Impact of Special Phosphorus Removal Procedures

in the Upper Pelican River Watershed, 1977-78

INTERIM REPORT

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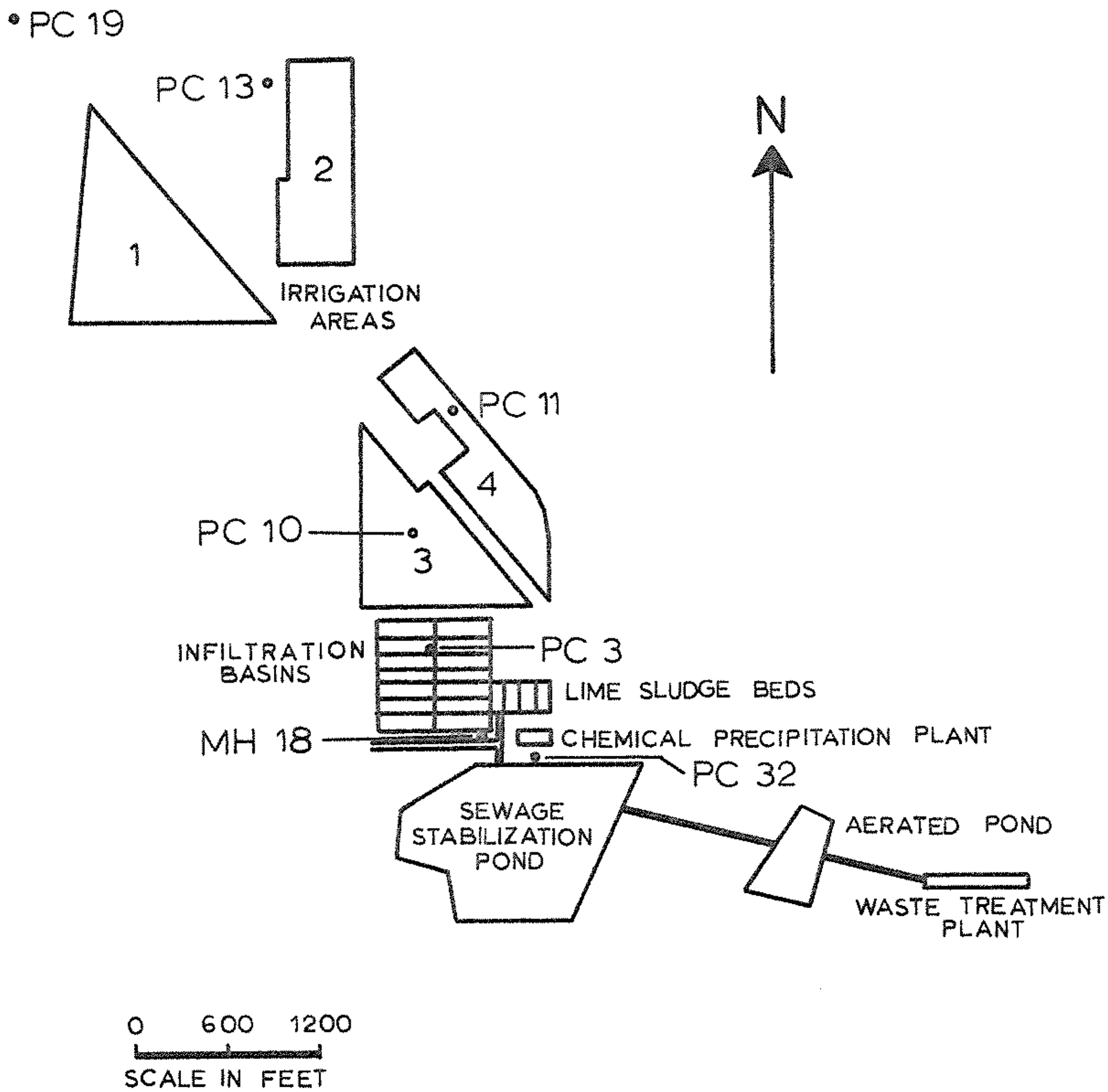
INTRODUCTION

The area dealt with in study of special phosphorus removal procedures in the upper Pelican River watershed has been described in two previous documents (1 and 2) and is not detailed in this progress report. The phosphorus removal facilities completed in 1976 include a lime precipitation plant operated from December 12, 1977 until April 18, 1978, and two types of ground application areas, spray irrigation plots, and infiltration basins permitting intermittent application of waste-water effluent in rotation (Figure 1). Ground application replaces lime precipitation as weather permits, usually from April until November or December. In 1977 spray irrigation ended November 24 and application to infiltration basins December 12. Use of basins was resumed April 18 and spray irrigation May 19, 1978.

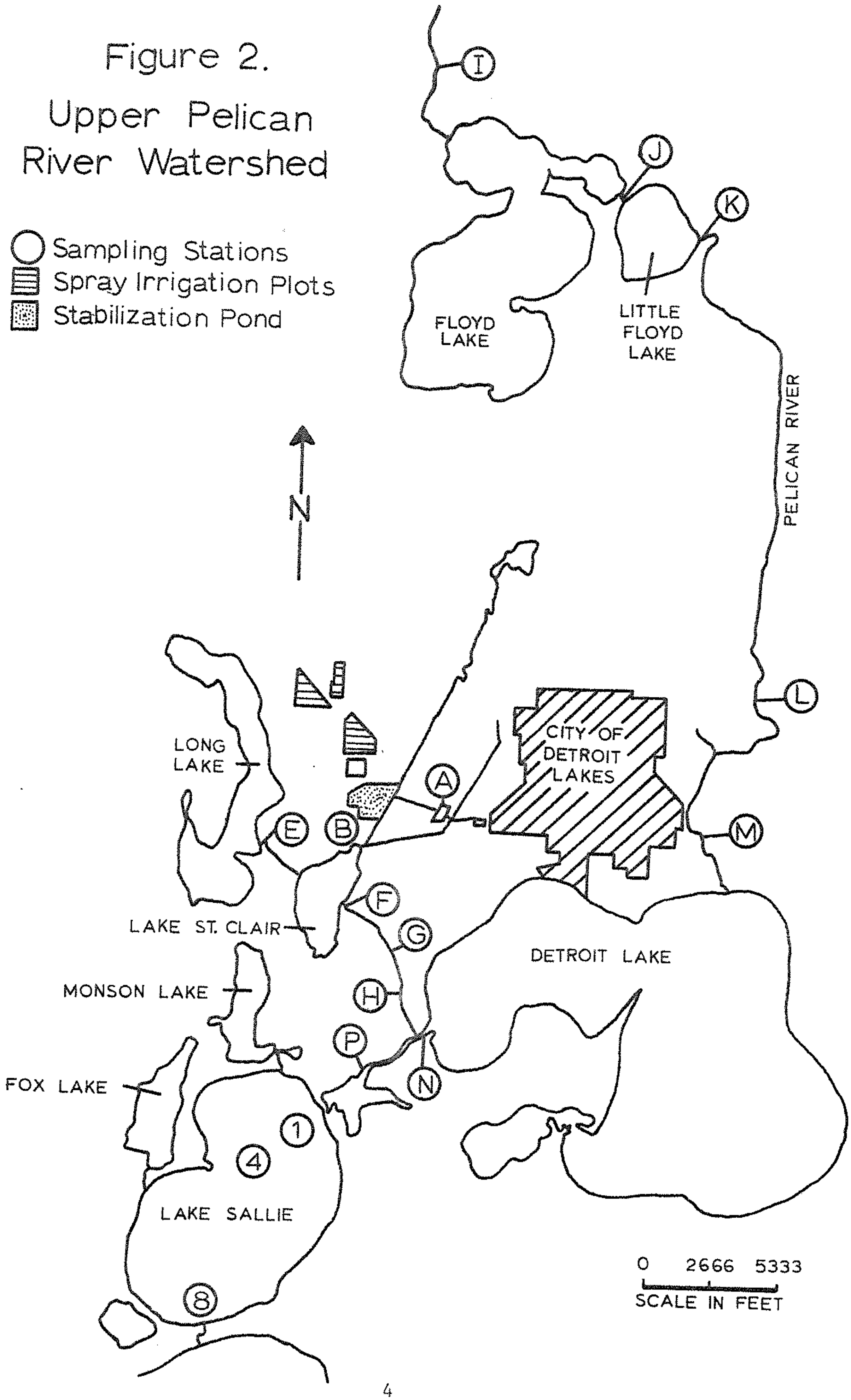
This study began June 23, 1977, when the stabilization pond effluent had been applied to infiltration basins and spray irrigation areas for a few weeks. Ground water quality (pH, alkalinity, hardness, calcium, magnesium, total and available phosphorus, ammonia-, nitrite-, and nitrate nitrogen, chloride, sulfate, conductivity and oxygen) was monitored at PC Wells Nos. 3, 10, 11, 13 (began January, 1978), 19 and 32 (dropped January, 1978) (see Figure 1) and at Manhole 18 on the line carrying ground drainage from the infiltration basins. Surface water quality (the above chemical parameters minus Cl and SO_4, and plus plankton) was checked at the outlets of Long Lake (E), Lake St. Clair (F), Detroit Lake (N), Muskrat Lake (1), and Lake Sallie (8), at varied

Figure 1. Details of Treatment Area



depths near the center of Lake Sallie (4-1 to 4-4), and the Pelican River immediately above Detroit Lake (M) (Figure 2). Wastewater effluent was sampled as it was pumped to infiltration basins and irrigated fields, or entered the chemical precipitation plant, whose effluent was also monitored.

Figure 2.
Upper Pelican River Watershed



GROUNDWATER

Dilution and Replacement by Wastewater Effluent

Chloride concentration in the wastewater effluent ranged from 225 to 400 mgl, whereas that in native groundwater was 18 to 30 mgl. This difference permitted recognition of effluent entry into and replacement of groundwater, and ground residence time of effluent at individual groundwater sites. At PC3, in the infiltration basin area, and at PC10, in Irrigation Area 3, Cl concentration indicated that the effluent had completely replaced native groundwater at the start of sampling in July, 1977 (Figure 3 and Table 1). Chloride concentration remained at the effluent level at these two sites until ground application of wastewater ceased, and then the effluent was rather quickly replaced by native groundwater. Chloride concentration increased sharply at PC3 when effluent application to infiltration basins was resumed, but no increase was evident at PC10 by June, 1978. Irrigation was delayed until May 19.

PC11, in Irrigation Area 4, evidently receives an exceptional share of surface runoff, since, as evidenced by total hardness, it has been diluted ten or more times as much as other sites during snow melt. Effluent did not completely replace native groundwater there, but chloride peaked at 69% of the mean effluent level in December and declined rapidly after January, dropping to the ambient level in April.

PC19, 750 feet WNW of Irrigation Area 1, where mean water level over 1973-75 was 1.39 feet higher than at PC20 within this effluent application area, did not show meaningful chloride increase until November and reached a maximum concentration (37% of the effluent mean) in January. It then declined, but did not drop to the ambient level until May.

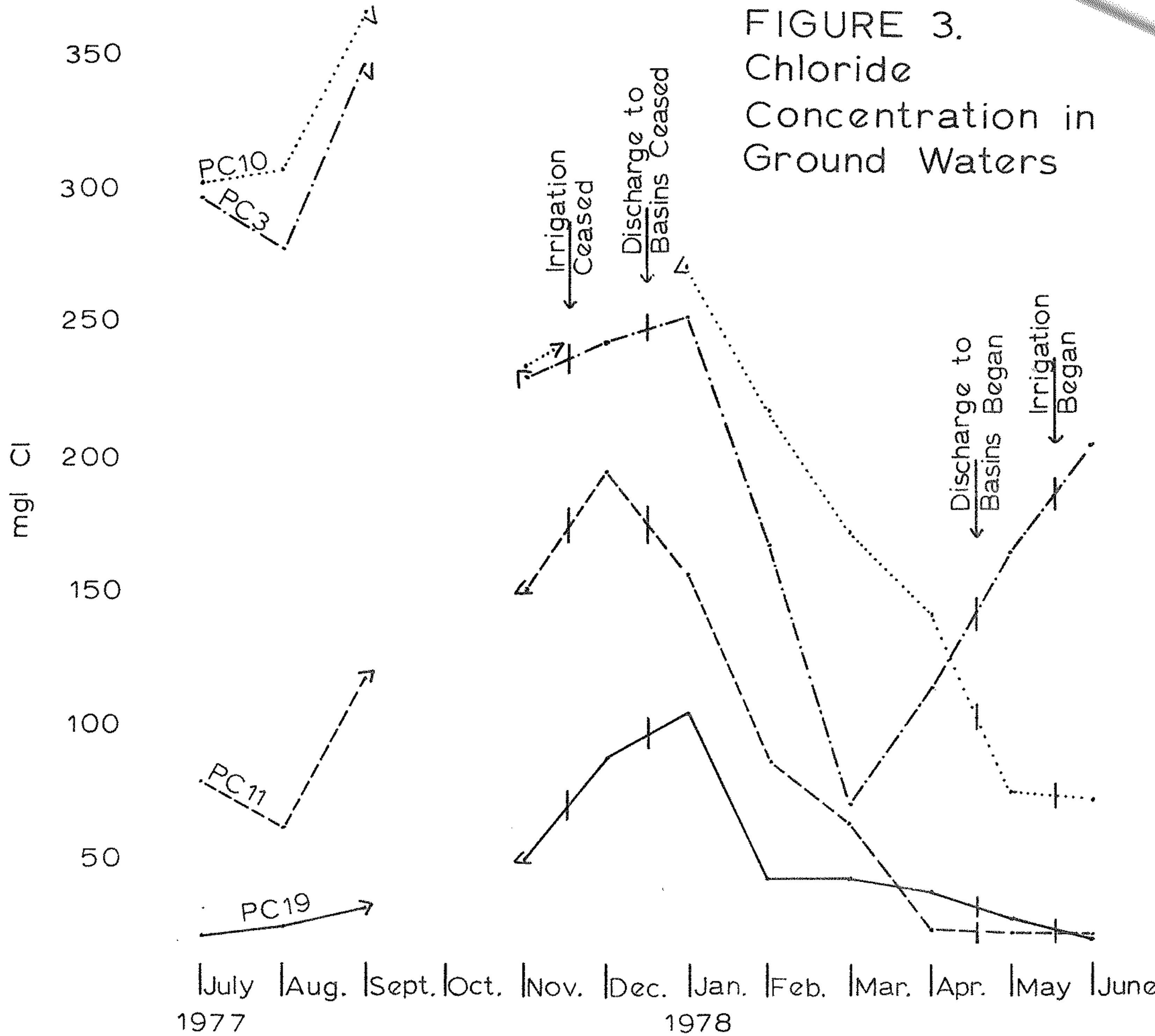


FIGURE 3. Chloride Concentration in Ground Waters

BLE 1. Chloride concentration in wastewater effluent and ground waters

	WELLS									
	PC3T*	PC3B	PC10	PC11T	PC11B	PC13	PC19	PC32T	PC32B	Waste-water Effl.
1977										
7/27	300	265	305	81	130	–	23	200	210	265
8/11	280	295	310	65	115	–	29	235	270	310
9/23	350	350	390	120	325	–	35	310	325	375
11/3	232	241	236	153	186	–	52	227	232	227
12/15	245	259	–	198	189	–	90	231	231	259
1978										
1/19	255	236	274	159	178	–	107	212	222	–
2/23	170	184	220	89	105	45	45	–	–	–
3/23	73	179	173	66	73	31	45	–	–	–
4/20	116	192	142	26	45	30	40	–	–	–
5/18	167	182	77	25	20	30	30	–	–	–

* T = near top of phreatic zone
B = near bottom of phreatic zone
No letter indicates near top of phreatic zone

At PC32, 200 feet SE of the infiltration basins, effluent chloride levels were maintained over the period July to January when sampling at that site was discontinued, and PC13 substituted.

The above account considers only upper layers of phreatic water, since this zone was too shallow for deeper sampling at PC10 and PC19. Deeper layers at PC3 showed complete displacement by the effluent in July (Table 1) and a loss in Cl concentration in January, as in the upper layers, but they were less diluted by snow melt in March. At PC11 deeper waters had higher Cl concentration than the upper phreatic zone over the reported sampling period, but they were much more influenced by snow melt than their counterparts at PC3. At PC32 upper and lower groundwaters were quite similar in chloride content.

Phosphorus

Mean total phosphorus concentration, mgl, in upper levels of the water table and in applied wastewater effluent were as follows:

PC3	PC10	PC11	PC19	Wastewater Effluent	Time Period
0.77	0.61	0.64	0.58	3.66	July-Dec.,1977
0.53	0.54	0.76	1.17	-	1973-1974
0.40	0.53	0.56	0.33	-	1974-1975

In the areas where effluent replaced native groundwater (PC3 and PC10) there was a 79% reduction in total phosphorus in effluent applied to infiltration basins (PC3) and an 83% reduction from spray irrigation (PC10) over the period July to December, 1977. Comparison of 1977 concentrations with those of 1973-74 and 1974-75 suggests that ground application of effluent increased phosphorus above prior groundwater levels at PC3 and PC10, but at PC11 and PC19 no such effect may be claimed (see above table). A previous report (2) noted year - to - year variation in groundwater phosphorus levels and this experience dictates no more than very cautious assumptions from one year's data. For concentrations at PC32 and in deeper groundwaters see Table 2; variation at the four sites listed above appears in Figure 4.

Nitrogen

From September to December, nitrogen content of the effluent with one exception exceeded that of groundwater, but in July and August it was considerably lower (Figure 5). It is assumed that N utilization by aquatic plants in the stabilization pond declined after August and again in December to give effluent values shown. Some groundwater nitrogen originated in sources other than the wastewater effluent as is shown by increases at PC3, PC10 and PC11 between December and April when no effluent was applied to the ground. PC19 also acquired N from other places as shown by high concentrations prior to arrival of the effluent at that site. During 1973-74, N was more than twice as concentrated at PC3 than in 1977-78, but was less abundant in upper groundwater there in 1974-75, although 1 mgl+ more concentrated in deeper water; PC10 had more N in 1977-78 than from 1973-75; PC11 and PC19 exhibited higher mean levels in 1973-75, which was contrary to events at PC32 (Table 3).

Alkalinity and Hardness

Groundwater under irrigation areas and infiltration basins showed increases over 1973-75 levels in the above two respects. Hardness concentrations of the wastewater effluent (mean, 298 mgl) increased with

TABLE 2. Mean monthly total phosphorus concentrations, ground waters, mgl

	WELLS								
	PC3T	PC3B	PC10	PC11T	PC11B	PC13	PC19	PC32T	PC32B
1977									
June	.97	1.23	.33	–	–	–	1.11	4.33	1.03
July	.65	.63	.92	.82	.70	–	.89	.55	1.02
Aug.	.86	.66	.28	.53	.31	–	.57	.30	.43
Sept.	.65	.53	.42	.31	.73	–	.42	.46	.34
Oct.	.87	.38	.34	.34	.32	–	.30	.28	.35
Nov.	.79	.55	.55	.62	.71	–	.40	.43	.33
Dec.	.47	.49	–	.47	.25	–	.36	.22	.28
1978									
Jan.	.27	.32	.27	.19	.30	–	.30	.24	.45
Feb.	.58	.55	.34	.32	.30	.30	.29	.36	.28
Mar.	.78	.58	.40	.36	.49	.37	.41	–	–
Apr.	.66	.45	.39	.67	.51	.50	.38	–	–
May	1.14	.80	.75	.87	.63	.73	.42	–	–

TABLE 3. Mean monthly total nitrogen concentrations, ground waters, mgl

	WELLS								
	PC3T	PC3B	PC10	PC11T	PC11B	PC13	PC19	PC32T	PC32B
1977									
June	2.01	4.94	2.27	-	-	-	5.66	7.15	5.69
July	1.87	4.19	3.40	1.18	3.17	-	6.32	5.60	6.35
Aug.	2.00	3.46	3.65	2.91	2.44	-	6.55	5.05	5.10
Sept.	1.62	3.04	.65	2.49	1.29	-	6.30	4.11	3.99
Oct.	2.29	2.58	.82	1.76	1.94	-	4.83	3.25	3.34
Nov.	2.50	2.57	.94	1.72	1.37	-	4.58	3.63	3.46
Dec.	2.72	2.93	-	1.50	1.23	-	3.58	4.10	3.43
1978									
Jan.	3.61	3.68	5.13	1.52	2.44	-	3.41	3.58	3.57
Feb.	3.66	3.73	5.64	2.16	1.85	6.70	3.13	-	-
Mar.	5.52	3.45	6.27	2.39	2.20	8.00	3.19	-	-
Apr.	4.83	3.69	6.56	.59	1.75	7.44	3.48	-	-
May	4.62	4.85	6.24	1.31	2.53	7.63	3.71	-	-

FIGURE 4.
Mean Monthly Total Phosphorus - Ground Waters

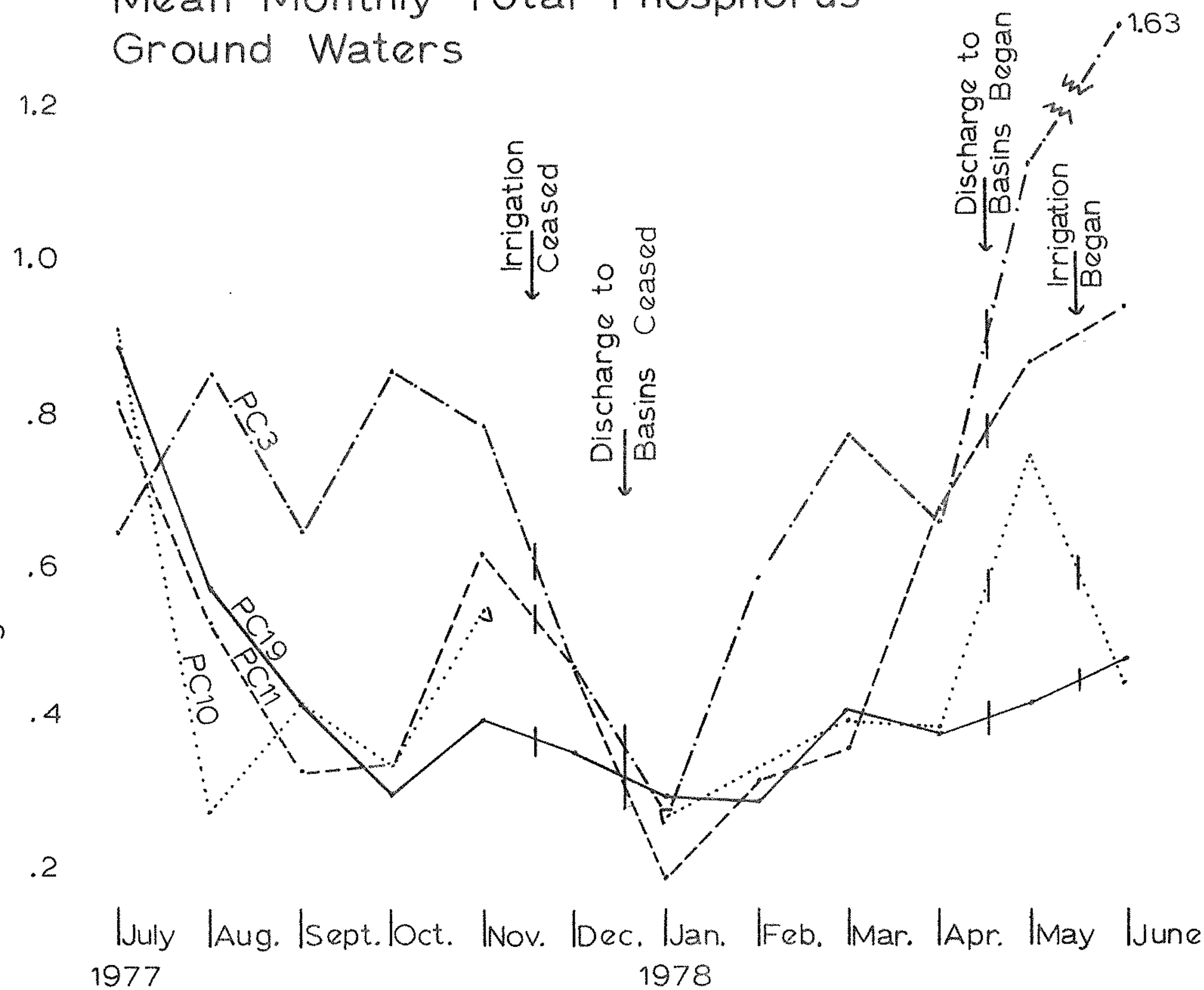
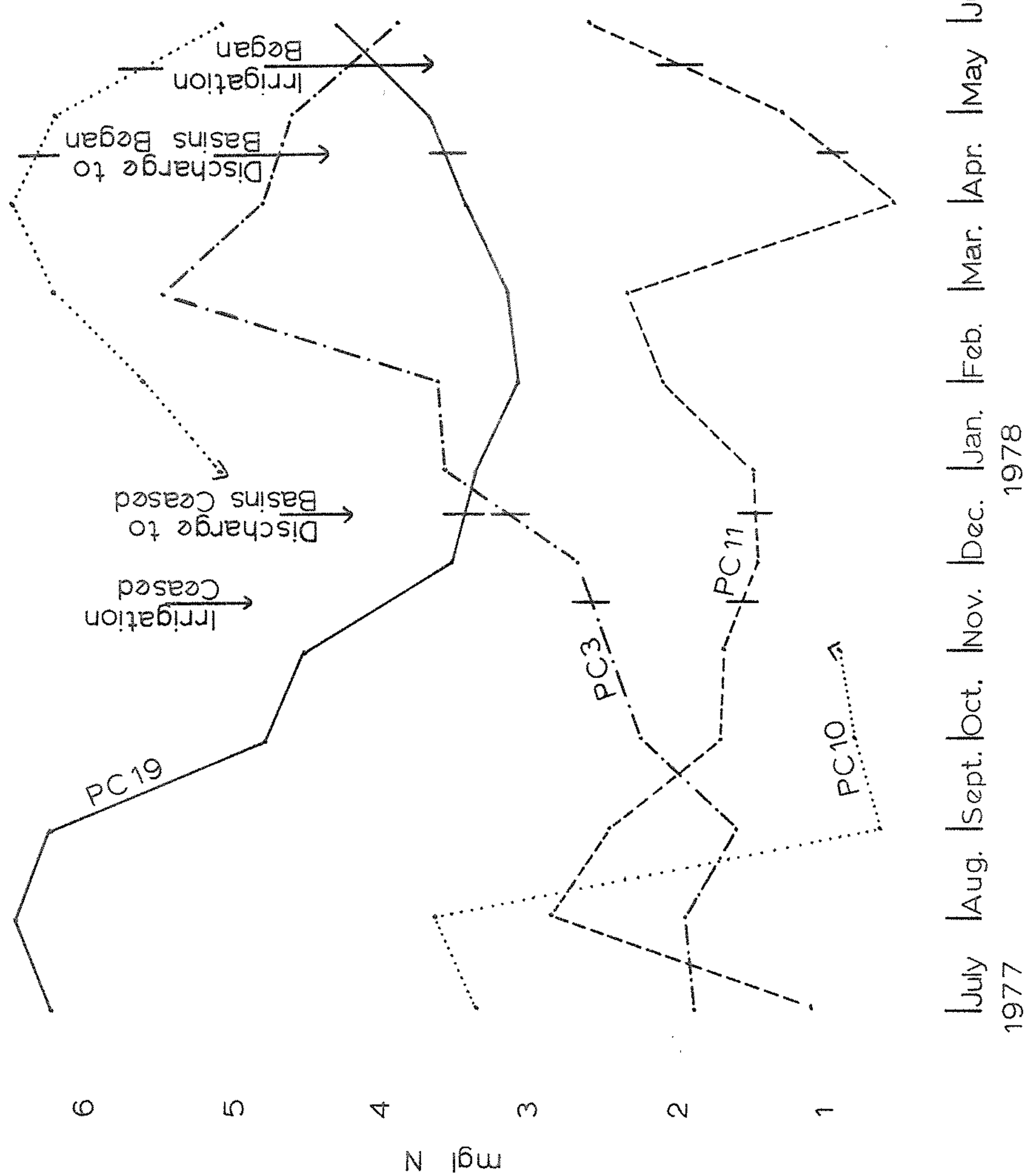


FIGURE 5.
Mean Monthly Total Nitrogen-
Ground Waters



flow through the earth, up to a mean of 506 mgl at PC10, 315 at PC3, 303 at PC11, and 372 at PC32. Alkalinity (mean 329 mgl in the effluent) increased less spectacularly at PC3, PC10 and PC32, and decreased at PC11 where dilution by surface runoff was considerably greater than at other sites. Gain in these two parameters represented pick up from soil strata penetrated plus some concentration by evaporation. The effluent is compared to groundwater at four sites in Figures 6 and 7.

Conductivity

As would be anticipated from mineral pick up mentioned above, conductivity at PC3 and PC10 generally exceeded that of the effluent (Figure 8). At PC19, where effluent replaced less than 50% of the groundwater, conductivity ranged far below that of the effluent, and at PC11, with a high natural recharge rate, conductivity exceeded that of the effluent only once.

SURFACE WATERS

Phosphorus

Lake St. Clair discharges (Station F) contained more phosphorus in the soluble reactive state than any other surface water sampling site (Figure 9, Table 4). Dilution by the Pelican River and use by aquatic plants reduced the annual mean concentration by 36% when it reached Lake Sallie (Station 1). It was fairly well consumed in this body, showing an annual mean at Station 8 that was 18% of that at Station F. Seasonal low points in soluble reactive phosphorus curves (Figure 9) are assumed to reflect utilization by phytoplankton and other aquatic plants.

FIGURE 6. Mean Monthly Hardness - Ground Waters

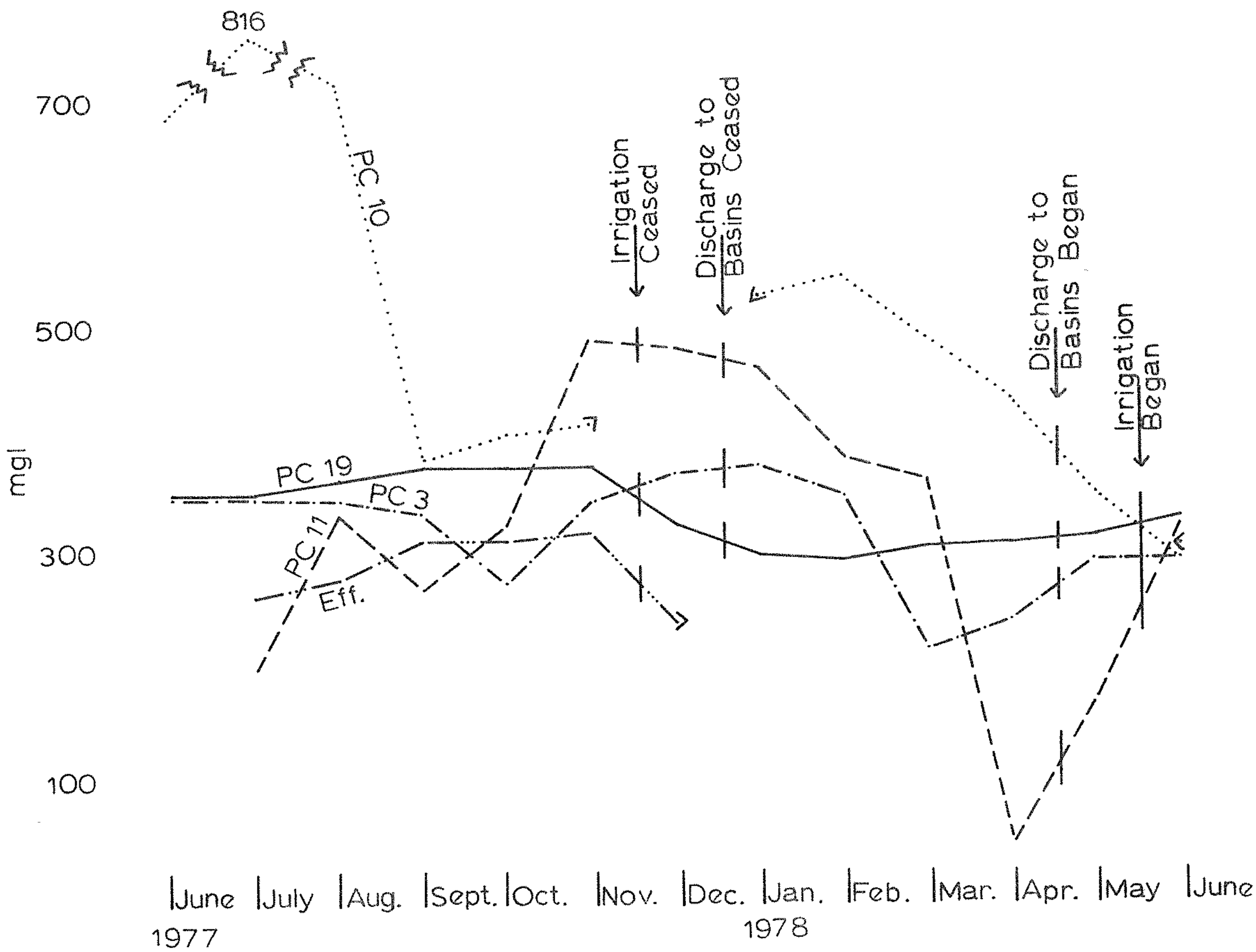


FIGURE 7.
Mean Monthly Alkalinity - Ground Waters

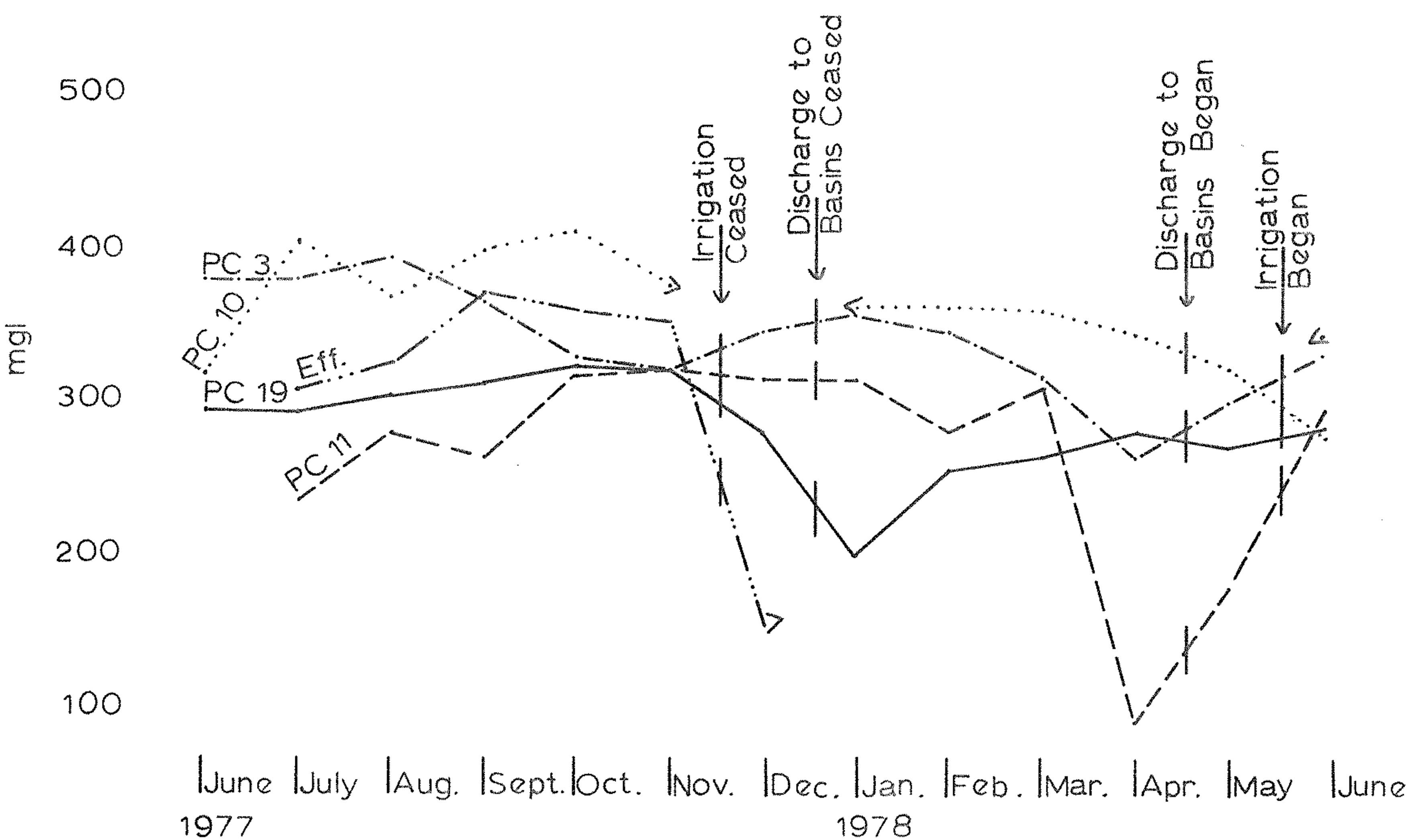


FIGURE 8.
Mean Monthly Conductivity - Ground Waters

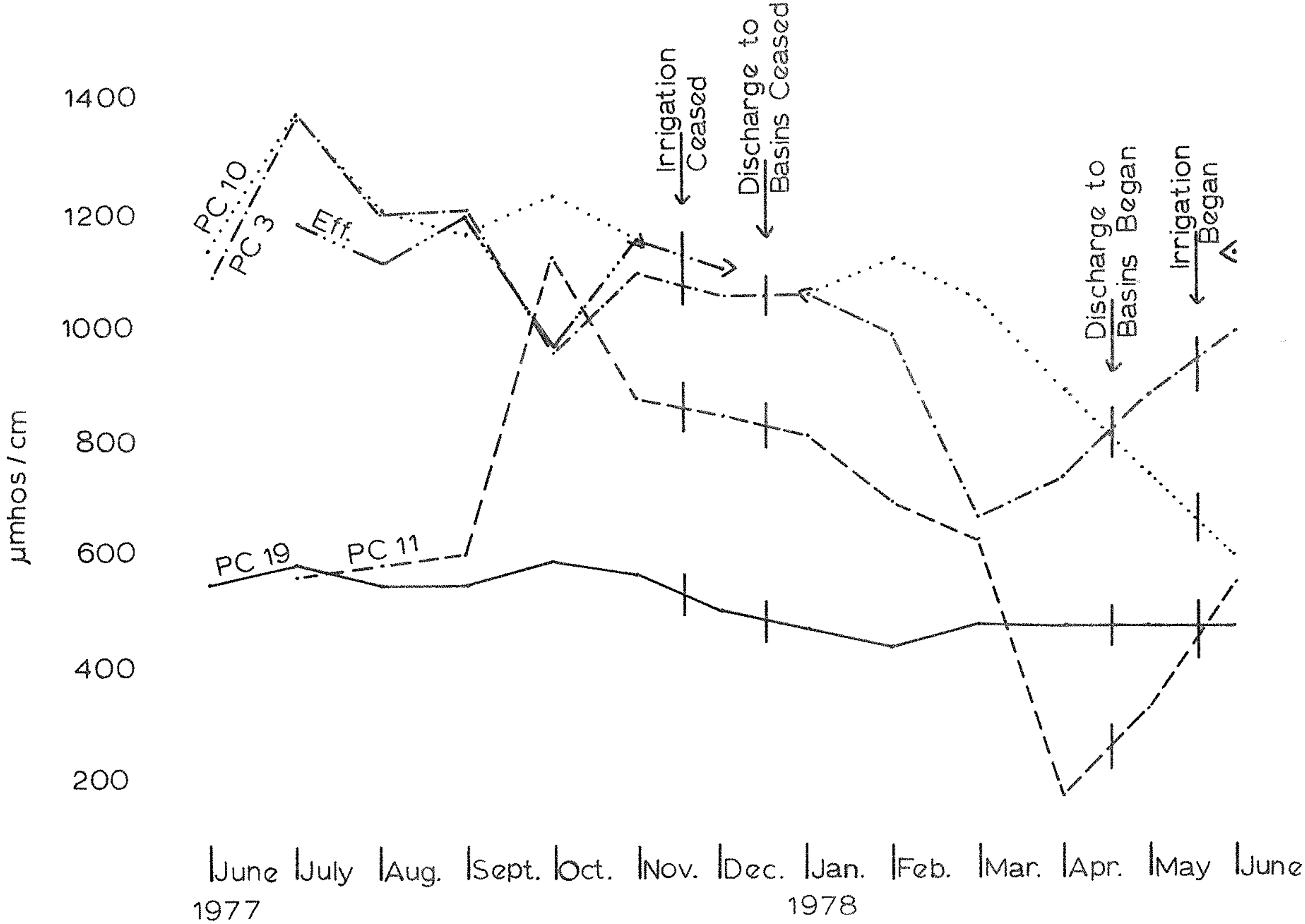


FIGURE 9.
Mean Monthly Soluble Reactive Phosphorus - Surface Waters

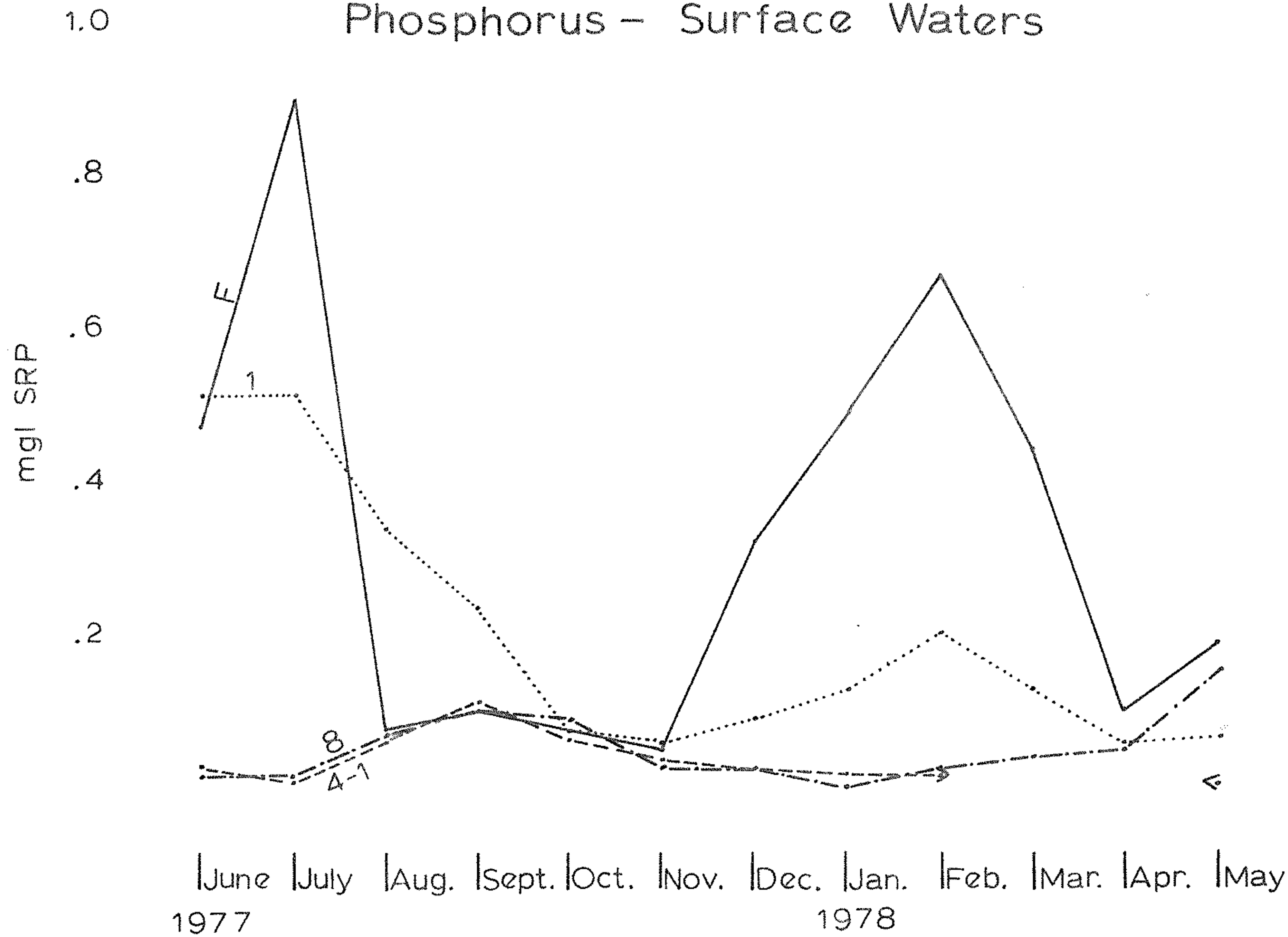


TABLE 4. Mean monthly soluble reactive phosphorus concentrations, surface waters, mgl

	STATIONS									
	E	F	M	N	R	1	4-1	4-2	4-3	4-4	8
1977											
June	–	.48*	.16*	.59*	–	.52	.033	.012	.033	.009*	.017
July	.27*	.91	.18	.25	.91*	.52	.007	.007	.006	.06	.019
Aug.	.21	.08	.16	.18	.40	.35*	.06	.06	.07	.06	.07
Sept.	.19	.11	.20	.18	.72*	.24	.12	.12	.10	.10	.11
Oct.	.15	.08	.20	.10	.36	.08	.07	.13	.16	.13	.10
Nov.	.08*	.05*	.08*	.06*	–	.06*	.04*	.08*	.04*	.04*	.03
Dec.	.08*	.33*	.11*	.06*	–	.10	.03	.04	.05	–	.03
1978											
Jan.	.10*	.50*	.24*	.07*	–	.14	.02	.02	.05	–	.003
Feb.	.09	.68	.14	.13	–	.21	.02	.05	.12	.12	.03
Mar.	.09	.45	.12	.14	–	.14	–	–	–	–	.05
Apr.	.07	.11	.08	.06	–	.07	–	–	–	–	.06
May	.20	.20	.17	.14	–	.08	.13	.11	.17	.11	.17

* 1 record only

Total phosphorus was also generally most concentrated at Stations F and 1, but very high levels occurred at Station 8 in late summer 1977 (Figure 10, Table 5). This analysis includes P in the bodies of plankton organisms, and Station 8 exhibited its highest plankton densities at this time (Figure 16). At Station 4, near the center of the lake, highs in plankton and total P were concurrent with those at Station 8 (Figures 10 and 15), but P concentration was lower, whereas plankton concentration was about 40% higher. Stations 1 and F are recipient of comparatively large quantities of wastewater effluent and they showed high total phosphorus concentrations when their plankton densities were low (Figures 10, 12 and 13), although their total P appeared affected by plankton in late summer 1977.

Mean total phosphorus was higher in 1977-78 than in either 1973-74 or 1974-75, with two exceptions as shown below:

Mean Total P, mgl

	E	F	M	N	1	8
1973-74	.27	1.62	-	.28	.47	.19
1974-75	.30	1.48	.44	.46	.47	.24
1977-78	.49	.81	.51	.37	.59	.47

At Station 4-1 mean total P was 0.40 mgl in 1975 and 0.44 mgl in 1977, but mean soluble P was generally higher in 1975.

Nitrogen

This element was most concentrated near the wastewater source (Station F) and declined down basin from this point, dropping to a minimum in Lake Sallie (Figure 11). It was most abundant during winter, and its marked decline in spring is believed referable to its utilization

TABLE 5. Mean monthly total phosphorus concentrations, surface waters, mgl

	STATIONS									
	E	F	M	N	1	4-1	4-2	4-3	4-4	8
1977										
June	-	1.50*	0.66*	1.06*#	1.82	0.52*	0.75*	0.69*	-	0.49*
July	1.07*	1.26	0.67	0.73#	1.10	0.51	0.47	0.33	0.51	0.51
Aug.	0.91	0.42	0.67	0.51	-**	0.41	0.79	0.92	0.65	0.74
Sept.	0.99	1.13	1.44	1.07	0.78	0.75	0.73	0.92	0.95	1.52*
Oct.	0.23	0.27	0.22	0.24	0.30	0.32	0.34	0.32	0.35	0.41
Nov.	0.25*	0.27*	0.27*	0.19*	0.28	0.18*	0.23*	0.22*	0.20*	0.20
Dec.	0.24*	0.53*	0.22*	0.18*	0.25	0.15	0.15	0.20	-	0.18
1978										
Jan.	0.27*	0.91*	0.43*	0.15*	0.26	0.23	0.24	0.33	-	0.25
Feb.	0.29	1.04	0.40	0.33	0.41	0.26	0.26	0.29	0.28	0.24
Mar.	0.36	1.00	0.42	0.37	0.58	-	-	-	-	0.42
Apr.	0.31	0.51	0.33	0.30	0.41	-	-	-	-	0.41
May	0.48	0.98	0.54	0.41	0.52	0.44	0.38	0.45	0.46	0.48

* 1 record only
\# reverse flow
** no flow

FIGURE 10.
Mean Monthly Total Phosphorus – Surface Waters

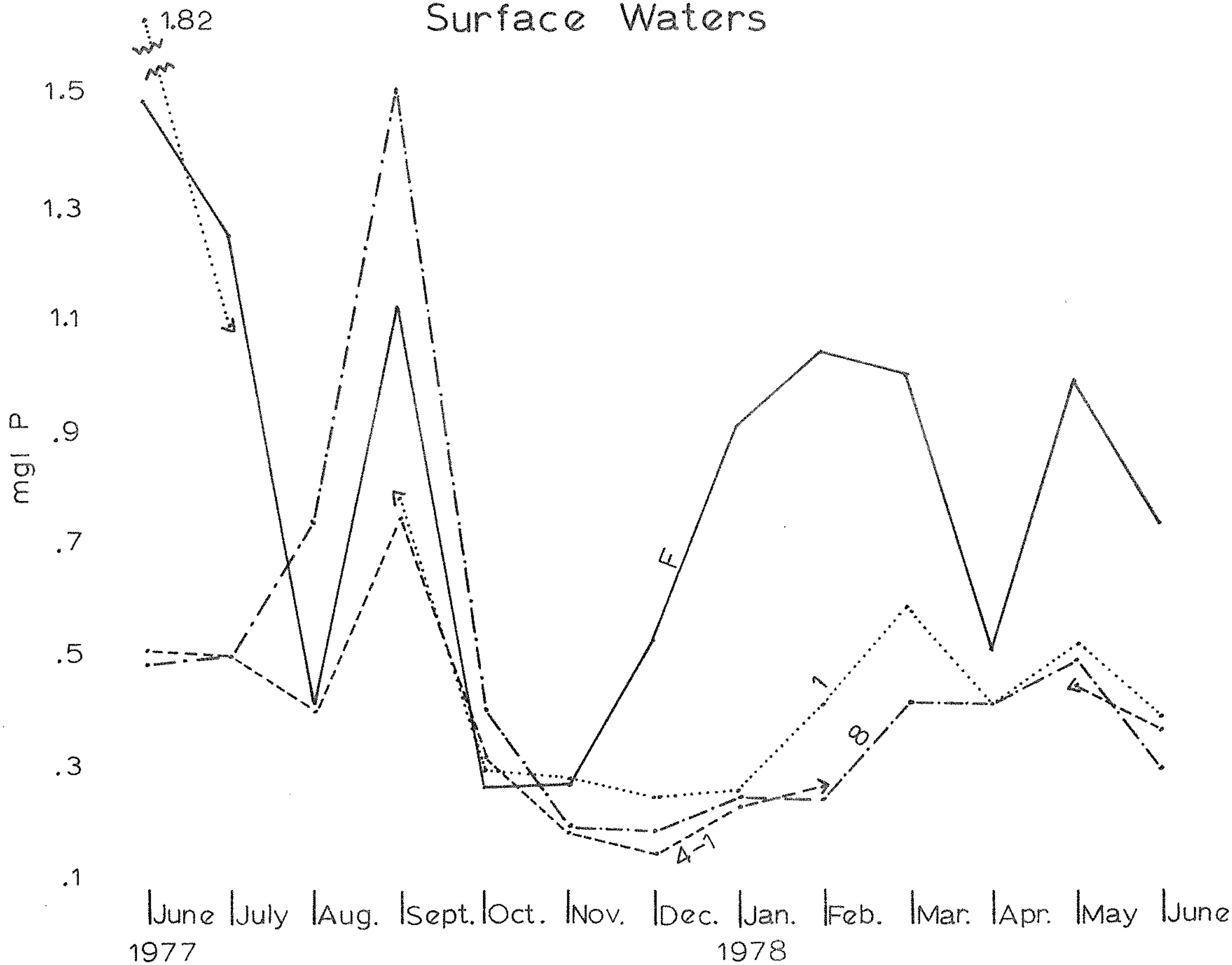


FIGURE 11.
Mean Monthly Total
Nitrogen - Surface Waters

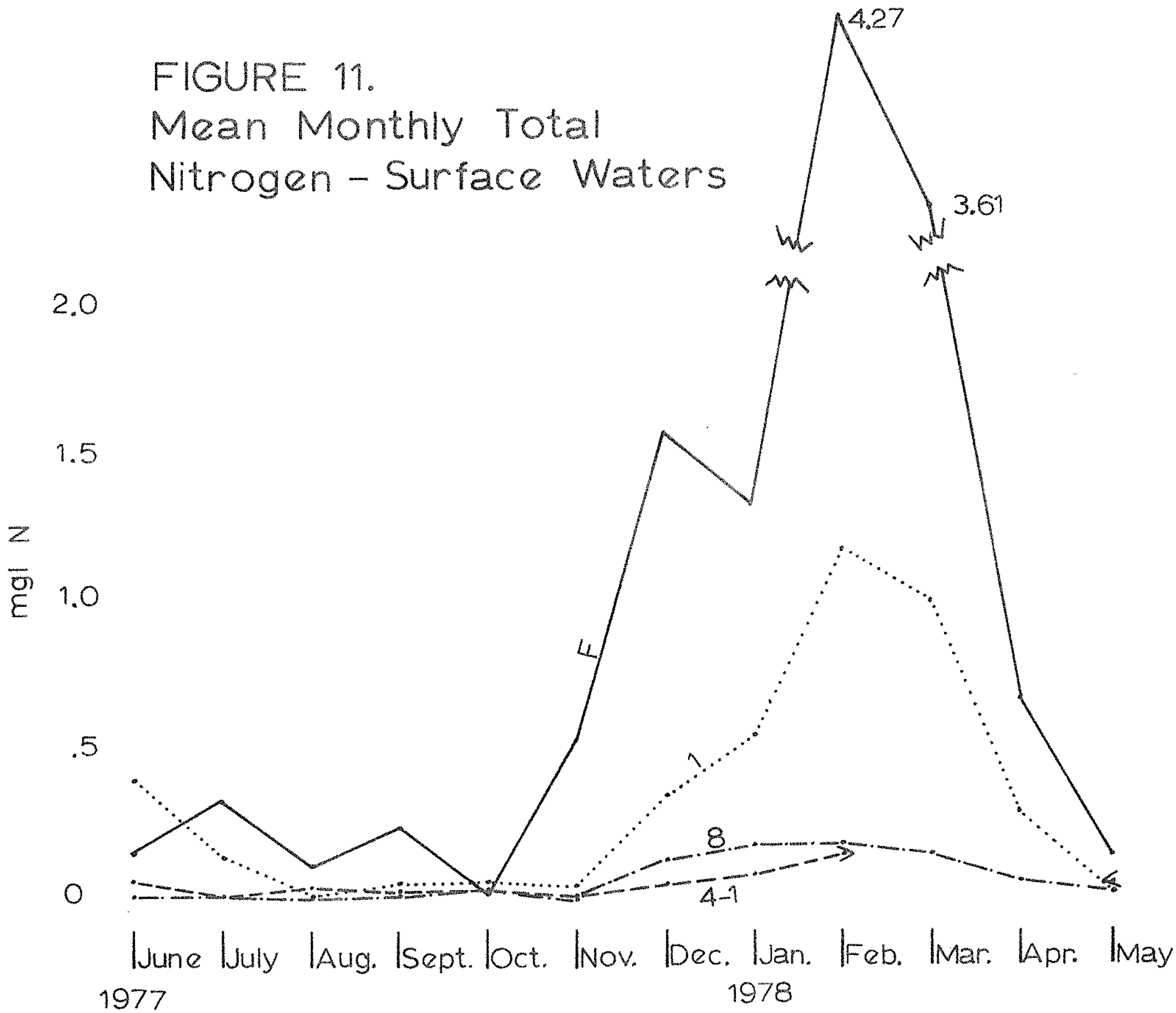


FIGURE 12.
Variation in Total Phytoplankton at Station F

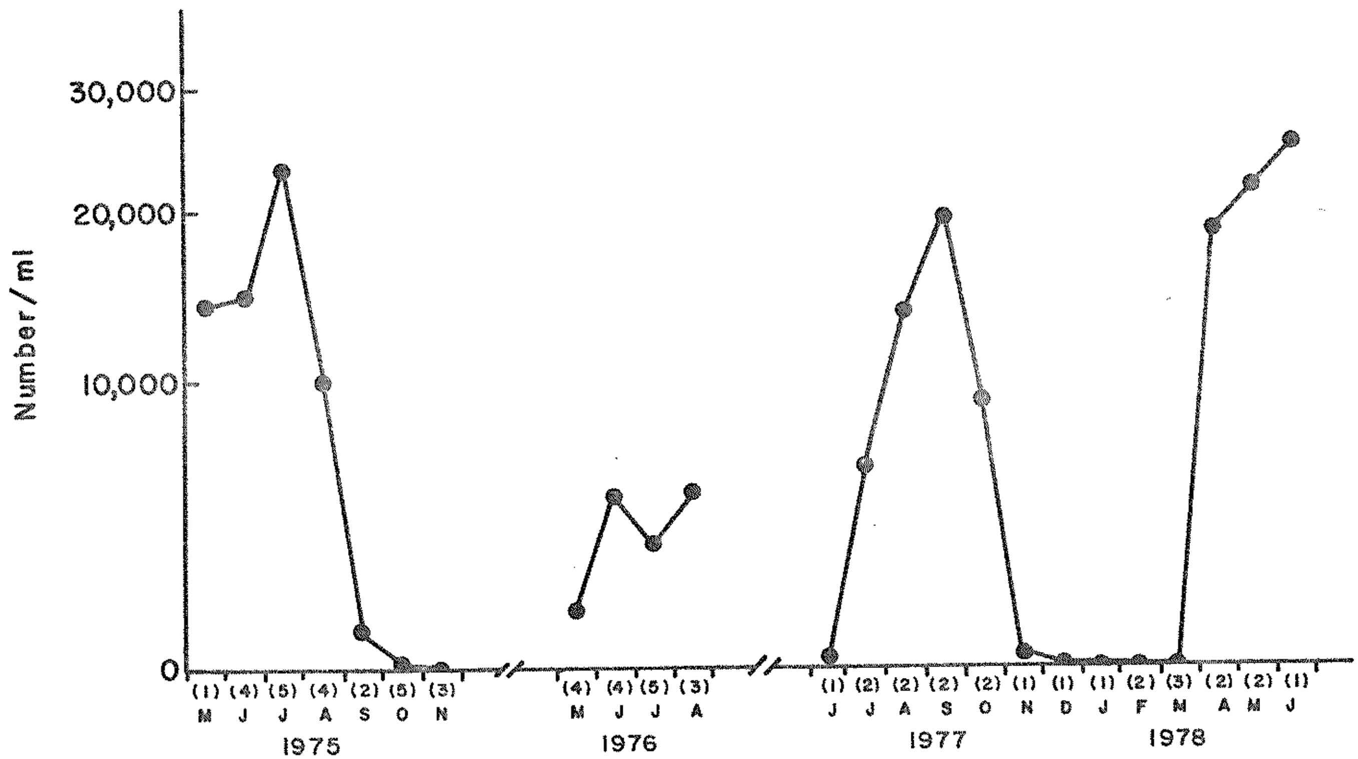


FIGURE 13.
Variation in Total Phytoplankton at Station 1

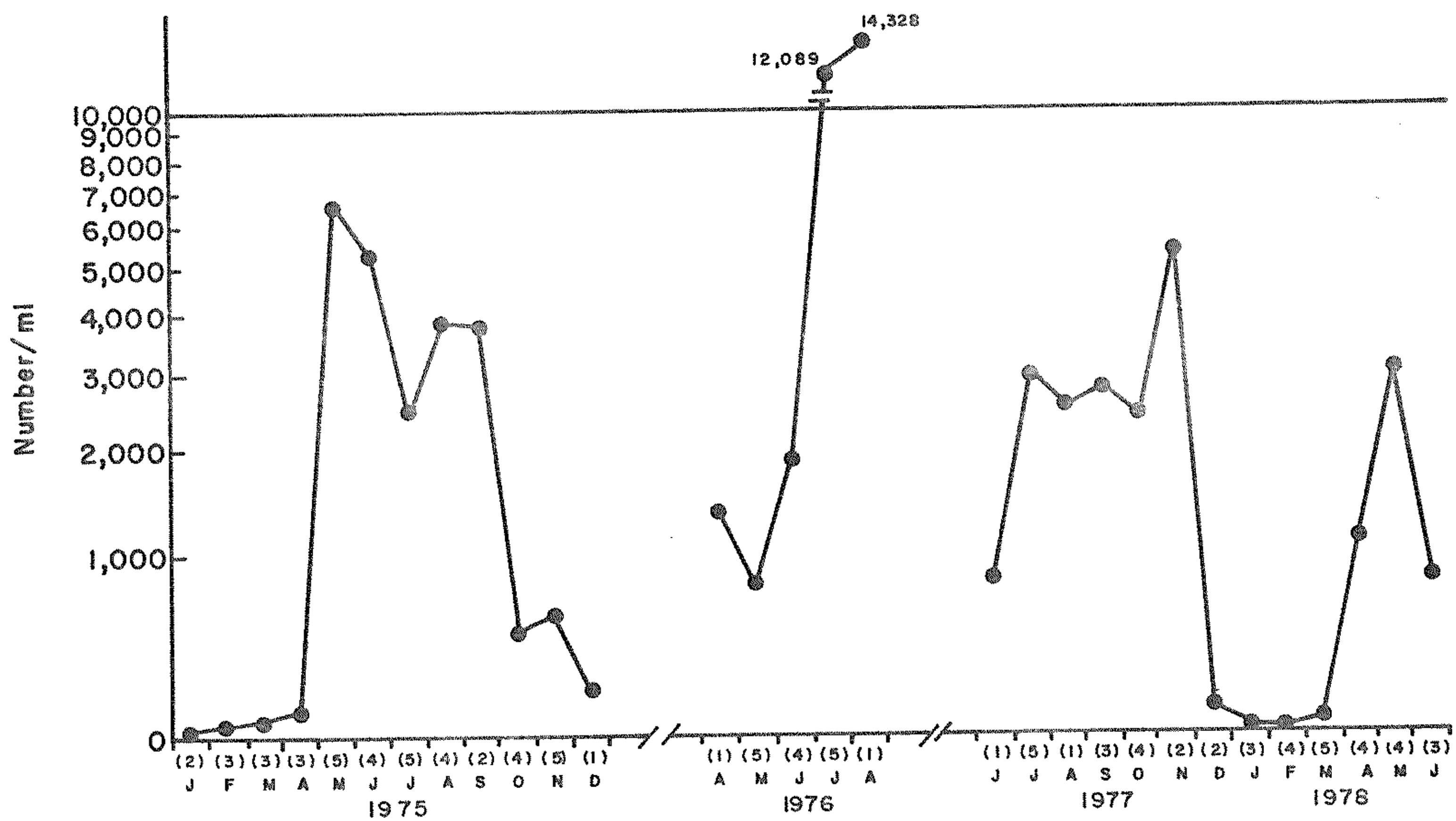


FIGURE 14.
Variation in Total Phytoplankton at Station N

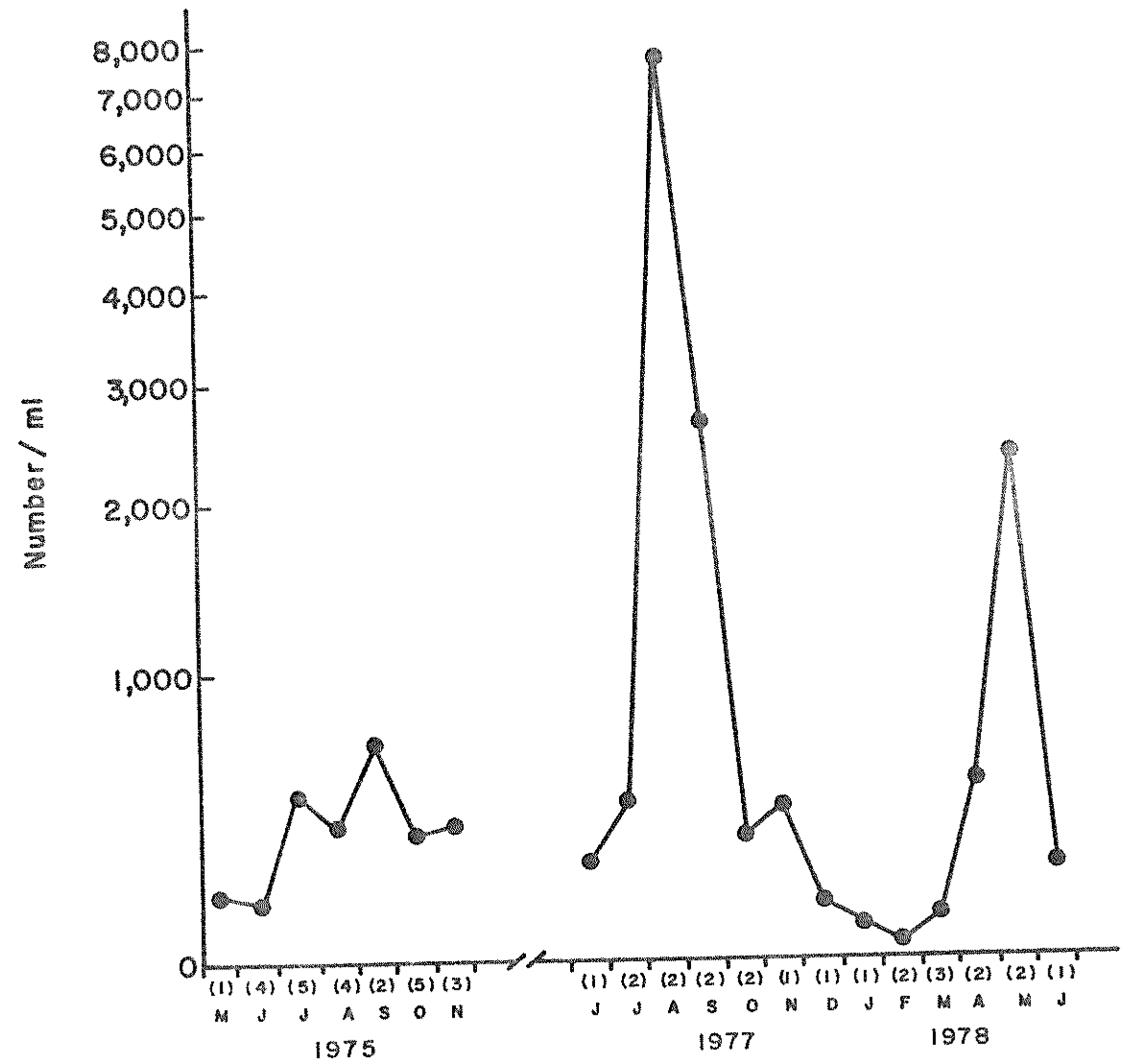


FIGURE 15.
Variation in Total Phytoplankton at Station 4-1

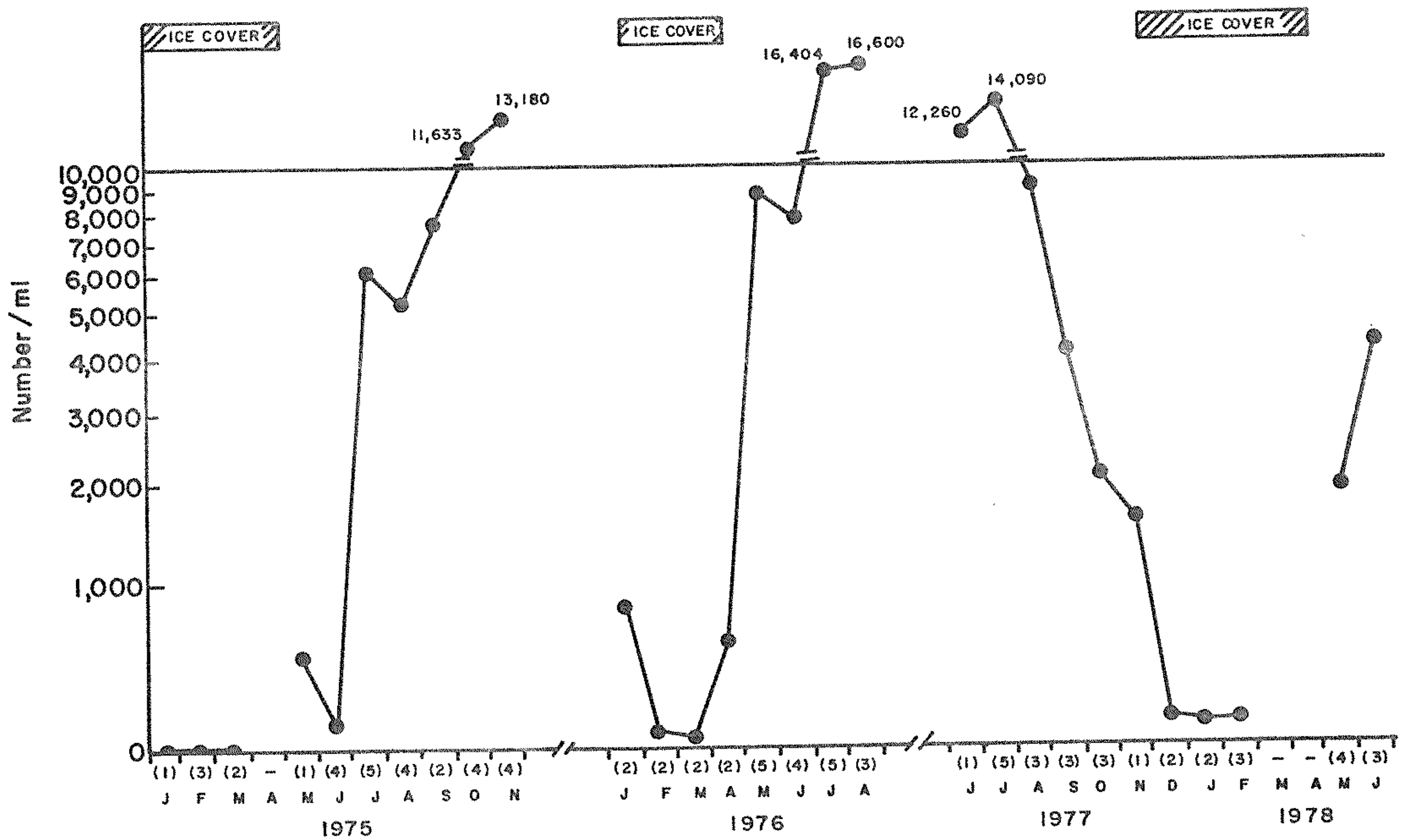
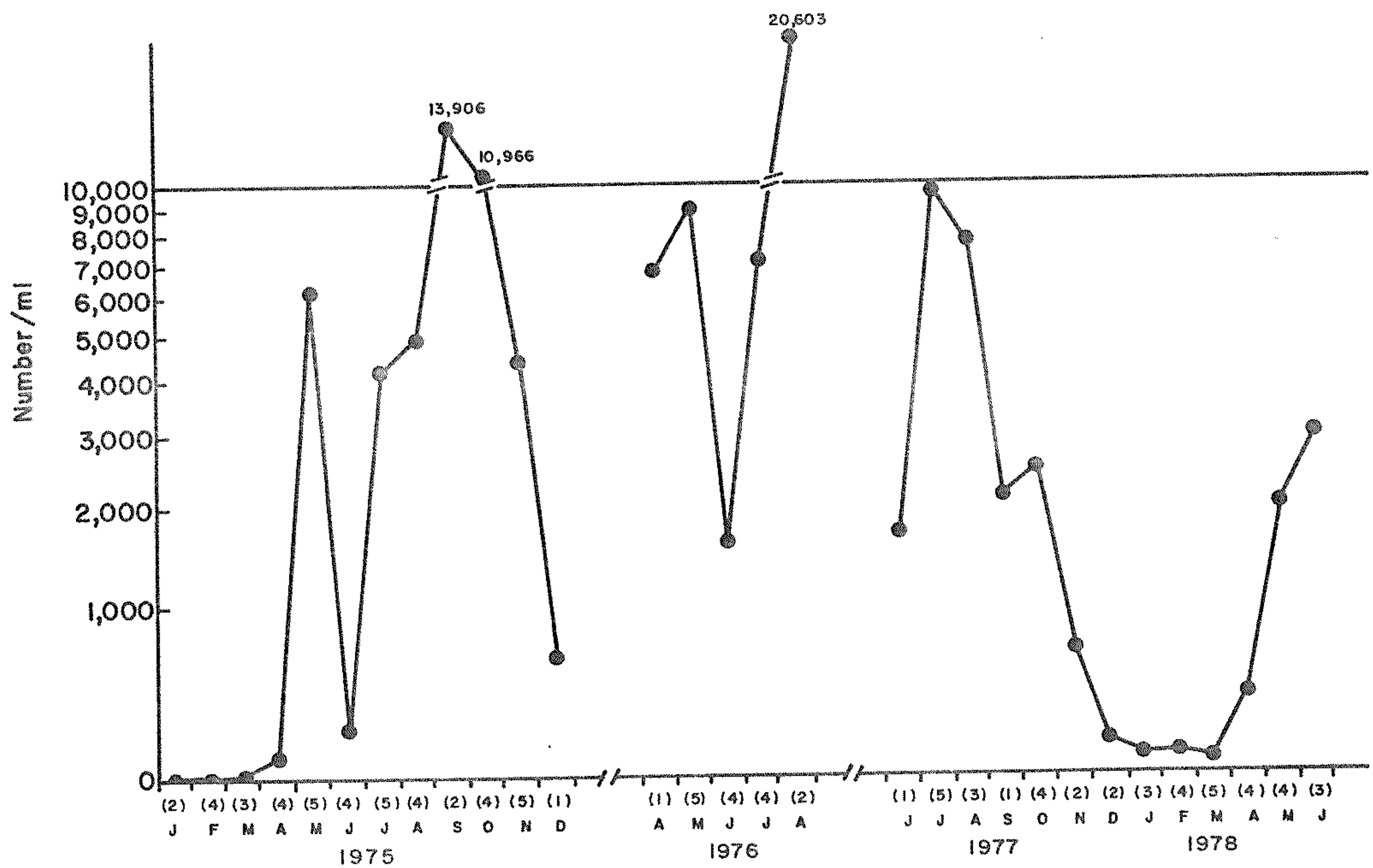


FIGURE 16.
Variation in Total Phytoplankton at Station 8



by aquatic plants in areas above and below Station F down to Station 1.

Total N concentration was generally less in 1977-78 than in either 1973-74 or 1974-75, with some exceptions that appear below.

Mean Total Nitrogen, mgl

	E	F	M	N	1	8
1973-74	-	1.54	-	.137	.29	.33
1974-75	.305	1.26	.56	.275	.474	.27
1977-78	.136	1.08	.23	.187	.346	.064

Phytoplankton

Growths of blue-green phytoplankton that have annually produced odors and other conditions considered objectionable by most persons have been salient features of Lake Sallie and Muskrat Lake in recent years. Comparison of annual mean blue-green phytoplankton concentrations in 1975 and 1977, as μ^3 per ml, shows a noteworthy decline in 1977 in Muskrat Lake (75%) and a slight decrease (14%) in Lake Sallie. However, in Muskrat Lake lower concentrations occurred, with two exceptions, throughout the growing season, whereas 1977 Lake Sallie concentrations, with one exception, were greater in summer and less in fall than those of 1975 (Table 6).

Total phytoplankton production for the period 1975 to '78 is shown in Figures 12 to 16. At Station F (Figure 12) institution of the special phosphorus removal procedures has had no effects on plankton production that were apparent in 1977 and '78. The limited sampling period in 1976 probably missed peaks attained that year.

At Station 1 1977-78 total plankton densities were considerably below those of 1976, and demonstrably lower than 1975 levels (Figure 13).

TABLE 6. Blue-green phytoplankton volume, 1,000 μ^3/ml

	Muskrat Lake		Lake Sallie	
	1975	1977	1975	1977
6/24	1,525	594	3,297	8,115
7/1	1,400	897	1,105	4,701
7/8	2,141	33	2,780	17,963
7/16	1,853	720	21,736	12,623
7/22	5,665	814	14,073	36,056
7/28	6,902	1,123	14,460	23,700
8/5	6,797	1,850	756	13,843
8/12			13,626	15,649
8/19			6,944	25,614
9/5			25,948	-
9/16	5,204	704	7,113	6,699
9/24			-	4,902
9/30	15	519	16,399	4,178
10/8	23	595		
10/14	4	7	20,524	5,523
10/21	35	12	19,017	1,918
10/28			25,869	567
11/4	1	4	17,167	217

: N (Figure 14) 1977 levels were greater than those of 1975 or 1978, ıd the 1977 peak occurred when there was backflow into Detroit Lake :om the ditch from Lake St. Clair. At Station 4 near the center of ıke Sallie total plankton has made no response to the special treatment :ocedures (Figure 15), but at the Sallie outlet (Station 8) a decline ıy be claimed for 1977 (Figure 16).

TREATMENT REALIZED

Phosphorus and nitrogen reduction following both types of ground- ıter application are given under Groundwater and will not be mentioned :re except to note that phosphorus reductions were 79 and 83%, :spectively, for the infiltration basins and irrigation plots.

Chemical Precipitation Plant

Analyses of influent to and effluent from this facility appear in .ble 7. Mean phosphorus reduction by this process was 81%; the maximum :moval noted was 90% on February 16, 1978, and the minimum, 69% on ›ril 13, 1978. Lime precipitation had no effect on nitrogen in the .ant influent, but it elevated pH and lowered alkalinity and hardness ı manners that were anticipated. Sulfuric acid adjustment of pH in :is plant increased sulfate concentration in water discharged to Lake .. Clair in winter.

Manhole 18

Comparison of water from this discharge with the stabilization pond fluent (Table 8) shows the same level of phosphorus reduction as that parent in the upper water table at PC3, which suggests that MH18 gives

TABLE 7. Analyses of chemical precipitation plant influent and effluent

	Total Phosphorus		Total Nitrogen		pH		Total Alkalinity		Total Hardness	
	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.
1977										
12/21	6.00	1.33	16.56	15.89	7.88	7.28	393	83	340	206
1978										
1/12	6.54	1.20	16.95	16.60	7.90	8.87	444	112	376	180
2/2	6.48	.96	22.01	22.51	7.78	8.32	443	64	350	134
2/16	6.82	.69	20.90	21.07	7.80	9.09	421	73	340	149
3/2	6.06	1.36	21.81	22.72	7.87	8.20	417	75	324	134
3/16	5.47	.90	17.20	17.51	7.88	8.38	391	62	314	134
3/30	4.78	1.07	11.17	11.75	8.63	8.78	349	60	288	180
4/13	3.62	1.14	9.86	10.26	8.78	11.03	307	203	299	443

TABLE 8. Comparison of wastewater effluent and manhole 18 water chemistry values, mgl

		Total P	Total N	Total Hardness	Ca	Mg	Alkalinity
				E F F L U E N T			
1977	7/27	1.89	.86	270	148	122	314
	8/11	1.75	.56	281	170	111	331
	9/23	5.35	5.86	319	237	82	378
	10/7	4.73	6.59	319	237	82	373
	10/20	4.56	4.04	319	227	93	353
	11/3	5.01	4.72	324	237	87	358
	12/5	2.35	15.47	242	149	93	160
				M A N H O L E 1 8			
1977	6/23	1.44	3.75	419	313	106	402
	7/7	0.74	3.73	382	281	101	390
	7/21	1.06	2.47	350	249	101	365
	8/4	0.41	0.028	350	265	85	360
	8/18	0.71	2.09	355	260	95	355
	9/15	0.83	–	375	267	108	366
	9/29	0.96	2.73	474	350	124	375
	10/13	0.26	3.14	427	319	108	373
	10/27	0.64	1.41	381	288	93	355
	11/25	1.16	4.15	366	278	88	357

essentially the same water as that taken at PC3. Deeper water at PC3 showed a 7% additional P reduction, indicating continued adsorption with further passage through the ground.

RESUMÉ

Despite higher phosphorus concentrations than those present in 1975 Muskrat Lake showed noteworthy (75%) lower blue-green phytoplankton densities in 1977. The central area of Lake Sallie (Station 4-1), with slightly higher phosphorus than 1975, had 14% less blue-green phytoplankters in 1977. The latter occurrence may represent natural variation, but differences shown by Muskrat Lake seem too great to be accounted for in this fashion, and they cannot be attributed to a phosphorus change. Diversion of the wastewater effluent over the growing season appears the most likely cause at this time, and, if this proves true, withholding of critical elements other than phosphorus will probably prove responsible. The much lower response of Lake Sallie to effluent diversion may reflect a greater backlog of such elements, their supply from other sources (e.g. lakeshore septic tanks), or greater time lag.

Reverse discharges that put ditch water into Detroit Lake also introduced phytoplankton at Station N that had developed in Lake St. Clair and possibly the ditch below. 1977 densities reached at N suggest that this water earlier was not completely lacking in nutrients other than phosphorus, and it is possible that their utilization in St. Clair and between there and Muskrat led to a paucity in the latter lake. In any event, it now appears that their supply to Muskrat was lower than in preceding years, and that a former excess over demands in St. Clair and the ditch and river below was not present in 1977.

Effluent applied to the soil spread both up- and downgrade in the water table but moved completely out of affected regions that were not recharged within 3.5 months following halt of ground application, and was largely gone, even from areas receiving the most, within 2.5 months. These observations are based upon chloride changes, concentration in the effluent being great enough to serve as a tracer.

Groundwater sampling conducted over 1973-75 showed variation from year to year in phosphorus content, and higher levels noted at PC10 and PC3 in 1977 may not at this time be ascribed to wastewater application with a 100% confidence level. No increases over prior years were evident at other sites sampled. Nitrogen and phosphorus reached groundwater from other sources as well as the wastewater effluent, and nitrogen variation in the phreatic zone permits no link-up with wastewater application at present. Water collected at Manhole 18 showed a mean nitrogen concentration 35% lower than that of the wastewater effluent.

As far as effects on surface water are concerned, ground application of wastewater cannot be assumed to have added any nutrients or chloride that were not there before. Hardness and alkalinity were increased, but decrease in these two parameters resulting from lime precipitation in winter probably more than offset these additions on an annual basis.

These special phosphorus removal procedures have so far had no discernible effects upon phosphorus concentration in Lake Sallie and water entering it, but benefits seem to accrue from diversion of wastewater effluent that seemingly removes other elements that play a part in algae stimulation.

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