WATER RENOVATION BY DISCHARGE INTO DEEP NATURAL SAND FILTERS

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Abstract

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Lake George is a beautiful recreational lake in New York whose waters are used for drinking without any treatment by many lake residents. In order to preserve its high quality, no discharges of wastes, treated or not, are permitted to the lake or any tributary streams thereof. To accomplish this goal, "complete" treatment was provided when the Lake George Village sewage treatment plant was constructed, with operation beginning in 1939. The plant consists of conventional primary sedimentation, trickling filters, and secondary sedimentation, but the final effluent is discharged without chlorination onto natural delta sand beds whose depths reach 21 m (70 ft).

Until April 1973, no knowledge was available as to the ultimate residence of the liquid. Investigations at that time revealed a considerable seepage from the banks of the flood plain of West Brook which ultimately flows into Lake George. This has since been identified as the effluent from the sewage treatment plant. Studies have been made of the quality of this seepage and its effects upon West Brook.

Wells have been placed between the sand beds and West Brook to trace the contaminant transport through the sand. Analysis has shown that aerobic conditions persist in the ground water between the sewage treatment plant and West Brook. Coliforms, BOD, ammonia, organic nitrogen, and phosphate are completely removed before the effluent reaches West Brook 600 m (2000 ft) away. Chlorides are not diminished and nitrates are increased. The nitrate increase represents oxidation of ammonia and organic nitrogen, but a nitrogen balance could not be established.

The effects of the seepage upon West Brook were also determined. The dissolved solids, alkalinity, chlorides, and nitrates in West Brook were increased in passing the area where the seepage enters the stream. There was no measurable change in phosphate concentration. The quality of the water in West Brook was not degraded below acceptable drinking water standards. There was little detectable effect upon Lake George with the exception of a measurable increase in nitrate content near the discharge of West Brook.

The natural delta sand filter of the Lake George Village sewage treatment plant appears to be providing adequate purification of the applied effluent to allow reuse of the water for most purposes.

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INTRODUCTION

Although no one was aware of it until recently, the Lake George sewage treatment plant system does involve complete recycling of the treated and polished effluent back to the water supply system for the Village of Lake George. Lake George itself is a beautiful recreational lake noted for its clarity of water, located in the southeastern portion of the Adirondack Forest Preserve in the State of New York (Figure 1). Prior to the most recent glacier, the Lake George area consisted of two separate river basins. One flowed from what is presently Northwest Bay through the present Dunham Bay area and into the Hudson River. The other flowed northward through what is presently the Rogers Rock area and into the Lake Champlain basin. When the glacier receded approximately ten thousand years ago, moraine was deposited in the outlets of both of these streams, forming two lakes. The moraine deposit reached a slightly higher level at the southern end and the southern lake overflowed into the northern lake, all of which now flows out at Ticonderoga and into Lake Champlain. The area which previously separated the two river basins is now a rather constricted island-studded area known as The Narrows. In general, the Lake George watershed is underlain by rock consisting of pre-Cambrian gneisses with valleys underlain by lower Paleozoic strata (Hill, 1965). However, in a few areas, there are some natural delta sand deposits created by outwash from the receding glaciers. One such delta sand deposit is located at the southwest corner of Lake George as shown in Figure 2 (Hill, 1965; and Newland and Vaughan, 1942).

Plans were initiated in 1936 to construct a sewage treatment plant for the Village of Lake George. Special efforts were made even then to assure that Lake George would remain as a pure recreational lake. The lake was given a special class AA rating which required that there shall be no discharge of any liquid wastes, treated or untreated, directly into Lake George or into any tributary thereof. Since this regulation does not limit discharge into the ground, (particularly to allow the use of septic tanks around the lake), the design engineer looked around for a suitable place to discharge the treated effluent into the soil. The site for the sewage treatment plant was chosen on one of the delta sand deposits as indicated in Figure 2. The sewage is collected at a central pumping station at the shore of the lake and pumped by force main with a relay station to the sewage treatment plant, an elevation of about 180 ft (55 m) and a distance of approximately 1 mi (1.6 km).

The treatment plant, shown in Figure 3, initially was comprised of units built in triplicate. This design was chosen due to the fact that the summer flows during the tourist season were approximately three times the winter flows. Thus one-third of the treatment system could be utilized during the winter and the entire system during the summer. Sewage now enters the treatment plant through one of two force mains, one originating from the Village and the other from the Town of Lake George. Each of these flows passes through a Parshall flume after which the two flows are combined together and with the recycle from the trickling filter effluent. The flow is divided into three settling tanks, one being one of the original Imhoff type tanks and the other two newer tanks utilizing sludge scrapers and skimmers. The settled effluent is passed through one of three trickling filters, one of which is a fixed nozzle type which is covered and used exclusively in the winter, and the other two are standard high rate rotary trickling filters. After secondary sedimentation, the

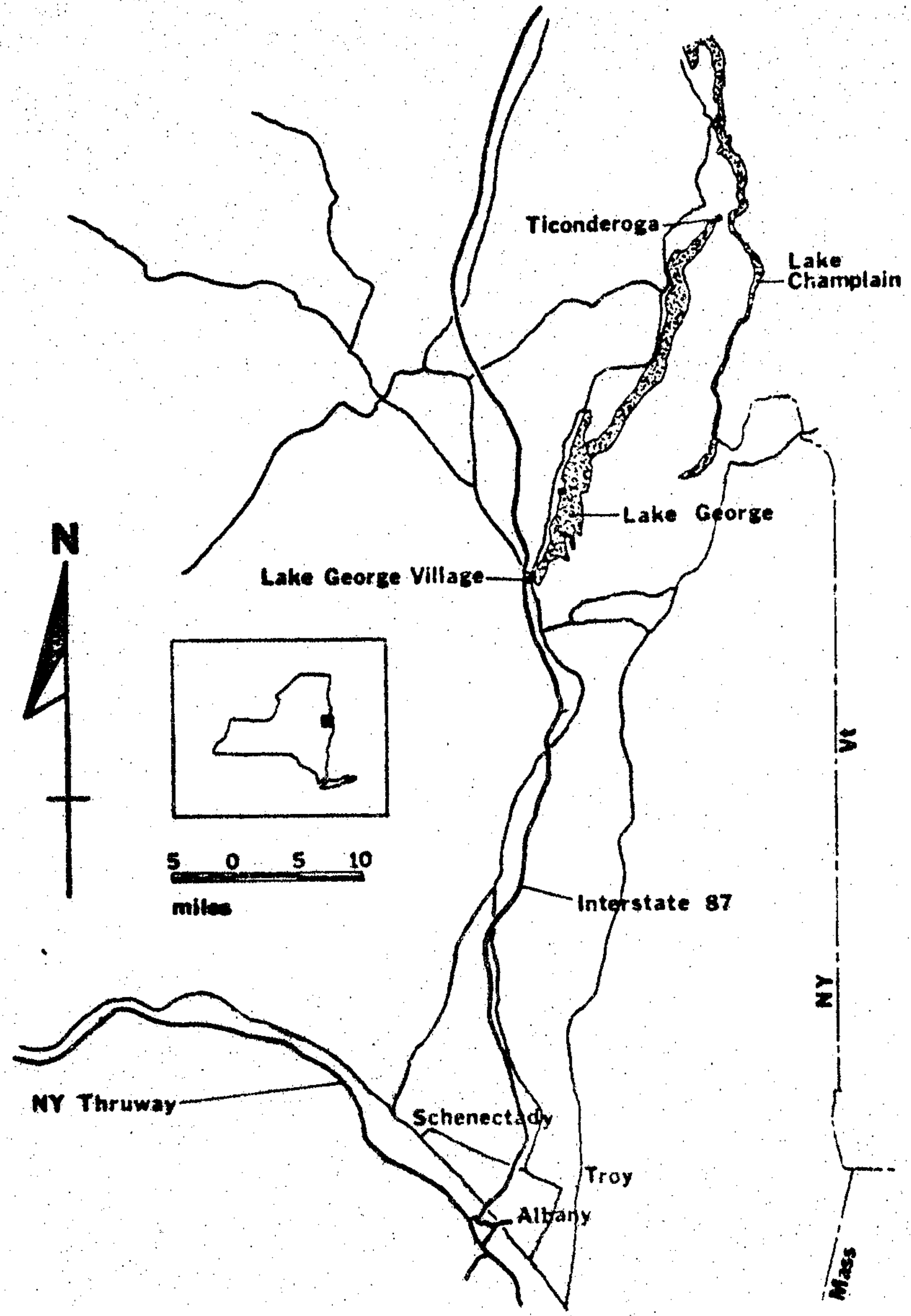
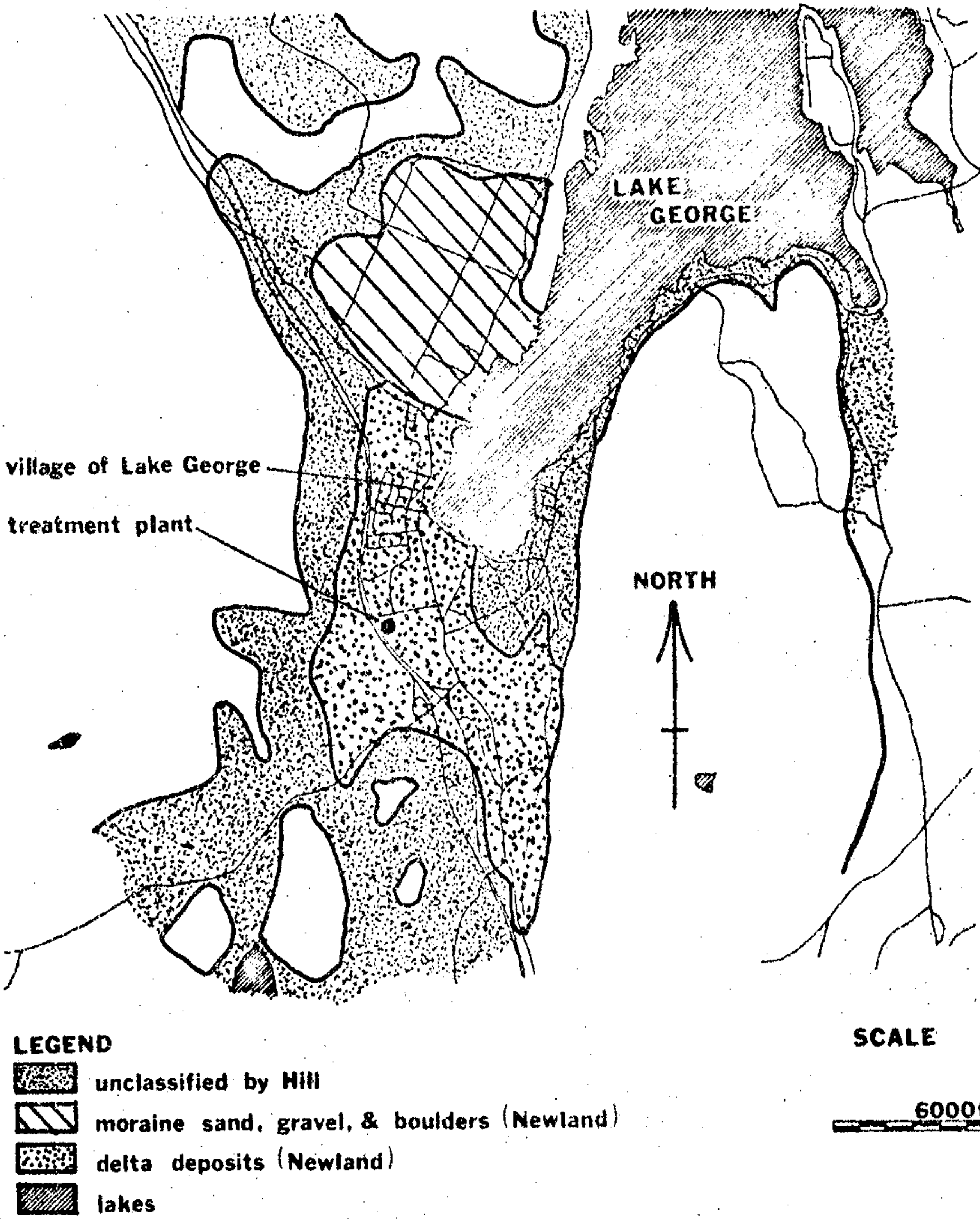


FIGURE 1

LOCATION OF LAKE GEORGE, N. Y.



GEOLOGY OF THE SOUTHERN LAKE GEORGE DRAINAGE BASIN

FIGURE 2

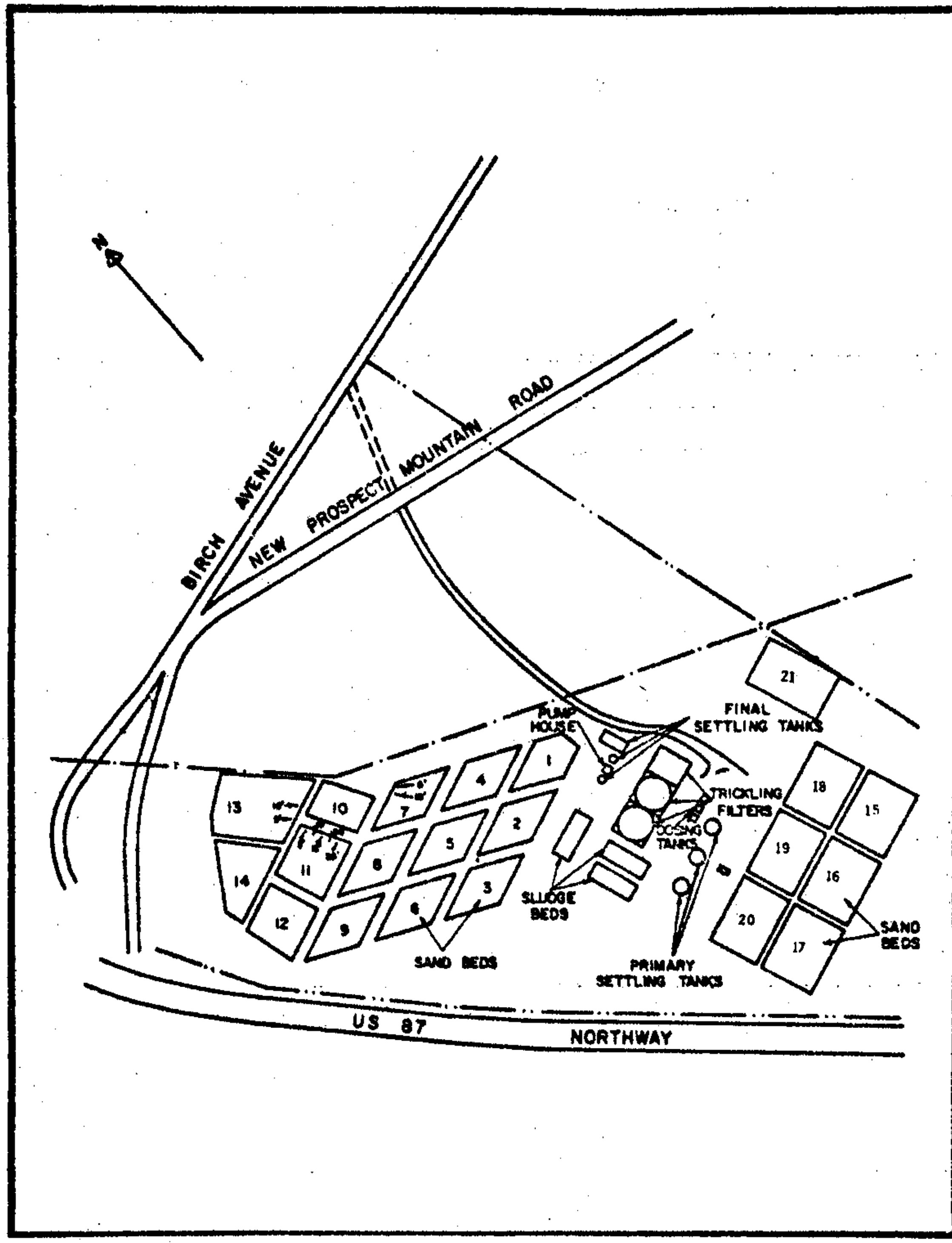


FIGURE 3

LAKE GEORGE VILLAGE SEWAGE TREATMENT PLANT unchlorinated effluent is passed onto the natural delta sand beds where it infiltrates into the soil. Originally, there were six sand beds located in what is now called the north (lower) sand bed area. These have been expanded over the years with one bed being added in 1947, two in 1950, three in 1956, and the last two in the northern (lower) section in 1965, bringing the total in this area to the present 14 beds. The first six beds in the southern (upper) section were added in 1965, and the last bed in this area was added in 1970. The combined area of the sand beds is presently 6.4 acres (2.6 hectares).

Presently, the flow at the treatment plant reaches slightly over 1 mgd (3,800 m^3/day) during the summer tourist season, whereas the winter flows are in the order of 0.3 mgd (1,100 m^3/day). The normal operation of the sand beds is to dose one north and one south bed during the day and to direct the flow to another similar pair of beds at night. Most beds drain to dryness in 0.5 to 2 days. Depending upon the need for the beds, they may be flooded several times before they are allowed to remain dry for reconditioning, which involves removing the surface mat by scraping or by raking followed by releveling.

The engineer who designed the treatment system described it as "complete treatment... for a small community. The final effluent becomes ground-water which in all probability seeps, eventually, to some watercourse as a highly purified liquid which cannot be identified as a sewage effluent." (Vrooman, 1940) The studies reported here serve to determine the validity of this statement.

PREVIOUS STUDIES

Rensselaer Polytechnic Institute (RPI) initially became interested in the operation of the Lake George Village sewage treatment plant during 1968. The intent of the first study was to determine the direction of flow of the treated effluent after application to the sand beds. Previous information provided indicated that the depth to ground water was in the order of 12 to 15 ft.

Thus it was anticipated that a series of driven well points around the sand beds could provide the needed information as to direction of flow. However, when the study was begun, it was found that a 56 ft well did not reach the ground water in the area of the sand beds. Thus this study had to be modified. Well points were driven at 5 ft intervals down to 25 ft in three of the sand beds. No samples could be secured from the well points in bed 7 and water was able to be pumped from only the 5 and 10 ft depths in beds 11 and 13. Apparently, the upper levels of the sand beds were saturated with water due to the application of the sewage effluent; however, by the time the effluent percolated down beyond 10 to 15 ft, the water became dispersed and could no longer be recovered by a normal well point and screen. The study (Aulenbach, et al. 1974a) did provide useful information showing that BOD, coliforms, ammonia and organic nitrogen were almost completely removed in the top 10 ft of the sand beds, but that chlorides were not removed and nitrates increased apparently due to the oxidation of the organic and ammonia nitrogen. Phosphate removal appeared to be a function of previous use of the beds. Bed 11 had been in almost constant use and exhibited little phosphorus removal, whereas bed 13 had not been used for a period of nearly one year and exhibited significant phosphorus removal.

A second study (Fink and Aulenbach, 1974) to evaluate the direction of the flow of the effluent from the sand beds was conducted during 1972 utilizing a ground water resistivity survey. This method is based on the fact that sewage effluent, containing more dissolved material, would have less resistivity (or greater conductivity) than the natural ground water in the area. The results of this study are shown in Figure 4. The arrow drawn on this map indicates the area of lowest resistivity and the estimated direction of flow of the ground water from the treatment plant. It may be seen that the flow appears to be in

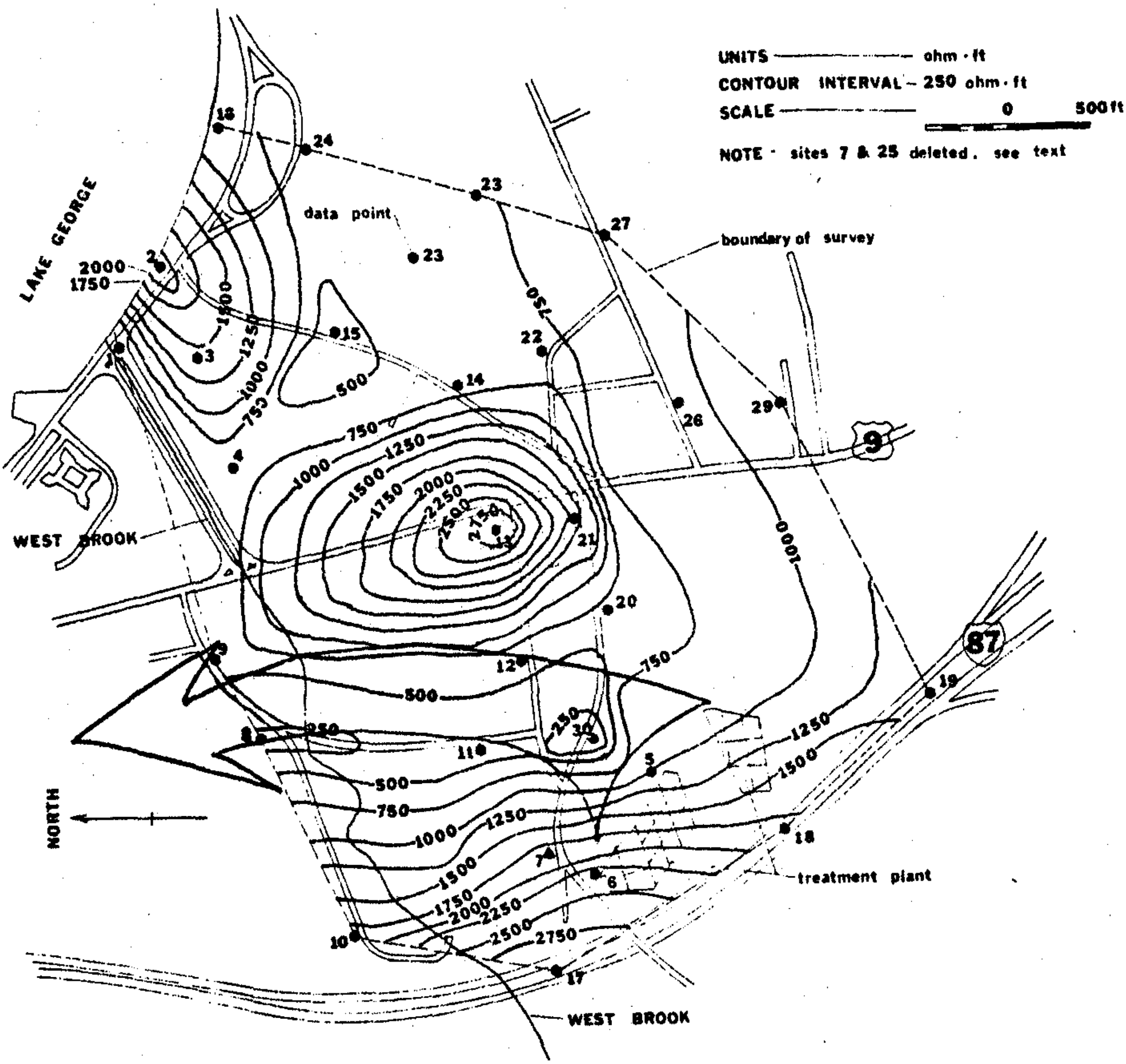


FIGURE 4

FLOW OF GROUND WATER BY RESISTIVITY STUDIES a generally northerly direction from the treatment plant toward West Brook. Unfortunately, other complications prevented the determination of whether or not the low resistivity profile continued across West Brook or whether it ended at West Brook.

The results of this study prompted a more thorough investigation of the area in and around West Brook as shown in Figure 5 (Aulenbach et al., 1974b). Armed with only a conductivity meter, a walking survey was made of West Brook during April of 1973. A large amount of seepage was observed coming out of the lower 5 ft of the steep bank which defines the edge of the flood plain of West Brook. This flood plain is broken by the artificial grading of Gage Road across West Brook at this location. All of the seepage which occurs upstream from Gage Road collects in a separate stream which flows into West Brook immediately above the dual culvert under Gage Road. The seepage which occurs from the bank downstream from Gage Road flows into West Brook in three or four different small channels. The results of two surveys in this area are summarized in Figure 5. The conductivity of the water seeping out of the ground was measured and it may be seen from the figure that the conductivity decreased proceeding upstream from Gage Road. On the downstream side of Gage Road, the conductivity measurements increased with the highest values being located up a side valley perpendicular to West Brook. It was later discovered that the local highway department had a salt storage area on the plateau immediately above this area. Thus the extremely high conductivity measurements found were attributed to leaching of the salt through the ground to this area. Measurements in West Brook above and below the influence of this seepage indicate that there was a definite increase in the conductivity of the stream as it flowed past this area. These results gave a strong indication that the sewage effluent applied to the sand beds reappears as surface water along the south bank of West Brook and then

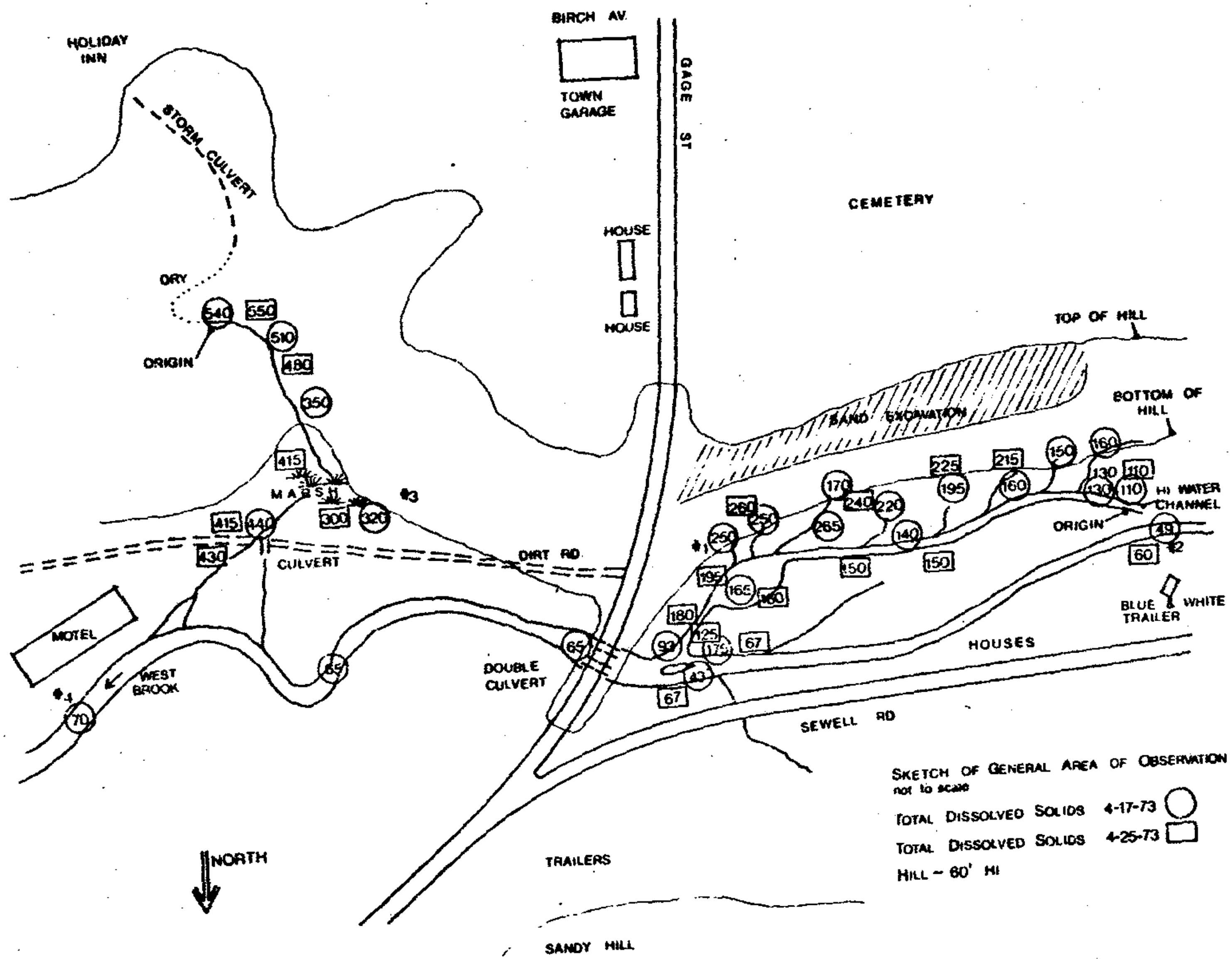


FIGURE 5 OBSERVATION OF SEEPAGE ALONG WEST BROOK

flows into West Brook and ultimately back into Lake George. The Village of Lake George and many individual homes around the lake utilize Lake George as their water supply with no treatment except for chlorination of public supplies. Thus it may be seen that the sewage treatment effluent is completely recycled, albeit with a great dilution factor before reuse.

PRESENT STUDIES

Figure 6 shows the overall relation of the treatment plant to the surrounding area. In order to get a better picture of the changes in ground water quality as the sewage effluent passes through the sand to West Brook, a series of wells was placed in and around the sewage treatment plant as indicated in Figure 7. Some of the well locations indicated on this figure have points and screens at various depths in the aquifer. The data for each well is shown in Table 1 and depicted in Figure 8. Well 1 is located in north sand bed 4, well location 2 is near West Brook, well site 3 is adjacent to West Brook, well 5 is located in south sand bed 3, well site 6 is approximately halfway between the north sand beds and West Brook and well 10 is a control not influenced by the effluent from the treatment plant.

Beginning in April 1973, samples have been secured from the various wells as they were installed, from West Brook above and below the influence of the seepage from the stream banks, and from the sewage treatment plant influent and effluent. Although in some instances the period of data acquisition is short due to recent installation of a well, and there are some other data points which are questioned, the mean values of the data relating to the quality changes as the sewage treatment effluent passes through the soil are summarized in Table 2. Details of the amount of data available and the period of time covered for each sampling location are shown in Tables A1 through A10 of the Appendix.

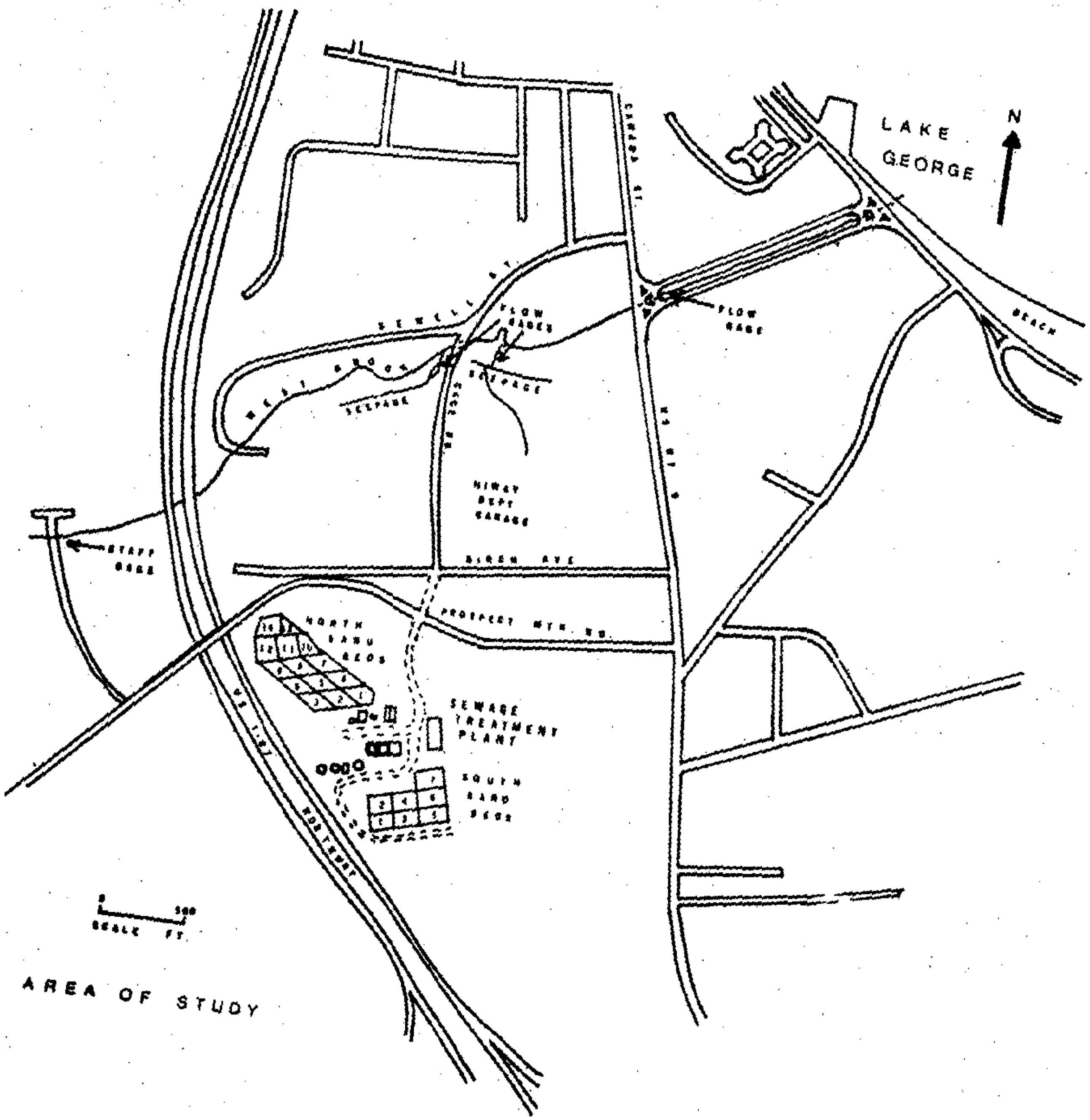

LAKE GEORGE
N
FLOW GAGES
FLOW GAGE
SEEPAGE
STAFF GAGE
NORTH SAND BEDS
SEWAGE TREATMENT PLANT
SOUTH SAND BEDS
PROSPECT MTN. RD.
AREA OF STUDY

FIGURE 6

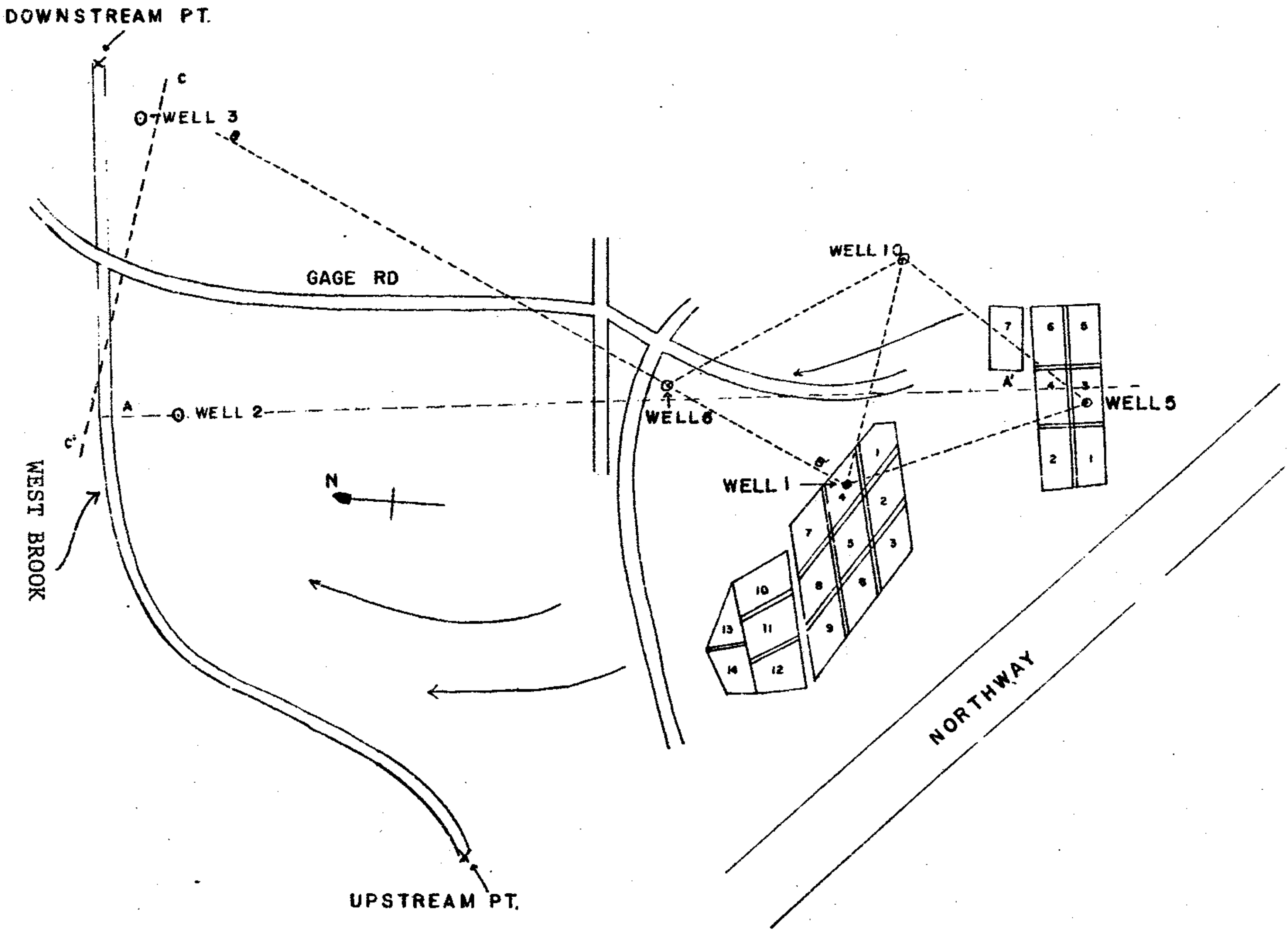


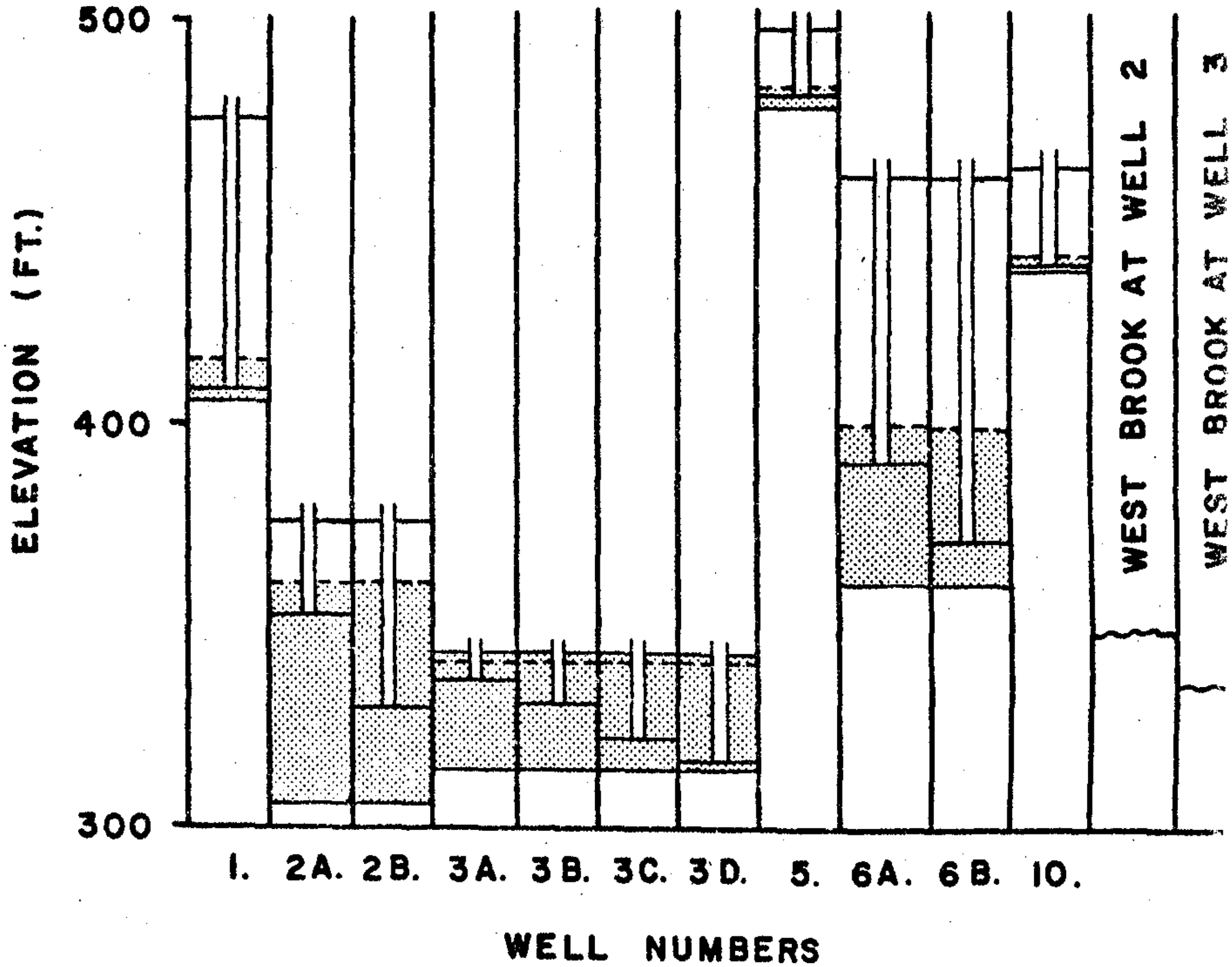
FIGURE 7 LOCATION OF WELLS IN RELATION TO LAKE GEORGE VILLAGE SEWAGE TREATMENT PLANT

TABLE 1

WELL DATA

	Surface Elevation	Groundwater Elevation	Bottom of Point	Bedrock Elevation
Well 1	475.0	415.66	407.80	405.0
Well 2A	375.40	359.22	352.13	306
Well 2B	375.40	359.2	330.35	306
Well 3A	339.90	339.74	336.44	314
Well 3B	339.90	340.01	329.06	314
Well 3C	339.90	340.08	321.23	314
Well 3D	339.90	340.0	315.64	314
Well 4	-	-	-	-
Well 5	495.37	480.98	479.40	477.40
Well 6A	458.7	397.6	388.13	360.0
Well 6B	458.7	397.6	370.68	360.0
Well 10	462.73	441.7	438.91	438.91
West Brook at Well 2	348.0	-	-	-
West Brook at Well 3	334.9	-	-	-

WELL ELEVATION DATA



UPPER SOLID LINE IS GROUND SURFACE LEVEL

UPPER BROKEN LINE IS GROUND WATER LEVEL

NEXT SOLID LINE IS BOTTOM OF WELL POINT

BOTTOM SOLID LINE IS BEDROCK LEVEL

SHADED AREA REPRESENTS GROUND WATER SATURATION

WAVY LINE IS WEST BROOK WATER SURFACE

FIGURE 8

TABLE 2

Mean Values of Data Relating to
the Effluent Discharged from the
Lake George Village Sewage Treatment Plant
During the Period 4/17/73-9/19/74

Sample Location	Temp. °C	DO mg/l	Diss. Sols. mg/l	pH	Alk. mg/l	Cl. mg/l	Tot. Sol. P ug/l	NO_3 N mg/l	NH_3 N mg/l	TKN mg/l
Well 1	14.7	5.8	205	6.51	90.4	41	440	7.82	0.35	0.612
Well 2A	11.9	9.4	195	7.66	134	28	67.6	4.06	0.08	0.082
Well 2B	-	1.6	-	8.50	-	44	126	0.14	0.44	-
Well 3A	18.9	4.6	330	7.13	313	36	47.6	0.43	0.42	0.381
Well 3B	16.9	4.0	332	7.05	188	55	36.2	7.70	0.09	0.182
Well 3C	14.5	3.4	301	6.94	166	54	42.7	9.28	0.05	0.092
Well 3D	-	1.4	262	8.51	184	48.5	50	0.41	2.05	-
Well 5	21.8	6.1	127	6.37	53.3	26	936	7.81	0.13	0.623
Well 6A	-	2.8	-	8.10	-	28	80	14.2	0.59	-
Well 6B	12.8	3.2	186	8.79	142	36	68.4	2.58	3.24	3.80
Well 10	-	6.3	71	6.86	43.4	6.3	24.9	0.31	0.11	0.594
West Brook Upstream	13.0	12.0	61	7.49	40.3	12	49.9	0.35	0.05	0.065
West Brook Downstream	13.4	11.5	98	7.49	69.8	19	57.7	1.43	0.10	0.107
STP Inf.	22.5	2.3	243	7.20	163	38	4,471	-	-	13.01
STP Eff.	22.5	2.6	206	6.94	135	38	2,172	1.08	2.67	11.47

The temperature of the sewage was consistently higher than the temperature of any of the ground water or the stream samples secured. There was no significant change in temperature between the influent and the effluent of the treatment plant. The shallowest wells showed the highest temperature. In general, the temperature decreased with depth. It may be seen that West Brook is a cold water stream. The highest temperature ever recorded during the sampling period was 14.5°C.

The DO results were quite variable. However, the one important point that the DO measurements indicate is that there was sufficient dissolved oxygen present in the ground water at all times to maintain aerobic conditions. This is considered desirable for the continuing process of renovating the wastewater as it passes through the soil.

Dissolved solids and chlorides could normally be used as a tracer of the treated effluent applied to the sand beds. The exception in this case occurs at well location 3. It may be seen that both the dissolved solids and the chloride content of the wells at all depths at this location exceeded the corresponding values of the sewage treatment plant effluent. This seemingly unusual situation has been attributed to a former open salt storage area operated by the local highway department, located at the top of the hill near well site 3. It has been surmised that this salt has entered the ground water and reappears at well site 3, thus producing the high values and ruling out the use of dissolved solids and chloride as a tracer of the sewage effluent. Excluding the results from well site 3, the dissolved solids and chloride content were generally highest in the sewage effluent. The values of these parameters were nearly the same in well 1 located in the sand recharge beds. Where sufficient data were available to compare the data from the well points at two different depths at a well location, the chloride content was consistently higher at the deeper well point. Well 10 was low in both dissolved solids and chloride, confirming the use of well 10 as a control not contaminated by the sewage effluent. West Brook above the entrance of the seepage was also low in dissolved solids, and chlorides; however, the downstream location shows increases in both of these parameters due to the influence of the seepage which enters the stream between these two locations.

Again excluding the results in wells at location 3, the alkalinity in the test wells showing the influence of the sewage was generally as high as the alkalinity of the sewage with the exception of well 5. It is felt that the low alkalinity at well 5 represents an average which includes periods during which the infiltration bed in which the well is located was dry and the alkalinity during this period of time was that of the natural ground water in the area. The alkalinity in control well 10 was quite low. The alkalinity in West Brook shows the influence of the seepage between the upstream and downstream sampling locations.

The total soluble phosphorus results indicate that the sewage treatment plant is capable of reducing the phosphorus content by about 50 percent. The effluent from the treatment plant contains approximately 2 mg/l as it is discharged onto the sand beds. Wells 1 and 5 in the sand beds contained the highest concentration of phosphorus in the ground water. With the exception of scant results at well 2B, the phosphorus content of all the other wells averaged less than 100 ug/l. Well 10 had the lowest phosphorus concentration of approximately 25 ug/l. The phosphorus content of West Brook above the seepage was approximately 50 ug/l. A slight increase in phosphorus content from the upstream to the downstream sampling locations was indicated; however, due to the sampling and analytical techniques, this is not considered to be a significant increase.

The nitrogen analyses indicate a small but significant concentration of nitrate in the sewage treatment plant effluent. This symbolizes a reasonably high degree of treatment of the sewage. However, over 2 mg/l of ammonia nitrogen and over 11 mg/l of total Kjeldahl nitrogen in the sewage treatment plant effluent indicate that there remains some unoxidized nitrogen which is discharged into the ground. Nitrate values higher than the sewage effluent were found in wells 1, 2A, 3B, 3C, 5, 6A and 6B. Slightly less nitrate was found in the deeper well 2B and in the control well 10. At well site 3, low values were found at the shallowest well 3A and the deepest well 3D; whereas high values were found at the two in-between depths. The relatively low value of 0.35 mg/l of nitrate nitrogen in the upstream area of West Brook was significantly increased to 1.43 mg/l below the seepage. With the exception of well 6B, there was a reduction in the ammonia content from the initial values applied at the sand beds to each one of the test wells. At both well sites 2 and 6, the deeper well points contained greater concentrations of ammonia nitrogen. At well location 3, the upper well 3A had a higher value than wells 3B and 3C but well 3D had an ammonia nitrogen content only slightly lower than that of the applied sewage effluent. Only a slight increase in ammonia nitrogen content of West Brook was observed as the stream passed the seepage area. Little reduction in total Kjeldahl nitrogen was observed through the treatment plant, but the total Kjeldahl nitrogen was reduced to low values in all wells with the possible exception of well 6B. The change in total Kjeldahl-nitrogen of West Brook in the area of the seepage was insignificant.

In order to evaluate the amount of dilution provided for the treated effluent through the system, a system of stream flow monitoring has been established. A continuous water level recording gage has been in existence on West Brook just east of Route 9 at a location which includes all of the seepage from the stream banks into West Brook (see Figure 6). Mean monthly flows for the period beginning in August 1973 are shown in Table 3. The highest flow occurred in April 1974, representing spring snowmelt. The lowest flow was in August 1974. The mean flow for the water year 10/1/73 - 9/30/74 was 7.91 mgd. Precipitation during this period was generally above average. There is also a staff gage located west of where the Northway crosses West Brook. This is upstream from any of the seepage involved in this study. Whereas continuous records are not available here, occasional spot checks for flow can be calculated. In November 1974, two additional stream flow recording gages were installed to determine the volume of flow of the seepage. Since the seepage upstream from Gage Road has naturally combined to form a separate stream, this entire stream is gaged at a point just above its confluence with West Brook. The seepage downstream from Gage Road flowed in several separate channels which discharged into West Brook. Some ditching has been performed which collects nearly all of this seepage into one main channel which is now also being monitored. The first data available from these two locations indicate a flow of 0.6 mgd (2,300 m^3/day) at the upstream seepage location and approximately 0.4 mgd (1,500 m^3/day) at the downstream location. Thus the total seepage in the area is in the order of 1 mgd (3,800 m^3/day). These measurements were made in November 1974 during which time the average flow at the treatment plant was approximately 0.5 mgd (1,900 m^3/day). On the basis of this, it appears that the contribution of the ground water is approximately equal to the amount of sewage discharged onto the sand beds, or at this particular time of the year the sewage is diluted approximately 50 percent by the ground water. During this same time, the average weekly flow in West Brook was 4.5 mgd (1,700 m^3/day) This provides an additional dilutional factor of 4.5 when the seepage reaches

TABLE 3

Mean Monthly Flows in West Brook, N. Y.

Month	Mean Discharge			
	1973		1974	
	cfs	mgd	cfs	mgd
January			14.85	9.60
February			11.08	7.16
March			15.49	10.01
April			26.76	17.30
May			21.40	13.83
June			9.80	6.34
July			4.82	3.11
August	7.66	4.95	3.29	2.13
September	7.06	4.56	8.26	5.34
October	6.84	4.42		
November	6.52	4.21		
December	17.87	11.55		

Mean for water year 10/1/73 - 9/30/74

12.24 cfs

7.91 mgd

West Brook. When corresponding flow data and water quality parameters are available for the seepage and for West Brook, a mass balance for these parameters will be calculated. During the approximately six weeks from the installation of the flow recorder until the completion of this paper, the flow of the seepage at both locations was amazingly constant. This indicates that the ground water flow is controlled by the transmissivity of the soil.

In addition, when West Brook reaches Lake George there is a distance of approximately 0.8 mile (1.3 km) between the discharge of West Brook and the intake for the Village of Lake George water supply system. It is difficult to evaluate the amount of dilution which occurs in this distance in Lake George; however, it is considered to be a large value. Thus there does not appear to be any significant problem from the standpoint of water quality from the reuse of the treated sewage effluent which ultimately reaches Lake George.

On the other hand, there may be some significant influences in Lake George from the discharge of nutrients from West Brook into the southern area of Lake George. As may be seen, the nitrate content of West Brook is increased significantly as the stream passes the seepage area. This may provide sufficient additional nitrogen to support greater plant and algae growths in the southern portion of Lake George. Nitrogen and phosphorus also are contributed from other sources around Lake George. Previous estimates (Aulenbach and Clesceri, 1973) have indicated that the major source, 79%, of nitrogen to Lake George is from precipitation which falls directly on the lake, whereas only 4% is attributed to the effluent from the Lake George Village sewage treatment plant. Thus any additional efforts to reduce the nitrate content of the sewage effluent as it passes through the soil and into Lake George via West Brook would not result in a significant reduction in the total nitrogen present in Lake George; however, there may be some local benefits in the vicinity of the discharge of West Brook into Lake George.

SUMMARY

Sewage from the Village and Town of Lake George is treated by trickling filters and discharged into the ground through natural delta sand beds. The water reappears along the south bank of West Brook approximately 2000 ft (600 m) from the sand beds. Passage through this soil reduces the phosphorus, ammonia and organic nitrogen to very low values. The chlorides are not reduced and the nitrogen is increased apparently from the oxidation of the organic and ammonia nitrogen. This nitrate exerts a measurable influence on the nitrate content of West Brook as it flows past this area. However, the nitrate content of the seepage is within the acceptable limits for drinking water standards and when the water finally reaches Lake George prior to reuse, the concentrations of all potentially polluting materials are reduced well below objectionable limits. Moreover, the nitrate, which is the substance present in the highest concentration from the treatment plant effluent, is still only a very small fraction of the total nitrogen input to Lake George. Thus there appear to be no adverse effects upon the drinking water supply of Lake George due to the treatment of the sewage by trickling filters, followed by passage through the soil, the reoccurrence of the ground water as surface water along the banks of West Brook, and the reintroduction of the water to Lake George via West Brook.

REFERENCES

Aulenbach, D. B. and N. L. Clesceri, "Nutrient Inputs to a Lake and Their Effects Upon Water Quality," pp. 11-38 in Chemistry of Water Supply, Treatment, and Disposal, Edited by Alan J. Rubin, Ann Arbor Science Publishers, Inc. (1974).

Aulenbach, D. B., T. P. Glavin, and J. A. Romero Rojas, "Protracted Recharge of Treated Sewage into Sand: Part I - Quality Changes in Vertical Transport Through the Sand," Ground Water 12, 3, p. 161 (1974a).

Aulenbach, D. B., N. L. Clesceri, J. J. Ferris, and T. J. Tofflemire, "Protracted Recharge of Treated Sewage into Sand: Part III - Nutrient Transport Through the Sand," Ground Water 12, 5, p. 301 (1974b).

Fink, W. B. and D. B. Aulenbach, "Protracted Recharge of Treated Sewage into Sand: Part II - Tracing the Flow of Contaminated Ground Water with a Resistivity Survey," Ground Water 12, 4, p. 219 (1974).

Hill, F. A., The Precambrian Geology of the Glens Falls and Fort Ann Quadrangles, Southeastern Adirondack Mountains, New York, Ph.D. Thesis, Yale Univ. (1965). Univ. Microfilm Order # 05-15, 057.

Newland, D. H. and H. Vaughan, Guide to the Geology of the Lake George Region, New York State Museum Handbook #19, University of the State of New York (1942).

Vrooman, M., "Complete Sewage Disposal for a Small Community," Water Works and Sewerage, 87, 130 (March 1940).

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APPENDIX

TABLE A1

Summary of Temperature Data
as of 10/1/74

Sample Location	No. of Samples	Period Covered		Temp., °C		
		From	To	Avg.	Min.	Max.
Well 1	3	6/19/73	8/16/73	14.7	11.8	17.0
Well 2A	4	6/19/73	8/16/73	11.9	10.1	14.4
Well 2B	-	-	-	-	-	-
Well 3A	4	6/19/73	8/16/73	18.9	16.4	20.4
Well 3B	4	6/19/73	8/16/73	16.9	15.1	19.2
Well 3C	4	6/19/73	8/16/73	14.5	14.3	15.0
Well 3D	-	-	-	-	-	-
Well 5	2	7/25/73	8/16/73	21.8	20.0	23.6
Well 6A	-	-	-	-	-	-
Well 6B	2	7/25/73	8/16/73	12.8	12.1	13.6
Well 10	2	7/25/73	8/16/73	-	14.0	23.4 (?)
West Brook Upstream	3	7/6/73	8/16/73	13.0	11.0	14.5
West Brook Downstream	3	7/6/73	8/16/73	13.4	12.7	14.1
STP Inf.	3	7/6/73	8/16/73	22.5	20.0	24.9
STP Eff.	3	7/6/73	8/16/73	22.5	20.0	24.5

TABLE A2

Summary of DO Data
as of 10/1/74

Sample Location	No. of Samples	Period Covered		DO, mg/l		
		From	To	Avg.	Min.	Max.
Well 1	5	6/19/73	2/28/74	5.8	3.4	7.5
Well 2A	10	6/19/73	9/19/74	9.4	7.1	12.7
Well 2B	6	11/19/73	9/19/74	1.6	0.7	3.4
Well 3A	9	6/19/73	9/19/74	4.6	2.0	7.0
Well 3B	10	6/19/73	9/19/74	4.0	1.1	5.7
Well 3C	10	6/19/73	9/19/74	3.4	1.6	6.2
Well 3D	7	10/17/73	9/19/74	1.4	0.4	2.7
Well 5	8	7/25/73	5/30/74	6.1	1.7	9.0
Well 6A	7	10/17/73	9/19/74	2.8	1.4	4.3
Well 6B	10	7/25/73	9/19/74	3.2	1.1	6.6
Well 10	6	7/25/73	9/19/74	6.3	3.4	8.0
West Brook Upstream	8	7/6/73	5/30/74	12.0	9.6	14.0
West Brook Downstream	8	7/6/73	5/30/74	11.5	9.6	13.8
STP Inf.	1	8/16/73	-	2.3	-	-
STP Eff.	4	7/6/73	11/29/73	2.6	1.3	4.1

TABLE A3

Summary of Dissolved Solids Data
as of 10/1/74

Sample Location	No. of Samples	Period Covered From	Period Covered To	Diss. Sols., mg/l Avg.	Min.	Max.
Well 1	4	6/19/73	11/29/73	205	160	230
Well 2A	6	6/19/73	11/29/73	195	165	260
Well 2B	-	-	-	-	-	-
Well 3A	6	"	11/29/73	330	270	390
Well 3B	6	"	"	332	300	360
Well 3C	6	"	"	301	285	330
Well 3D	2	9/8/73	-	262	245	280
Well 5	3	7/25/73	11/29/73	127	82	138
Well 6A	-	-	-	-	-	-
Well 6B	2	7/25/73	8/16/73	186	162	210
Well 10	2	"	"	71	43	99
West Brook Upstream	5	4/17/73	"	61	49	75
West Brook Downstream	4			98	70	120
STP Inf.	4	6/26/73	8/16/73	243	232	250
STP Eff.	5	"	11/29/73	206	190	240

TABLE A4

Summary of pH Data
as of 10/1/74

Sample Location	No. of Samples	Period Covered From	To	pH Avg.	Min.	Max.
Well 1	6	6/7/73	2/28/74	6.51	5.9	6.7
Well 2A	11	"	5/30/74	7.66	7.0	8.3
Well 2B	5	11/19/73	"	8.50	7.8	9.6
Well 3A	9	6/7/73	"	7.13	5.7	7.5
Well 3B	10	6/7/73	"	7.05	5.9	7.43
Well 3C	10	"	"	6.94	5.9	7.48
Well 3D	5	9/8/73	"	8.51	7.75	9.0
Well 5	6	7/25/73	"	6.37	5.2	7.4
Well 6A	4	11/19/73	"	8.10	7.6	9.1
Well 6B	7	7/25/73	"	8.79	8.5	9.11
Well 10	5	"	"	6.86	6.42	7.2
West Brook Upstream	8	4/25/73	"	7.49	7.1	7.80
West Brook Downstream	8	"	"	7.49	7.1	7.71
STP Inf.	4	6/26/73	8/16/73	7.20	6.88	7.6
STP Eff.	7	"	5/30/74	6.94	6.53	8.0

TABLE A5

Summary of Alkalinity Data
as of 10/1/74

Sample Location	No. of Samples	Period Covered From	Period Covered To	Alkalinity, mg/l as $CaCO_3$ Avg.	Alkalinity, mg/l as $CaCO_3$ Min.	Alkalinity, mg/l as $CaCO_3$ Max.
Well 1	3	6/19/73	8/16/73	90.4	87.3	96
Well 2A	4	"	"	134	122	147
Well 2B	-	-	-	-	-	-
Well 3A	4	6/19/73	8/16/73	313	276	352
Well 3B	4	"	"	188	162	223
Well 3C	4	"	"	166	159	173
Well 3D	1	9/8/73	-	184	-	-
Well 5	2	7/25/73	8/16/73	53.3	31	75.7
Well 6A	-	-	-	-	-	-
Well 6B	2	7/25/73	8/16/73	142	106	178
Well 10	2	"	"	43.4	42	44.8
West Brook Upstream	3	7/6/73	"	40.3	33.3	44.8
West Brook Downstream	3	"	"	69.8	56.7	83.5
STP Inf.	3	"	"	163	142	186
STP Eff.	3	"	"	135	106.5	150

TABLE A6

Summary of Chloride Data
as of 10/1/74

Sample Location	No. of Samples	Period Covered From	Period Covered To	Chloride, mg/l Avg.	Chloride, mg/l Min.	Chloride, mg/l Max.
Well 1	7	6/7/73	2/28/74	41	20	60
Well 2A	12	"	5/30/74	28	13	38
Well 2B	6	10/17/73	"	44	31	54
Well 3A	7	6/7/73	4/16/74	36	9	45
Well 3B	11	"	5/30/74	55	30	71
Well 3C	10	6/19/73	"	54	30	80
Well 3D	6	9/8/73	"	48.5	20	84
Well 5	6	7/25/73	"	26	8	36
Well 6A	6	10/17/73	"	28	7	41
Well 6B	9	7/8/73	"	36	30	39
Well 10	6	7/25/73	"	6.3	1	21
West Brook Upstream	9	4/25/73	"	12	5	21
West Brook Downstream	9	"	"	19	9	30
STP Inf.	4	6/26/73	8/16/73	38	35	46
STP Eff.	10	4/19/73	5/30/73	38	31	53

TABLE A7

Summary of Total Soluble Phosphorus Data
as of 10/1/74

Sample Location	No. of Samples	Period Covered		Tot. Sol. P, ug/l		
		From	To	Avg.	Min.	Max.
Well 1		6/19/73	2/28/74	519	200	990
Well 2A	11	6/7/73	5/30/74	67.6	17.9	200
Well 2B	5	10/17/73	"	126	20	200
Well 3A	8	6/19/73	"	47.6	29.9	100
Well 3B	9	"	"	36.2	16.3	100
Well 3C	10	6/7/73	"	42.7	18.0	100
Well 3D	5	8/16/73	"	50	20	100
Well 5	6	7/25/73	"	936	300	1,900
Well 6A	5	10/17/73	"	80	30	100
Well 6B	7	7/25/73	"	68.4	13	200
Well 10	6	7/11/73	"	33.3	8.4	70
West Brook Upstream	8	4/17/73	"	49.9	11	117.6
West Brook Downstream	8	"	"	57.7	7.2	120
STP Inf.	4	6/26/73	8/16/73	4,471	4,010	5,240
STP Eff.	8	4/19/73	5/30/74	2,172	700	4,310

TABLE A8

Summary of Nitrate Nitrogen Data
as of 10/1/74

Sample Location	No. of Samples	Period Covered From	Period Covered To	NO_3-N, mg/l Avg.	NO_3-N, mg/l Min.	NO_3-N, mg/l Max.
Well 1	7	6/7/73	2/28/74	7.82	1.20	14.38
Well 2A	11	6/26/73	5/30/74	4.06	2.34	7.0
Well 2B	5	10/17/73	"	0.14	0.1	0.2
Well 3A	8	6/ 7/73	"	0.43	0.065	2
Well 3B	11	6/ 7/73	"	7.70	3	10.32
Well 3C	11	"	"	9.28	4	14
Well 3D	6	9/8/73	"	0.41	0.1	0.7
Well 5	6	7/25/73	"	7.81	1	21.32
Well 6A	5	10/17/73	"	14.2	4.1	21
Well 6B	9	7/8/73	"	2.58	0.1	5.0
Well 10	5	7/11/73	"	0.31	0.09	0.6
West Brook Upstream	8	4/17/73	"	0.35	0.18	0.439
West Brook Downstream	9	"	"	1.43	0.4	3.218
STP Inf.	-	-	-	-	-	-
STP Eff.	6	4/19/73	5/30/74	1.08	0.40	2.3

TABLE A9

Summary of Ammonia Nitrogen Data
as of 10/1/74

Sample Location	No. of Samples	Period Covered From	Period Covered To	Ammonia N, mg/l Avg.	Ammonia N, mg/l Min.	Ammonia N, mg/l Max.
Well 1	4	6/7/73	11/29/73	0.35	0.1	0.64
Well 2A	9	"	5/30/74	0.08	0.02	0.18
Well 2B	5	10/17/73	"	0.44	0.19	0.62
Well 3A	8	6/7/73	"	0.42	0.05	0.80
Well 3B	8	"	"	0.09	0.02	0.19
Well 3C	7	6/19/73	4/16/74	0.05	0.02	0.08
Well 3D	5	9/8/73	5/30/74	2.05	0.66	4.2
Well 5	4	7/25/73	"	0.13	0.04	0.26
Well 6A	4	10/17/73	"	0.59	0.21	1.4
Well 6B	5	7/25/73	"	3.24	1.1	6.0
Well 10	3	7/11/73	"	0.11	0.09	0.15
West Brook Upstream	7	4/17/73	"	0.05	0.02	0.12
West Brook Downstream	7	"	"	0.10	0.02	0.40
STP Inf.	-	-	-	-	-	-
STP Eff.	6	4/19/73	5/30/74	2.67	0.40	4.8

TABLE A10

Summary of Total Kjeldahl Nitrogen Data
as of 10/1/74

Sample Location	No. of Samples	Period Covered From	Period Covered To	TKN, mg/l Avg.	TKN, mg/l Min.	TKN, mg/l Max.
Well 1	3	6/19/73	8/16/73	0.612	0.0207	1.713
Well 2A	4	"	"	0.082	0.0245	0.144
Well 2B	-	-	-	-	-	-
Well 3A	4	6/19/73	8/16/73	0.381	0.033	0.975
Well 3B	3	"	"	0.182	0.047	0.393
Well 3C	2	"	"	0.092	0.087	0.097
Well 3D	-	-	-	-	-	-
Well 5	2	7/25/73	8/16/73	0.623	0.533	0.712
Well 6A	-	-	-	-	-	-
Well 6B	2	7/25/73	8/16/73	3.80	3.65	3.95
Well 10	2	"	"	0.594	0.038	1.15
West Brook Upstream	3	4/17/73	"	0.065	0.063	0.069
West Brook Downstream	3	"	"	0.107	0.028	0.191
STP Inf.	2	7/25/73	"	13.01	8.20	17.82
STP Eff.	6	"	5/30/74	11.47	1.58	26