	-	0.9	96	1.0
CN	µg/l	-	-	-	-	-	-	-	200
COD	mg/k	108	53	-	45	13		88	30*
As	µg/l	2.5	1.1	-	1.1	1.1	-	56	50
Ba	µg/l	81	41	-	32	33	-	59	1000
Cd	µg/l	9	2.9	-	2.5	2.2	-	76	10
Cr	µg/l	192	88	-	84	48	-	75	50
Cu	µg/l	285	93	-	88	27	-	91	1000
Fe	µg/l	179	17	-	40	45	-	75	300
Pb	µg/l	40	23	-	22	26	-	35	50
Mn	µg/l	38	1.5	-	2.3	4.1	-	89	50
Hg	µg/l	1.2	0.9	-	1.2	4.9	-	0	5
Se	µg/l	6.2	6.5	-	6.3	6.4	-	0	10
Ag	µg/l	13	8	-	12	14	-	0	50
Zn	µg/l	300	29	-	670	124	-	59	-
Gross α	pCi/l	-	-	-	-	-	0.3	-	-
Gross β	pCi/l	-	-	-	-	-	28	-	-
E.coli	No./100 ml						< 2.0		< 2.0

*Regulatory requirement for effluent COD pertains to carbon effluent (Q8).

area, corresponding to a 3000 m^3/m^3 air to water ratio at ambient air temperatures. During this period, however, it was observed that significant air short circuiting occurred within the tower. Therefore, it is believed that the actual air to water ratios were only about 700 to 1500 m^3/m^3. From January through April, the average ammonia removal was only 54 percent.

TABLE 7. CHANGES IN GENERAL PARAMETERS BY CHEMICAL CLARIFICATION
January through June 1976 (Monthly Mean Values)

Parameter	Units	Jan	Feb	Mar	Apr	May	June	Avg.
COD								
Inf., Q1	mg/1	-	113	101	96	107	120	107
Eff., Q2	mg/1	-	54	51	47	51	59	52
Reduct.	%	-	52	50	51	52	51	51
PO_4-P								
Inf., Q1	mg/1	5.7	5.9	4.9	5.8	4.3	4.7	5.2
Eff., Q2	mg/1	0.05	0.08	0.17	0.02	0.05	0.16	0.09
Reduct.	%	99	99	97	100	99	97	98
Turbidity								
Inf., Q1	mg/1	21	23	22	17	25	33	24
Eff., Q2	mg/1	1.3	2.3	1.5	1.6	1.7	2.2	1.8
Reduct.	%	94	90	93	91	93	93	92
pH								
Inf., Q1	units	7.6	7.7	7.7	7.7	7.7	7.6	7.7
Eff., Q2	units	11.5	11.4	11.4	11.4	11.3	11.3	11.4
Magnesium								
Inf., Q1	mg/1	26	26	24	24	24	-	25
Eff., Q2	mg/1	2.0	1.1	1.3	0.8	0.7	-	1.2
Reduct.	%	92	96	95	97	97	-	95
Calcium								
Inf., Q1	mg/1	109	94	111	105	106	98	104
Eff., Q2	mg/1	135	141	162	151	129	138	143
Increase	%	24	50	46	44	22	41	38

TABLE 8. CHEMICAL CLARIFICATION. HEAVY METALS REMOVAL
January through June 1976

Parameter	Units	Plant Influent Q1	Clarifier Effluent Q2	Percent Removed
As	µg/1	2.5	1.1	56
Ba	µg/1	81	41	49
Cd	µg/1	9	2.9	68
Cr	µg/1	192	88	54
Cu	µg/1	285	93	67
Fe	µg/1	179	17	91
Pb	µg/1	40	23	43
Mn	µg/1	38	1.5	96
Hg	µg/1	1.2	0.9	25
Se	µg/1	6.2	6.5	no change
Ag	µg/1	13	8	38
Zn	µg/1	300	29	90

Ammonia tower No. 2 was modified to reduce short circuiting and was placed in operation about May 1, 1976. During May and June ammonia removal increased to 63 percent as indicated in Table 9. Ammonia-nitrogen influent concentrations varied from a high of 100 mg/l during May to a low of 27 mg/l during January, with a mean of 43 mg/l. Effluent ammonia-nitrogen concentrations averaged 18 mg/l during the entire six months. Since the water being treated at this time was not injected, no further nitrogen control was practiced prior to October, 1976.

Recarbonation--

Recarbonation was achieved by diffusing carbon dioxide gas into the flow in two stages with allowance for intermediate settling. The first stage reduced pH between 9.5 and 10.3. Following intermediate settling, additional CO_2 was added in the second stage to reduce pH to about 7.0. The cool and compressed stack gases from the lime recalcining furnace provided the source of CO_2. The purpose of two-stage recarbonation is to remove as much calcium as possible and thus reduce TDS. However, during actual operation the calcium carbonate floc which precipitated in the intermediate settling basin was very fine and difficult to settle and so the performance of the recarbonation basin for removing TDS and calcium was poor.

Mixed-Media Filtration--

Following pH adjustment in the recarbonation basin, the wastewater flows into open gravity-flow multimedia filters. Enhancement of turbidity removal is accomplished by the addition of alum (12 mg/l) and Dow A23 anionic polymer (0.05 mg/l). Typical filter runs averaged 20-22 hours at a mean effluent turbidity of 0.5 TU.

Activated-Carbon Adsorption--

The activated-carbon adsorption process follows mixed-media filtration. The plant design includes 17 parallel carbon contactors, 16 can be operated in parallel, with one remaining unit available for carbon storage. Columns No. 3, 4, and 5 were used primarily during this period of operation. Results

TABLE 9. AMMONIA REMOVAL BY STRIPPING
January Through June 1976

Month	Stripping Tower Number	Mean NH_3-N, mg/l		Percent Removal
		Influent Q2	Effluent Q4	
January	1	38	18	53
February	1	49	22	55
March	1	45	21	53
April	1	43	18	58
May	2	44	16	64
June	2	38	14	63
Average		43	18	58

on organic removals by activated carbon are given later. Activated carbon was effective in reducing the concentration of cadmium, chromium, copper, and zinc as listed in Table 10. The data also show that activated-carbon treatment resulted in significant increases in iron and manganese concentrations, although the resulting concentrations were below regulatory limits and resulted in no adverse effect. Data also show that activated-carbon treatment had little effect on arsenic, barium, lead, mercury, selenium, and silver at the low concentrations which were present in the influent.

October 1976 through June 1977

During this period, breakpoint chlorination was initiated to reduce the ammonia concentration to meet requirements for injection. One part of treated water was then blended with two parts of well water from a deep aquifer in order to reduce the mineral content as required by regulations. Injection of blended water was initiated during this period. In addition, pilot studies were started with reverse osmosis treatment of reclaimed wastewater as an alternative method for reducing the mineral content to an acceptable level.

A summary of water quality at different points in the treatment system and a comparison with the regulatory requirements is given in Table 11. Each volume of Water Factory 21 effluent is blended with two volumes of water obtained from deep wells to form blended injection water (Q10). The quality of this blended water is compared in Table 11 with the quality requirements for injection water as issued by the California State Water Quality Control Board --Santa Ana Region. The regulatory limit of 1 mg/l of ammonia is presently under question. In addition, the need for demineralization is apparent and it is anticipated that with the completion of a new 0.22 m^3/s RO plant, the overall reduction in EC required will be met in the future without the need to blend with groundwater.

TABLE 10. HEAVY METALS REMOVAL BY CARBON ADSORPTION
January through June 1976

Parameter	Units	Carbon Col Influent Q6	Carbon Col Effluent Q8	Percent Removal
As	µg/l	1.1	1.1	no change
Ba	µg/l	32	33	no change
Cd	µg/l	2.5	2.2	12
Cr	µg/l	84	48	43
Cu	µg/l	88	27	69
Fe	µg/l	40	45	increase
Pb	µg/l	22	26	no change
Mn	µg/l	2.3	4.1	increase
Hg	µg/l	1.2	4.9	increase
Se	µg/l	6.3	6.4	no change
Ag	µg/l	12	14	no change
Zn	µg/l	670	124	81

TABLE 11. MEAN CHARACTERISTICS OF TREATED WATER AND REGULATORY REQUIREMENTS
October 1976 through June 1977

Parameter	Units	Plant Infl. Q1	Clarif. Effl. Q2	Recarb. Effl. Q5	Filter Effl. Q6	Carbon Effl. Q8	Reduction Q1 to Q8 Percent	Blended Injection Water: Mean Conc. Q10	Blended Injection Water: Regulatory Requirement
Alk	mg/l	-	-	-	116	-	-	121	-
NH_3-N*	mg/l	45	37	-	-	3.3	93	0.9	1.0
NO_3-N	mg/l	-	-	-	-	-	-	1.0	-
Org-N	mg/l	-	-	-	-	-	-	0.7	-
TKN	mg/l	53	41	-	-	4.6	91	1.6	10
B	mg/l	1.0	0.84	-	-	-	-	0.36	0.5
Ca	mg/l	110	0	103	-	-	-	37	-
Cl	mg/l	258	-	-	-	-	-	103	120
E Coli	MPN/ 100 ml	41×10^6	-	-	16	-	-	< 2	< 2
EC	µS/cm	1850	2070	-	-	-	-	780	900
F	mg/l	-	-	-	-	-	-	0.53	0.8
Mg	mg/l	24	0.2	-	-	-	-	0.6	-
pH		7.5	11.5	8.1	-	-	-	7.6	6.5-8.0
PO_4-P	mg/l	5.6	0.07	-	-	-	-	-	-
Na	mg/l	218	-	-	-	-	-	127	110
SO_4	mg/l	-	-	-	-	-	-	83	125
TH	mg/l	-	-	-	-	-	-	99	220
Turb.	TU	42	1.1	1.2	0.34	-	-	0.42	1.0
COD	mg/l	142	52	-	45	18	87	11	30**
TOC	mg/l	-	-	-	14	6.7	-	-	-
MBAS	mg/l	-	-	-	-	-	-	0.05	0.5
As	µg/l	3.3	2.5	-	1.8	2.4	27	2.6	50
Ba	µg/l	81	36	-	31	31	62	14	1000
Cd	µg/l	29	2.4	-	1.8	1.7	94	0.6	10
Cr	µg/l	154	37	-	41	26	83	8.8	50
Cu	µg/l	266	73	-	49	32	88	12	1000
Fe	µg/l	325	40	-	207	66	80	71	300
Pb	µg/l	19	3.6	-	4.7	5.3	72	2.8	50
Mn	µg/l	35	4.4	-	6.2	4.9	86	4.6	50
Hg	µg/l	9	2.6	-	3.6	6.7	26	2.4	5
Se	µg/l	<2.5	<2.5	-	<2.5	<2.5	-	1.8	10
Ag	µg/l	5.5	0.8	-	1.3	1.5	73	0.8	50
Zn	µg/l	380	239	-	412	162	57	160	-
CN	µg/l	-	-	-	-	-	-	<0.01	200
Phenol	µg/l	-	-	-	-	-	-	1.3	-

*Ammonia tower effluent (Q4) = 6.5.

**COD of 30 mg/l applies to carbon effluent (Q8).

Chemical Clarification--

The general performance of the chemical clarifier during the second period is given in Table 12. Chemical clarification continued to be effective for reducing COD, turbidity, phosphate, and magnesium when operated at pH values of greater than 11.3. Chemical clarification also reduced several heavy metals concentrations as indicated by the summary in Table 13. The metals removed include barium, cadmium, chromium, copper, iron, lead, manganese, silver, and zinc.

Ammonia Stripping--

During the operational period prior to October 1976, ammonia removal efficiencies had averaged a maximum of 65 percent. In an attempt to improve the efficiency of this operation, the ammonia towers were modified during the plant shutdown and repiped so that two towers could be operated in series. The effect of this modification on the performance of ammonia stripping is indicated in Table 14. Overall performance was increased to achieve over 80 percent removal of ammonia nitrogen. During the summer months, ammonia nitrogen removals exceeded 90 percent. The first stripping tower reduced ammonia concentrations from an average of 32 mg/l to 11.2 mg/l, for a reduction of 65 percent. The second tower then further reduced this concentration to a mean average of 5.7 mg/l or by an additional 49 percent. Influent ammonia nitrogen concentrations ranged from a high of 85 mg/l in November to a low of 13 mg/l during January.

Recarbonation and Breakpoint Chlorination--

Since two-stage recarbonation had proven to be difficult to operate during the first evaluation period, it was decided to operate the recarbonation basin as a single-stage system. Thus sufficient carbon dioxide was added to reduce the pH from 11.3 to a range between 7.5 and 8.0. Since the residual ammonia remaining after stripping still exceeded the injection requirements, the District also began breakpoint chlorination in October. Large quantities of chlorine were required (9:1 chlorine to ammonia ratio) which reduced the pH. In order to prevent excessive pH decrease it was found desirable to use breakpoint chlorination in conjunction with recarbonation. At this point chlorination reduced the quantity of CO_2 needed for pH reduction and pH control was easier. Addition of chlorine in the recarbonation basin provided sufficient contact time for ammonia oxidation and resulted in a reduction of ammonia nitrogen from an average of 5.7 mg/l to less than 1 mg/l, as well as reducing pH to an average of 8.3.

As discussed in a subsequent section on organics, breakpoint chlorination had an undesirable effect in that it resulted in the production of chlorinated organics, particularly various haloforms, and these were only partially removed by activated-carbon adsorption. For this reason, breakpoint chlorination at the recarbonation basins was discontinued in April 1977 and was attempted with effluent from the activated-carbon contactors. Here, pH control proved difficult and ammonia removal was less efficient.

The requirement for 1 mg/l maximum ammonia nitrogen in the injection water has been questioned by the OCWD and they have appealed to have the limit raised. Some removal of ammonia through ion exchange is expected as the injected water moves through the aquifer. Also, the high costs for

TABLE 12. CHANGES IN GENERAL PARAMETERS BY CHEMICAL CLARIFICATION
October 1976 through June 1977 (Monthly Mean Values)

Parameter	Units	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Avg.
COD											
Inf., Q1	mg/l	142	138	142	127	130	122	130	122	208	142
Eff., Q2	mg/l	56	49	51	46	48	44	46	48	72	52
Reduct.	%	61	64	64	64	63	64	65	61	65	63
PO_4-P											
Inf., Q1	mg/l	5.9	5.3	6.0	6.1	5.9	5.5	5.1	5.5	5.2	5.6
Eff., Q2	mg/l	0.12	0.03	0.10	0.10	0.08	0.05	0.05	0.06	0.05	0.07
Reduct.	%	98	99	98	98	99	99	99	99	99	99
Turbidity											
Inf., Q1	TU	26	33	49	-	41	44	41	35	53	42
Eff., Q2	TU	1.3	1.1	1.3	-	0.9	1.1	1.3	1.2	1.0	1.1
Reduct.	%	95	97	97	-	98	98	97	97	98	97
pH											
Inf., Q1	pH	7.6	7.6	7.5	7.5	7.5	7.6	7.6	7.3	7.4	7.5
Eff., Q2	pH	11.3	11.6	11.6	11.5	11.5	11.5	11.4	11.4	11.6	11.5
Magnesium											
Inf., Q1	mg/l	22	22	22	22	24	24	24	26	27	24
Eff., Q2	mg/l	0.3	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.2	0.2
Reduct.	%	98.6	99.6	99.6	99.6	99.2	99.2	99.2	98.9	99.3	99.2

TABLE 13. EFFECT OF CHEMICAL TREATMENT ON HEAVY METALS
October 1976 through June 1977

Heavy Metal	Clarifier Influent (Q1), μg/l	Clarifier Effluent (Q2), μg/l	Percent Removal
As	3.3	2.5	24
Ba	81	36	56
Cd	29	2.4	92
Cr	154	37	76
Cu	266	73	73
Fe	325	40	88
Pb	19	3.6	81
Mn	35	4.4	87
Hg	9	2.6	71
Se	< 2.5	< 2.5	-
Ag	5.5	0.8	85
Zn	380	239	37

TABLE 14. EFFECTIVENESS OF AMMONIA STRIPPING PROCESS
October 1976 through June 1977

Month	Mean NH_3-N conc., mg/l		Percent Removal
	Influent (Q2)	Effluent (Q4)	
October	34	5.7	83
November	33	4.9	85
December	30	5.4	82
January	24	6.0	75
February	37	5.5	85
March	36	7.6	79
April	41	8.7	79
May	37	7.5	80
June	46	6.5	86
Average	35	6.4	82

breakpoint chlorination, the increased concentrations of chlorinated organics which result, and the potential decrease in activated-carbon adsorption have made the OCWD question whether the benefits of the low ammonia requirements are worth the costs.

Filtration--

Following single-stage recarbonation, the water receives mixed-media filtration prior to activated-carbon adsorption. Again, alum (12 mg/l) and Dow A23 anionic polymer (0.05 mg/l) were added to improve turbidity removal. Typical filter runs were 20-30 hours, with a mean filter run of 26 hours, resulting in an average effluent turbidity of 0.28 TU. Table 15 summarizes

TABLE 15. FILTER PERFORMANCE FOR TURBIDITY REDUCTION
October 1976 through June 1977

Month	Mean Turbidity, TU		Percent Removal
	Influent (Q5)	Effluent (Q6)	
October	6.7	0.72	89
November	1.4	0.31	79
December	1.4	0.24	83
January	0.90	0.18	80
February	1.2	0.24	80
March	1.1	0.34	69
April	1.1	0.3	73
May	1.3	0.5	62
June	1.4	0.4	71
Average	1.8	0.36	80

filter performance for the second period of plant operation. These data demonstrate the consistent performance of the mixed-media filters and their ability to produce water with turbidities below 1 TU as required by State regulations.

Activated-Carbon Adsorption--

During the second period the activated-carbon columns were operated in a packed-bed upflow configuration, with a 30-minute contact time. Overall performance of the granular activated-carbon system was good. Ability to remove organics is summarized later under organics.

Activated-carbon treatment was also effective in reducing several heavy metals as summarized in Table 16. Chromium, copper, iron, lead and zinc were reduced in concentration, and all other metals exhibited essentially no change or a slight increase in concentration. However, effluent concentrations of all heavy metals are sufficiently low to meet U.S. EPA drinking water standards.

Chlorination--

Following activated-carbon treatment, the water flows by gravity to the chlorine contact basin, primarily for post-chlorination to destroy any bacteria or virus. Prior to April 1977 breakpoint chlorination was practiced at the recarbonation basin and post-chlorination required only a small chlorine dose of 2-5 mg/l to insure complete disinfection and removal of bacteria and virus as discussed later under VIRUS.

ORGANICS

COD and TOC

The COD analysis gives a general measurement of the total concentration

TABLE 16. HEAVY METALS REMOVAL BY ACTIVATED CARBON
October 1976 through June 1977

Heavy Metal	Mean Concentration, μg/l		Percent Removal
	Influent (Q6)	Effluent (Q8)	
As	1.8	2.4	increase
Ba	31	31	0
Cd	1.8	1.7	6
Cr	41	26	37
Cu	49	32	35
Fe	207	66	68
Pb	4.7	5.3	increase
Mn	6.2	4.9	21
Hg	3.6	6.7	increase
Se	< 2.5	< 2.5	-
Ag	1.3	1.5	increase
Zn	412	162	61

of organics present in a water in terms of the quantity of oxygen which would be required for oxidation to carbon dioxide, water and ammonia. Results of COD analysis on composite samples taken at various locations at Water Factory 21 during the first and second periods of operation, and over the entire period are summarized in Table 17. Influent COD and plant performance in the removal of COD were similar during the two periods. Influent COD averaged 131 mg/l, and this was reduced by 60 percent to 52 mg/l by chemical treatment. This only partly resulted from removal of suspended organics. The filter effluent contained 45 mg/l COD, and this was reduced 67 percent to 15 mg/l by passage through activated carbon, which was particularly effective for dissolved organics. Water Factory 21 overall removed 90 percent of the influent organics.

TOC is also a general parameter for total organics. The mean influent (Q6) and effluent (Q8) concentrations for activated carbon adsorption listed in Table 18 indicate this process removed approximately 49 percent of the organic carbon passing through it, which is somewhat less than for COD removal. Perhaps activated carbon is more selective in the removal of reduced organics having a higher COD to TOC ratio.

The coefficient of variation (100 standard deviation/mean) for effluent COD was 53 percent and for TOC was 35 percent. These values are quite small and indicate that the treatment systems produce an effluent which is relatively consistent in general organic content.

Volatile Organic Analysis

This analysis was conducted on grab samples obtained periodically since February 1976. Concentrations of the two major haloforms found during the first period before breakpoint chlorination was initiated are indicated in

TABLE 17. COD REMOVAL BY WATER FACTORY 21

Sampling Period and Characteristic	Plant Influent Q1	Chem.Treat. Effluent Q2	Filter Effluent Q6	Act.Carb. Effluent Q8	RO Influent Q21A	RO Effluent Q21B
Jan. through June 1976						
Mean, mg/l	108	53	45	13		
Std. dev.,mg/l	16	7	7	8		
Range, mg/l	78-144	23-69	25-67	2-52		
No. samples	78	80	87	238		
Oct. 1976 through June 1977						
Mean, mg/l	142	52	45	18	24	1.8
Std. dev.,mg/l	37	11	7	7	14	1.5
Range, mg/l	89-272	20-109	31-78	4-51	4-69	< 1-9
No. samples	160	160	160	159	118	119
Total Period, Jan. 1976 through June 1977						
Mean, mg/l	131	52	45	15		
Std. dev.,mg/l	35	10	7	8		
Range, mg/l	78-272	20-109	25-78	2-52		
No. samples	238	240	247	397		

TABLE 18. TOC REMOVAL BY WATER FACTORY 21

Sampling Period and Characteristic	Activated Carbon Influent Q6	Activated Carbon Effluent Q8
January through June 1976		
Mean, mg/l	15	7.3
Std. dev., mg/l	4	2.6
Range, mg/l	8-31	3.5-20
No. samples	82	238
October 1976 through June 1977		
Mean, mg/l	14	6.7
Std. dev., mg/l	3	2.2
Range, mg/l	0.5-28	2.5-14
No. samples	111	117
Total Period, January 1976 through June 1977		
Mean, mg/l	14	7.1
Std. dev., mg/l	3	2.5
Range, mg/l	0.5-31	2.5-20
No. samples	193	355

Table 19. Influent concentrations were low and were decreased even further through ammonia stripping. Lime treatment had essentially no effect on haloform concentration. Chlorination for disinfection only (< 10 mg/l Cl_2) after activated-carbon treatment appears to have increased the concentration of chloroform ($CHCl_3$) and bromodichloromethane ($CHBrCl_2$) slightly.

Following the initiation of breakpoint chlorination in October 1976, concentrations of the various haloforms increased significantly during treatment (Table 20). Breakpoint chlorination generally followed ammonia stripping and maximum concentrations of haloforms were noted in samples taken prior to activated-carbon contacting. Activated-carbon treatment was responsible for a reduction in haloform levels.

These results are better illustrated in Figure 3 showing haloform concentrations for the influent to the carbon contactors and for the final effluent. Haloform formation was variable. For the first month, chlorine dosages varied widely as did haloform concentration while seeking good operational procedures. After this period, however, haloform concentrations still varied considerably. For a few days in December, breakpoint chlorination was practiced in the final chlorine contact chamber rather than after ammonia stripping, and resulted in a decrease in haloforms at point Q6. From April through June chlorination for ammonia removal was practiced at Q8 only, resulting in a significant reduction in haloforms at Q6.

Figure 3 illustrates that the haloform concentration in the final effluent was less variable and lower than in samples taken before activated-carbon treatment. Of particular significance is the decrease in effluent haloform concentration during December which resulted when the flow was diverted to carbon contactors containing fresh activated carbon. Haloforms soon began passing through the contactors, but at significantly reduced concentrations.

TABLE 19. HALOFORM CONCENTRATIONS PRIOR TO BREAKPOINT CHLORINATION
January 1976 through June 1976

Characteristic	Sampling Location			
	Influent Q1	Act.-Carb. Influent Q6	Act.-Carb. Effluent Q8	Final Effluent Q9
$CHCl_3$				
Mean, µg/l	1.5	0.3	0.6	2.1
Standard deviation, µg/l	1.0	0.2	0.4	1.1
Range, µg/l	0.4-5.5	0.1-0.6	0.4-1.0	0.6-5.3
Number of samples	39	4	3	40
$CHBrCl_2$				
Mean, µg/l	0.2	0.0	0.1	0.9
Standard deviation, µg/l	0.3	0.0	0.2	1.0
Range, µg/l	0.0-1.2	0.0	0.0-0.3	0.0-3.9
Number of samples	14	4	3	40

TABLE 20. HALOFORM CONCENTRATIONS DURING SECOND PERIOD
October 1976 through June 1977

	Sample Location							
	Influent Q1	Clarif. Effluent Q2	Ammonia Tower Effluent Q4	Filter Effluent Q6	Activ.-Carbon Effluent Q8	Contact Basin Effluent Q9	RO Influent Q21A	RO Effluent Q21B
$CHCl_3$								
Mean, µg/l	2.5	1.2	0.2	19	9.3	10	5.5	9.6
Std. Dev., µg/l	6.1	0.7	0.1	22	8.5	8.4	8.1	10.5
Range, µg/l	0.2-39	0.4-2.3	0.1-0.5	0.1-97	0.3-36	0.8-40	0.1-21	0.1-35
No. of Samples	40	11	32	36	39	40	6	16
$CHBrCl_2$								
Mean, µg/l	0.24	0.4	0.03	8.8	2.1	3.6	4.6	5.7
Std. Dev., µg/l	0.22	0.6	0.1	70	2.4	3.0	9.1	8.0
Range, µg/l	0-1.1	0-1.4	0-0.2	0-32	Tr-10	0.2-14.0	0-23	Tr-22
No. of Samples	26	9	20	38	39	40	6	16
$CHBr_2Cl$								
Mean, µg/l	2.2	0.1	0.06	4.0	0.6	2.0	1.8	2.2
Std. Dev., µg/l	3.2	0.3	0.10	5.0	0.9	2.3	3.4	4.6
Range, µg/l	0-10.0	0-0.7	0-0.3	0-18.0	0-3.5	0-10	0-7.9	0-17
No. of Samples	20	9	10	33	31	38	6	15
$CHBr_3$								
Mean, µg/l	0.5	0	0	1.8	0.2	0.4	0.1	0.5
Std. Dev., µg/l	1.0	0	0	5.1	0.5	0.6	0.2	1.0
Range, µg/l	0-2.9	0	0	0-23	0-2.3	0-1.8	0-0.4	0-2.8
No. of Samples	14	5	9	23	23	26	3	10

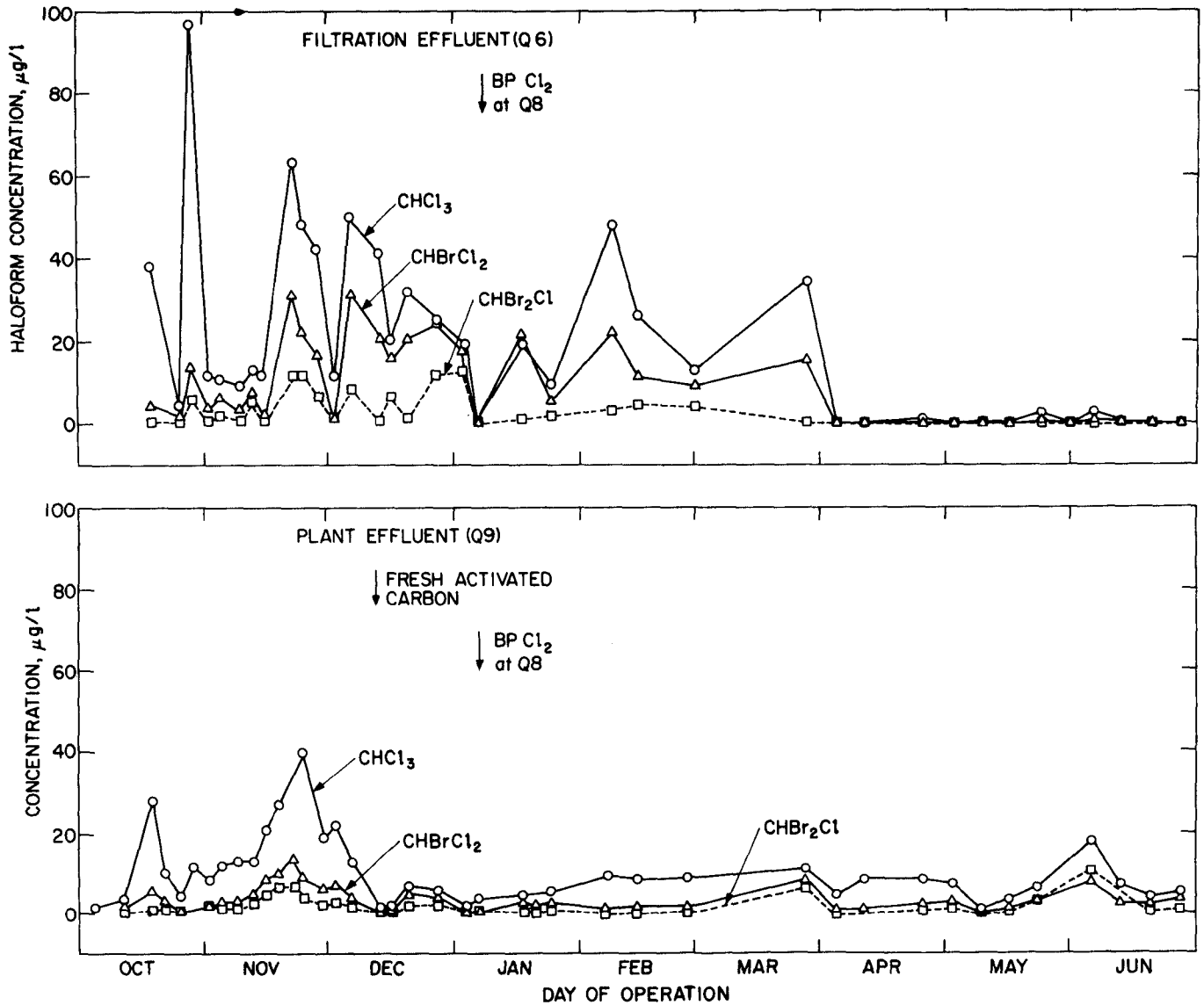


Figure 3. Haloform concentrations at filtration effluent and activated-carbon effluent during second period of operation (October 1976 through June 1977).

During periods when breakpoint chlorination was changed to point Q8, the effluent haloform concentration did not increase above the previous effluent level, suggesting perhaps that the major organic precursors of the haloforms were effectively removed by carbon contacting. However, the required 9:1 ratio of chlorine to ammonia could not be maintained at Q8 due to pH problems and this may have reduced the potential for haloform formation also. Some haloforms were formed as can be seen by a comparison of Q6 and Q9 concentrations after April 1977 (Figure 3).

The VOA analysis allows measurement for chlorinated compounds other than haloforms as listed in Table 21 for the period since October 1976. The chromatographic peaks for 1,1,1-trichloroethane and carbon tetrachloride coincided so that differentiation between these compounds was not possible. However, the presence of 1,1,1-trichloroethane, but not carbon tetrachloride, was verified by GC/MS. Because insufficient samples were analyzed, it is difficult to draw firm conclusions.

The data in Table 21 do illustrate the effectiveness of ammonia stripping in removal of volatile compounds (compare Q4 with Q2 values). No other process at Water Factory 21, including activated-carbon contacting, was generally as effective in the removal of these materials, although each process played a part in the overall removals obtained.

Closed-Loop Stripping Analysis

Samples taken between 1/19/77 and 6/12/77 and from various stages of the treatment were extracted and analyzed. On 9 sampling dates complete sets of samples (Q1, Q2, Q4, Q6, Q8, Q9) were taken, and on 4 sampling dates only the chlorinated effluent and the reverse osmosis plant effluent were sampled. In Q1, the load of organics was often too high and results were not reliable.

Eight of the most prominent substances of health significance (ethylbenzene; chlorobenzene/o-xylene; 1,3-,1,4-, and 1,2-dichlorobenzene; 1,2,4-trichlorobenzene and naphthalene) were selected as indicators for the efficiency of the various treatment processes. Mean values, standard deviation, range, and number of samples are given in Table 22. Average concentrations in Q1 vary from 210 ng/l for 1,2,4-trichlorobenzene to 2000 ng/l for 1,4- and 1,2-dichlorobenzenes. Individual measurements vary more than one hundred percent and the standard deviations in some cases are larger than the mean value. Therefore direct comparisons of the mean values are difficult.

A better picture of the effect of the treatment is obtained by averaging the change of the paired values (values obtained from samples taken at the same time). For the 2 processes which are effective in removing volatile trace organics (ammonia stripping, and activated-carbon treatment) these values are included in Table 23. All selected trace contaminants showed an average removal of more than 60 percent during ammonia stripping with the exception of naphthalene (40 percent) and 1,2,4-trichlorobenzene (50 percent). In a few cases, an apparent increase in the concentration was measured which probably was caused by variations in the influent concentrations. The effectiveness of ammonia stripping in removing this broad range of organic

TABLE 21. CONCENTRATIONS OF HIGHLY VOLATILE CONSTITUENTS OTHER THAN HALOFORMS (μg/l)
October 1976 through June 1977

	Sample Location							
	Influent Q1	Clarif. Effluent Q2	Ammonia Tower Effluent Q4	Filter Effluent Q6	Activ.-Carbon Effluent Q8	Contact Basin Effluent Q9	RO Influent Q21A	RO Effluent Q21B
CH_2Cl_2								
Mean	24	6.2	2.7	3.3	2.6	3.4	0.8	1.4
Std. Dev.	20	7.1	3.1	4.1	8.9	5.6	0.4	1.6
Range	1.7-74	0.9-12	Tr.-12	0.1-18	0.2-12	0.2-33	0.4-1.5	0.2-6.2
No. of Samples	40	11	32	38	38	40	6	16
Cl_3C-CH_3/CCl_4								
Mean	6.3	3.9	0.2	0.08	0.08	0.1	0	0.03
Std. Dev.	4.7	9.1	0.6	0.2	0.2	0.3	0	0.08
Range	0-24	0-28	0-2.5	0-1.2	0-1.0	0-1.2	0-Tr.	0-0.3
No. of Samples	37	11	28	36	34	37	6	16
$Cl_2C = CHCl$								
Mean	1.5	0.7	0.1	0.1	0.03	0.04	Tr.	0.03
Std. Dev.	1.5	0.9	0.3	0.4	0.06	0.1	Tr.	0.06
Range	0-39	0-2.4	0-1.4	0-2.4	0-0.2	0-0.3	0-Tr.	0-0.02
No. of Samples	33	10	27	33	33	34	6	15
$CCl_2 = CCl_2$								
Mean	1.3	0.4	0.03	0.3	0.1	0.1	Tr.	0.04
Std. Dev.	3.0	0.4	0.07	0.6	0.3	0.3	Tr.	0.07
Range	0-15	0-1.0	0-0.2	0-20	0-0.9	0-0.9	0-0.1	0-0.2
No. of Samples	24	9	12	33	31	38	6	14

Tr ≡ less than 0.05

TABLE 22. CLOSED-LOOP STRIPPING ANALYSES FOR SELECTED ORGANICS (ng/l)
October 1976 through June 1977

	Sample Location						
	Influent Q1	Clarif. Effluent Q2	Ammonia Tower Effluent Q4	Filter Effluent Q6	Activ.-Carbon Effluent Q8	Contact Basin Effluent Q9	RO Effluent Q21B
Ethyl benzene							
Mean	1300	310	70	60	30	40	35
Std. Dev.	± 910	260	60	20	20	50	20
Range	230-1900	110-880	10-170	30-100	Tr.-50	Tr.-180	Tr.-60
No. of Samples	3	7	8	8	7	16	6
Chlorobz/O-Xylene							
Mean	900	540	130	100	50	70	90
Std. Dev.	540	490	80	60	50	90	65
Range	200-1300	130-1700	25-240	30-210	Tr.-130	Tr.-370	Tr.-150
No. of Samples	4	8	8	8	5	16	6
1,3-Dichlorobenzene							
Mean	300	130	30	30	5	140	16
Std. Dev.	310	170	30	60	10	180	20
Range	60-840	15-530	0-60	0-160	0-20	0-500	0-40
No. of Samples	5	8	8	8	8	14	5
1,4-Dichlorobenzene							
Mean	2000	800	50	30	20	15	20
Std. Dev.	1790	540	40	10	20	10	30
Range	600-4900	130-1900	Tr.-120	Tr.-40	0-50	Tr.-30	0-60
No. of Samples	5	8	7	7	8	14	5
1,2-Dichlorobenzene							
Mean	2000	1100	340	300	60	100	70
Std. Dev.	1560	1070	320	450	50	80	70
Range	600-4700	40-3200	Tr.-750	10-1200	0-130	Tr.-320	Tr.-200
No. of Samples	5	8	8	8	7	15	6

Table 22 continued

TABLE 22 (continued)

	Sample Location						
	Influent Q1	Clarif. Effluent Q2	Ammonia Tower Effluent Q4	Filter Effluent Q6	Activ.-Carbon Effluent Q8	Contact Basin Effluent Q9	RO Effluent Q21B
1,2,4-Trichlorobenzene							
Mean	210	190	70	20	10	120	60
Std. Dev.	270	170	70	50	10	190	80
Range	Tr.-520	0 -510	0-160	0-110	0-20	0-500	0-120
No. of Samples	4	8	8	8	8	16	6
Naphthalene							
Mean	220	530	180	110	40	30	20
Std. Dev.	130	380	160	100	40	30	10
Range	130-410	90-940	40-500	0-230	0-100	0-80	Tr.-40
No. of Samples	4	7	8	8	8	14	6

Tr ≈ 20 ng/l.

volatiles is not surprising since the enrichment procedure in the analytical test is similar to the ammonia-stripping process.

The effectiveness of the activated-carbon treatment can be seen from the averaged relative removals calculated from the paired values Q6 and Q8 in Table 23. The data indicate an average removal of more than 50 percent for all of the selected compounds. Again in a few cases, the concentration of the effluent was found to be higher than the corresponding concentration of the influent, thus causing a big variation in the averaged removal. For the other processes, an interpretation of removal efficiency is more difficult. Lime clarification (Q1, Q2) reduced concentrations in all cases except for naphthalene (Table 22). The influent water contained particulate as well as soluble organic matter, and this made quantification unreliable; therefore no valid data on removal efficiency can be given for this process at this time.

Recarbonation and filtration (Q4, Q6) do not affect the concentration of the volatile compounds significantly. Also, for the reverse osmosis (RO) process, no significant removal effect could be found. The RO effluent (Q21B) samples showed approximately the same mean concentrations as the chlorination effluent (Q9). The same was found for the haloforms (Table 20). However, RO was quite effective in overall COD removal (Table 17). Thus, many organics are removed by RO, but not the more volatile and low molecular weight substances measured by VOA and CLSA. Removal of volatiles by the overall plant

TABLE 23. EFFICIENCY OF AMMONIA STRIPPING AND CARBON ADSORPTION FOR REMOVAL OF SELECTED TRACE ORGANICS BASED UPON PAIRED SAMPLES

	Process					
	Ammonia Stripping			Carbon Adsorption		
	No. of Paired Samples	Percent Removal		No. of Paired Samples	Percent Removal	
		Mean	Std. Dev.		Mean	Std. Dev.
Ethylbenzene	6	80	10	6	50	25
Chlorobenzene/ o-xylene	7	60	25	5	50	40
1,3-Dichlorobenzene	7	80	20		*	
1,4-Dichlorobenzene	7	90	10	6	60	40
1,2-Dichlorobenzene	7	70	35	6	70	35
1,2,4-Trichlorobenzene	6	50	60		*	
Naphthalene	6	40	70	5	70	30

*Values too close to the detection limit to calculate reliably the efficiency of removal.

(except lime treatment) is illustrated in Figure 4. Illustration A represents a chromatogram of a CLS extract of a Q2 sample, illustration B one of a Q9 sample (samples taken 6/23/77). The column effluent was detected simultaneously with a flame-ionization detector and with an electron capture detector. The major contaminants remaining at Q9 are those with a strong ECD response, which represents halogenated substances produced by chlorination, mainly trihalogenated methanes as indicated previously under VOA analysis.

Solvent Extraction Analysis

Pesticides and PCBs--

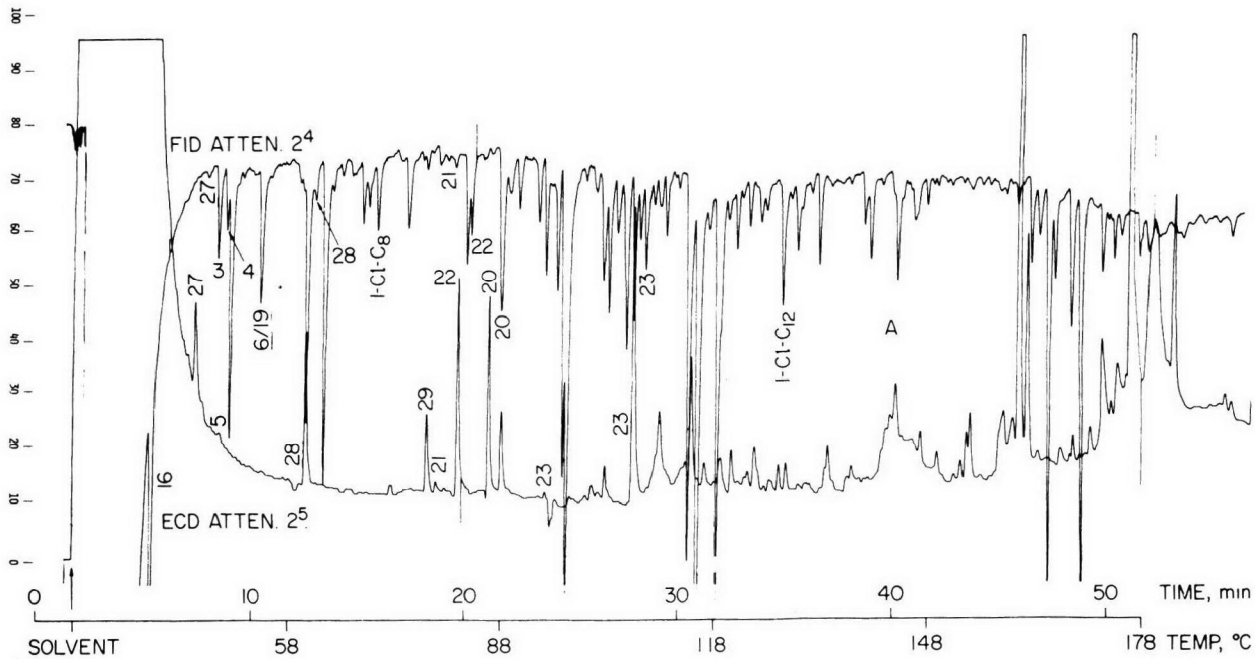
During the initial period of WF21 operation, effluent samples were extracted with hexane and tested for the organochlorine pesticides indicated in the following. The detection limits for BHC, lindane, DDE, dieldrin, endrin, aldrin, and heptachlor were around 10 ng/l, and for DDT and methoxychlor around 100 ng/l. In the 15 samples analyzed between February 12 and June 24, 1976, no pesticides were found above these limits. In the second period from October 1976 through June 1977, samples were analyzed and again, no pesticides could be found in the effluent within the above detection limits (see Appendix Table B-8).

Figure 5 shows the profiles of a typical chromatogram obtained from a hexane extract of an influent sample (Q1). Figures 6A and 6B represent similar analyses of pesticide and PCB standards. None of the peaks matches unambiguously with those of the pesticides except for heptachlor. However, investigations with GC/MS did not confirm this finding since no trace of heptachlor could be found. There is a pattern of peaks which matches a test chromatogram of a PCB 1242 solution. Elemental sulfur was occasionally identified in the influent. Other peaks not belonging to the PCB pattern have not yet been identified.

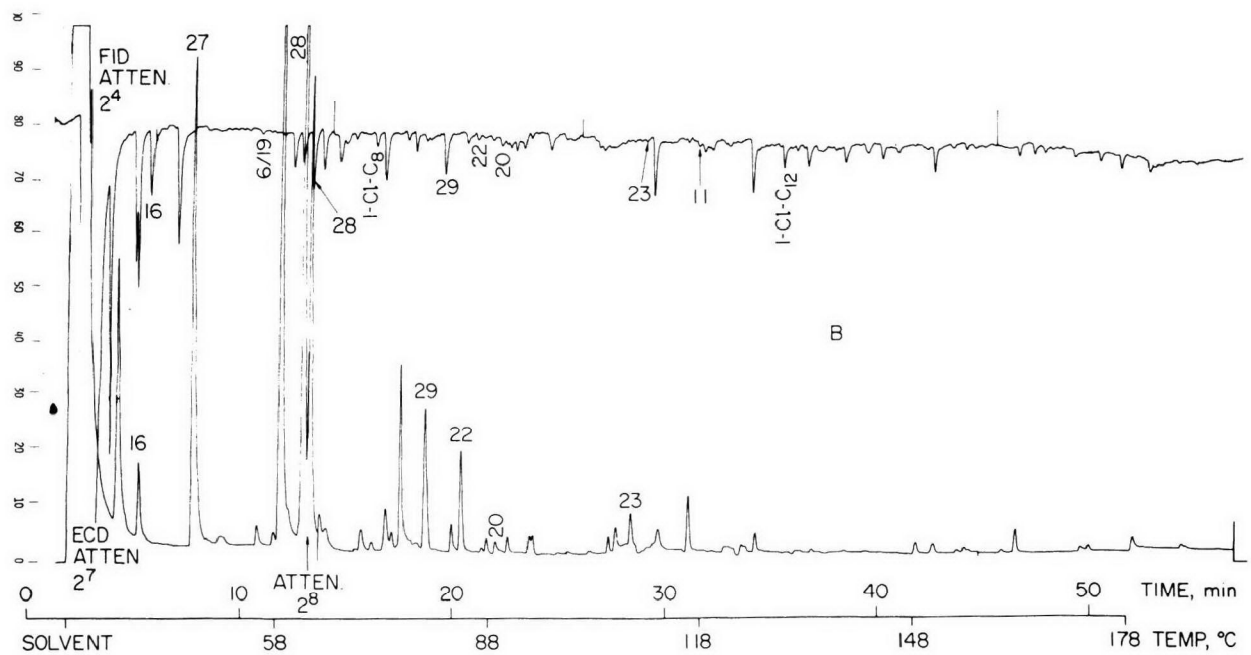
The measured PCB values are given in Table 24. Their concentrations in the influent were consistently high. Values varied from 2.3 to 7.8 μg/l and the average was 4.8 μg/l. Lime clarification reduced the mean concentration to 1.3 μg/l and in all subsequent samples the mean values remained around 0.4 μg/l. This is the detection limit at this time and there may well be interferences which cause this relatively high number. In addition, the pattern changes in some cases and no reliable quantification was possible. Estimated values are given in parentheses.

Phthalates--

Diethylphthalate and dioctylphthalate (bis(2-ethylhexyl)-phthalate) were quantified by means of the same internal standard. The dibutylphthalate peak was obscured by a sulfur peak which prevented quantification. The mean values of the determined quantities of diethylphthalate and dioctylphthalate are also given in Table 24. In the influent (Q1) and the lime-treated effluent (Q2) the concentrations found are consistently in the low microgram per liter level. Values range from approximately 1 to more than 10 μg/l. For diethylphthalate no clear removal effects can be seen since individual measurements seem erratic for unknown reasons. The mean value for dioctylphthalate was lower after lime treatment (by about 60 percent). However during the



A.



B.

Figure 4. Chromatograms of CLS extracts with simultaneous flame ionization and electron capture detection. A: Q2 taken 6/12-13/1977; B: Q9 taken 6/12-13/1977 (numbers refer to Table 25).

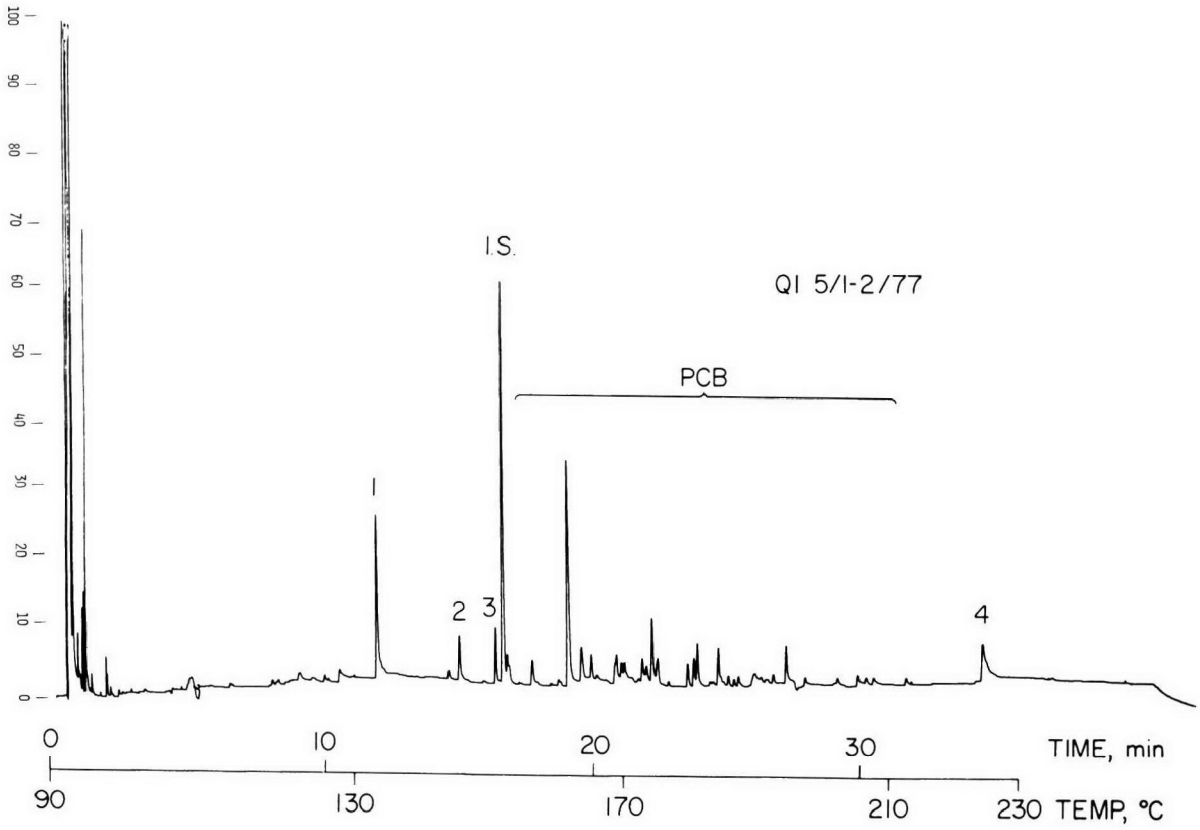


Figure 5. ECD-chromatogram (setting $337/2^4$) of Q1 extract, internal standard 2.34 µg/l. 1: diethylphthalate; 4: dioctylphthalate; 3: retention time as lindane; 2: unknown.

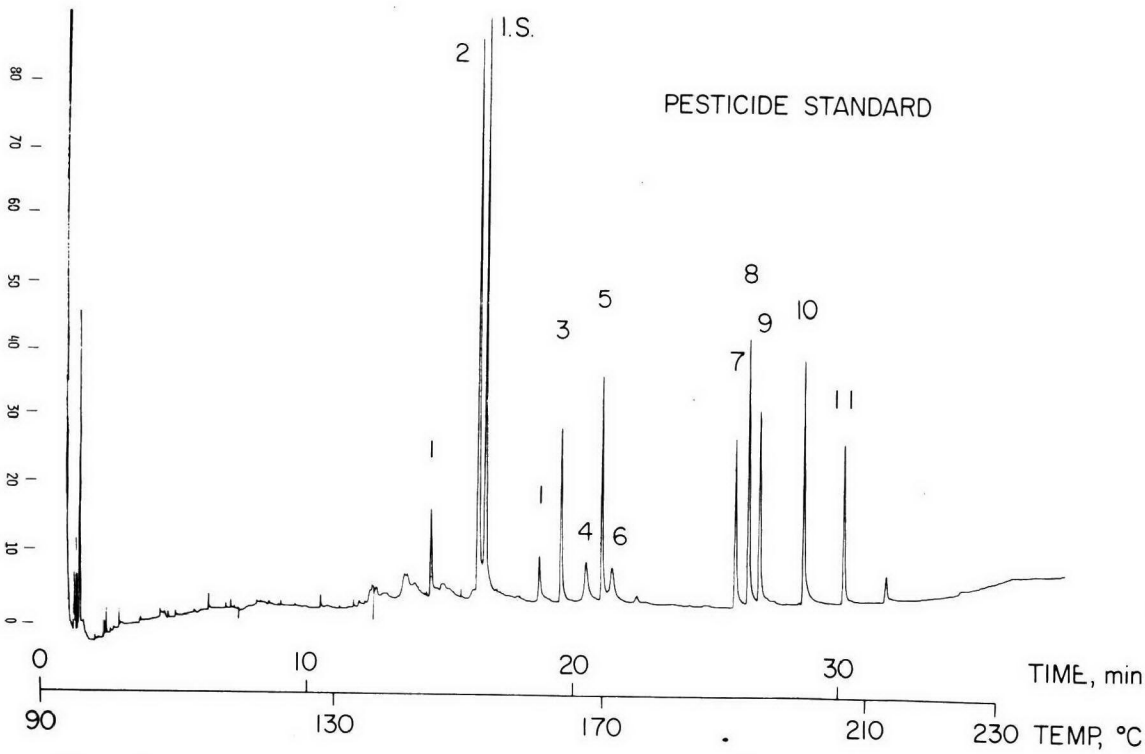


Figure 6A. Pesticide standard (ECD setting $337/2^5$). 1: BHC isomers 260 pg; 2: lindane 260 pg; 3: heptachlor 160 pg; aldrin 160 pg; 7: dieldrin 160 pg; 8: DDE 194 pg; 9: endrin 170 pg; 10: TDE 500 pg; 11: DDT 240 pg; i.s.: internal standard, 1170 pg; 4,6: impurities.

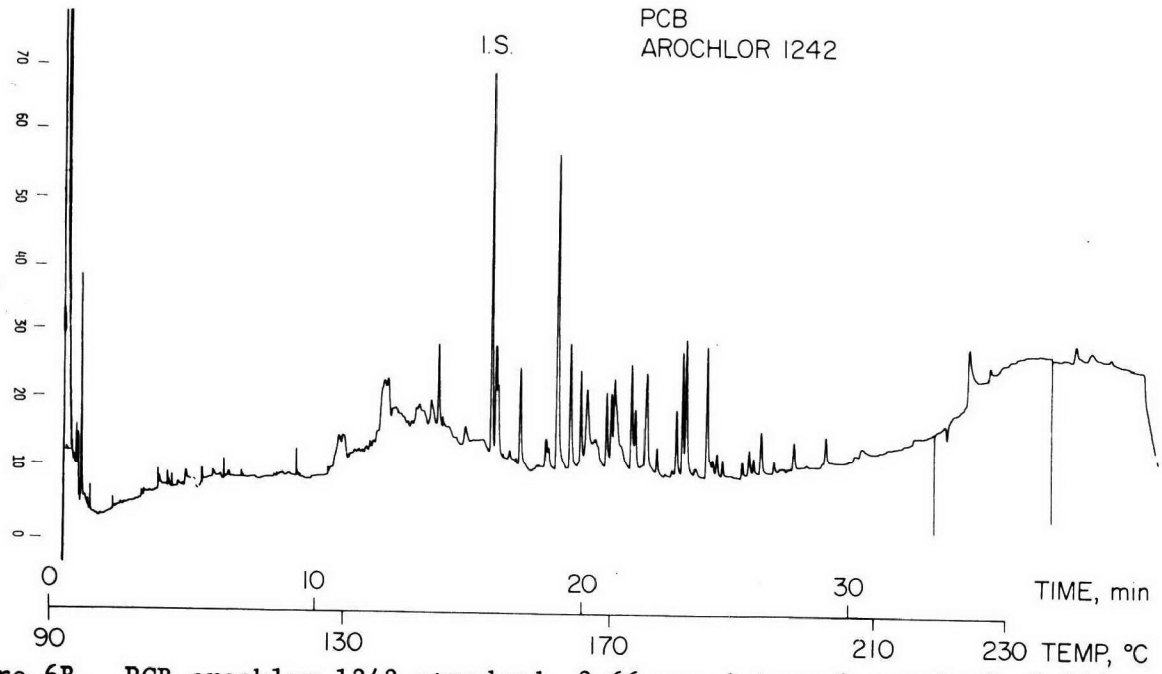


Figure 6B. PCB arochlor 1242 standard, 2.66 ng; internal standard, 0.464 ng. Detector $337/2^4$.

TABLE 24. PCBs AND PHTHALATE CONCENTRATIONS AT VARIOUS SAMPLING POINTS*
April 1977 through June 1977

	Sample Location						
	Influent Q1	Clarif. Effluent Q2	Ammonia Tower Effluent Q4	Filter Effluent Q6	Activ.-Carbon Effluent Q8	Basin Effluent Q9	RO Effluent Q21B
PCB 1242							
Mean, μg/l	4.8	1.3	(0.3)	(0.3)	(0.2)	(0.3)	0
Std. Dev., μg/l	2.0	1.0	0.5	0.4	0.4	0.4	
Range, μg/l	2.3-7.8	0.3-3.1	0.1-0.8	0-0.8	0-0.8	0-1.0	
No. of Samples	6	6	6	5	6	8	3
Diethyl phthalate							
Mean, μg/l	6.1	8.3	5.6	10.9	5.8	2.5	1.3
Std. Dev., μg/l	4.4	3.7	3.7	8.2	4.9	2.6	
Range, μg/l	2.5-13	1.7-19	2.1-10	3.6-21	0-13	0-6	0-2.7
No. of Samples	5	5	6	5	6	8	3
Dioctyl phthalate							
Mean, μg/l	8.2	2.8	1.0	1.3	1.4	2.0	2.0
Std. Dev., μg/l	5.0	2.9	0.6	0.7	1.4	2.0	
Range, μg/l	1.7-14	0.3-7.6	0-2.0	0.4-2.0	0-4.0	0.4-6	0.4-5.3
No. of Samples	5	6	6	5	6	8	3

*Values in parentheses are estimates.

subsequent treatment, the average concentration did not change significantly. At this point the origin of these materials present in secondary effluent is not known.

Detailed Characterization

A number of extracts have been investigated with GC/MS without an attempt at quantification. The main emphasis to date has been to detect the presence or absence of substances of toxicological concern. Since only a small number of samples have been analyzed, no definite conclusions about variability in contaminant levels can be drawn.

The organics found can be divided into the following categories based upon their presumed origin.

A. Aromatic hydrocarbons
B. Synthetic chlorinated compounds
C. Chlorination products
D. Natural products
E. Miscellaneous

The organic substances tentatively identified by GC/MS are listed in Table 25. The numbers refer to Figure 7 which shows a total ion chromatogram of a CLS extract of the Q2 sample taken on 2/6/77. The amount of internal standards added (1-chloroalkanes; 1-Cl-C_2, 1-Cl-C_8, 1-Cl-C_{10}) were 500 ng/l and comparison of the peak heights may be used to approximate the concentrations. In Table 25 relative heights in different sample locations are given which give an indication of the degree of removal or formation during treatment. The trend observed is the same as in the routine analysis: Ammonia stripping and activated-carbon treatment are effective in removing the volatile organics. Chlorination products are found in the influent and in the effluent. Their concentration increases upon chlorination (see volatile organic analysis). In addition to the haloforms, which are analyzed by the VOA, a number of other substances which are produced by chlorination have been found: Halogenated ketones (Peak 32, 24, 25) and chloroxylene (33). Their concentration is in the low nanogram per liter range.

In Table 26 substances are listed which were found in the hexane extracts. Identifications are based on mass spectra only and are tentative for most substances.

TABLE 25. COMPOUNDS IN WF-21 SAMPLES ANALYZED BY CLSA AND THEIR TOTAL ION CURRENT PEAK HEIGHTS RELATIVE TO THE INTERNAL STANDARD, 1-Cl-C8*

Peak No. in Figure 7	Compound	Sample Location			
		Clarif. Effl. Q2	Filter Effl. Q6	Activ.-Carbon Effl. Q8	Basin Effl. Q9
	A. Aromatic Hydrocarbons				
1	Benzene				
2	Toluene	3.32	0.76	0.26	0.24
3	Ethylbenzene	1.34	0.17	0.09	0.05
4	p-xylene	0.80	0.15	0.08	0.05
5	m-xylene	2.98	0.44	0.13	0.12
6	o-xylene	1.27	0.44	0.13	0.12
7	C_3-benzenes†	0.5	0.15	0.06	0.05
8	C_4-benzenes				
9	Indane				
10	C_1-indanes				
11	Naphthalene	1.06	0.24	0.25	0.11
12	Methylnaphthalenes	0.67	0.18	0.06	0.1
13	C_2-naphthalenes				
14	Styrene				
	B. Synthetic Chlorinated Compounds				
15	Trichloroethylene	1.12			
16	Tetrachloroethylene				
17	Trichloroethane	Tr			
18	Hexachloroethane	0.4	0.24	0.08	0.08
19	Chlorobenzene				
20	1,2-dichlorobenzene				
21	1,3-dichlorobenzene	1.11	0.09		0.01
22	1,4-dichlorobenzene	2.94	0.29		0.05
23	Trichlorobenzene	0.87	0.06		0.01
24	Tetrachlorobenzene				
25	PCB (1- and 2-chlorines)	Tr			
	C. Chlorination Products				
26	Chloroform				
27	Dichlorobromomethane	0.3	0.53	0.23	0.20
28	Chlorodibromomethane	6.3	0.27	0.32	
29	Bromoform				0.45
30	Dichloroiodomethane	0.09	0.09	0.03	
31	Chlorobromoiodomethane				
32	1,1,1-trichloroacetone				
33	Chloroxylene				
34	Chlorobromopentanone				
35	Bromoketone	0.3	1.1	0.12	0.12

TABLE 25 continued

TABLE 25 continued

Peak No. in Figure 7	Compound	Sample Location			
		Clarif. Effl. Q2	Filter Effl. Q6	Activ.-Carbon Effl. Q8	Basin Effl. Q9
	D. Natural Products				
36	Terpene				
37	Terpene alcohol				
	E. Miscellaneous				
38	Phthalates				
39	Benzaldehyde		1.97	0.34	0.20
40	Tolualdehydes†				1.0
41	Ethylphenol	0.05			
42	Apparent MW 196	> 4	1		

*blank indicates peak height not measurable.

†value of one typical compound of this group measured.

TABLE 26. SUBSTANCES TENTATIVELY IDENTIFIED IN HEXANE EXTRACTS

Substance	Sample Location*	
	Clarif. Effl. Q2	Basin Effl. Q9
PCB (see Table 24)	x	Tr
Biphenyl	x	--
Alkylated biphenyls	x	
Phenanthrene/Anthracene	x	Tr
Methylphenanthrene	x	Tr
Diethylphthalate (Table 24)	x	x
Dibutylphthalate	x	x
Dioctylphthalate (Table 24)	x	x
Sulfur S_8	x	

*x = present in measurable concentration.
Tr = close to detection limit.
-- = not detectable

The complexity of the mass spectra did not allow an identification of a number of peaks yet.

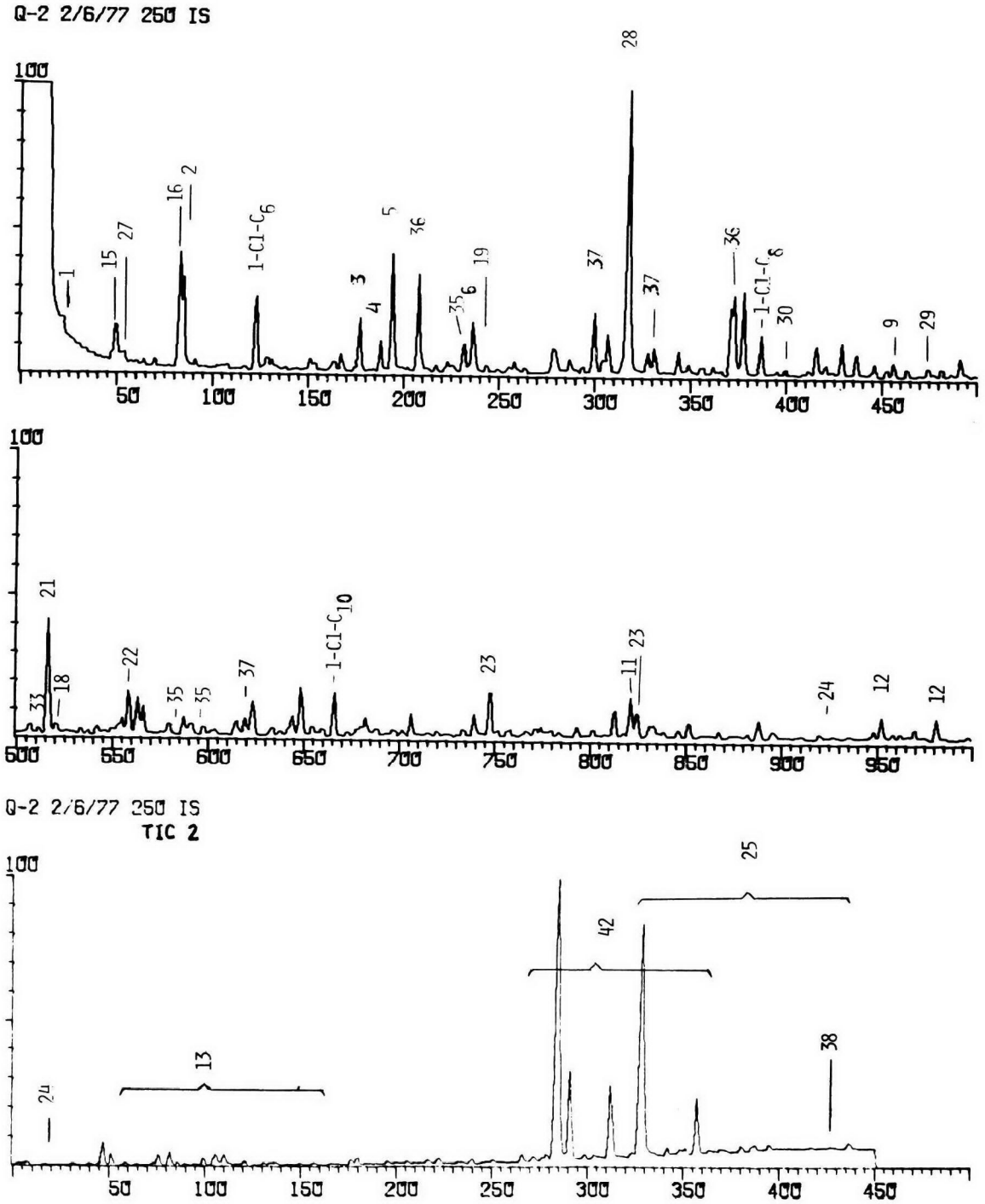


Figure 7. Typical total ion chromatogram (computer reconstructed) of a CLS extract from Q2. Lower graph is independently normalized. Numbers refer to substances in Table 25.

VIRUS

James M. Montgomery Engineers (JMM) determined the number of virus in samples taken from the following locations at Water Factory 21: (1) the influent, Q1, (2) the lime-clarifier effluent, Q2, and (3) the final effluent, Q9. In addition, samples were analyzed occasionally to determine the types of virus present. Most identifications were conducted by the California Department of Public Health, but some were made by JMM.

Virus in Water Factory 21 Influent

A summary of results for native virus assays of influent samples is given in Table 27 and Figure 8. The geometric mean values listed at the bottom of Table 27 were taken from the 50-percent value from Figure 8 for the period from November 1975 through June 1976, and from a similar plot for the data from October 1976 through July 1977. Several samples analyzed had no detectable viruses. For example, of the 77 samples analyzed between October 1976 and July 1977, 29 contained no detectable viruses (Table 27). The number of viruses which were measured in the remaining samples are listed in increasing order in the tables.

A comparison of the data in Table 27 for the two different periods indicates that for the BGM procedure, plaque confirmation as defined in the Sampling and Analytical Procedures section is essential. The values obtained for the second period when confirmation of the assay results was made were thirty-fold lower than for the first period when it was not.

Figure 9 illustrates the seasonal distribution of virus, and as commonly believed, the data suggest that virus levels are lowest during the winter and highest during the summer. Also, between December 1, 1976 and March 15, 1977 only 48 percent of the samples were positive for virus, while during the warmer remainder of the year, 68 percent of the samples were positive.

Table 28 presents a summary of the viruses identified in influent samples to Water Factory 21. The significance of these particular virus isolates in relation to human disease has not been investigated.

Virus in Chemical Clarifier Effluent

Virus were measured in the effluent from the clarifier after lime treatment (Q2) only during the first period from November 1975 through June 1976. The purpose was to determine the effectiveness of lime treatment at pH greater than 11.3 on virus reduction. During this period, however, the viral assays were not confirmed as this was then not known to be necessary, and so actual effluent concentrations are not known. The results do suggest, however, that reductions by lime treatment are significant. A summary of the analyses conducted is given in Table 29. The geometric mean values were obtained as before from the intersection of the drawn line through data on log-probability paper with the 50-percent point on the graph. A comparison of the calculated geometric mean values with those for the same period and same assay procedure in Table 27 indicates that lime treatment resulted in 99.88 percent reduction

TABLE 27. VIRUS CONCENTRATION IN INFLUENT (Q1)

November 1975 through June 1976				Oct. 1976 through July 1977	
PAG (unconfirmed)		BGM (unconfirmed)		BGM (confirmed)	
No. of Samples	10^3 pfu/m^3	No. of Samples	10^3 pfu/m^3	No. of Samples	10^3 pfu/m^3
1	N.D.*	0	N.D.*	29	N.D.*
1	0.18	1	4.0	5	0.5
1	2.0	1	6.6	5	0.8
1	2.5	1	10.6	2	1.1
1	3.2	1	12.5	7	1.3
2	4.0	1	13.2	1	1.6
1	5.0	1	16	3	1.9
1	5.3	1	26	3	2.1
1	8.7	1	29	1	2.4
1	9.3	1	40	1	2.6
1	13.2	1	49	1	2.9
1	148	1	52	1	3.2
		1	63	2	3.4
		1	160	1	3.7
		1	260	2	4.2
				1	4.5
				1	4.8
				2	5.0
				2	5.3
				1	5.6
				1	5.8
				1	6.1
				1	6.6
				1	6.9
				1	7.1
				1	48
13 (Total Samples)	4.5 (Geom. Mean)	14 (Total Samples)	27 (Geom. Mean)	77 (Total Samples)	1.1 (Geom. Mean)

*None detected.

as determined by the unconfirmed PAG procedure and 97.7 percent by the unconfirmed BGM procedure.

Samples obtained during this period were also analyzed by the California Department of Public Health. For influent samples the State laboratory found all 12 samples analyzed to be positive. For samples after chemical treatment,

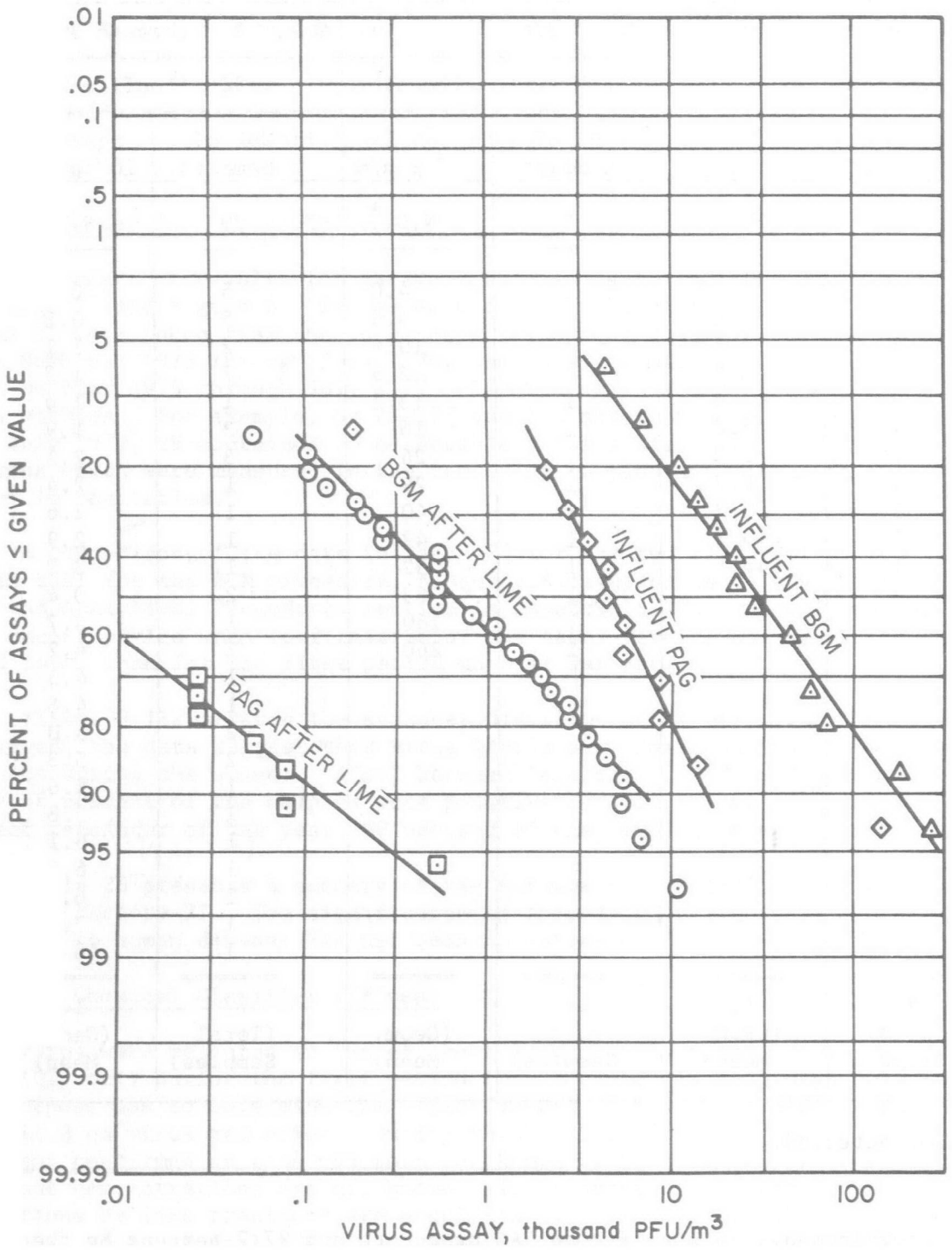


Figure 8. Probability plot of virus assay levels.

TABLE 28. VIRUSES IDENTIFIED IN WATER FACTORY 21 INFLUENT (Q1)

Virus	Calif. Dept. of Health		James Montgomery	
	No. of Samples	Total No. of Plaques	No. of Samples	Total No. of Plaques
Polio 2	16	27	1	4
Echo 1	8	17		
Echo 7	7	16		
Reo 2	5	12		
Echo 14	7	8		
Coxsackie B5	6	8	1	1
Polio 3	7	7		
Echo 8	6	6		
Reo	6	6		
Unknown	5	5		
Echo 12	3	5		
Coxsackie B4	5	5		
Coxsackie B2	3	4		
Coxsackie B3	1	3		
Echo 11	2	3		
Reo 1	3	3		
Coxsackie B6	2	2		
Coxsackie A17	2	2		
Coxsackie A13	1	1		
Coxsackie A18	1	1		
Coxsackie A20	1	1		
Echo 3	1	1		
Echo 9	1	1		
Echo 19	1	1		
Echo 25			1	1
Polio 1	1	1	1	1
Total No. Samples with Virus	46		4	

the State laboratory found only 3 samples to be positive while JMM found 28 positives. This discrepancy again indicates the importance of conducting confirmed analyses. It also leaves open the question of the true effectiveness of lime treatment on virus reduction. The three viruses identified in the three positive samples by the State laboratory for lime-treated effluent samples were Echo 8, Echo 20, and Polio 1. Of the three, only Echo 8 was also found in the plant influent during this period.

Viruses in Final Effluent (Q9)

Over the period of this study, 77 samples of chlorinated final effluent (Q9) were analyzed for virus. Only one of the samples analyzed was positive for virus. This sample was collected on March 1, 1977. There was one confirmed plaque in the four ml assayed in this sample. Identification by the

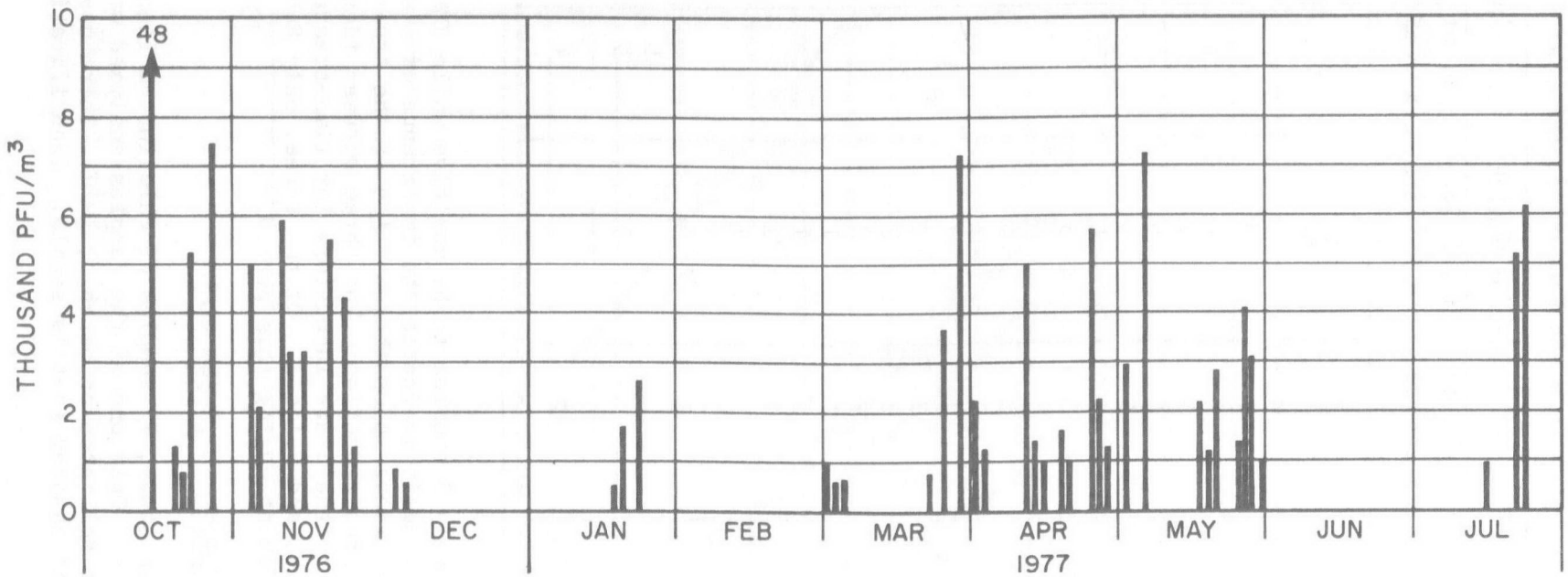


Figure 9. Seasonal variation in natural viruses in Water Factory 21 influent.

TABLE 29. VIRUS CONCENTRATION IN CHEMICAL CLARIFIER EFFLUENT (Q2)
November 1975 through June 1976

PAG (unconfirmed)		BGM (unconfirmed)	
No. of Samples	10^3 pfu/m^3	No. of Samples	10^3 pfu/m^3
15	N.D.	4	N.D.
3	0.03	1	0.05
1	0.05	2	0.11
2	0.08	1	0.13
1	0.53	1	0.19
		1	0.20
		2	0.3
		5	0.5
		1	0.8
		2	1.1
		1	1.3
		1	1.6
		1	1.8
		1	2.1
		2	2.6
		1	3
		1	4
		2	5
		1	7
		1	11
22 (Total Samples)	0.005 (Geom. Mean)	32 (Total Samples)	0.6 (Geom. Mean)

plaque reduction technique indicated that it was Polio Type 2. The one confirmed plaque in four ml assayed for the plant influent (Q1) on that same day was also identified as Polio Type 2.

The firm of JMM which conducted the assays for virus indicated the possibility that the virus could have resulted either from cross-contamination or was actually indigenous to the effluent sample analyzed. They felt that the possibility of cross-contamination was low and thus the virus was most likely indigenous to the sample.

On the day that the virus was detected, there was an operational problem. An unusually high concentration of activated-carbon fines was in the effluent; for this reason the turbidity was 2.3 and the pH was 6.6. At the time of sampling, the chlorine residual was not determined, but because of normal interactions between chlorine and activated carbon, it could have been low.

It has been well documented that the presence of particulates interferes with disinfection. Activated carbon has been shown to be a very effective virus adsorbent, consequently any virus in the effluent would likely be on the carbon. Activated carbon also reacts very quickly to remove chlorine and as a result the attached virus are likely to have been protected from its action. The release of activated-carbon fines has been an occasional problem at Water Factory 21 and for this reason, some major modifications have been completed in an effort to reduce the problem.

SECTION 7

DISCUSSION

BACKGROUND

This study has been conducted to evaluate the effectiveness of advanced wastewater treatment for removal of inorganic, organic, and biological contaminants which remain in municipal wastewater after normal secondary treatment. The performance of Water Factory 21 was evaluated during the first one and one-half years of its operation. This advanced treatment plant receives up to 0.66 m^3/sec (15 mgd) of trickling filter effluent from the Orange County Sanitation District and treats it by a combination of physical and chemical processes. The ability of this treatment plant to effectively remove many materials of toxicological significance prior to reuse or groundwater injection has been demonstrated. The information this study has generated should be useful in evaluations of the reliability of advanced treatment plant operation and the determination of quality of reclaimed waters relative to that of potential alternative supplies.

GENERAL INORGANICS

The advanced wastewater treatment at Water Factory 21 has resulted in changes in the concentrations of ammonia, phosphate, calcium and magnesium. In addition, treatment of a portion of the wastewater by a reverse osmosis pilot plant has resulted in a significant reduction of inorganics in general.

Ammonia is removed both by air stripping and by breakpoint chlorination. During the first six months of operation only ammonia stripping was practiced, and this process reduced the concentration of ammonia nitrogen from 43 to 19 mg/l for an average removal of 56 percent. The operation of the two stripping towers was then modified to provide for series rather than parallel operation. Even though the same quantity of air was used (3000 m^3 air/m^3 water), this change resulted in decreasing the ammonia nitrogen from 37 to 6.5 mg/l, which is a reduction of 82 percent. Thus, series operation offers a decided advantage.

Breakpoint chlorination resulted in reduction of ammonia nitrogen to the 1 mg/l level required by regulations. This necessitated a chlorine to ammonia nitrogen weight ratio of 9 or greater. Breakpoint chlorination was difficult to control when it was combined with disinfection in the final chlorine contact chamber because the high concentration of chlorine required resulted in an excessive decrease in pH. This problem was solved by moving the

breakpoint chlorination process upstream to the effluent from the ammonia stripping tower. Here, the pH was near 11 and the water had a good buffering capacity. After chlorine addition, the pH was lowered to the desired level by recarbonation, and the recarbonation basins provided the time required for ammonia oxidation to be completed.

A significant disadvantage of breakpoint chlorination, however, was the formation of several chlorinated organics which were not efficiently removed by activated-carbon adsorption. This was previously discussed more fully under the section on Organics. There was also concern over the effect the resulting free chlorine residual might have on the capacity of the activated-carbon columns. For these reasons and because the cost of breakpoint chlorination is high, the OCWD has requested that the 1 mg/l limit on ammonia nitrogen in injection water be reviewed, especially since some additional removal by ion exchange in the aquifer is likely.

Chemical treatment with lime at a pH greater than 11.3 is very effective for the removal of phosphates and magnesium. Over the entire one and one-half years of this study, phosphate phosphorus was reduced from a mean influent concentration of 5.5 mg/l to 0.08 mg/l, or 99 percent, and magnesium was reduced from a mean influent concentration of 25 mg/l to 0.7 mg/l, or 97 percent. Calcium concentration, however, increased through lime addition during the first six months of operation from 102 mg/l to 142 mg/l, but was reduced during ammonia stripping, recarbonation and settling to a final effluent concentration which averaged 107 mg/l.

During the last year of operation, a pilot reverse osmosis (RO) system was operated to determine efficiency for dissolved salt removal which could be expected when the 0.22 m^3/s (5 mgd) full-scale facility was completed. The pilot RO unit reduced the specific conductance from a mean value of 1530 to 80 µS/cm, or by 95 percent. It also reduced the sodium, chloride, sulfate, and COD concentrations by 93, 94, 100, and 93 percent, respectively. Certain low molecular weight organics were not removed effectively as discussed later under the section on Organics. However, the above results indicate that RO treatment is quite effective for removal of a broad range of general inorganics and organics.

HEAVY METALS

Of the several heavy metal trace contaminants monitored, only one was continuously higher in concentration in the secondary influent to Water Factory 21 than the regulatory requirements for the effluent from the advanced wastewater treatment plant. This was chromium, and it was removed down to the regulatory requirement of 50 µg/l by the treatment processes. Thus, heavy metal removal is not a critical aspect of Water Factory 21 operation. However, it is worthwhile to consider the effectiveness of heavy metal removal by the treatment plant both for other applications and because several trace metals in the influent on occasion rise above the limits.

Two metals, mercury and selenium, were not removed to a significant degree by the advanced wastewater treatment system. Also, arsenic was not

removed significantly during the last year of operation, although during the first six months there was an indication that chemical treatment removed somewhat over 50 percent. All three metals were in the low μg/l range, near the detection limit. Therefore, firm conclusions about removability cannot be made.

All other trace heavy metals monitored were generally removed 50 percent or more by chemical treatment. These included barium, cadmium, chromium, iron, lead, manganese, silver, and zinc. Subsequent treatment (RO was not evaluated, however) did not result in additional removal except for chromium, copper, and zinc which were reduced an additional 41, 64, and 78 percent, respectively, by activated-carbon treatment.

Chemical treatment was consistently good for iron and manganese, providing over 85 percent removal. Copper removals averaged between 65 and 75 percent for the two different periods, and barium removal varied between 50 and 60 percent. Silver, chromium, lead, and cadmium removals averaged from 40 to 65 percent during the first six months, but increased during the last year of operation to over 75 percent, with cadmium reductions the best at 94 percent. On the other hand, zinc removal was highest during the first period (90 percent) and lowest during the second period (37 percent).

Iron and zinc concentrations were quite variable throughout the plant, especially during the first six months of operation, due to corrosion, especially in the ammonia stripping tower. Zinc in particular increased in concentration from 29 to 670 μg/l through ammonia stripping, although the concentration was then reduced to 133 μg/l by activated-carbon treatment. The corrosion problem was not so severe during the last year of the study.

These results indicate that the concentration of many heavy metals of health concern can be reduced by chemical treatment with lime at a pH greater than 11.3. This treatment should provide a good safeguard against occasional high concentrations of heavy metals, which may be present in municipal wastewaters. In the case at hand, however, in the influent water only chromium exceeded the regulatory requirements for the effluent and necessitated reduction on a continuous basis. Some of the other metals exceeded requirements occasionally, thus treatment was required to insure continuous compliance with regulations. Lime treatment was the most effective process in general at Water Factory 21 for this purpose.

ORGANICS

General

The COD analysis measures a broad group of organic compounds and thus changes in this parameter provide indications of the overall performance of the treatment system for organics in general. The COD of the secondary influent to Water Factory 21 averaged 131 mg/l. This was reduced by 60 percent (about 36 percent particulate and 24 percent dissolved) to a mean concentration of 52 mg/l by chemical treatment due to the removal of suspended organics.

An additional reduction in the mean COD concentration to 45 mg/l took place after ammonia stripping and filtration. Activated-carbon adsorption provided an additional 67 percent reduction to a mean value of 15 mg/l, which had a standard deviation of 8 mg/l in the 397 samples analyzed over the one and one-half years of operation. Thus, overall COD reduction by the advanced wastewater treatment plant was almost 90 percent. While the COD procedure provides information on organics in general, it does not indicate the performance for removal of many individual organics which may be of toxicological concern.

Trace Organic Contaminants

The trace organics identifiable by closed-loop stripping analysis have been divided arbitrarily into five separate groups as related to their most probable origin. Presence of Group A compounds reflects contamination of water with petroleum products. This can be concluded from the fact that various groups of isomers such as the xylenes are present in typical relative concentrations. Quantification of the complex mixture of substances in petroleum products is obviously very difficult. The aliphatic portion of such products are probably removed to a large degree during secondary treatment, either due to their better microbial degradability or through aeration. This was indicated in an earlier investigation (6).

The Group B synthetic chlorinated products are widely used in household and in industry. They are commonly found in natural waters and in drinking water supplies of all industrialized nations (8). Their occurrence in Water Factory 21 samples is therefore not surprising. The first quantitative estimates indicate that they are present all the time.

The Group C compounds are formed during the chlorination process in water and wastewater treatment plants, and include the well-known haloforms (2,3,10). However, other chlorinated organics such as chloroxylene (7), and alpha-haloketones (6) are also known to be formed, leading us to assume that these compounds as well as the bromochloroketone and trichloroacetone found are products of chlorination at Water Factory 21 and of its chlorinated influent. The Group A alkylated benzenes may also be chlorinated (7). The structure of some of the organics which resulted from chlorination remain to be elucidated.

Natural products identified include terpenes and terpene alcohols. Little attention has been given to these materials since they are not of health concern. They are removed effectively during treatment.

The Group E substances do not fit into the other categories. Except for phthalates, which are widely used as plasticizers, little is known of their origin.

The SEA analysis permits the identification of additional groups of compounds, including chlorinated pesticides, PCBs, and some of the polynuclear aromatics. They are of public health concern and some members are included in the EPA primary drinking water standards and those formulated by the World Health Organization (13). Additional information on their frequency distribution in reclaimed waters is desirable.

A major concern is the high concentration of polychlorinated biphenyls in the plant influent. It was found to be about 10 times higher than in an earlier investigation (16). Although they are removed to a large extent, traces have been found in the effluent. A more sensitive procedure will allow more precise monitoring of PCBs in the product water. On the other hand, chlorinated hydrocarbon pesticides were not detected. Schmidt, Risebrough, and Gress (16) reported a DDT concentration up to 0.64 μg/l. The current lack of detection probably reflects the fact that this pesticide is no longer in heavy use.

Efficiency of Advanced Wastewater Treatment

The initial results from this study indicate that advanced wastewater treatment is capable of removing about 90 percent of the total organic material remaining after primary and secondary treatment of municipal wastewaters. For many of the relatively low molecular weight organics of health concern, the efficiency of removal was greater than 90 to 95 percent. On the other hand, there was a group of organics which were formed by chlorination, and the effluent concentration of these was greater than the influent concentration. A problem for future operation is how to minimize the formation of such chlorination products and at the same time satisfy other effluent requirements related to pathogens and nitrogen species.

Chemical clarification and activated-carbon adsorption are well-known processes for removing organic materials. This study has demonstrated that air stripping for ammonia removal is also highly effective for the removal of a wide range of organic materials of toxicological significance. In particular this process is effective in removing a wide range of highly volatile, low molecular weight, and relatively nonpolar organics which are not easily removed by activated-carbon adsorption or reverse osmosis. Included are several one- and two-carbon halogenated solvents and chlorination products. In addition, several aromatic compounds such as chlorinated and alkylated benzenes and naphthalenes are significantly removed by air stripping, thus reducing the need for reliance solely on activated-carbon adsorption. An additional important aspect for Water Factory 21 is that the group of organics removed by air stripping are some of the most likely compounds to cause problems if injected into a groundwater aquifer, because of their refractory nature and potential for movement with little hinderance from adsorption.

The intermedia transfer of organics from the water to the air by ammonia stripping may cause some concern, and the environmental implications need to be considered. This should be viewed in a broad context since a similar intermedia transfer would no doubt result from any discharge of wastewaters to surface waters, whether or not ammonia stripping is employed. An additional consideration is that the lifetime of many refractory organics is less in the air because of exposure to solar radiation than in the ground. A resolution of these complex issues was not attempted in this study.

The formation of chlorinated organics by breakpoint chlorination raises additional issues which need to be resolved. Are health risks in a groundwater injection system greater from pathogens or from chlorinated organics? Is removal of ammonia to low levels, requiring breakpoint chlorination,

necessary to the satisfactory operation of an injection system and to the quality of withdrawn water? These questions also have not been addressed in this study but remain for future research.

This study has shown that the combination of processes used at Water Factory 21 is effective for reducing the concentration of a broad range of organic materials present in effluents from secondary wastewater treatment. Future studies will be concerned with additional quantification of materials of health concern, seeking of analytical procedures for other organics of importance, and determining their variation with time in Water Factory 21 effluent. The information provided should aid in the formulation of policy decisions about wastewater reuse in general, and in particular for municipal purposes.

VIRUS

Enteric viruses have been found present in a majority of the influent samples to Water Factory 21. Over 25 different viruses have been identified in these samples. A reduction in viral numbers appears to occur during chemical treatment, although this analysis was conducted during the first six months of operation, when confirmed assays were not conducted. Subsequent studies have indicated that confirmed analyses are essential to a good interpretation of data.

Over 77 samples of final effluent were analyzed for virus concentration. Only one sample was positive for virus. This positive response appears to be related to the discharge of a relatively high concentration of activated-carbon fines in the effluent. Water Factory 21 has recently undergone modification to reduce such carbon fines in the future, which should also reduce the potential for virus passage.

PLANT RELIABILITY

An important aspect of this study was an evaluation of the reliability of Water Factory 21 to produce an effluent with good consistency in quality. In order for a plant to be reliable, either (1) the plant must be able to successfully treat wastewaters with great variability in quality, (2) the flexibility must be available so that the treatment plant need not accept a wastewater for treatment if it is of questionable quality, or (3) if the treated water does not meet the intended reuse criteria, then it must be possible to dispose of it by other means. In addition, the treatment plant must be able to treat the wastewater with its normal variability and consistently and reliably improve its quality to the required level.

Water Factory 21 has been designed to provide considerable flexibility in line with the above. The OCWD can treat wastewater at whatever constant flow rate it desires. The Orange County Sanitation Districts, which supply the secondary effluent to OCWD, have on occasion had problems either in the operation of their biological treatment plant or with the introduction of unusual wastes into the contributing sewers. They have then notified the OCWD, and if found desirable for water quality considerations, Water Factory 21 has

been shut down. Water Factory 21 is also routinely shut down for a period of two to three months each year for general maintenance or plant modifications. In addition, plant operation is stopped whenever desirable for emergency maintenance or less extensive modifications. When the plant is restarted, treated water can be discharged to a sewer until the quality is consistent with regulatory requirements. This flexibility is possible since the effluent is recharged to the groundwater aquifer which is a large storage basin, unaffected by short-term stoppages in the injection of treated water.

The plant operation can be properly balanced within one day after starting and effluent quality is then consistent and adequate. The ability to stop plant operation at will and to restart it rapidly gives a good measure of assurance on plant reliability.

The other measure of reliability is consistency in the characteristics of the reclaimed water. A measure of this can be obtained from the variability in measured effluent quality. Table 30 indicates the variability of inorganic constituents and Table 31 the variability of organic constituents in Water Factory 21 effluent. Most values represent analyses of final effluent after chlorine contact (Q9), although some as indicated are from before chlorine contact (Q8). The values are summarized from the detailed results listed in Appendix B.

TABLE 30. VARIABILITY OF INORGANIC CONSTITUENTS IN WATER FACTORY 21 EFFLUENT

Constituent	January through June 1976		October 1976 through June 1977	
	Mean Conc.	Coef. of Var., %	Mean Conc.	Coef. of Var., %
Ca, mg/l	107	22		
Na, mg/l	205	9		
Cl, mg/l	246	9		
SO_4, mg/l	312	13		
Alkalinity, mg/l	137	19		
B, mg/l	0.63	22		
F, mg/l	0.64	25		
EC, µS/cm	1470	9		
pH	6.7	2		
Turbidity, TU	0.85	45		
NH_3-N, mg/l			3.3	88
As, µg/l	1.1	27	2.4	75
Ba, µg/l	33	70	31	71
Cd, µg/l	2.2	82	1.7	100
Cr, µg/l	48	67	26	92
Cu, µg/l	27	52	32	47
Fe, µg/l	45	150	66	120
Pb, µg/l	26	123	5.2	240
Mn, µg/l	4.1	34	4.9	90
Hg, µg/l	4.9	430	6.7	210
Se, µg/l	6.4	55	<2.5	-
Ag, µg/l	14	410	1.5	190
Zn, µg/l	124	58	162	48

TABLE 31. VARIABILITY OF ORGANIC CONSTITUENTS IN WATER FACTORY 21 EFFLUENT

Constituent	January through June 1976		October 1976 through June 1977	
	Mean Conc.	Coef. of Var., %	Mean Conc.	Coef. of Var., %
COD, mg/l	13	62	18	39
TOC, mg/l	7.3	36	6.7	33
Org-N, mg/l	0.6	67	1.3	38
$CHCl_3$, μg/l	2.1	52	10	84
$CHBrCl_2$, μg/l	0.9	111	3.6	83
$CHBr_2Cl$, μg/l			2.0	115
$CHBr_3$, μg/l			0.4	150
CH_2Cl_2, μg/l			3.4	160
Cl_3C-CH_3/CCl_4, μg/l			0.1	300
$Cl_2C=CHCl$, μg/l			0.04	250
$CCl_2=CCl_2$, μg/l			0.1	300
Ethyl benzene, ng/l			40	125
Chlorobenzene/ o-xylene, ng/l			70	130
1,3-dichloro-benzene, ng/l			140	130
1,4-dichloro-benzene, ng/l			20	50
1,2-dichloro-benzene, ng/l			100	80
1,2,4-trichloro-benzene, ng/l			120	160
Naphthalene, ng/l			30	67
PCB 1242, ng/l			300	130
Diethyl-phthalate, ng/l			2500	104
Dioctyl-phthalate, ng/l			2000	100

The coefficients of variation listed in Tables 30 and 31 were obtained by dividing the standard deviation for each constituent analysis by the mean value and multiplying by 100. The result indicates the magnitude of the standard deviation in relationship to the mean. The mean and standard deviation indicate the magnitude and spread of the data. If the data followed a normal distribution, one could calculate from these values the frequency at which a given effluent concentration for a given constituent would be exceeded in the treated effluent.

Table 30 indicates that the variability of the general inorganic constituents which comprise the major portion of the total dissolved solids is low, the coefficient of variation is generally less than 25 percent. The

variability of turbidity, ammonia concentration, and heavy metals in general is much greater, sometimes exceeding 100 percent. Constituents falling in the latter category are cadmium, iron, lead, mercury, and silver. A portion of this variability is due to the fact that these concentrations are near the analytical limit, at which point analytical errors tend to be quite high. At such concentrations, contamination of samples can be a serious problem and may contribute to the variability found. The high coefficients of variation indicate that the mean values are affected significantly by a few high values. Also, coefficients of variation greater than 100 percent, and indeed somewhat lower than this, suggest that the data do not follow a normal distribution. Probably a log normal distribution would fit the data much better. This will be studied in more detail during the coming year of research.

The variability of organic constituents is shown in Table 31. That of the gross parameters such as COD, TOC, and organic nitrogen are not as great as for the individual constituents. Again this is partly reflective of the variability of the analysis itself. The coefficient of variation is particularly high for constituents such as Cl_3C-CH_3/CCl_4, $Cl_2C=CHCl$, and $CCl_2=CCl_2$ which are present in concentrations just at the borderline of detection. The great variability here can be attributed largely to analytical problems. For other constituents, with coefficients of variation near 100 percent, analytical problems are partly responsible, but most of the variation probably can be attributed to actual variation in effluent quality.

It is no doubt desirable to be able to separate that portion of the measured constituent variability which is due to analytical errors and that which is due to actual variation in treatment plant quality. However, for each constituent of concern this can be a costly undertaking. The decision to make the effort required should properly be related to the actual need for more refined numbers. If the constituent is at a measured concentration which is near a required limit, or if it exceeds the limit on occasion, then for that constituent, more refined measurements may be fully justified. If even at the highest concentrations measured, a given constituent is far below the required limit, then additional refinement can probably not be justified. Since there are presently no regulatory requirements for organics except COD, additional refinements for most of the organics listed are perhaps not justified at this time.

Another aspect of reliability in performance which must be considered at Water Factory 21 is ability of the aquifer itself to even out the variations which occur. The aquifer system represents a very large reservoir. As the reclaimed wastewater is injected into it, the organics will adsorb to and then be desorbed from the clays, and by this process they will move more slowly through the system than the water itself. This process of adsorption and desorption will result in spreading of the peak and valley concentrations of given organics so that variations of a given constituent at an observation well will be very much less than in the injected water. This effect will be greater the further the distance of the observation well from the point of injection. For this reason, the mean concentration may be a much more meaningful value than the extremes in reclaimed effluents used for groundwater injection. It must be kept in mind, however, that if variation in effluent quality is great, then many more samples must be analyzed in order to calculate a mean value which is sufficiently close to the true mean.

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APPENDIX A

TABLE A-1. MAJOR DESIGN CRITERIA
OCWD 0.66 m^3/s ADVANCED WASTEWATER TREATMENT PLANT

INFLUENT PUMP STATION

Number of pumps: 2
Capacity: 0.41 m^3/s @ 8.8 m TDH 0.44 m^3/s @ 8.2 m TDH
Type: Vertical mixed flow

CHEMICAL CLARIFICATION SYSTEM

Rapid Mixing
Number of basins: 2 in series
Mechanical mixer in each basin
Dimension: length - 3.7 m; width - 3.7 m; depth - 3.7 m
Detention time: 2.4 minutes total @ 0.66 m^3/s
Chemical addition: First basin - lime, alum, recycled lime sludge
Second basin - polymer

Flocculation
Number of basins: 2, three compartments each
Detention time: 10 min/compartment (30 min total) @ 0.66 m^3/s
Chemical addition: Polymer, 1st and 3rd compartments
Dimensions: length - 15 m; width - 12.5 m; depth - 3.4 m
Flocculator mechanism: Oscillating type

Settling Basins
Number of basins: 2 rectangular
Dimensions: 37 m long x 12 m wide, each
Surface Overflow Rate: 2.7 m^3/m^2-hr @ 0.66 m^3/s
Each basin equipped with settling tubes

Clarifier Effluent Pump Station
Number of pumps: 4
Capacity: 0.21 m^3/s @ 23 m; 0.22 m^3/s @ 20 m
Discharge: To ammonia stripping tower or to the OCSD plant or to the recarbonation basins

Lime Feeders and Slakers
Number: 2 gravimetric feeders and paste type slakers
Capacity: 0.5 kg/s

TABLE A-1. (continued)

Polymer Feed System

Number of mixing tanks: 2 (4 m^3 each)
Number of feed pumps: 4 dual head
Capacity: 0 to 0.1 m^3/h each head

Alum Feed System

Number of storage tanks: 2 (18 m^3 each)
Number of feed pumps: 3 (2 double head and 1 single head)
Capacity: 0.1 m^3/h each head

AMMONIA STRIPPING/COOLING TOWERS

Number of towers: 2
Dimensions: length - 63 m; width - 19 m; depth of packing = 7.6 m
Capacity: 0.33 m^3/s each @ 0.044 m^3/m^2-min
Number of fans: 6 per tower, 5.5 m diameter, 2 speed electric motors
Air Capacity: 990 m^3/s per tower (3000 m^3/m^3)
Not water streams: Tower No. 1 - 0.50 m^3/s cool 46°C to 26°C
Tower No. 2 - 0.69 m^3/s cool 50°C to 30°C

RECARBONATION

Number: 2 (3 compartment basins: 1st stage recarbonation, intermediate settling, 2nd stage recarbonation)
Detention Time, 1st and 2nd stage recarbonation: 15 minutes each
Overflow rate, intermediate settling: 5 m^3/m^3-h @ 0.66 m^3/s

FILTRATION

Number of filters: 4
Dimensions: 6.7 m x 7.3 m
Type: open, gravity, mixed media
Hydraulic loading rate: 0.2 m^3/m^2-min @ 0.66 m^3/s
Maximum operating head loss: 3 m
Filter aids: alum and polymers
Backwash system: Hydraulic with rotating surface wash arms
Backwash rate - 0.6 m^3/m^2-min
Surface wash rate - 0.024 m^3/m^2-min
Backwash water receiving tank volume: 705 m^3

ACTIVATED CARBON ADSORPTION

Number of contactors: 17
Normal Service: 16 in parallel operation, 1 for carbon storage and standby service
Type: Upflow, countercurrent, in steel pressure vessels
Dimensions: Overall height - 12.5 m; Sidewall height - 7.3 m; Diameter - 3.7 m
Contact Time: 34 minutes at 0.66 m^3/s
Carbon Size: 8 x 30 mesh
Carbon Weight: 35 Mg per contactor (660 Mg total)

TABLE A-1. (continued)

CHLORINATION

Number of contact basins: 1
In-line feeding and mixing
Contact Time: 30 minutes
Chlorine Feeders: 3 (900 kg/day each)
On site generation of chlorine: 900 kg/day

CHEMICAL SLUDGE TREATMENT AND RECOVERY SYSTEMS

Sludge Pumps
Number: 3
Capacity: 0.032 to 0.044 m^3/s
Influent solids capability: 5% maximum

Sludge Thickener
Number: 1
Dimensions: 14 m diameter, 2.5 m sidewater depth
Loading: 24 m^3/m^2-d @ 1.5% solids from clarifier at flow of 0.66 m^3/s
dry solids loading = 15 kg/m^3-h
Thickened sludge concentration: 8 to 15% solids

Thickened Sludge Pumps
Number: 3
Capacity: 5 liter/m at 18 m head each, variable speed
Influent solids capability: 18% maximum

Centrifuges
Number: 2
Capacity: 900 kg/hour each
Feed Rate: 3 to 6.6 liters/m

Recalcining Furnace
Number: 1,6 hearth
Dimensions: 6.8 m OD; 6.1 m ID
Capacity: 0.1 to 0.5 kg/s dry CaO
Scrubber: 3 stage jet impingement
Fuel: natural gas with propane standby

Lime Storage Bins
Number: 2
Capacity: 32 Mg each
Dimensions: 3.8 m diameter by 4.6 m storage depth (overall height = 8.7 m)

Carbon Dioxide Compressors
Number: 3
Capacity: 0.76 m^3/s (12% CO_2) each

TABLE A-1. (continued)

ACTIVATED CARBON REGENERATION

Regeneration Furnace

Number of furnaces: 1, 6 hearth
Dimensions: 2.8 m OD; 2.1 m ID
Capacity: 0.01 to 0.063 kg/s (dry basis)
Steam Addition: No. 4 and No. 6 hearths (optional); 1 kg steam per kg carbon
Air Pollution Control:
Fuel: natural gas with propane standby
Scrubber: Venturi followed by water separator
Afterburner: Vertical, refractory lined steel, 760°C at 0.5 seconds minimum gas retention time

Carbon Wash and Transfer Tanks

Number: 2
Dimensions: 1.5 m diameter by 3 m high
Equipped with bag dump and dust collector

Regenerated Carbon Wash Tanks

Number: 2
Dimension: 1.5 m diameter by 3 m high

Spent Carbon Dewatering Tanks

Number: 2 (open top)
Dimensions: 1.5 m x 1.5 m x 4.4 m high
Furnace feed system: 0.3 m diameter screw conveyor, stainless steel with capacity of 0.01 to 0.063 kg/s on a dry basis

Carbon Slurry Pumps (transfer carbon from regeneration furnace to carbon wash tanks)

Number:
Type: Diaphragm slurry, air operated, 7.6 cm suction and discharge
Capacity: 0.03 m^3/s max. with 4:1 turndown ratio

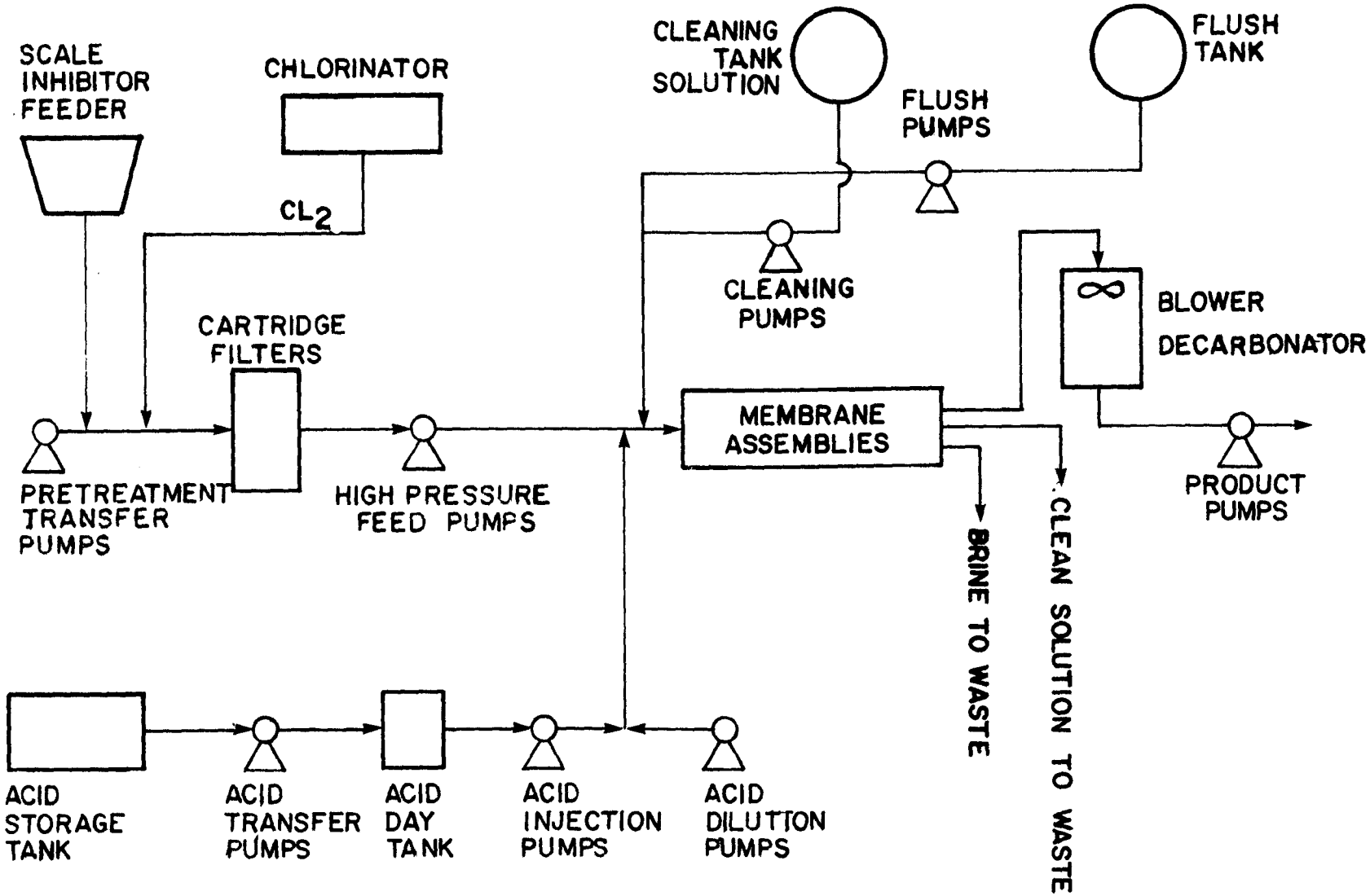

Figure A-1. Reverse Osmosis Plant Flow Diagram.

APPENDIX B

SUMMARY ANALYSES FOR GENERAL CONSTITUENTS, TRACE INORGANICS, RADIOACTIVITY AND PESTICIDES*

Table Number		Page
B-1	Summary Analyses for General Constituents, January through June 1976	72
B-2	Summary Analyses for General Constituents, October 1976 through June 1977	74
B-3	Summary Analyses for General Constituents, January 1976 through June 1977 (Entire Period of Study).	77
B-4	Summary Analyses for Trace Inorganics, January through June 1976	80
B-5	Summary Analyses for Trace Inorganics October 1976 through June 1977	82
B-6	Summary Analyses for Trace Inorganics, January 1976 through June 1977 (Entire Period of Study).	84
B-7	Radioactivity Analysis at Q9	86
B-8	Pesticide Analyses	87

*Description of sample locations referred to in tables are as follows: Q1, Influent; Q2, Clarifier Effluent; Q4, Ammonia Tower Effluent; Q6, Filter Effluent; Q8, Activated-Carbon Effluent; Q9, Chlorine Contact Basin Effluent; Q21A, Reverse Osmosis Influent; and Q21B, Reverse Osmosis Effluent.

TABLE B-1. SUMMARY ANALYSES FOR GENERAL CONSTITUENTS
January through June 1976

Constituent and Parameter	Location*					
	Q1	Q2	Q4	Q6	Q8	Q9
Ca, mg/l						
Mean	102	142				107
Std. dev.	10	29				23
Range	72-134	98-253				85-268
No. samples	90	90				87
Mg, mg/l						
Mean	25	1.0				
Std. dev.	1.5	1.0				
Range	20-29	0.1-5				
No. samples	70	68				
Na, mg/l						
Mean	209					205
Std. dev.	19					19
Range	178-284					173-261
No. samples	70					68
NH_3-N, mg/l						
Mean		43	19			
Std. dev.		10	5			
Range		27-100	10-36			
No. samples		84	75			
Cl, mg/l						
Mean	231					246
Std. dev.	20					23
Range	201-311					158-306
No. samples	90					87
SO_4, mg/l						
Mean	284					312
Std. dev.	45					39
Range	219-403					238-408
No. samples	90					87
Alkalinity, mg/l						
Mean	306					137
Std. dev.	35					26
Range	206-460					?
No. samples	89					86
B, mg/l						
Mean						0.63
Std. dev.						0.14
Range						0.3-1.1
No. samples						85

TABLE B-1 continued

TABLE B-1 (continued)

Constituent and Parameter	Location*					
	Q1	Q2	Q4	Q6	Q8	Q9
F, mg/l						
Mean						0.64
Std. dev.						0.16
Range						0.3-1
No. samples						86
PO_4-P, mg/l						
Mean	5.2	0.09				
Std. dev.	1.2	0.17				
Range	0-8	0.00-1.3				
No. samples	90	90				
EC, µS/cm						
Mean	1870					1470
Std. dev.	160					130
Range	1270-2540					980-1820
No. samples	85					82
pH						
Mean	7.6	11.4				6.7
Std. dev.	0.1	0.1				0.15
Range	7.4-8.1	11.2-11.7				6.3-7.2
No. samples	87	87				83
Turbidity, TU						
Mean	24	1.9				0.85
Std. dev.	8	1.6				0.38
Range	0-45	0-13				0-3
No. samples	89	89				86
COD, mg/l						
Mean	108	53		45	13	
Std. dev.	16	7		7	8	
Range	78-144	23-69		25-67	2-52	
No. samples	78	80		87	238	
TOC, mg/l						
Mean				15	7.3	
Std. dev.				4	2.6	
Range				8-31	3.5-20	
No. samples				82	238	
Org-N, mg/l						
Mean	1.6	1.1				0.6
Std. dev.	0.8	0.8				0.4
Range	0.5-5.3	0.2-4.8				0.2-2.6
No. samples	86	86				80

*Sample Locations: Q1, Influent; Q2, Clarifier Effluent; Q4, Ammonia Tower Effluent; Q6, Filter Effluent; Q8, Activated-Carbon Effluent; and Q9, Chlorine Contact Basin Effluent.

TABLE B-2. SUMMARY ANALYSES FOR GENERAL CONSTITUENTS
October 1976 through June 1977

Constituent and Parameter	Location*						
	Q1	Q2	Q6	Q8	Q9	Q21A	Q21B
Ca, mg/l							
Mean	110						
Std. dev.	22						
Range	59-148						
No. samples	37						
Mg, mg/l							
Mean	24	0.2					
Std. dev.	2	0.1					
Range	20-28	0.1-0.2					
No. samples	34	35					
Na, mg/l							
Mean	218					210	14
Std. dev.	31					27	6
Range	165-264					81-263	8-27
No. samples	34					113	114
NH_3-N, mg/l							
Mean	45	37			3.3		
Std. dev.	15	12			2.9		
Range	18-138	13-85			0.0-14		
No. samples	153	153			152		
Cl, mg/l							
Mean	258					277	18
Std. dev.	82					37	6
Range	191-737					179-523	10-42
No. samples	35					119	120
SO_4, mg/l							
Mean						248	1
Std. dev.						63	2
Range						150-500	< 1-22
Alkalinity, mg/l $CaCO_3$							
Mean			116				
Std. dev.			49				
Range			27-330				
No. samples			156				
B, mg/l							
Mean	1.0	0.84					
Std. dev.	0.2	0.21					
Range	0.7-1.8	0.1-1.6					
No. samples	34	34					

TABLE B-2 continued

TABLE B-2 (continued)

Constituent and Parameter	Location *						
	Q1	Q2	Q6	Q8	Q9	Q21A	Q21B
F, mg/l							
Mean							
Std. dev.							
Range							
No. samples							
PO_4-P, mg/l							
Mean	5.6	0.07					
Std. dev.	0.8	0.04					
Range	4-9	0.00-0.25					
No. samples	156	155					
TDS, mg/l							
Mean	1020						
Std. dev.	100						
Range	860-1260						
No. samples	51						
EC, µS/cm							
Mean	1850	2070				1530	88
Std. dev.	280	240				200	36
Range	1230-2700	1500-3100				620-1950	37-230
No. samples	177	179				108	118
pH							
Mean	7.5	11.5					
Std. dev.	0.2	0.2					
Range	6.5-7.9	11.6-11.9					
No. samples	165	183					
Turbidity, TU							
Mean	42	1.1					
Std. dev.	14	0.5					
Range	19-95	0.1-4					
No. samples	161	115					
COD, mg/l							
Mean	142	52	45	18		24	1.8
Std. dev.	37	11	7	7		14	1.5
Range	89-272	109-160	31-78	4-51		4-69	< 1-9
No. samples	160	160	160	159		118	. 119
TOC, mg/l							
Mean			13.8	6.7			
Std. dev.			2.9	2.2			
Range			0.5-28	2.5-14			
No. samples			111	117			

TABLE B-2 continued

TABLE B-2 (continued)

Constituent and Parameter	Location*						
	Q1	Q2	Q6	Q8	Q9	Q21A	Q21B
Org-N, mg/l							
Mean	8.3	3.9			1.26		
Std. dev.	2.0	1.5			0.48		
Range	5-23	1.7-10			0.0-3.8		
No. samples	157	157			156		
Phenol, µg/l							
Mean							
Std. dev.							
Range							
No. samples							
CN,							
Mean							
Std. dev.							
Range							
No. samples							
MBAS, mg/l							
Mean							
Std. dev.							
Range							
No. samples							

*Sample Locations: Q1, Influent; Q2, Clarifier Effluent; Q6, Filter Effluent; Q8, Activated-Carbon Effluent; Q9, Chlorine Contact Basin Effluent; Q21A, Reverse Osmosis Influent; and Q21B, Reverse Osmosis Effluent.

TABLE B-3. SUMMARY ANALYSES FOR GENERAL CONSTITUENTS
January 1976 through June 1977 (Entire Period of Study)

Constituent and Parameter	Location*				
	Q1	Q2	Q4	Q6	Q8
Ca, mg/l					
Mean	104				
Std. dev.	15				
Range	59-148				
No. Samples	127				
Mg, mg/l					
Mean	25	0.7			
Std. dev.	1.7	0.9			
Range	20-29	0.1-5			
No. samples	104	103			
Na, mg/l					
Mean	212				
Std. dev.	24				
Range	165-284				
No. samples	104				
NH_3-N, mg/l					
Mean		39			
Std. dev.		12			
Range		13-100			
No. samples		237			
Cl, mg/l					
Mean	239				
Std. dev.	48				
Range	191-737				
No. samples	125				
SO_4, mg/l					
Mean					
Std. dev.					
Range					
No. samples					
Alkalinity, mg/l					
Mean					
Std. dev.					
Range					
No. samples					
B, mg/l					
Mean					
Std. dev.					
Range					
No. samples					

TABLE B-3 continued

TABLE B-3 (continued)

Constituent and Parameter	Location*				
	Q1	Q2	Q4	Q6	Q8
F, mg/l					
Mean					
Std. dev.					
Range					
No. samples					
PO_4-P, mg/l					
Mean	515	0.08			
Std. dev.	1.0	0.11			
Range	0-9	0.0-1.3			
No. samples	246	245			
TDS, mg/l					
Mean					
Std. dev.					
Range					
No. samples					
EC, µS/cm					
Mean	1860				
Std. dev.	250				
Range	1230-2700				
No. samples	262				
pH					
Mean	7.5	11.5			
Std. dev.	0.2	0.2			
Range	6.5-8.1	11.2-11.7			
No. samples	252	270			
Turbidity, TU					
Mean	36	1.4			
Std. dev.	15	1.2			
Range	0-95	0-13			
No. samples	250	204			
COD, mg/l					
Mean	131	52	45	15	
Std. dev.	35	10	7	8	
Range	78-272	20-109	25-78	2-52	
No. samples	238	240	247	397	
TOC, mg/l					
Mean			14	7.1	
Std. dev.			3	2.5	
Range			0.5-31	2.5-20	
No. samples			193	355	

TABLE B-3 continued

TABLE B-3 (continued)

Constituent and Parameter	Location*				
	Q1	Q2	Q4	Q6	Q8
Org-N, mg/l					
Mean	5.9	2.9			
Std. dev.	3.6	1.9			
Range	0.5-23	0.2-10			
No. samples	243	243			
Phenol, μg/l					
Mean					
Std. dev.					
Range					
No. samples					
CN					
Mean					
Std. dev.					
Range					
No. samples					
MBAS, mg/l					
Mean					
Std. dev.					
Range					
No. samples					

*Sample Locations: Q1, Influent; Q2, Clarifier Effluent; Q4, Ammonia Tower Effluent; Q6, Filter Effluent; and Q8, Activated-Carbon Effluent.

TABLE B-4. SUMMARY ANALYSES FOR TRACE INORGANICS
January through June 1976

Constituent and Parameter	Location*			
	Q1	Q2	Q6	Q8
As, μg/l				
Mean	2.5	1.1	1.1	1.1
Std. dev.	1.1	0.7	0.4	0.3
Range	1-5.5	0-2.8	0.7-2.8	0.5-2.5
No. samples	74	74	71	76
Ba, μg/l				
Mean	81	41	32	33
Std. dev.	21	22	22	23
Range	33-134	20-120	8-93	11-97
No. samples	74	74	71	76
Cd, μg/l				
Mean	9	2.9	2.5	2.2
Std. dev.	6	1.7	1.6	1.8
Range	4-30	0.7-10	0.7-8	0.6-7.8
No. samples	74	74	71	76
Cr, μg/l				
Mean	192	88	84	48
Std. dev.	86	51	45	32
Range	76-582	16-289	16-228	3-128
No. samples	74	74	71	76
Cu, μg/l				
Mean	285	93	88	27
Std. dev.	67	28	24	14
Range	152-436	29-172	32-164	5-80
No. samples	74	74	71	76
Fe, μg/l				
Mean	179	17	40	45
Std. dev.	68	11	25	67
Range	58-398	6-53	15-185	18-309
No. samples	74	74	71	76
Pb, μg/l				
Mean	40	23	22	26
Std. dev.	77	39	31	32
Range	10-650	6-359	6-213	6-174
No. samples	74	74	71	76
Mn, μg/l				
Mean	35	1.5	2.3	4.1
Std. dev.	10	1.5	1.1	1.4
Range	14-75	0.3-9	0.6-9	1.5-9
No. samples	74	74	71	76

TABLE B-4 continued

TABLE B-4 (continued)

Constituent and Parameter	Location*			
	Q1	Q2	Q6	Q8
Hg, μg/l				
Mean	1.2	0.9	1.2	4.9
Std. dev.	3.4	2.2	3.2	21
Range	0.1-20	0.1-15	0.1-16	0.2-168
No. samples	54	54	51	56
Se, μg/l				
Mean	6.2	6.5	6.3	6.4
Std. dev.	2.9	3.5	3.3	3.5
Range	2-13	2-17	2-14	2-22
No. samples	74	74	72	76
Ag, μg/l				
Mean	13	8	12	14
Std. dev.	52	33	64	58
Range	2-423	1-234	0.3-516	0.0-457
No. samples	57	57	54	59
Zn, μg/l				
Mean	300	29	670	124
Std. dev.	210	84	320	72
Range	140-1930	5-740	150-2400	12-536
No. samples	74	74	71	76

*Sample Locations: Q1, Influent; Q2, Clarifier Effluent; Q6, Filter Effluent; and Q8, Activated-Carbon Effluent.

TABLE B-5. SUMMARY ANALYSES FOR TRACE INORGANICS
October 1976 through June 1977

Constituent and Parameter	Location*			
	Q1	Q2	Q6	Q8
As, µg/l				
Mean	3.3	2.5	1.8	2.4
Std. dev.	1.2	1.7	1.2	1.8
Range	1.5-5.0	0.0-5.0	0.0-5.0	0.0-5.0
No. samples	27	27	27	27
Ba, µg/l				
Mean	81	36	31	31
Std. dev.	26	21	19	22
Range	40-177	15-114	10-97	12-114
No. samples	26	26	26	26
Cd, µg/l				
Mean	29	2.4	1.8	1.7
Std. dev.	16	1.6	1.0	1.7
Range	12-97	0.3-8.4	0.3-5.4	0.3-9.8
No. samples	32	32	32	32
Cr, µg/l				
Mean	154	37	41	26
Std. dev.	76	25	39	24
Range	62-490	9-111	8-219	4-112
No. samples	33	33	33	33
Cu, µg/l				
Mean	266	73	49	32
Std. dev.	87	25	34	15
Range	130-470	19-112	3-114	6-69
No. samples	27	27	27	27
Fe, µg/l				
Mean	325	40	207	66
Std. dev.	156	45	275	77
Range	51-779	4-216	12-1520	12-449
No. samples	33	33	33	33
Pb, µg/l				
Mean	19	3.6	8.0	5.3
Std. dev.	11	2.5	15.5	12.5
Range	3-62	0.6-11	0.2-71	0.1-72
No. samples	26	26	26	27
Mn, µg/l				
Mean	35	4.4	6.2	4.9
Std. dev.	13	9.2	7.5	4.4
Range	9-98	0.2-45	0.3-34	0.3-26
No. samples	33	33	33	33

TABLE B-5 continued

TABLE B-5 (continued)

Constituent and Parameter	Location*			
	Q1	Q2	Q6	Q8
Hg, μg/l				
Mean	9	2.6	3.6	6.7
Std. dev.	30	2.0	7.7	13.8
Range	0.1-177	0.7-11	0.6-46	0.3-57
No. samples	26	20	26	13
Se, μg/l				
Mean	< 2.5	< 2.5	< 2.5	< 2.5
Std. dev.				
Range	< 2.5	< 2.5	< 2.5	< 2.5
No. samples	30	33	33	33
Ag, μg/l				
Mean	5.5	0.8	1.3	1.5
Std. dev.	1.4	0.6	1.6	2.8
Range	1.8-8	0.1-2.3	0.0-7.2	0.0-15
No. samples	21	16	21	21
Zn, μg/l				
Mean	380	239	412	162
Std. dev.	130	105	328	78
Range	130-830	20-512	70-1980	20-304
No. samples	27	17	27	23

*Sample Locations: Q1, Influent; Q2, Clarifier Effluent; Q6, Filter Effluent; and Q8, Activated-Carbon Effluent.

TABLE B-6. SUMMARY ANALYSES FOR TRACE INORGANICS
January 1976 through June 1977 (Entire Period of Study)

Constituent and Parameter	Location*				
	Q1	Q2	Q4	Q6	Q8
As, µg/l					
Mean	2.7	1.5		1.3	1.4
Std. dev.	1.2	1.2		0.8	1.1
Range	1-5.5	0.0-5		0.0-5	0.0-5
No. samples	101	101		98	103
Ba, µg/l					
Mean	81	40		32	32
Std. dev.	22	22		21	23
Range	33-177	15-120		8-97	11-114
No. samples	100	100		97	102
Cd, µg/l					
Mean	15	2.7		2.3	2.1
Std. dev.	14	1.7		1.5	1.8
Range	4-97	0.3-10		0.3-8	0.3-9.8
No. samples	106	106		103	108
Cr, µg/l					
Mean	180	72		70	41
Std. dev.	85	50		47	31
Range	62-582	9-289		8-228	3-128
No. samples	107	107		104	109
Cu, µg/l					
Mean	280	88		77	28
Std. dev.	73	29		32	14
Range	130-470	19-172		3-164	5-80
No. samples	101	101		98	103
Fe, µg/l					
Mean	224	24		93	121
Std. dev.	123	28		173	79
Range	51-779	4-216		12-1520	12-449
No. samples	107	107		104	109
Pb, µg/l					
Mean	35	18		18	21
Std. dev.	67	35		28	30
Range	3-650	1-359		0.2-213	0.1-174
No. samples	100	100		97	103
Mn, µg/l					
Mean	35	2.4		3.5	4.3
Std. dev.	11	5.4		4.7	2.7
Range	9-98	0.2-4.5		0.3-34	0.3-26
No. samples	107	107		104	109

TABLE B-6 continued

TABLE B-6 (continued)

Constituent and Parameter	Location*				
	Q1	Q2	Q4	Q6	Q8
Hg, μg/l					
Mean	4	1.2		2.0	5
Std. dev.	17	2.3		5.2	20
Range	0.1-177	0.1-15		0.1-46	0.2-168
No. samples	80	74		77	69
Se, μg/l					
Mean	5	5		5	5
Std. dev.	3	3		3	3
Range	< 2-13	< 2-17		< 2-14	< 2-22
No. samples	104	107		105	109
Ag, μg/l					
Mean	11	6		9	10
Std. dev.	44	29		54	50
Range	2-423	0.1-234		0-516	0-457
No. samples	78	73		75	80
Zn, μg/l					
Mean	321	68		600	133
Std. dev.	195	120		340	75
Range	130-1930	5-740		50-2400	12-536
No. samples	101	91		98	99

*Sample Locations: Q1, Influent; Q2, Clarifier Effluent; Q4, Ammonia Tower Effluent; Q6, Filter Effluent; and Q8, Activated-Carbon Effluent.

TABLE B-7. RADIOACTIVITY ANALYSIS OF EFFLUENT (Q9)

Sample Date	Gross Alpha Activity pCi/l	Gross Beta Activity pCi/l
Jan. 31, 1976	0.6 ± 1.5	28 ± 8
Feb. 5	0.0 ± 1.2	28 ± 8
Feb. 9	0.6 ± 1.9	25 ± 11
Feb. 26	0.3 ± 1.3	22 ± 10
Mar. 4	0.0 ± 1.8	20 ± 10
Mar. 11	0.0 ± 1.6	22 ± 10
Apr. 15	0.0 ± 0.5	29 ± 9
Apr. 22	0.1 ± 1.0	20 ± 9
Apr. 29	0.0 ± 0.4	28 ± 10
May 6	0.5 ± 0.9	41 ± 10
May 13	0.0 ± 0.8	40 ± 11
May 20	0.1 ± 0.9	42 ± 11
June 3	0.0 ± 0.5	31 ± 11
June 17	0.7 ± 2.0	38 ± 11
June 24	2.2 ± 1.8	23 ± 11
July 1	0.0 ± 0.5	44 ± 11
July 15	0.6 ± 1.0	50 ± 9
July 22	0.1 ± 0.8	51 ± 10
Oct. 14	0.0 ± 1.8	49 ± 19
Oct. 21	0.0 ± 2.0	63 ± 20

TABLE B-8. PESTICIDE ANALYSES

Pesticides Evaluated and Concentration Limit:

Pesticide	Concentration above which pesticide not found in any sample, μg/l
BHC	0.01
Lindane	0.01
Heptachlor	0.01
Aldrin	0.01
DDE	0.01
Dieldrin	0.01
Endrin	0.01
DDT	0.1
Methoxychlor	0.1

Number and Location of Samples Analyzed for Pesticides:

Sampling Period	Q1	Q2	Q6	Q9
January through June 1976	3		1	9
October 1976 through June 1977	10	10	8	19

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-78-076	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE WATER FACTORY 21: RECLAIMED WATER, VOLATILE ORGANICS, VIRUS, AND TREATMENT PERFORMANCE		5. REPORT DATE June 1978 (Issuing Date)
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Perry L. McCarty, Martin Reinhard, Carla Dolce, Huong Nguyen, and David G. Argo		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Civil Engineering, Stanford University, Stanford, California 94305		10. PROGRAM ELEMENT NO. 1BC611
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15. SUPPLEMENTARY NOTES
Project Officer: John N. English 513/684-7613

16. ABSTRACT
This report describes the performance of Water Factory 21, a 0.66 m^3/s advanced wastewater treatment plant designed to reclaim secondary effluent from a municipal wastewater treatment plant so that it can be used for injection and recharge of a groundwater system. Included in this evaluation of the first one and one-half years of performance are summary data for general inorganics, heavy metals, virus, and a broad range of organic materials. Processes included in the plant are lime treatment, ammonia stripping, breakpoint chlorination, filtration, activated-carbon adsorption, reverse osmosis, and final chlorination. The performance of individual processes as well as overall efficiency was evaluated.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Waste Treatment Water Reclamation Nutrients Viruses Organic Compounds Potable Water Microorganisms Treatment	Reuse Heavy Metals Haloforms Trihalomethanes Advanced Wastewater	13B

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