SEQUENTIAL USE OF RECLAIMED WASTEWATER DESTINED FOR AQUIFER RECHARGE

by

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ABSTRACT

Effluent from the advanced wastewater treatment plant in St. Croix, U.S. Virgin Islands, a water-deficient island, was used to recharge aquifers by use of spreading basins. Wells in the recharge area were monitored to determine changes in static levels and in quality. Results indicate an increase in the quantity of water in the aquifer and an upgrading in the quality of the effluent. An economic analysis showed the cost of recharge/recovery operations to be significantly less than the cost of desalination of sea water which supplies the major portion of water to the island.

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INTRODUCTION AND OVERVIEW

The U.S. Virgin Islands are located about 1,400 miles southeast of New York, 1,100 miles east-southeast of Miami and about 50 miles east of Puerto Rico (Figure I). The Virgin Islands are part of the Lesser Antilles of the West Indies which separate the Caribbean Sea from the Atlantic Ocean. St. Croix, the island on which this study takes place, is the largest (about 84 square miles) and southernmost of the Virgin Islands.

Potable water is not an abundant resource in St. Croix or any of the Virgin Islands. Average rainfall is about 44 inches per year, streamflow is mostly ephemeral and high temperatures along with constant tradewinds cause about 90 percent of the rainfall to be lost to evapotranspiration. Aquifers are small and limited.

While water consumption on St. Croix has been increasing due to population and life style changes, water production has not kept pace. Desalting of sea water accounts for about 60 percent of the water supply, ground water provides about 20 percent, rainwater stored in cisterns accounts for about 13 percent and the remaining 7 percent is usually attributed to recycled water. The high cost of desalting, about $15 per thousand gallons, and the increasing unreliability of the desalination plants have increased the importance of water conservation as well as the development of alternative sources of water.

With development of an alternative source in mind, this project was undertaken. The objectives of this study as proposed originally were to determine to what degree the use of advanced tertiary treated wastewater for (a) culture of fish for food, (b) trickle irrigation of vegetables and row crops, (c) spreading for irrigation of grasslands or (d) other related purposes might affect both the quality and quantity of wastewater for recharge.

Due to unforeseen circumstances, several of the proposed areas of study could not be addressed. However, some recharging was done and records were kept of the amount of rainfall and quantity of advanced treated water recharged and the quality of this water. Also monitored were several wells in the vicinity of the recharge area. Records of static water levels and several biological and chemical quality parameters of these wells were maintained. Interpretation of the data collected should provide some indication as to the effectiveness of aquifer recharge in St. Croix.

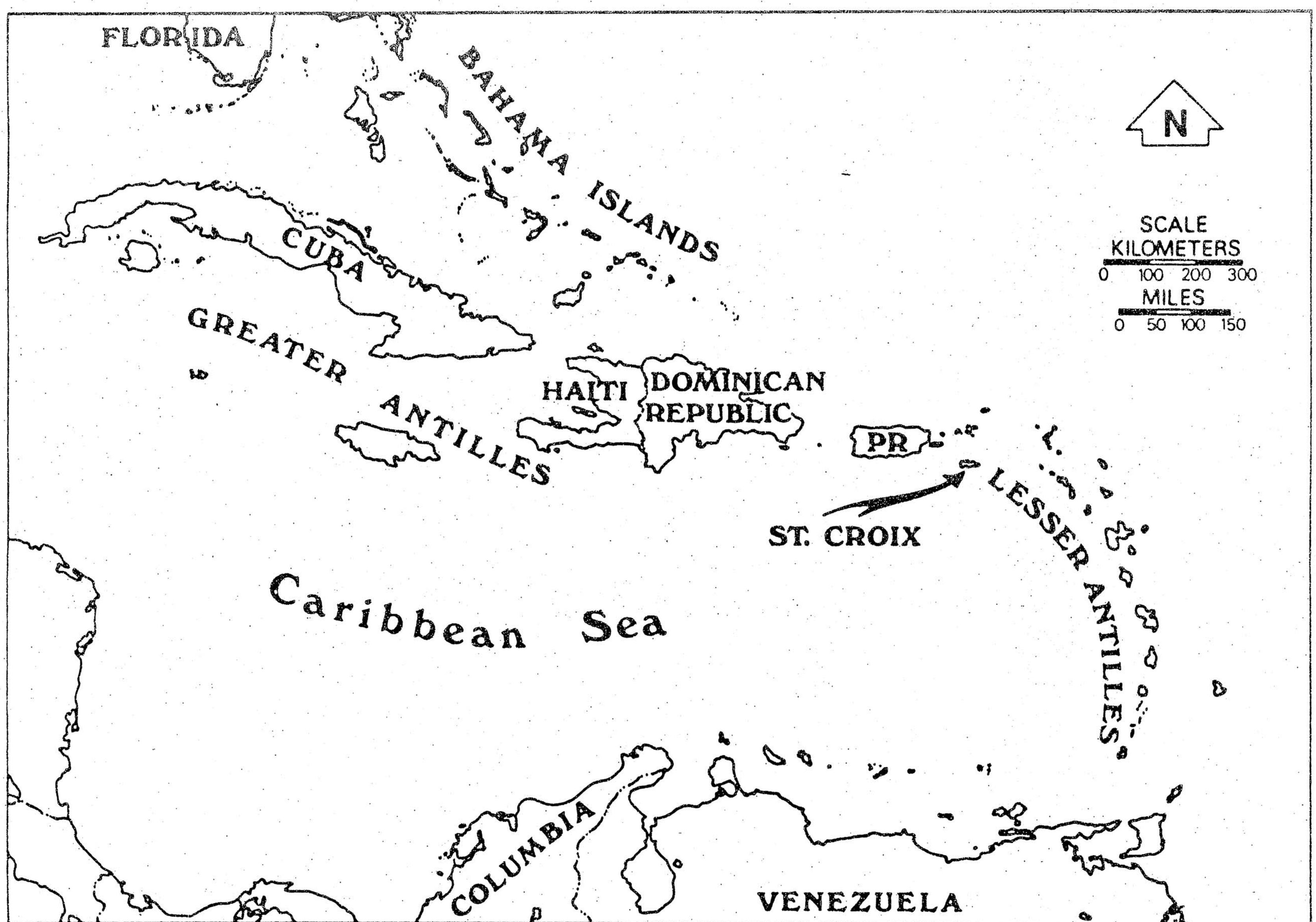


Figure I Location of St. Croix, U.S. Virgin Islands

(Buros: 1976a)

THE ADVANCED WASTEWATER TREATMENT PLANT

The source of water for recharge was the 0.5 million gallon per day (mgd) Advanced Wastewater Treatment Plant (AWWTP) at Estate Bethlehem Middle Works. The AWWTP receives effluent diverted from the primary treatment plant. It enters the aeration tanks at the AWWTP where colloidal and dissolved organic matter converts into larger microorganisms which can be mechanically removed. Large surface turbines stir and aerate the water to permit the microorganisms to metabolize the organic matter. In the clarifier the mixture of microorganisms from the aeration tanks is separated by gravity. The clear water flows to the solids contact tank where chemicals are added to the water to produce a floc which removes remaining particulate matter by increasing their size so that they settle out or are caught on the multi-media sand anthracite filters, which filter the water after it leaves the solids contact tank. After the sand-anthracite filter, the water enters the chlorine contact chamber and chlorine is added for disinfection before distribution to the recharge areas.

HYDROGEOLOGICAL BACKGROUND

The treated effluent was used in recharging two geologically dissimilar areas. Both of these areas, Negro Bay and Golden Grove, contain several wells, are relatively close to the AWWTP, are on government-owned land and are accessible for ready observation. These similarities as well as their differences made them ideal study locations.

In the Golden Grove area alluvial materials overlay the Kingshill Marl and fill an intermittent stream channel. This alluvium has a maximum thickness of 70 feet. It consits predominantly of montmorillonitic clay of low permeability with generally three or four water-bearing lenses of sandy-gravel material, each having a maximum thickness of five feet. Though these aquifers appear to be continuous throughout reaches of the stream valley, they are not interconnected except by wells which penetrate two or more of the lenses. The piezometric surface shows the water to be confined in the aquifers and a free water table does not exist. The ground surface in the Golden Grove recharge area is about 50 feet above sea level while the aquifers range between 35 feet above sea level to approximately sea level.

The Kingshill Marl in the Negro Bay area consists of coral debris and beds of sandy clay alternating with nearly pure limestone. In the recharge area the thickness of the marl is about 160 feet and the ground water level is about 80 feet below the surface. Solution channels are common and probably afford communication and infiltration throughout most of the thickness of the marl. However, at a depth of 10 feet below the surface, a dense and apparently impermeable bed occurs at the recharge site. Above this dense layer, the marl is permeable and capable of a high rate of infiltration. These conditions suggest that water will move into the upper 10 feet of the formation for storage and future recovery. Because of the depth to the permanent water table and the nature of the formation, no direct mixing of the wastewater and ground water was envisioned.

A yearly average of 44 inches of rain falls on St. Croix of which an estimated 90 percent is lost to evapotranspiration, about 6 percent becomes runoff and 4 percent recharges the ground water. Since the aquifer at Negro Bay is exposed at the surface, rainfall was expected to have some effect on direct recharge. The Golden Grove site is within a broad alluvial valley where infiltration from an area of some six square miles upstream from the recharge site contributes to the ground water source.

PROCEDURE

Spreading basins and spray irrigation were used in the recharge operations. In Golden Grove six basins, each having a bottom area of 10,000 square feet, were used on a rotating basis in order to maintain a wet-dry cycle. The basins were excavated earthen ponds planted with Bermuda grass to promote bank stabilization, nutrient removal and percolation. Throughout the project, a water depth of approximately 3.5 feet was maintained to permit natural surface aeration while minimizing evaporation losses and providing adequate head for rapid infiltration and percolation. Periodically, accumulated silt was scraped from the basin surface to maintain good infiltration rates.

In the Negro Bay recharge area, two smaller spreading basins were used. Each basin had a bottom area of approximately 2,500 square feet. In addition to spreading basins, water was also recharged at Negro Bay by spray irrigation. The spray irrigation area was approximately 80,000 square feet.

Recharging operations began in February 1974. Both quantity of water recharged and rainfall at the sites were monitored. Monthly records were also kept of the static well levels and several quality parameters of the effluent as well as the well water.

Wells used to monitor the effects of the recharge operations were located in the recharge areas while several wells in the vicinity not expected to be affected by recharging were monitored to serve as controls. The locations of the recharge areas and wells monitored are shown in Figure II.

RESULTS AND DISCUSSION

The recharge facility was initially in operation from February 1974 until October 1974. In June 1974 operations were interrupted due to failure of one of the effluent pumps. In October the Frederiksted service area was connected to the treatment plant. This resulted in recharge operations being halted because the town of Frederiksted, with its saltwater flush and fire fighting system, introduced about 0.08 mgd of saltwater causing a significant rise in the total dissolved solids (TDS) in the treated wastewater. Prior to this, the treatment facility serviced only the mid-island area of St. Croix. By March 1976, the saltwater system in Frederiksted was converted to potable water and recharge operations continued. In April 1976, the effluent force main was broken but recharge operations resumed in May. In August 1977 the Christiansted collection system was completed and connected to the treatment facility. Again, high chlorides in the effluent necessitated the suspension of the project.

Artificial recharging in the Negro Bay area was discontinued after August 1974 because the soil is unfavorable for recharge basin structures. During dry periods almost all of the water applied was lost to evapotranspiration and there was no buildup in the ground water.

Most recently a splitter box, designed to separate the Christiansted waste stream with its high chloride concentration from the other waste streams with an acceptable level of chloride, was installed at the reclamation plant. It is expected that recharging will resume shortly.

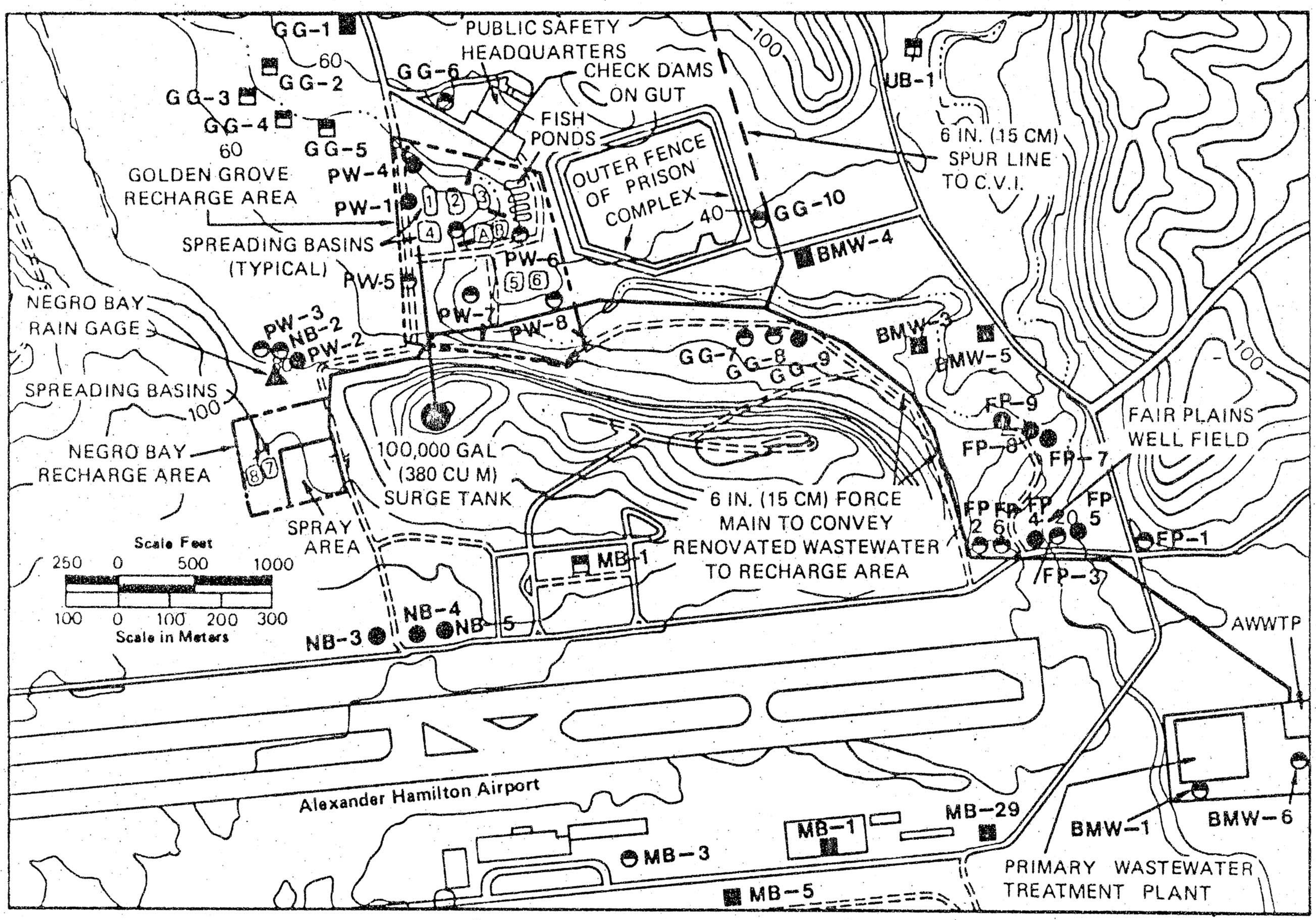


Figure II Project Location and Facilities

(Buros: 1976b)

An estimate of the amount of recharge water reaching the ground water during the 16-month period from March 1976 to July 1977 may be made. During this period 53.31 million gallons of effluent were applied to the recharge areas. Since the six spreading basins were used on a rotating basis, we will assume that at any given time half of the basins (30,000 sq. ft.) were covered with water. To determine the depth of water applied over the 16-month period it is first necessary to convert the total water applied to cubic feet.

53,310,000 gals. x 0.134 cu. ft./gal. = 7,143,540 cu. ft.

The depth of water over the area then is:

7,143,540 cu. ft. ÷ 30,000 sq. ft. = 238.12 ft.

The rainfall at the area must be considered. For this very rough estimate, the Virgin Islands average rainfall of 44 inches per year will be used. For a 16-month period this amounts to 4.89 ft. Depth of water added to the area then becomes:

238.12 ft. + 4.89 ft. = 243.01 ft.

According to Bowden (1968) the annual pan evaporation in the Virgin Islands is 70 inches (5.83 feet) or 7.78 feet in 16 months. This amount lost must be subtracted from the depth of water added.

243.01 ft. - 7.78 ft. = 235.23 ft.

Over the recharge area of 30,000 square feet this amounts to 7,056,900 cubic feet or 52,785,612 gallons. In the 16-month period during which 53.31 million gallons of water was recharged, assuming normal rainfall and evaporation, approximately 52.79 million gallons of water were added to the ground water in the recharge area.

Figures III-VII illustrate the effects of the recharge operations on the static well levels for 1976 and 1977. From the map of the site, Figure II, it can be seen that well PW-8

Figure III

Effect of Recharge Operations on Project Well PW-8

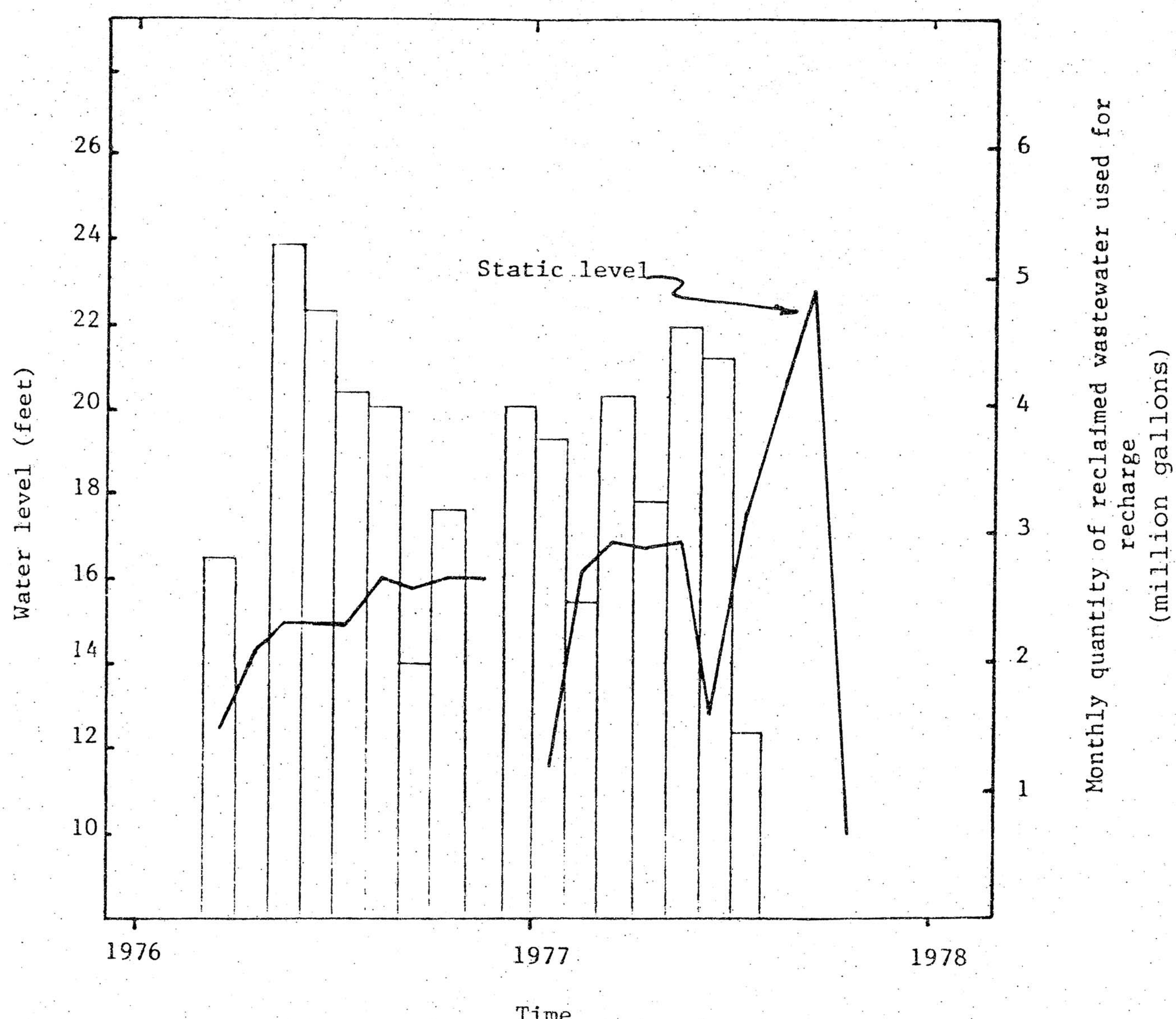


Figure IV

Effect of Recharge Operations on Project Well PW-9

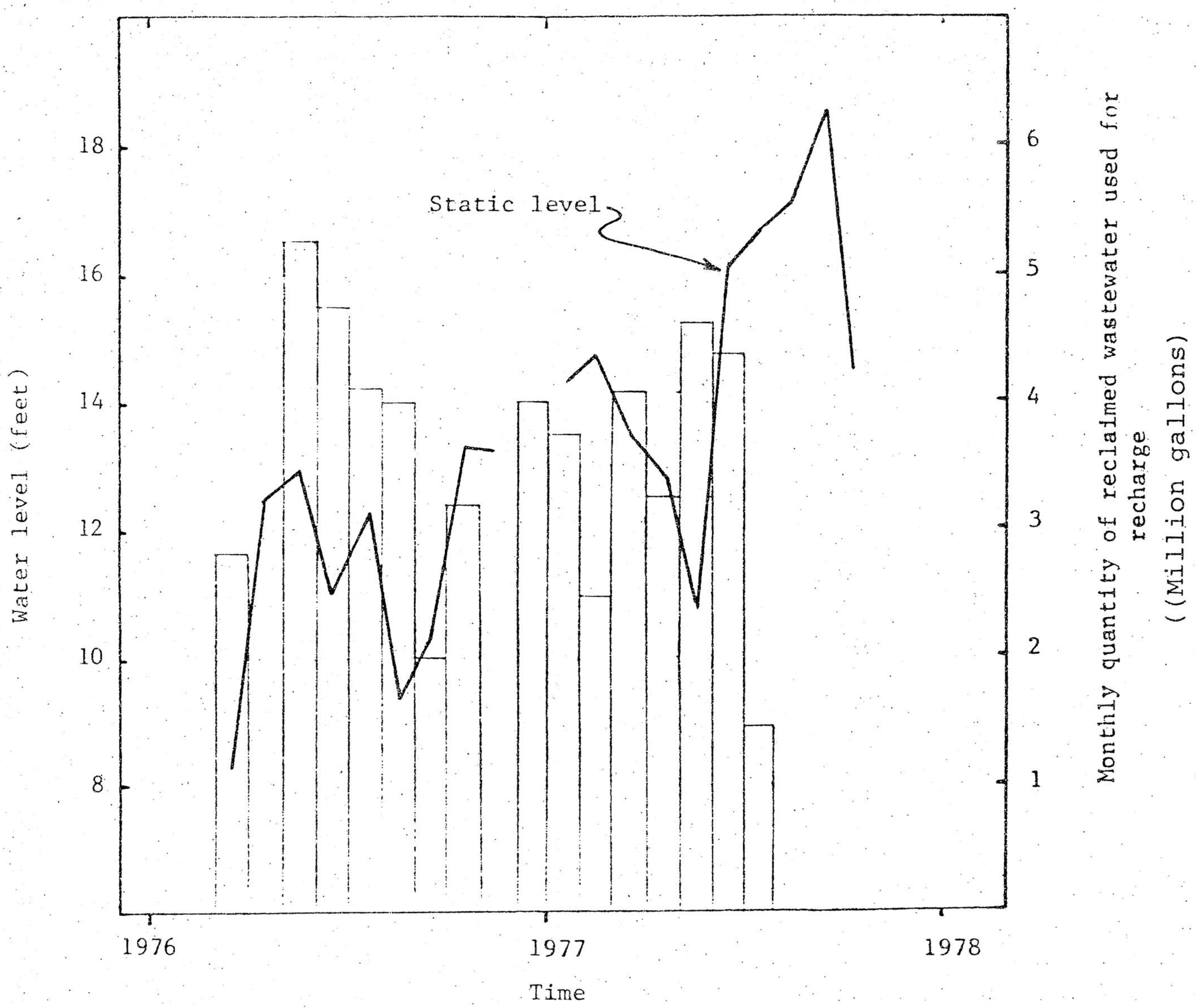


Figure V

Effect of Recharge Operations on Control Well A-18

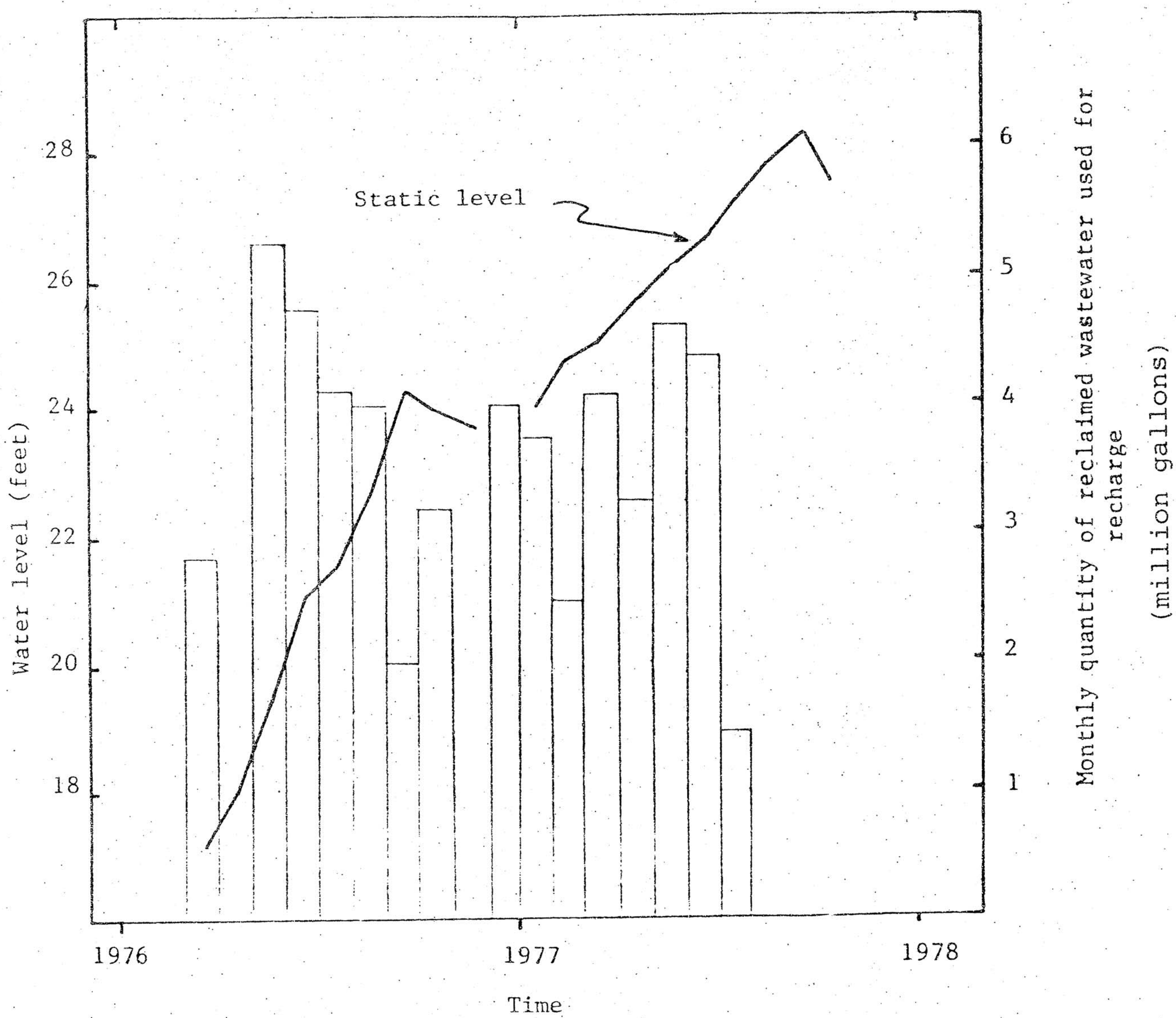


Figure VI

Effect of Recharge Operations on Control Well GG-7

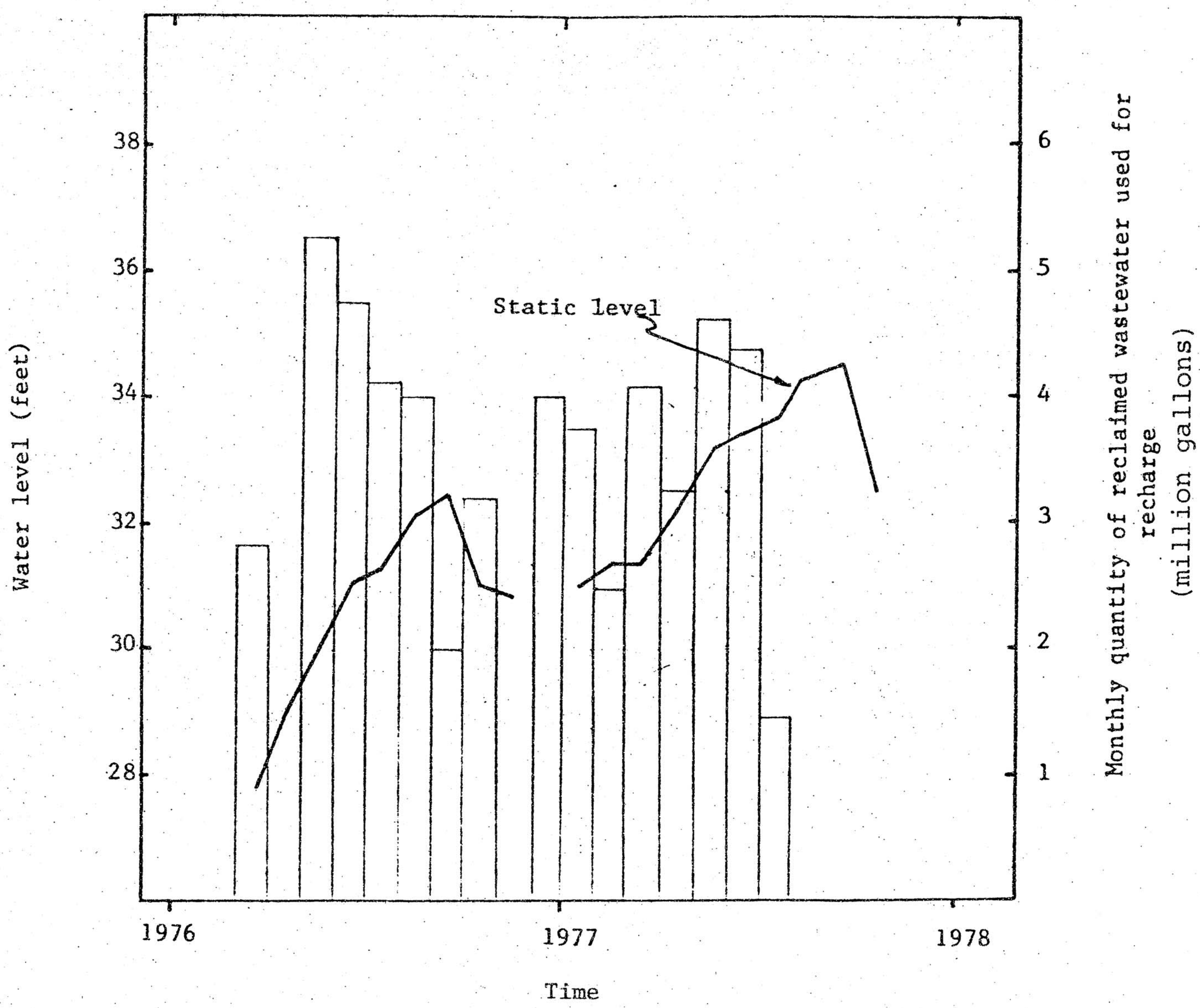
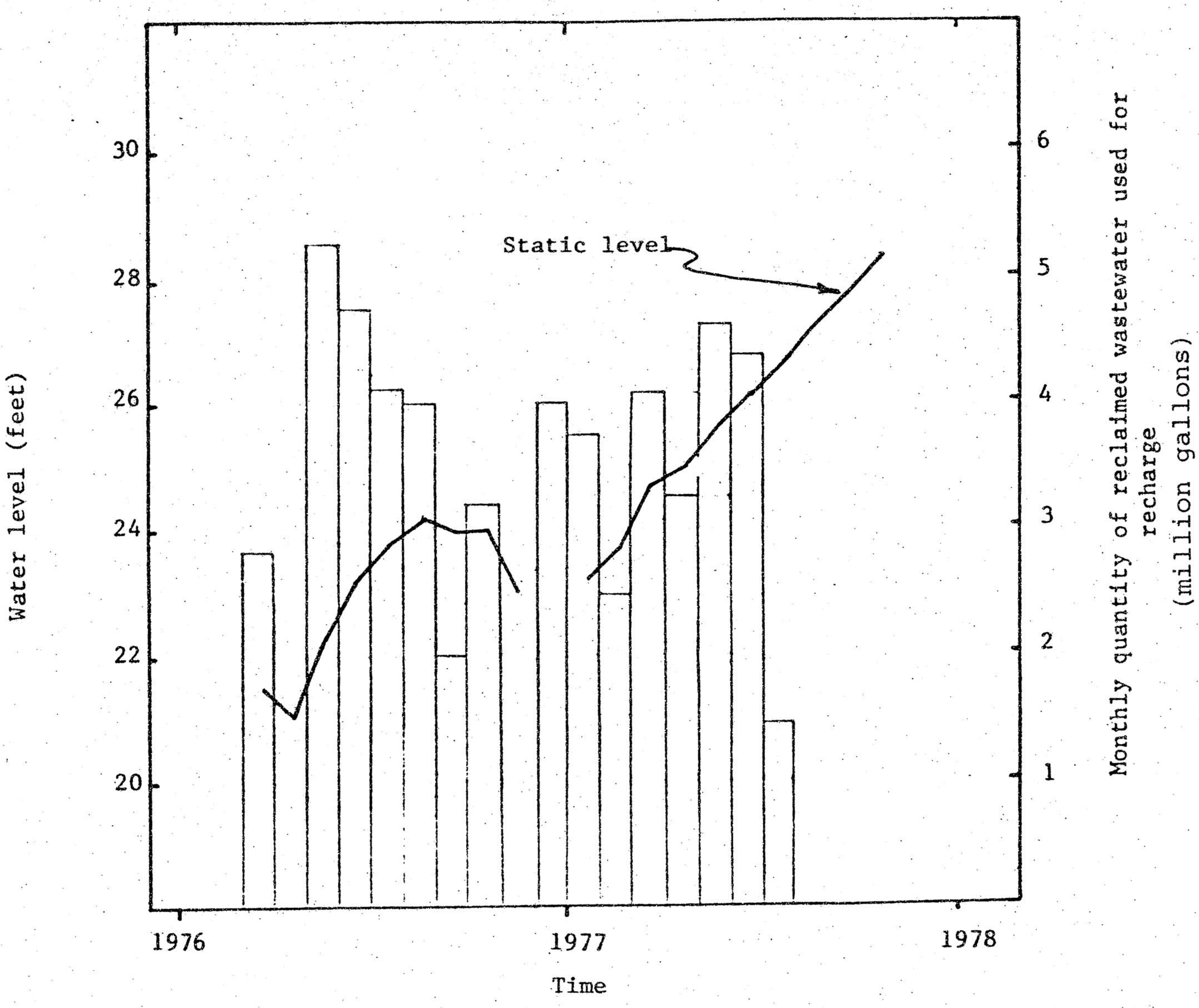


Figure VII

Effect of Recharge Operations on Control Well FP-2



and PW-9 are located in the Golden Grove recharge area and are expected to be influenced by the recharging while wells A-18, GG-7 and FP-2 should not be affected. Well A-18 is about 3,500 feet above the recharge area while wells GG-7 and FP-2 are below the recharge area. The curves of the static well levels of the control wells (A-18, GG-7 and FP_ 2) approximate the same shape showing the influence of rainfall during the project period. Rainfall for 1976 and 1977 is plotted in Figure VIII.

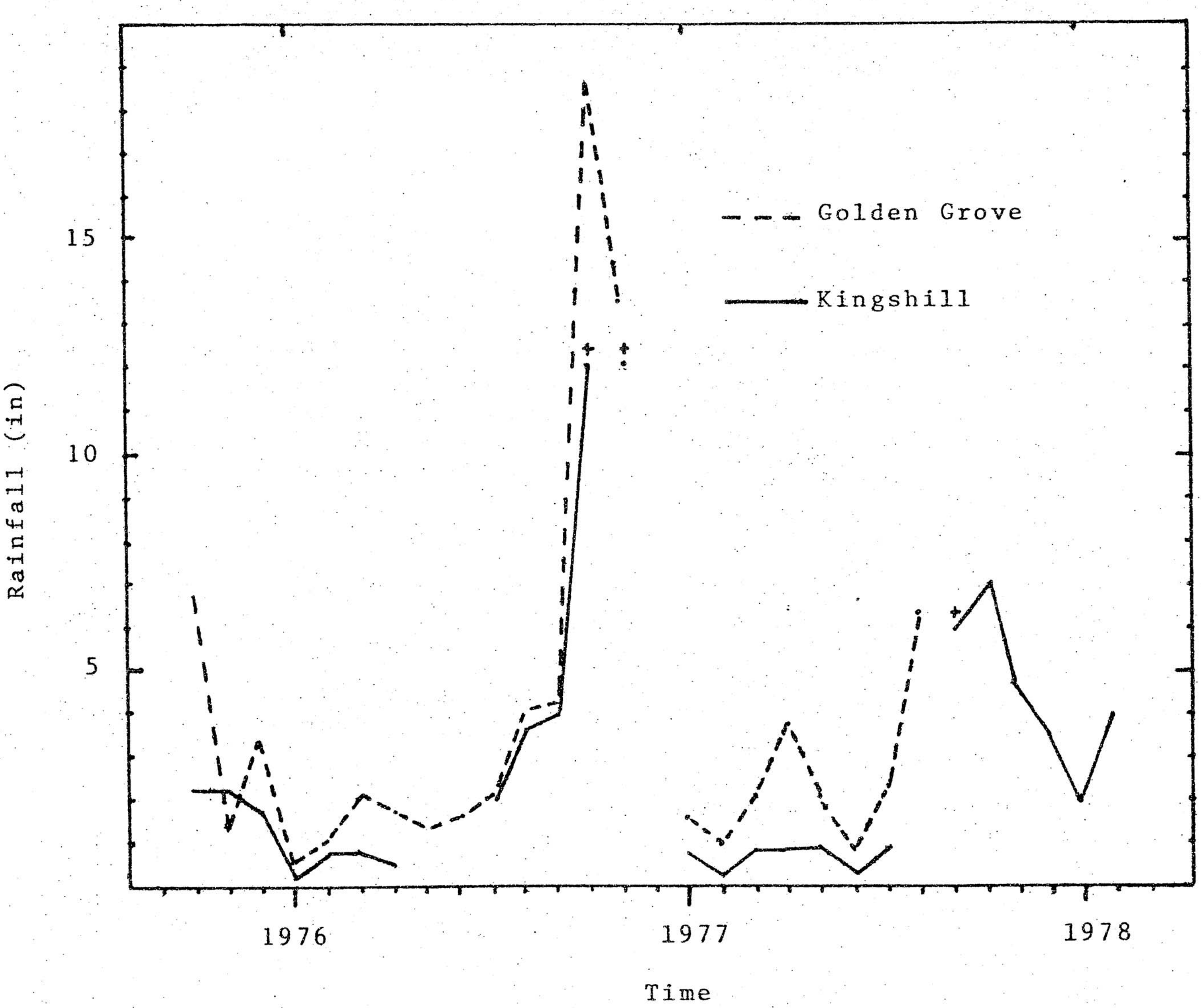
It is worthwhile to look in detail at two of the most significant quality parameters. Figure IX shows a comparison of chloride levels in the treated effluent and in samples obtained from the project wells PW-1 and PW-4. Table I lists these levels as well as those for the control wells A-16 and FP-8. The mean level of chlorides observed in the treated effluent was 417 mg/l while in PW-1 and PW-4 the mean levels were 285 and 281 mg/l respectively. Unfortunately, data was not collected prior to the start of the recharging operations so it is not possible to say definitely if and to what degree recharging of treated effluent raised or lowered chloride levels in the project wells. The control wells, A-16 and FP-8, showed average chloride of 163 and 582 mg/l respectively. This at least permits the conclusion to be made tha the chloride levels in wells in the recharge area are not higher or lower than the chloride levels of wells not in the recharge area.

Another interesting parameter to examine is nitrates. While the effluent had an average nitrate level of 17.5 mg/l, the average levels of nitrate in wells PW-1 and PW-8 were significantly lower at 3.8 and 2.6 mg/l respectively. This occurrence, reduction in nitrate levels of recharge water, has been observed elsewhere (Clark, 1977:765) and has been attributed to denitrification mainly by the vegetative cover of the ground surface. Figure X graphs the nitrate levels in the effluent and in the observation wells PW-1 and PW-4.

Table II through Table V show the characteristics of the effluent used for recharging, the water of the three wells in the project area (PW-1, PW-4 and PW-8) as well as the water of control wells A-16, FP-8 and GG-8. In many instances the water obtianed from the project wells was of better quality than the water used for recharging or water form the control wells.

The costs associated with the production and recovery of reclaimed water by ground water recharge are listed in Table VI. The total cost (production and recovery) of reclaimed

Figure VIII



Monthly rainfall data for Golden Grove and Kingshill in St. Croix from September 1975 to February 1978

TABLE I

Chloride Levels[a] Observed in Reclamation Project

	Effluent	PW-1[b]	PW-4[b]	A-16[c]	FP-8[c]
Sept. 1976	326	300	300	160	610
Oct.	390	310	270	150	560
Nov.	327	300	280	160	310
Dec.	365	300	290		
Jan. 1977	366	320	310		
Feb.	396	270	270	185	480
March	426	300	305		600
April	464	234	301		701
May		300	280		
June		258	300		665
July	531	290	305		650
Aug.		320	300	175	
Sept.	570	270	300	115	570
Oct.	428	212	293	172	550
Nov.					
Dec.					
Jan. 1978		270	300	180	650
Feb.		300	210	160	670
March					
April			230	170	545

[a]In mg/l [b]Project Well [c]Control Well

Figure IX

Comparison of Chloride Levels in Project Wells and Treated Effluent

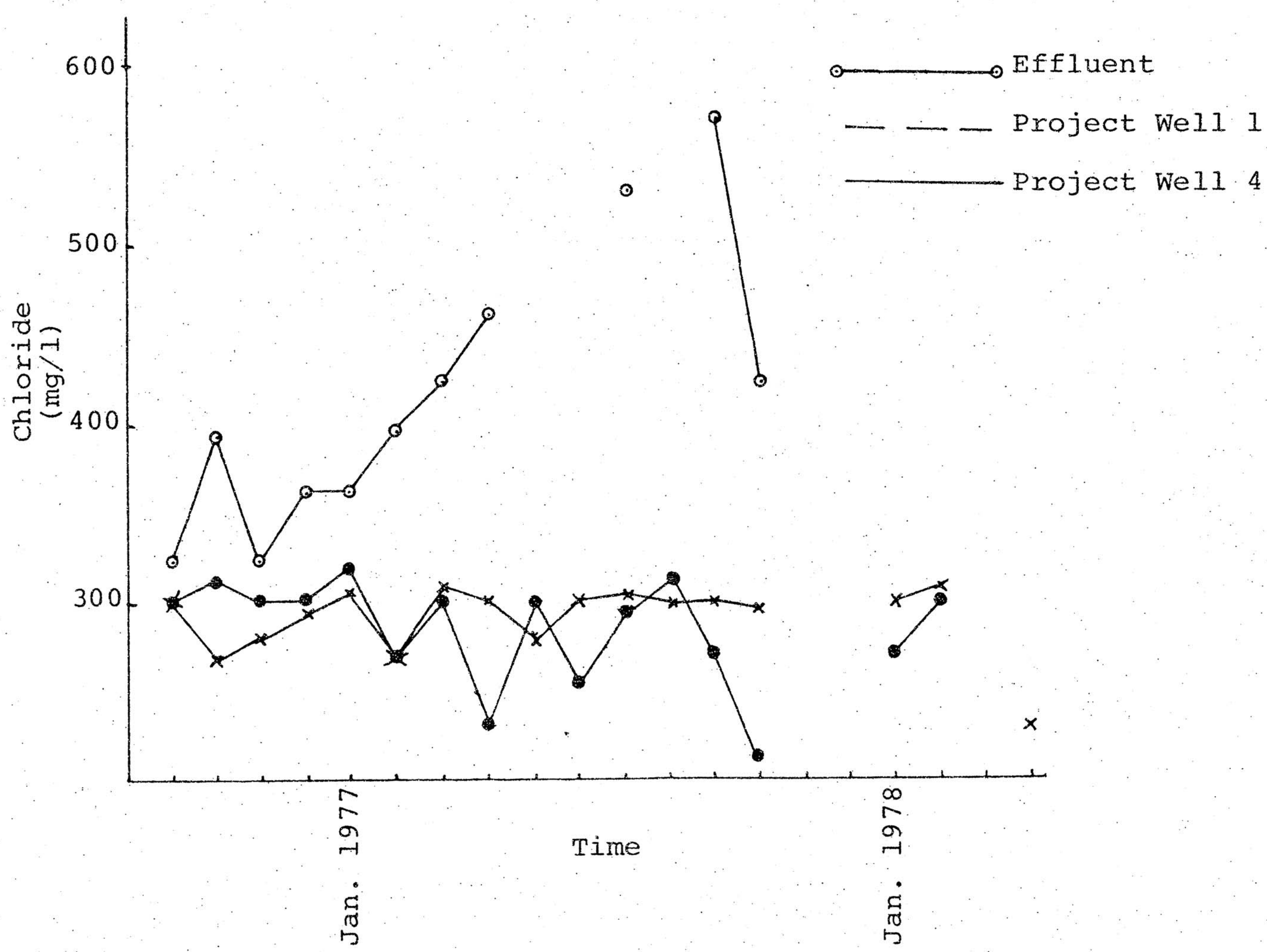


Figure X

Comparison of Nitrate Levels in Project Wells and Treated Effluent

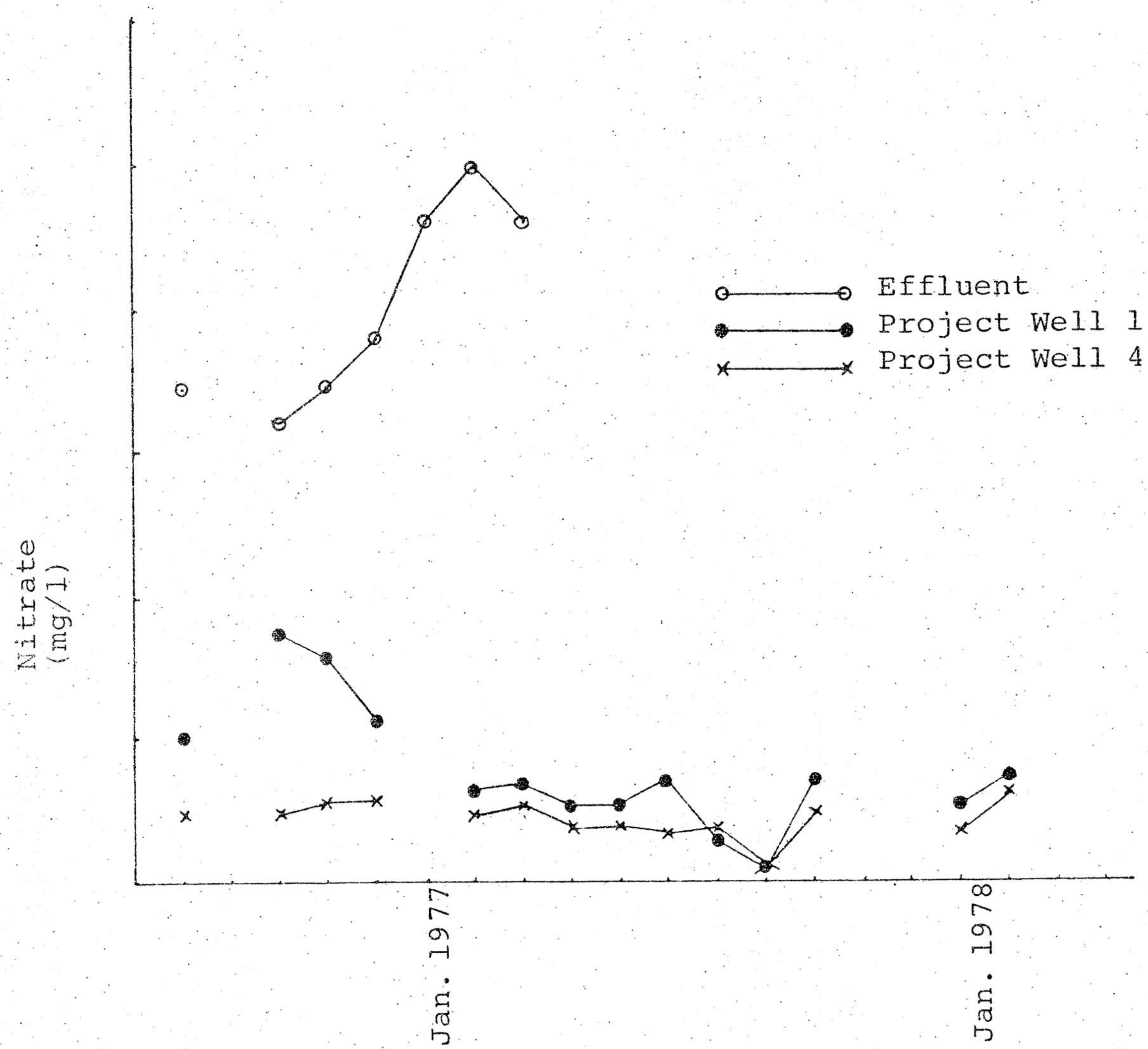


TABLE II

Hardness Levels[a] Observed in Reclamation Project

	Effluent	PW-1[b]	PW-4[b]	A-16[c]	FB-8[c]
Sept. 1976		280	372	268	456
Oct.		456	360	268	384
Nov.	144	416	356	292	324
Dec.		412	380		
Jan. 1977	148	392	356		
Feb.	154	398	372	284	352
March	190	460	360		430
April	194	384	388		424
May		388	360		
June		396	385		416
July	297	452	380		410
Aug.		384	372	260	420
Sept.		416	384	222	388
Oct.		384	380	268	384
Nov.					
Dec.					
Jan. 1978		376	388	248	420
Feb.		398	416	292	412
March					
April			394	276	400

[a]mg/l as C_aCo_3 [b]Project Well [c]Control Well

TABLE III

Turbidity Levels[a] Observed in Reclamation Project

	Effluent	PW-1[b]	PW-4[b]	A-16[c]	FP-8[c]
Sept. 1976	0.29	0.16	0.13	0.17	0.18
Oct.	0.48				
Nov.	0.46	0.42	0.26	2.6	0.57
Dec.	0.28	0.20	0.15		
Jan. 1977	0.60	0.18	0.22		
Feb.	0.55	0.23	0.39	0.44	0.41
March	0.32	0.19	0.26		0.23
April	0.24	0.19	0.26		0.27
May		0.50	0.20		
June		0.28	0.22		0.49
July	0.39	0.23	0.18		0.16
Aug.		0.25	0.19	0.36	0.26
Sept.		0.26	0.22		0.22
Oct.		0.31	0.43	0.42	0.16
Nov.					
Dec.					
Jan. 1978		0.19	0.38	2.4	0.19
Feb.		0.32	0.34	1.5	0.31
March					
April			0.41	0.91	0.28

[a]In Turbidity Units [b]Project [c]Control Well

TABLE IV

Conductivity[a] Observed in Reclamation Project

	Effluent	PW-1[b]	PW-4[b]	A-16[c]	FP-8[c]
Sept. 1976		1700	1800	1300	2800
Oct.	1500	1600	1700	1300	2600
Nov.	1200	1550	1700	1300	1750
Dec.	1207	1550	1700		
Jan. 1977	1190	1650	1750		
Feb.	1314	1700	2620	1350	2450
March	1710	1750	1880		3000
April	1460	1590	1700		2880
May		1800	1800		
June		1600	1800		2890
July	1794	1750	1900		2990
Aug.		1675	1800	1360	2950
Sept.		2500	2220	1550	3400
Oct.		1700	2000	1600	3000
Nov.					
Dec.					
Jan. 1978		2700	3100	2350	5000
Feb.		2750	3000	2300	5500
March			1800	1400	2600

[a] umhos/cm^2 at 25°C [b] Project Well [c] Control Well

TABLE V

Nitrate Levels[a] Observed in Reclamation Project

	Effluent	PW-1[b]	PW-4[b]	A-16[c]	FP-8[c]
Sept. 1976	17	4.9	2.2	3.6	3.8
Oct.					
Nov.	16	8.6	2.2	3.4	2.4
Dec.	17	7.8	2.4		
Jan. 1977	19	5.4	2.4		
Feb.	23		10.0	14.7	15.4
March	25	3.1	2.1		1.7
April	23	3.2	2.2		3.1
May		2.6	1.9		
June		2.6	1.9		2.2
July		3.4	1.7		1.5
Aug.		1.3	1.5	1.5	2.9
Sept.	0.3	0.3	0.3	0.1	0.3
Oct.		3.5	2.5	1.8	1.8
Nov.					
Dec.					
Jan. 1978		2.5	1.8	0.2	4.0
Feb.		3.7	3.2	4.0	4.3
March					
April			3.1	3.9	

[a] NO_3-N mg/l [b] Project Well [c] Control Well

TABLE VI

[1]Estimated Costs for the Production and Recovery of Reclaimed Wastewater by Ground Water Recharge

PROCUDTION-ANNUAL COSTS[2]			
I. Depreciation (20-YR, straight-line)			
Initial Cost		$800,000	$ 40,000
Phase 1 Improvements		30,000	1,500
Total Depreciation			$ 41,500
II. MAINTENANCE AND REPAIR			36,000
III. LABOR			
Project Director	@	$ 22,400	$ 22,400
Plant Superintendent	@	16,800	16,800
Chief Operator	@	11,500	11,500
Operator	@	9,775	19,600
Operator Trainee	@	8,050	16,100
Chemist	@	13,440	13,400
Secretary	@	8,050	4,000
Labor Subtoal			103.800
15 Percent Fringe Benefits			15,570
Total Labor			119,370
		TOTAL ANNUAL COST	$196,870
PRODUCTION-UNIT COSTS ($/Thousand Gal.)			
The annual cost on a unit basis with 15 percent downtime			$ 1.27
Coagulant-aluminum sulfate, 50 mg/lb @ $1.20/lb			.084
Chlorine, 20 mg/l @ $0.50/lb			.084
Power			.30
Total Production Costs			$ 1.74
Recovery-Unit Costs ($/thousand gal.)			
If 85 percent of recharged water is recovered by wells			2.04
Cost of ground water recovery[3]			0.30
Total Cost-Production and recovery ($/thousand gal.)			$ 2.34

1. Based on Buros, 1976b, p. 121
2. Includes operation of the recharge facilities
3. Includes all costs of drilling operating the wells

water at the AWWTP, as it is being operated now with a production capacity of 0.5 mgd, is estimated to be $2.34 per thousand gallons. This compares favorably with the price of desalted water ($15 per thousand gallons and cistern water $20 per thousand gallons).

As production capacity of the treatment plant increases, costs will decrease. With a plant production capacity of 0.75 mgd, cost of reclaimed water is expected to decrease to $2.10 per thousand gallons and with a production capacity of 1 mgd, cost will be $2.01 per thousand gallons. However, it must be kept in mind that as plant production increases the limiting factor becomes the capacity of the recharge areas. At some point the capacity of the aquifer will be exceeded and will not be able to accept additional treated effluent.

The cost of reclaimed water will be lowered if processing beyond primary treatment becomes required at the waste treatment plant before discharge. Once secondary treatment is required, Buros (1976b) estimates that costs attributable to reuse will drop by about 75 percent.

Use of the treated effluent for intermediate purposes before it becomes ground water (sequential use) promises to reduce the cost of recharge/recovery operations even further. Some of these intermediate uses have been determined to be irrigation, clam culture and pisciculture. Detailed investigation of these sequential uses were intended to be part of this study. Problems associated with power outages, equipment failure and insufficient wastewater available for treatment curtailed the extent of the study, yet what was done indicates that reclamation of wastewater is economically feasible even without sequential use.

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