

PURIFICATION OF SECONDARY TREATED EFFLUENT WITH DEPTH  
IN A NATURAL SAND FILTER

By

Donald B. Aulenbach  
Rensselaer Polytechnic Institute  
Troy, New York 12181

Robert R. Harris  
MSR Engineers  
Buffalo, New York 14202

Robert C. Reach  
Gee & Jenson Inc.  
W. Palm Beach, Florida 33401

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ABSTRACT

Studies were made of the degree of treatment of secondary effluent applied to a natural delta sand bed by a rapid infiltration system. Measurements were made of temperature, dissolved oxygen, pH, total dissolved solids, redox potential, chloride, ammonia, kjeldahl and nitrate nitrogen, ortho and total phosphorus, calcium, magnesium, alkalinity, iron, sodium, potassium, and copper. The soluble constituents moved through the sand with little to no change in concentration. The depth of sand required for removal of different constituents was variable. Nitrate was reduced to less than 1 mgN/l in the top 8 m. Total nitrogen required approximately 18 m for significant removal. Satisfactory removal of orthophosphate was achieved in the top 10 m. The approximately 20 m of sand in North Sand Bed 11 of the Lake George Village Sewage Treatment Plant is adequate to prevent nutrient contamination of the ground water.

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INTRODUCTION

For thirty seven years the Lake George Village Sewage Treatment Plant has been providing treatment of domestic wastes which exceeds the degree of treatment afforded by most tertiary treatment plants being designed today and at a cost that is far less than the conventional physical-chemical methods presently employed for tertiary treatment. This is accomplished by discharging the settled trickling filter effluent onto natural delta sand beds and allowing the sand system to purify the effluent. By the time the applied liquid re-emerges from the ground at West Brook approximately 600 m (2,000 ft) from the infiltration site, all BOD, coliforms, ammonia and organic nitrogen and phosphate have been removed from the effluent. Some nitrate appears in the seepage at West Brook, but evidence indicates that even this may not be directly attributable to the treatment system. Soluble substances such as chloride are not removed in the land application system.

The question arose as to the location within the sand system of the actual removal of the pollutants from the secondary effluent. Initially wells were installed between the sand beds and the seepage in order to determine the quality of the effluent as it flowed through the saturated portion of the aquifer. However, in order to determine the degree of treatment in passing through the unsaturated zone of the sand beds, additional wells and lysimeters were installed to measure the quality of the effluent as it passed vertically through the sand. It is the results of this latter

study which are reported in this paper.

#### BACKGROUND

Lake George is an oligotrophic lake (Figure 1) located in eastern New York State noted for the clarity of its waters and beauty of its' surrounding land. It serves as a recreational lake for swimming, boating, fishing and scuba diving, and also serves as the water supply for the Village of Lake George, numerous small communities and many individual cottages and homes surrounding the lake. With the exception of chlorination, which is mandated for public water supply, no treatment is provided of the lake waters prior to drinking.

Much of the credit for preservation of the beauty and purity of the lake must be attributed to 91 years of active efforts by the Lake George Association to keep the lake clean. Much credit must also be attributed to the Lake George Village and the Bolton Landing sewage treatment plants both of which include discharge of the secondary effluent into sand for further purification. The Lake George Village treatment plant which now includes the Town (township) of Lake George is more extensive and treats a flow which exceeds four million liters (1 mgd) during the summer tourist season. The treatment plant is located at the southwestern corner of the lake (Figure 2) approximately 1.6 kilometers (1 mile) from the lake. The sewage is conveyed to the treatment plant (Figure 3) through separate force mains from the Village and from the Town, each of which is metered at the influent of the treatment plant. Primary sedimentation is accomplished in Imhoff type tanks. During the summer two rotary trickling filters are employed, whereas during the winter a fixed nozzle trickling filter, which is covered by boards on

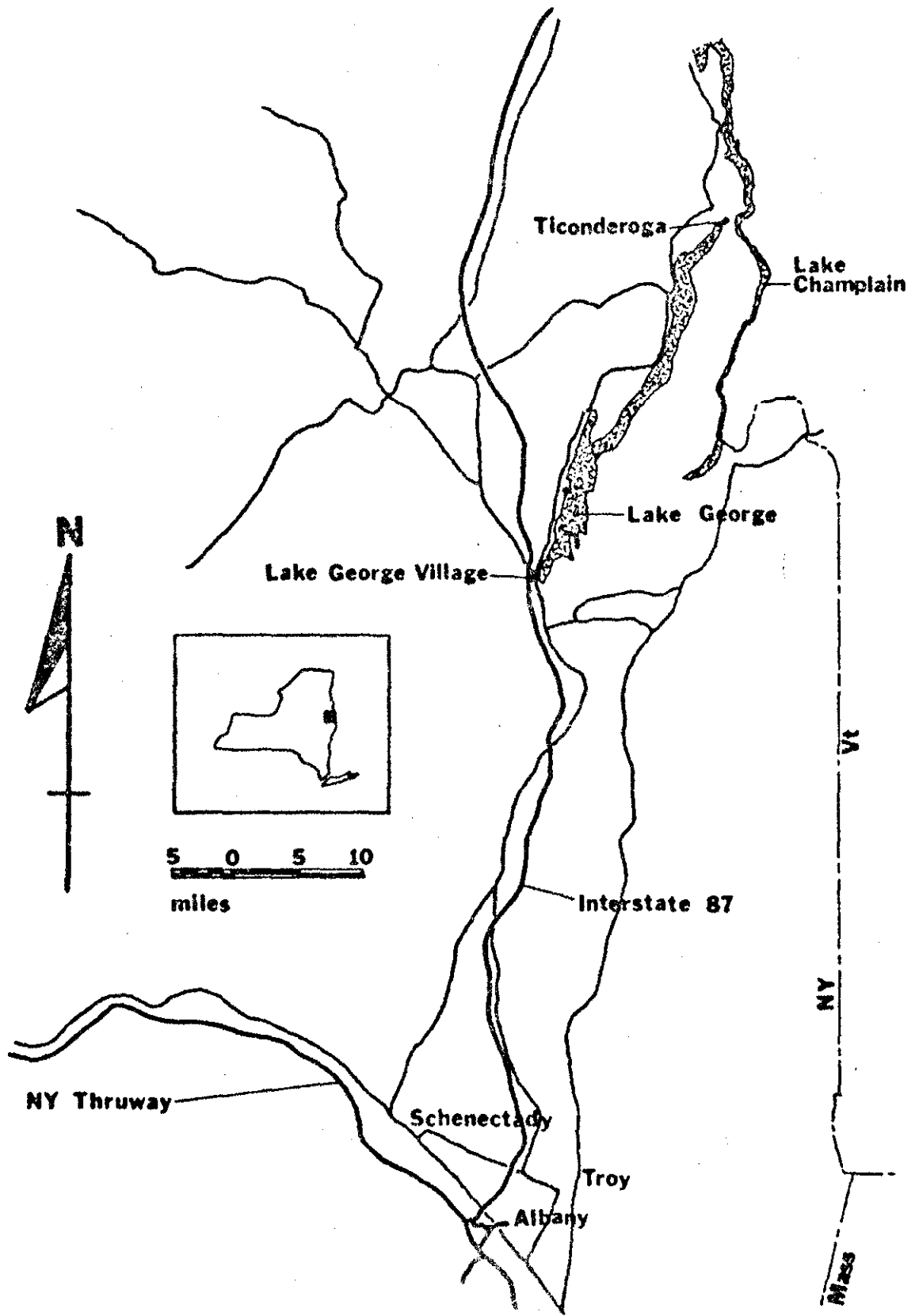
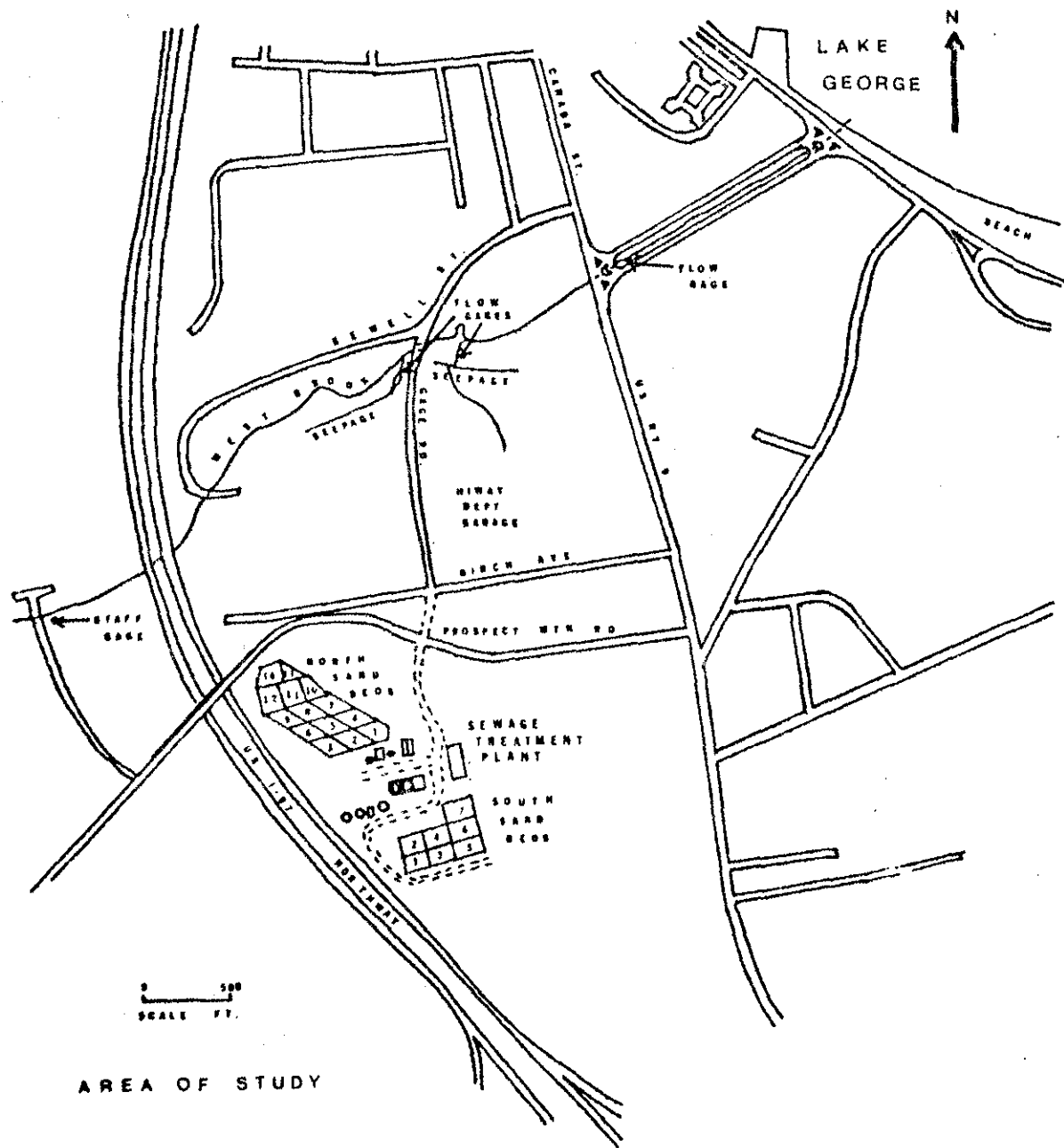
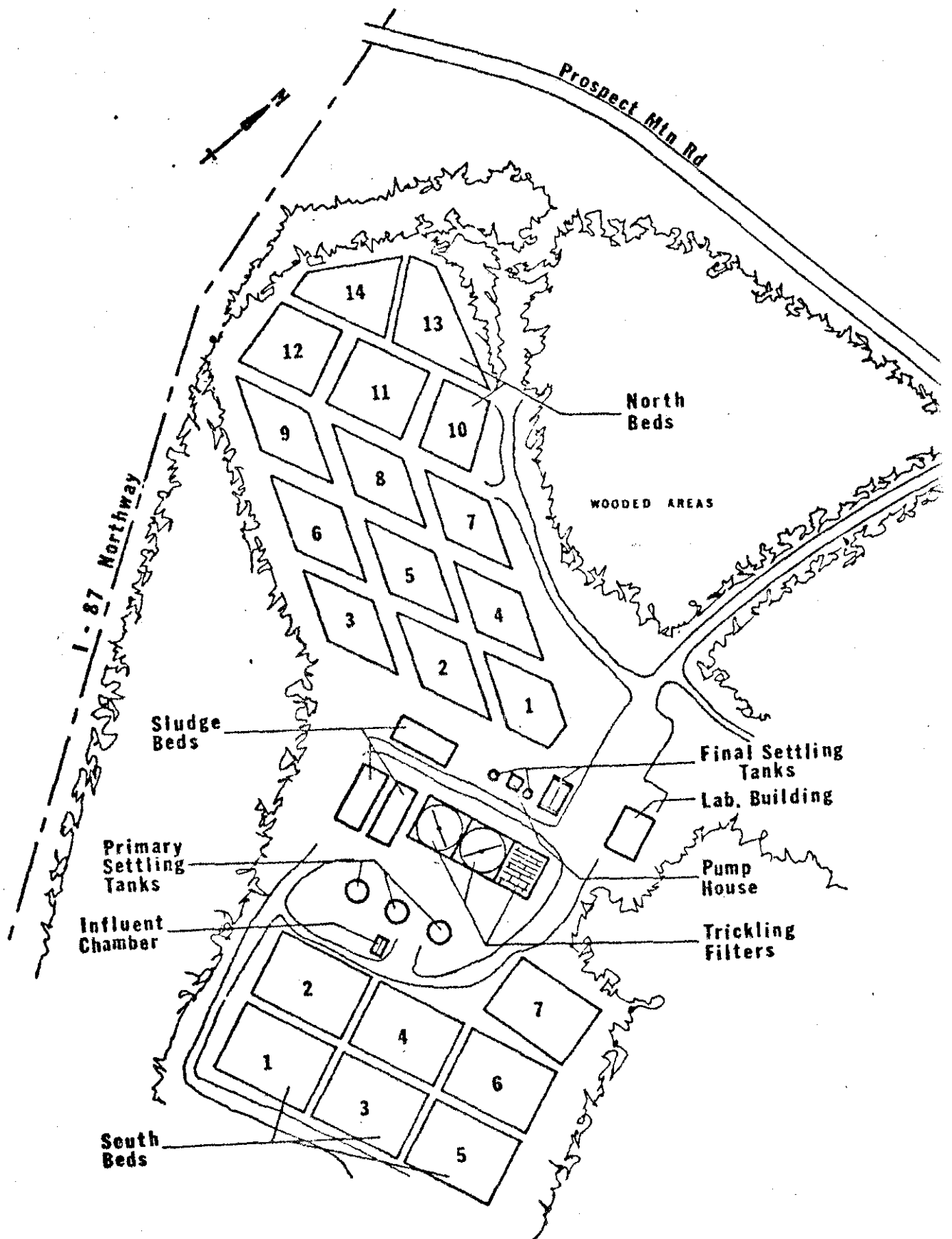


FIGURE 1



AREA OF STUDY

FIGURE 2

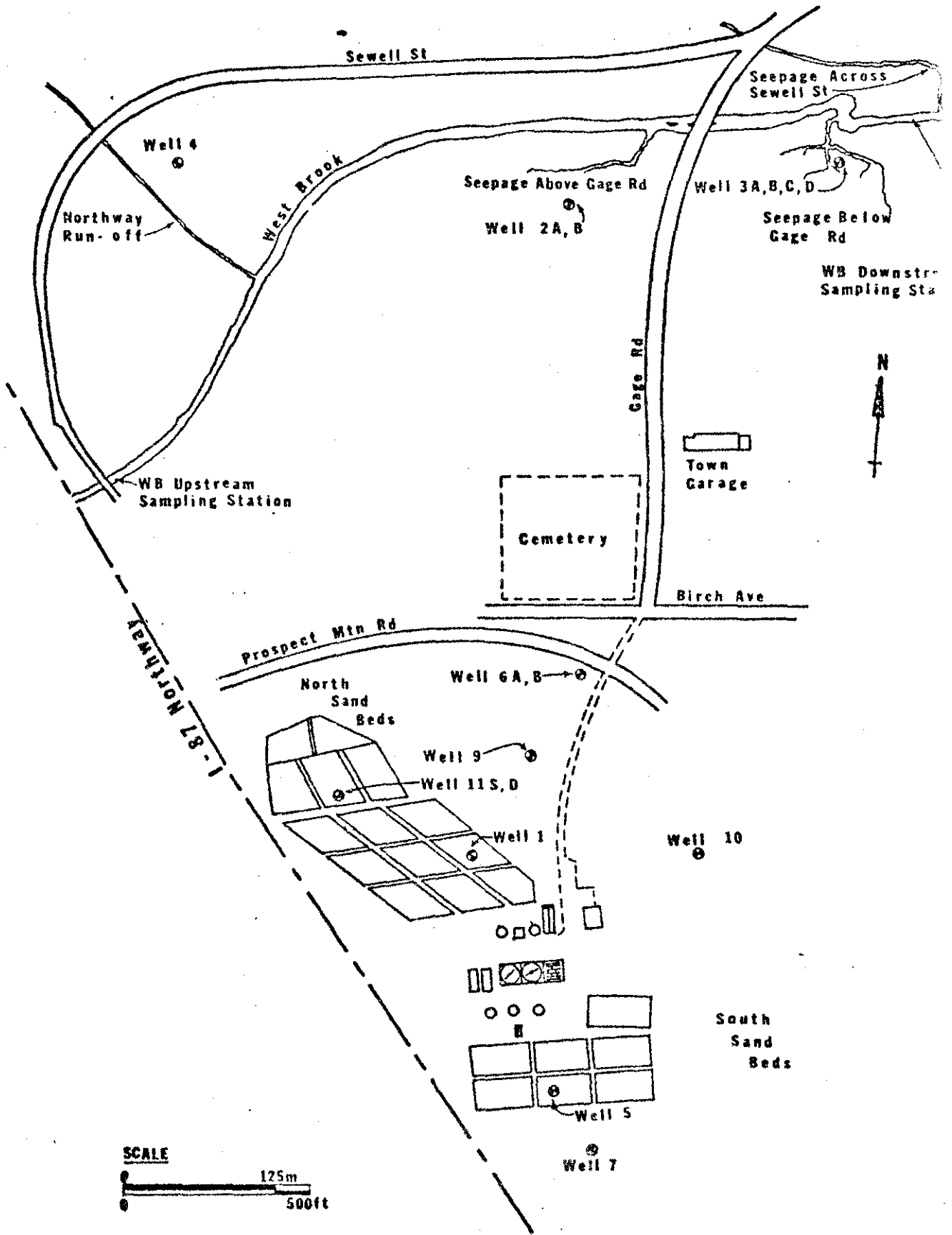


# SEWAGE TREATMENT PLANT LAYOUT

FIGURE 3

sawhorses, is used to prevent freezing of the sprayed liquid. The trickling filter effluent is provided with secondary sedimentation and the final effluent is then spread onto any one of the twenty-one rapid sand infiltration beds. The original six beds at the north end of the plant have been in continuous operation since the plant was completed in 1939. Additional beds have been added as the flows to the treatment plant have increased, with the most recent being completed in 1970. The total area of actual sand infiltration bed area is presently 2.2 hectares (5.4 acres). The procedure for dosing the sand beds is to apply the effluent to 1 north and to 1 south bed at the start of the working day, approximately 8 am. At approximately 4 pm, just prior to the close of the working day, the effluent is diverted to a fresh pair of north and south sand beds. During the week end when plant personnel are not on hand at all times, two north and two south beds are dosed for a full days' time. There is no set schedule as to which infiltration bed will be used on any particular day. Most of the sand beds dry in 1 to 3 days and the practice is to allow the sand beds to dry for a few days prior to the next application. The frequency of application increases with the increase in flow due to the tourist influx during the summer months. Occasionally the beds are scraped, removing the top few centimeters of sand which includes the algae mat which forms on the surface of the bed and any other clogging material. Weeds are removed as quickly as possible within the sand beds when they have been allowed to dry.

For many years it was not known what became of the effluent after it was discharged into the ground. In 1973, seepage was observed along the south banks of the flood plain of West Brook (Figure 4). All



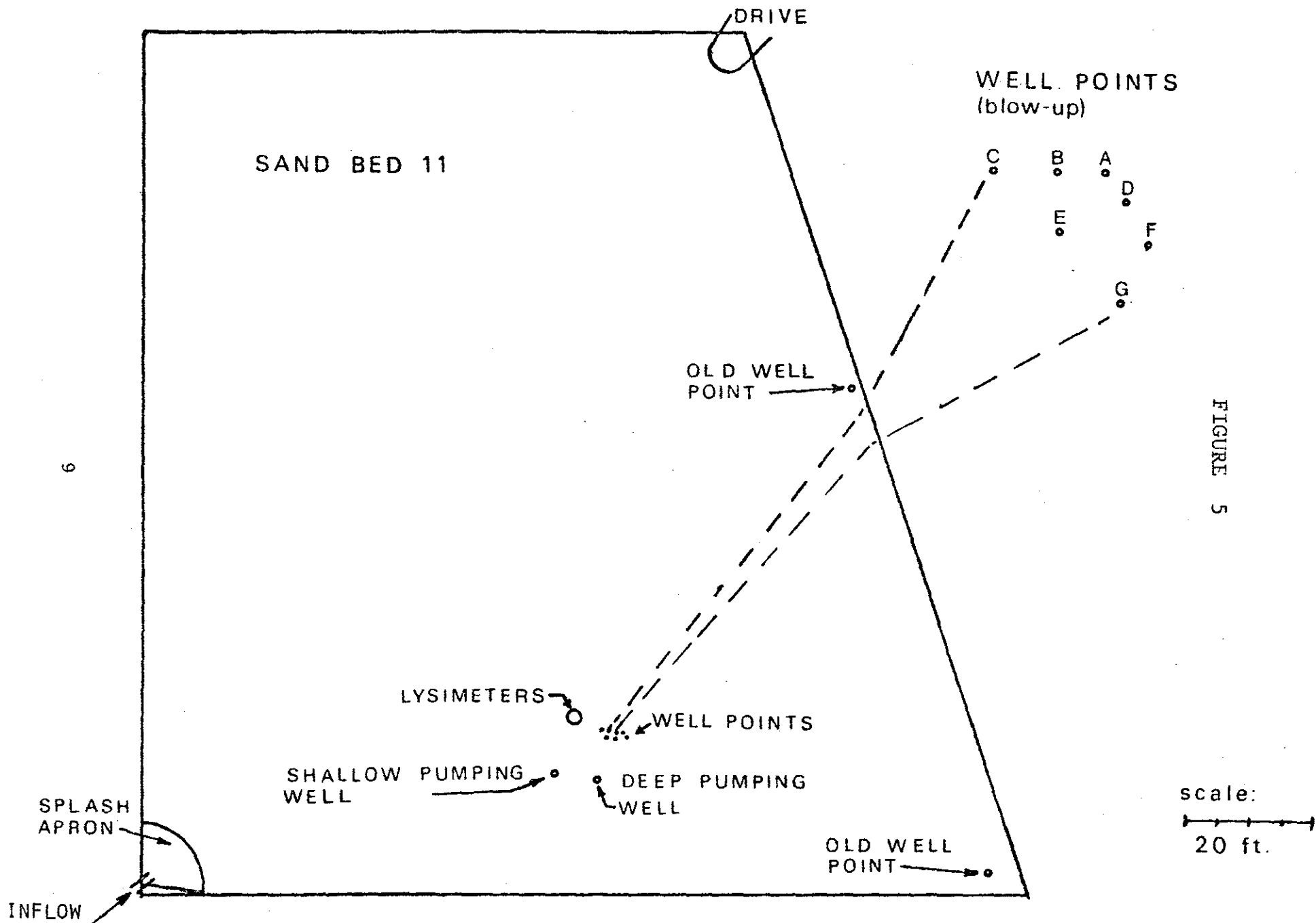
**AREA OF STUDY**

FIGURE 4

indications point to this seepage being the effluent from the treatment plant; presently other studies are under way to confirm this positively. Observation wells were installed in the aquifer between the treatment plant and the seepage at West Brook (Figure 4). Several control wells were installed in areas not subject to influence by the applied effluent. Studies made of the quality of the water in the wells and of the seepage<sup>1-8</sup> indicate complete removal of coliforms, BOD, COD, orthophosphate, ammonia, nitrogen and organic nitrogen. Chlorides pass through unaltered and there is a slight increase in the alkalinity. The nitrate nitrogen is reduced to levels lower than that of the applied sewage effluent, but is higher than the background, with values approximately 7 mg/liter. The quality of the water at the seepage represents the overall treatment afforded by the total soil treatment between the infiltration beds and the seepage. In an order to determine how much soil is needed to afford such treatment, some wells were located in the aquifer close to the sand infiltration beds. In addition, north bed 11 was chosen for some more intensive studies of the changes in water quality with depth in the sand bed from the surface to the aquifer.

#### EXPERIMENTAL

In order to secure samples for measurement of water quality, well points, lysimeters and pumping wells were installed within north bed 11. Well points consisting of one and one-quarter inch (3.2 cm) steel pipe with a 2 ft (60 cm) screen were driven into the sand bed at 2 ft (60 cm) depth intervals as shown in Figure 5. Lysimeters were installed at 5 ft (1.5 m) intervals to the 65 ft (20 m) depth. The individual lysimeter cups were placed in 100 mesh silica sand and separated from each other by



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FIGURE 5

the natural sand bed sand and a bentonite barrier as shown in Figure 6. Unfortunately, samples could be secured from only four of the lysimeters at depths of 3, 7, 11 and 18 m as indicated in Figure 7. Two pumping wells with submersible pumps placed in a six inch (15 cm) driven well casing were installed within the saturated aquifer with the shallower one (11S) near the top of the aquifer and the deeper one (11D) near the bottom of the aquifer as shown in Figure 7. Samples were secured on approximately a weekly basis beginning June 24, 1975 and continuing through July 2, 1976. To simplify the data and still indicate any variations with seasons, particularly the busy summer tourist season, averages of all the data collected were made on a seasonal basis. Fewer results were obtained during the winter due to difficulties caused by freezing of the sampling equipment and the sampling wells. Thus the average data for the winter season are not so reliable as for the other three seasons. In all of the figures depicting the data, the influent to the treatment plant is indicated at the top of the graph, and the values obtained at the zero depth represent the effluent from the treatment plant applied to the sand bed. The difference or change between these two values represents the degree of treatment or change in passing through the conventional secondary treatment plant. The level of water of the saturated aquifer was approximately 22.5 m from the surface. Thus, the (normally) two data points below the 22.5 m depth indicate the quality of the water within the saturated aquifer.

Figure 8 shows the temperature fluctuations within the bed during the full year of the study. In general the temperature increased with depth during the fall and the winter and decreased with depth during the

FIGURE 6

# LYSIMETER INSTALLATION

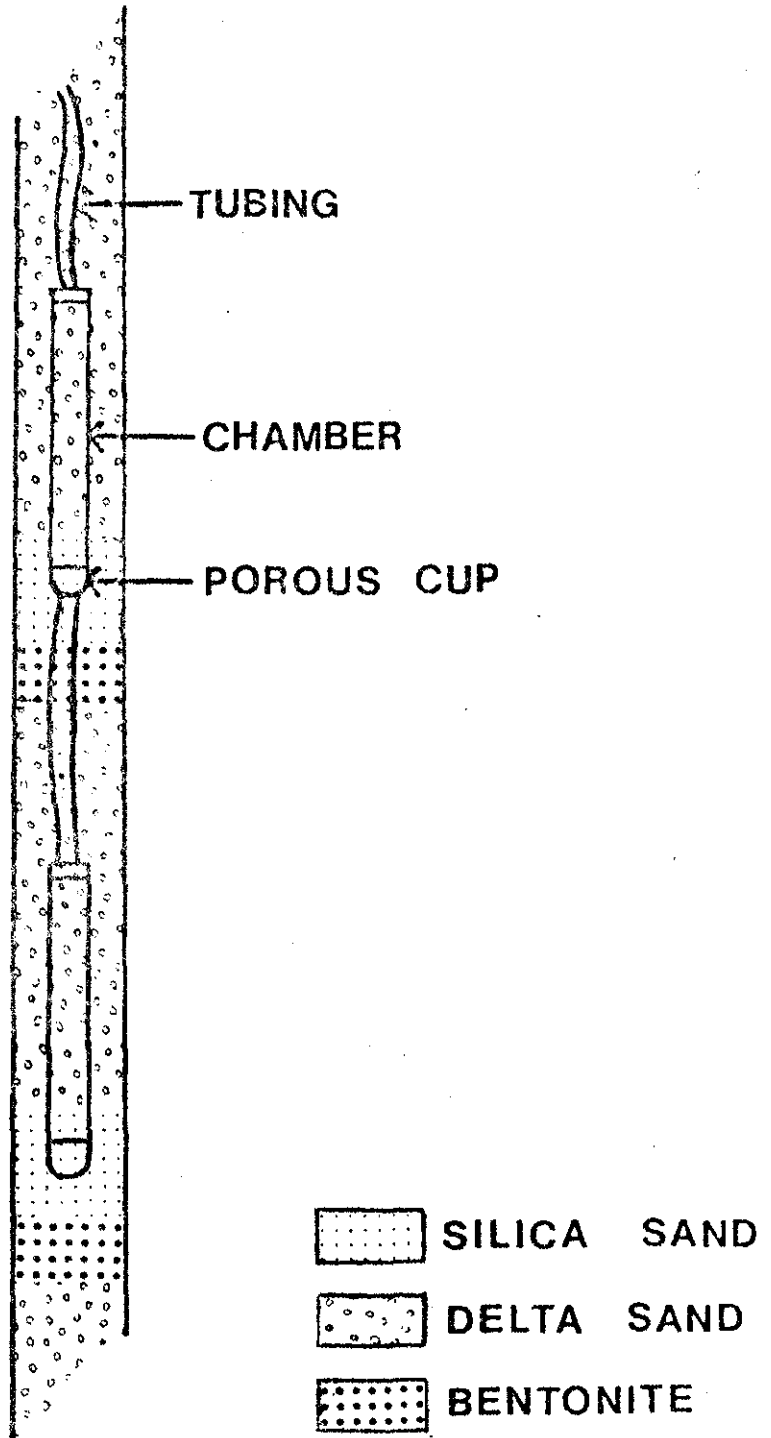


FIGURE 7

# SAND BED 11 PROFILE 1975

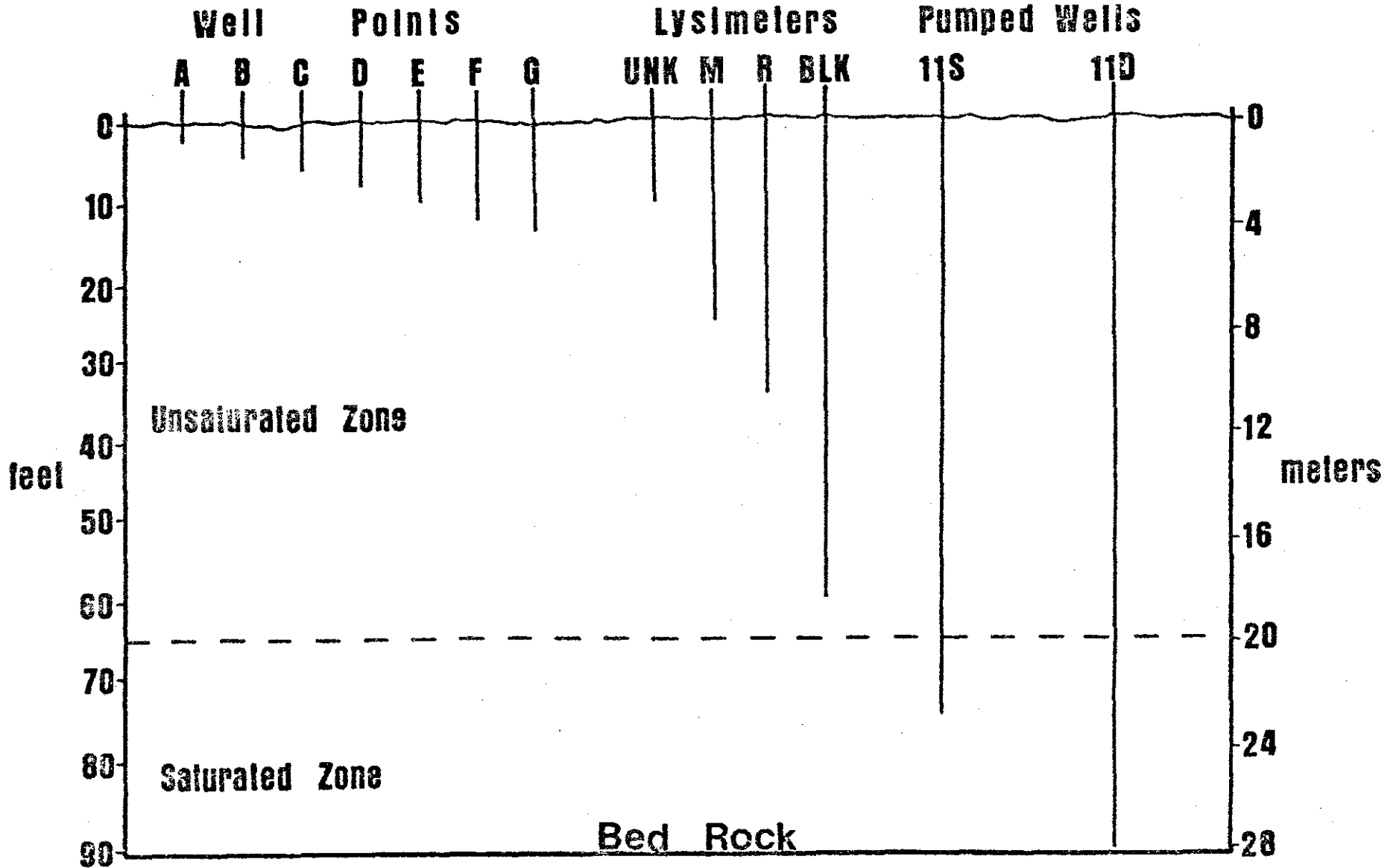
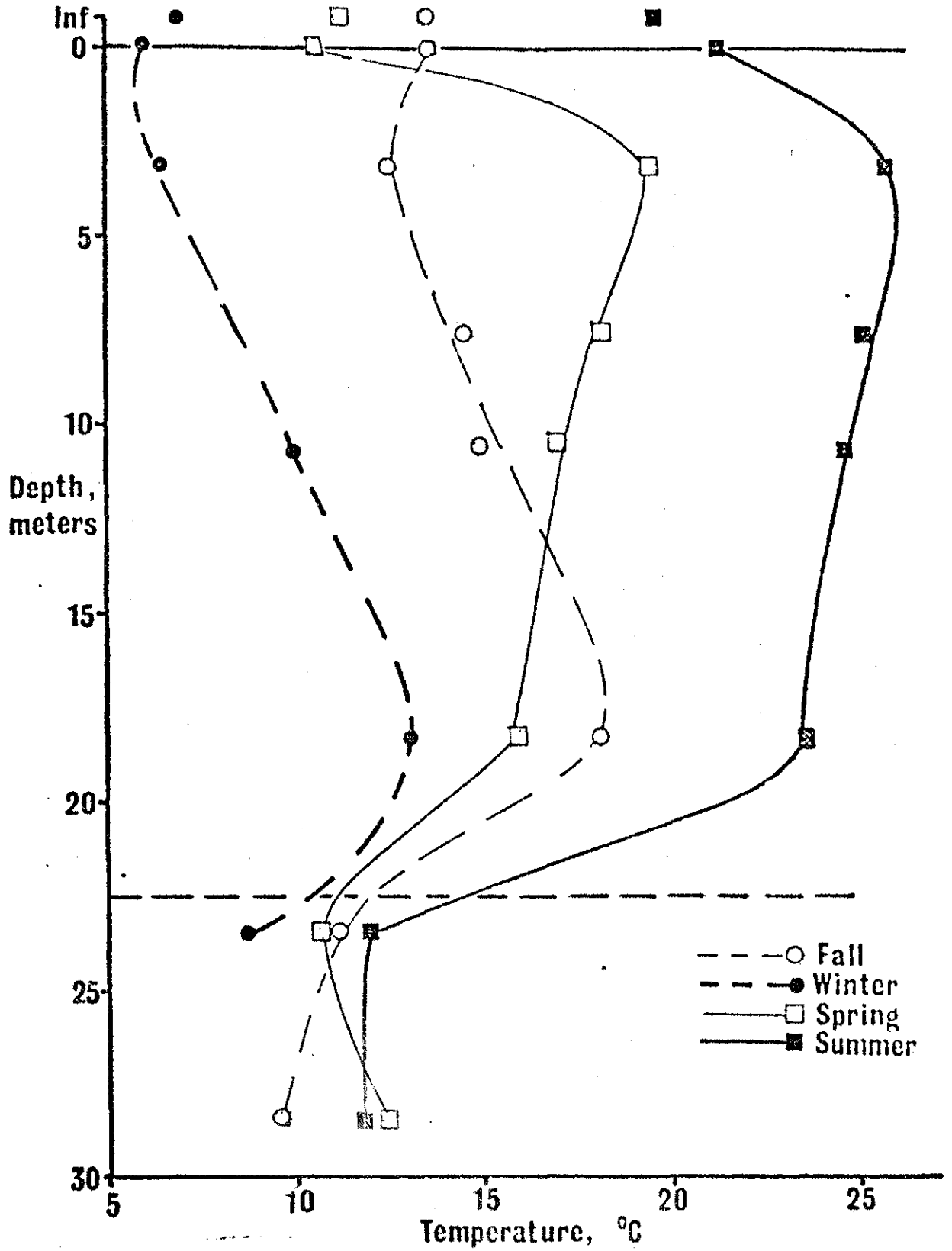


FIGURE 8  
TEMPERATURE vs. DEPTH



s spring and summer. The temperature of the water in the saturated aquifer was fairly constant throughout the year.

The pH (Figure 9) varied from a low of 6.5 at the 11 m depth in Fall to a high of 7.4 in the shallower pumped well during summer. There were no consistent trends in pH with depth although the spring and summer curves were similar. The fall results were similar to the spring and summer curves below the 11 m depth.

The total dissolved solids (figure 10) shows a slight increase in depth in the unsaturated zone of the sand bed. Values within the saturated aquifer were consistent throughout the year and were much lower than the values in the unsaturated zone. This suggests a considerable dilution of the high dissolved solids in the sewage effluent by low dissolved solids in the natural water in the aquifer.

There was an increase in the dissolved oxygen (DO) content of the waste as it passed through the treatment plant as indicated in Figure 11. The DO values obtained within the sand bed may be somewhat in error due to aeration caused by the sampling techniques used. Well 11S was monitored for DO in the fall, winter and spring by inserting the DO probe directly into the well. During the summer the DO was measured in samples pumped from this well to the surface. It may be seen that the values measured within the well were lower than the pumped values. This may indicate that all of the DO values for the samples from the wells within the sand bed, with the exception of the fall, winter and spring samples in well 11S, may be slightly high due to aeration of the samples.

The redox potential was determined during only the spring of 1976 after the required electrodes arrived (Figure 12). The treatment

FIGURE 9

pH vs. DEPTH

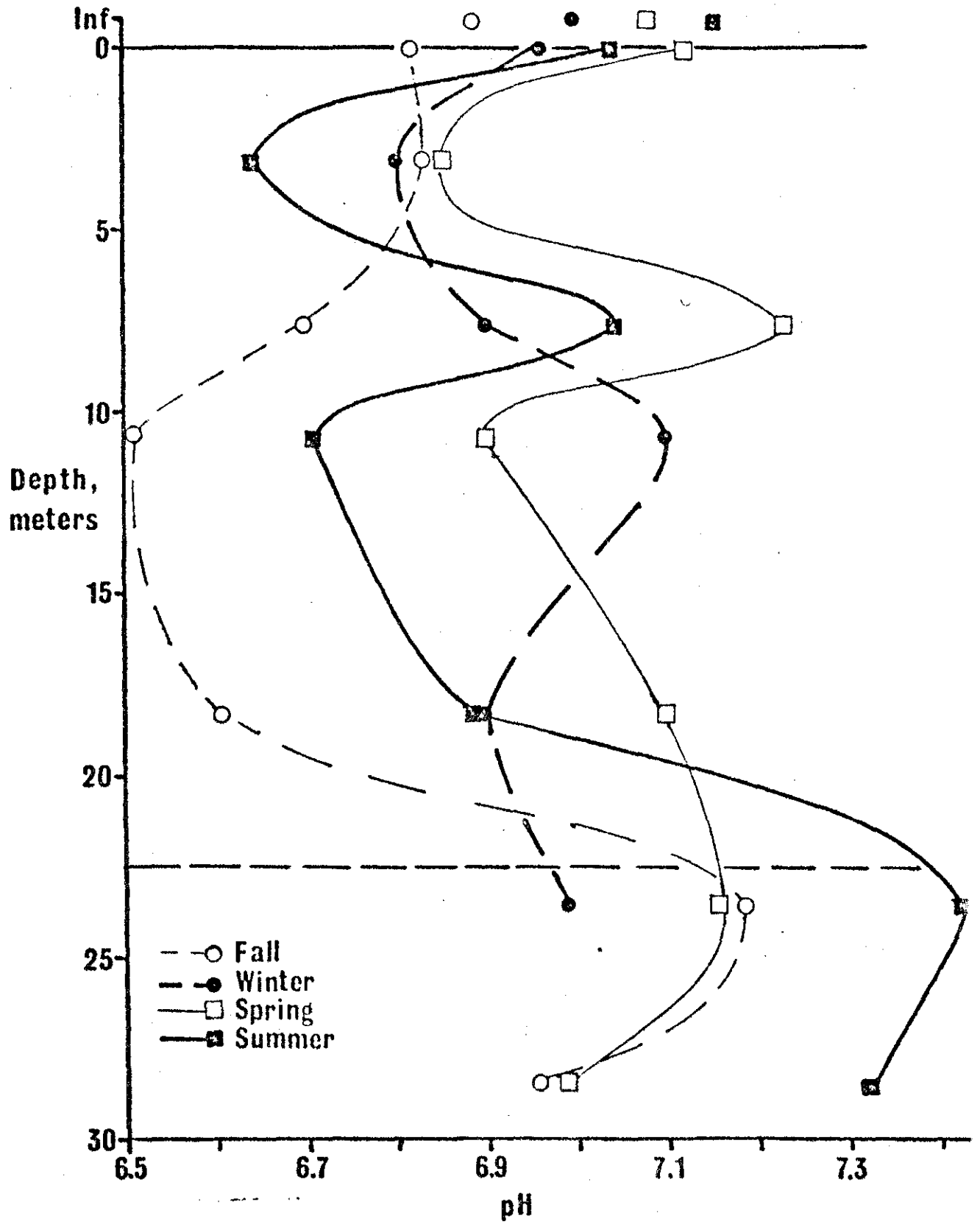


FIGURE 10

DISSOLVED SOLIDS vs. DEPTH

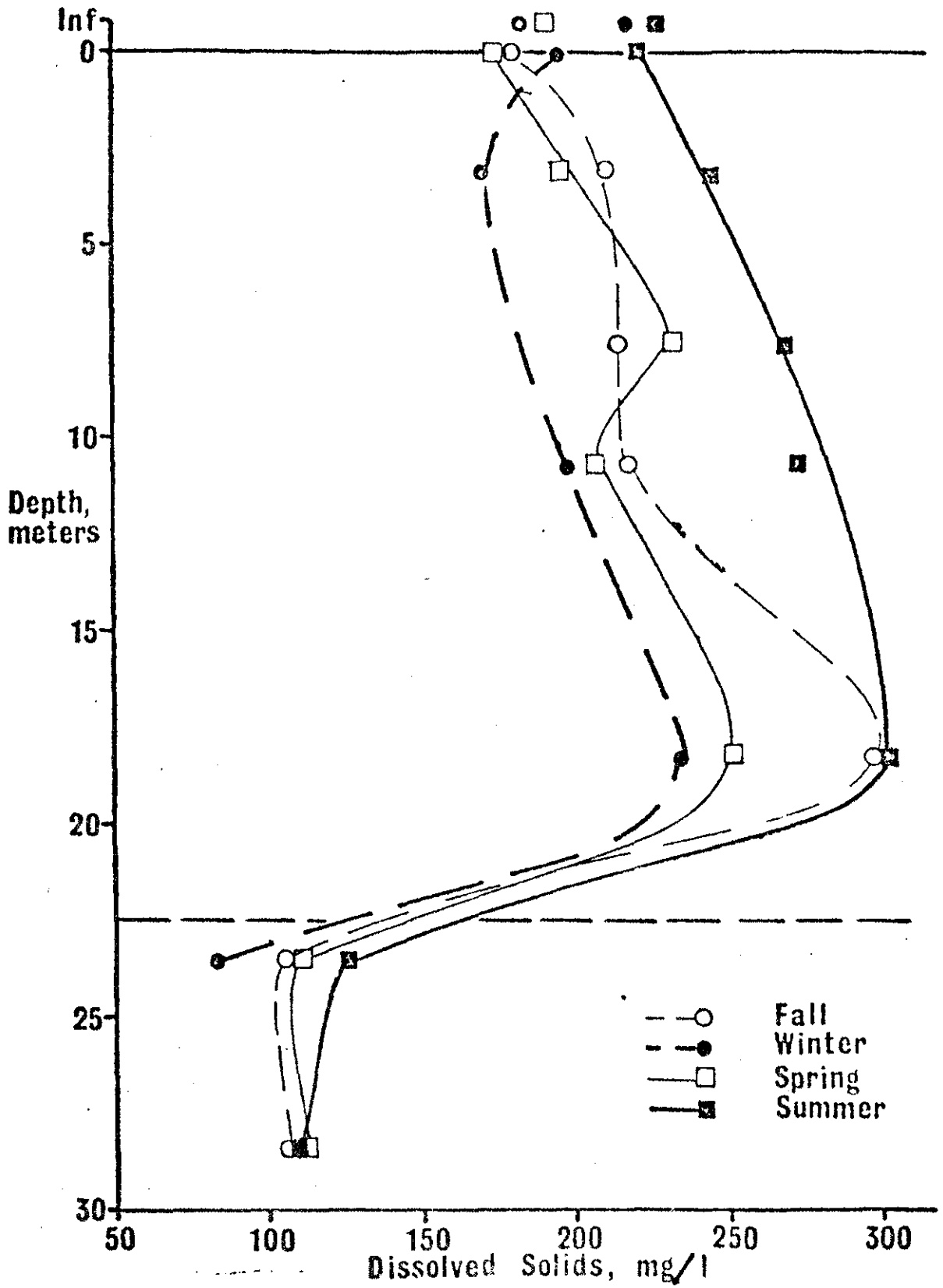


FIGURE 11

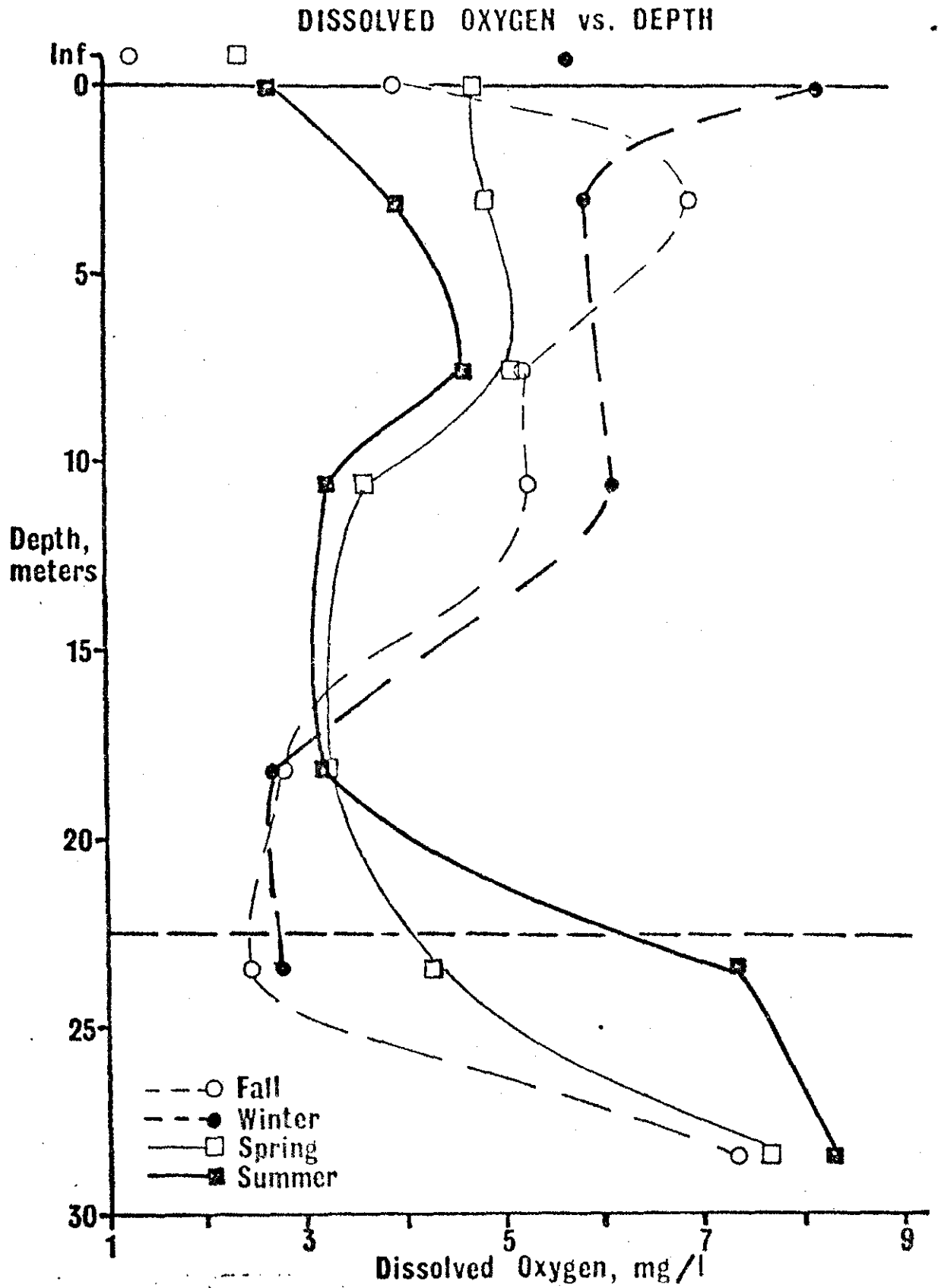
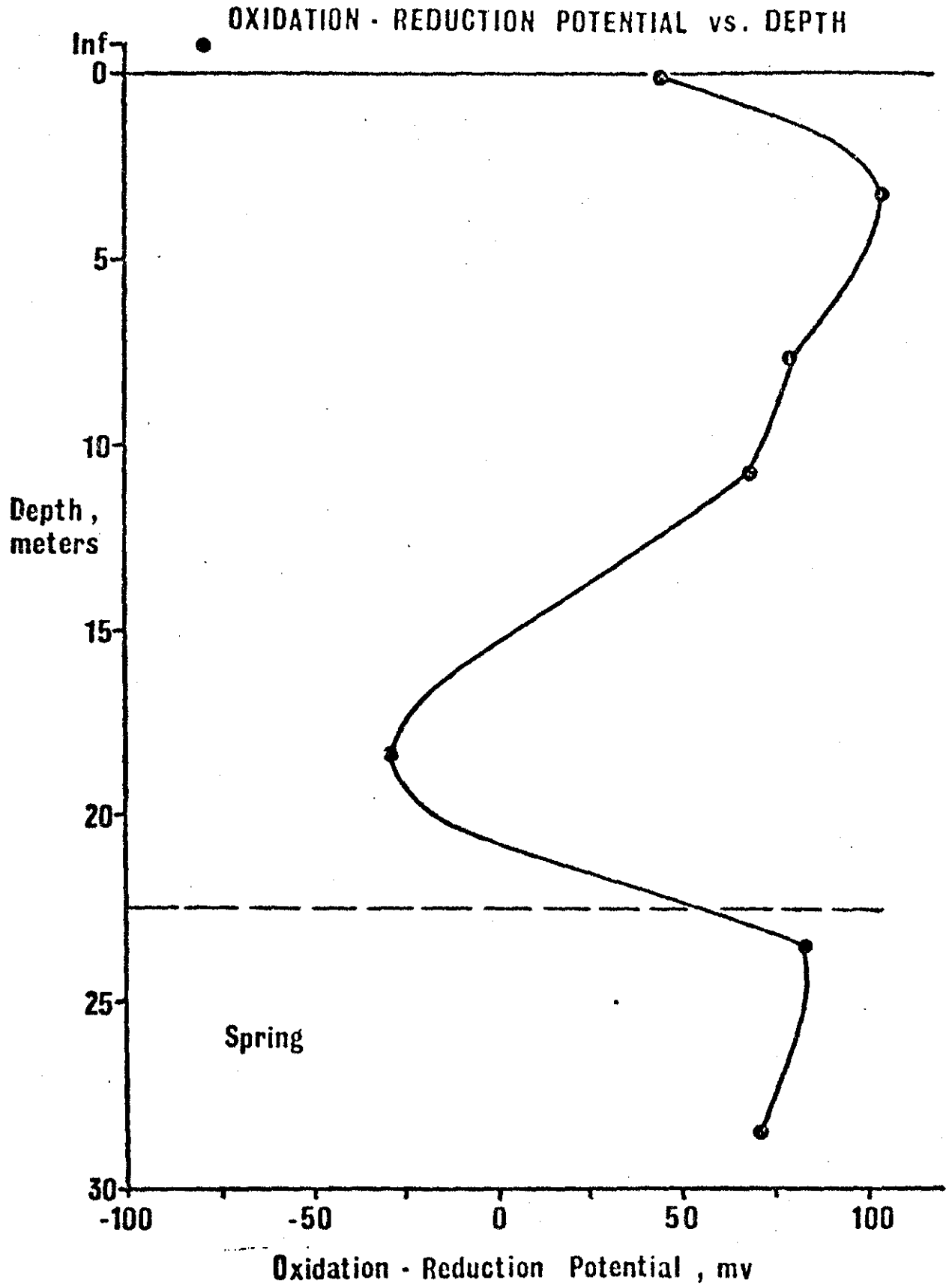


FIGURE 12



plant increased the redox potential markedly with effluent values slightly on the positive side as in all samples except at the 18 m depth. There appears to be significant reduction within the sand bed, at least during spring at this depth. This low value correlates fairly well with a consistently low DO value at the 18 m depth.

There was little significant variation in the chloride content with depth in any of the seasons as shown in Figure 13. What is interesting is that in the shallow pumped well the chloride levels were higher during the spring and summer than at the deeper pumped well, whereas in the fall the chloride levels were higher in the deeper pumped well.

In order to compare the changes in the various forms of nitrogen, all three forms measured (nitrate, ammonia and total kjeldahl nitrogen) are shown in one figure for each season. Insufficient data were obtained during the winter to justify plotting these data. The values for summer (Figure 14) and for the fall (Figure 15) show similar trends. In both cases there was a decrease in the ammonia and kjeldahl nitrogen content with a corresponding increase in the nitrate content at the 3 m depth. At slightly greater depths there was a reduction in nitrate with a significant increase in the ammonia and kjeldahl nitrogen followed by reduction in the ammonia and kjeldahl nitrogen as the liquid approached the 18 m depth. In both cases the nitrate content at the 18 m depth was less than 1 mgN/l. During the summer a relatively high nitrate content was observed in the shallow pumped well, but all other forms of nitrogen were low in concentration in both of the pumped wells. During the fall all forms of nitrogen were low in the two pumped wells. These figures suggest an oxidation of the reduced nitrogen compounds in the upper aerated portion

FIGURE 13

CHLORIDE vs. DEPTH

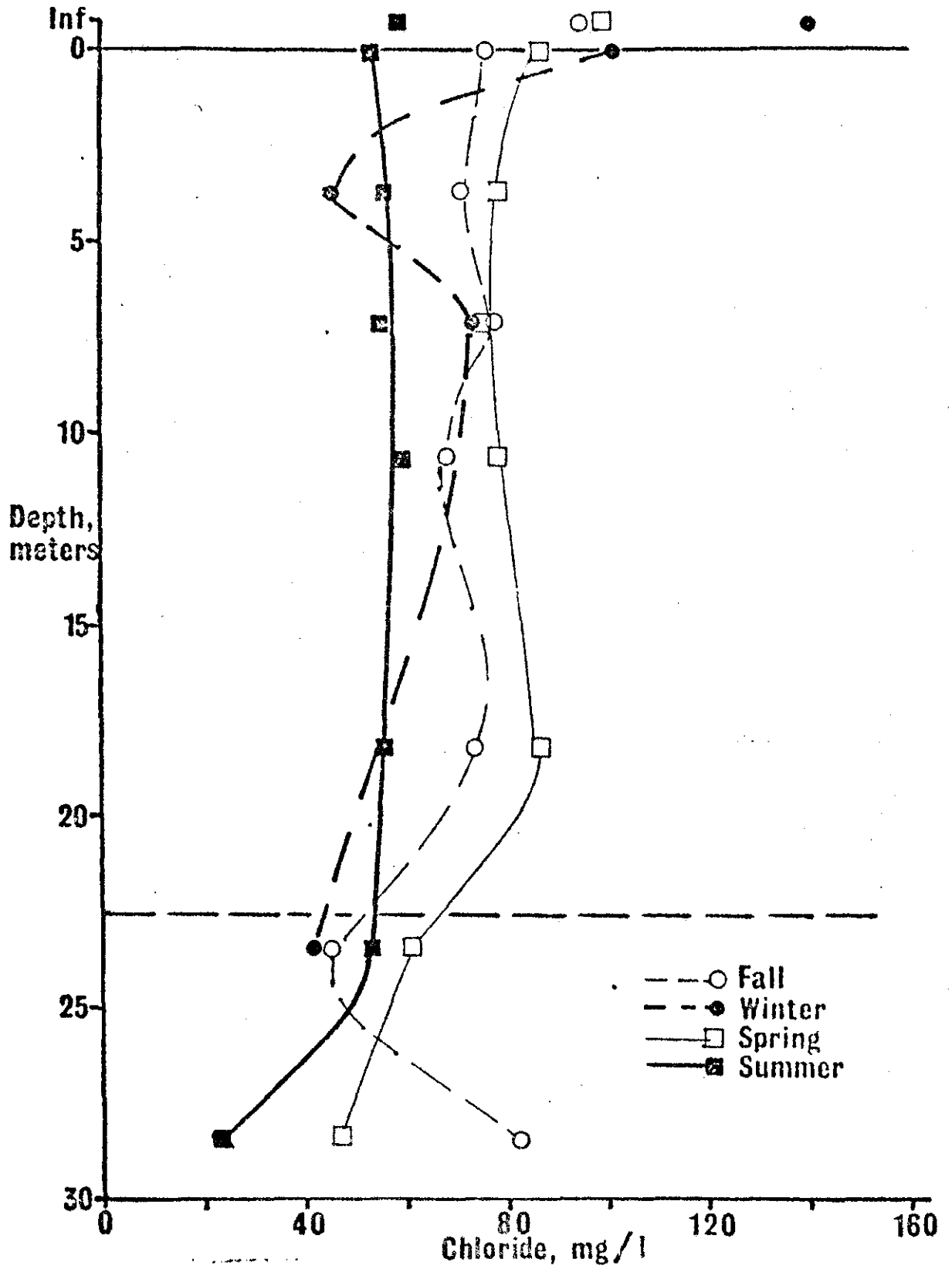


FIGURE 14

### NITROGEN vs. DEPTH - SUMMER

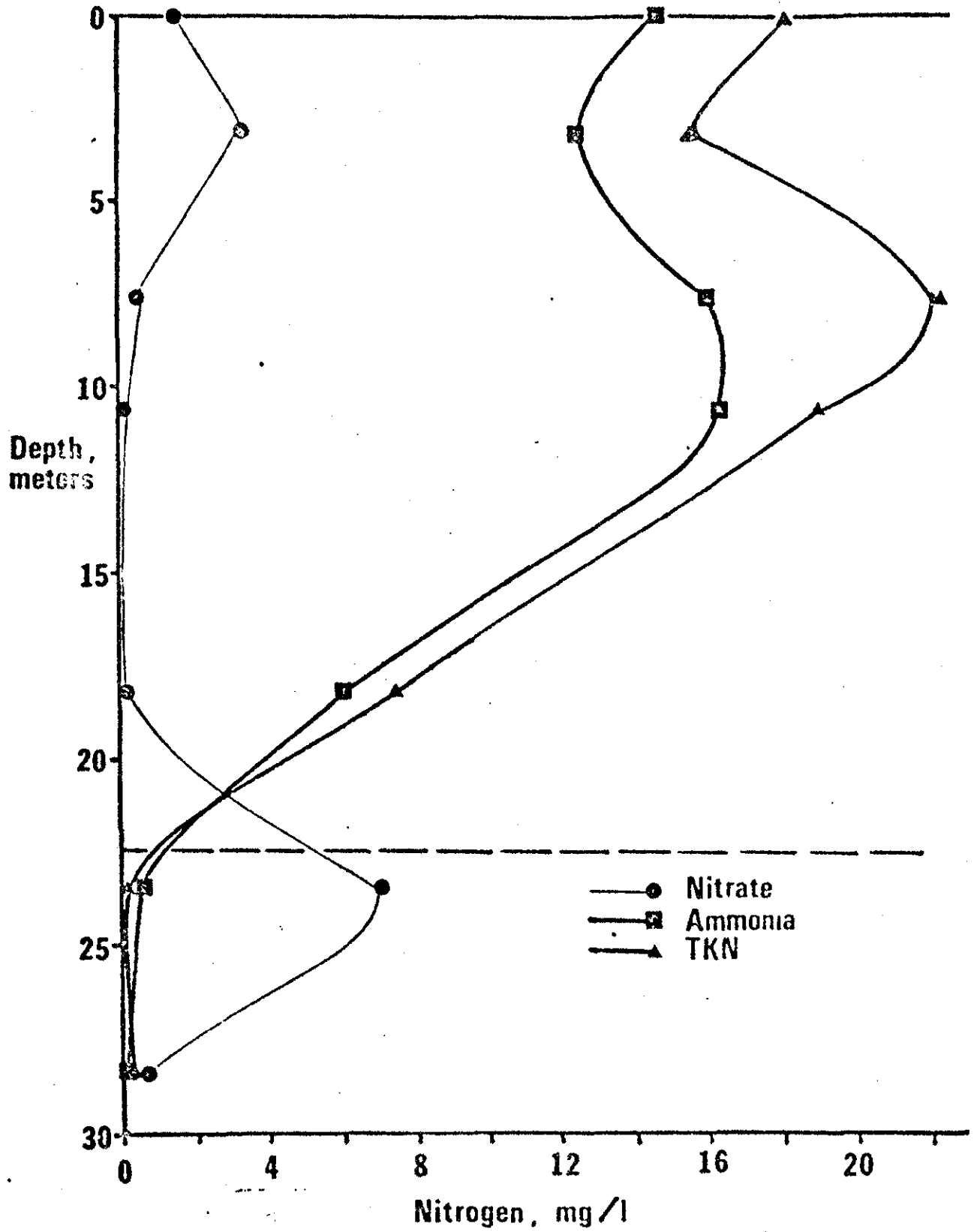
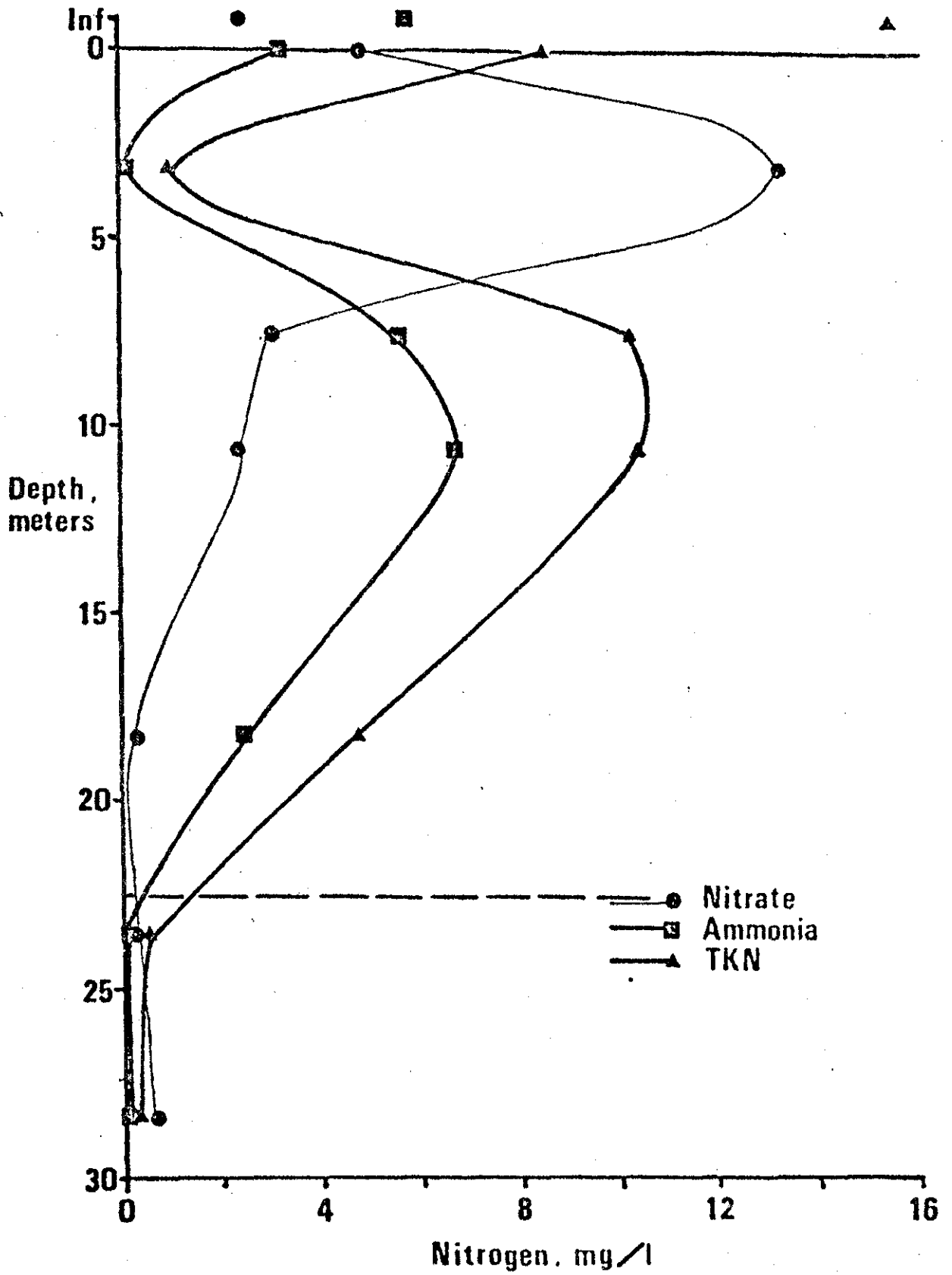


FIGURE 15

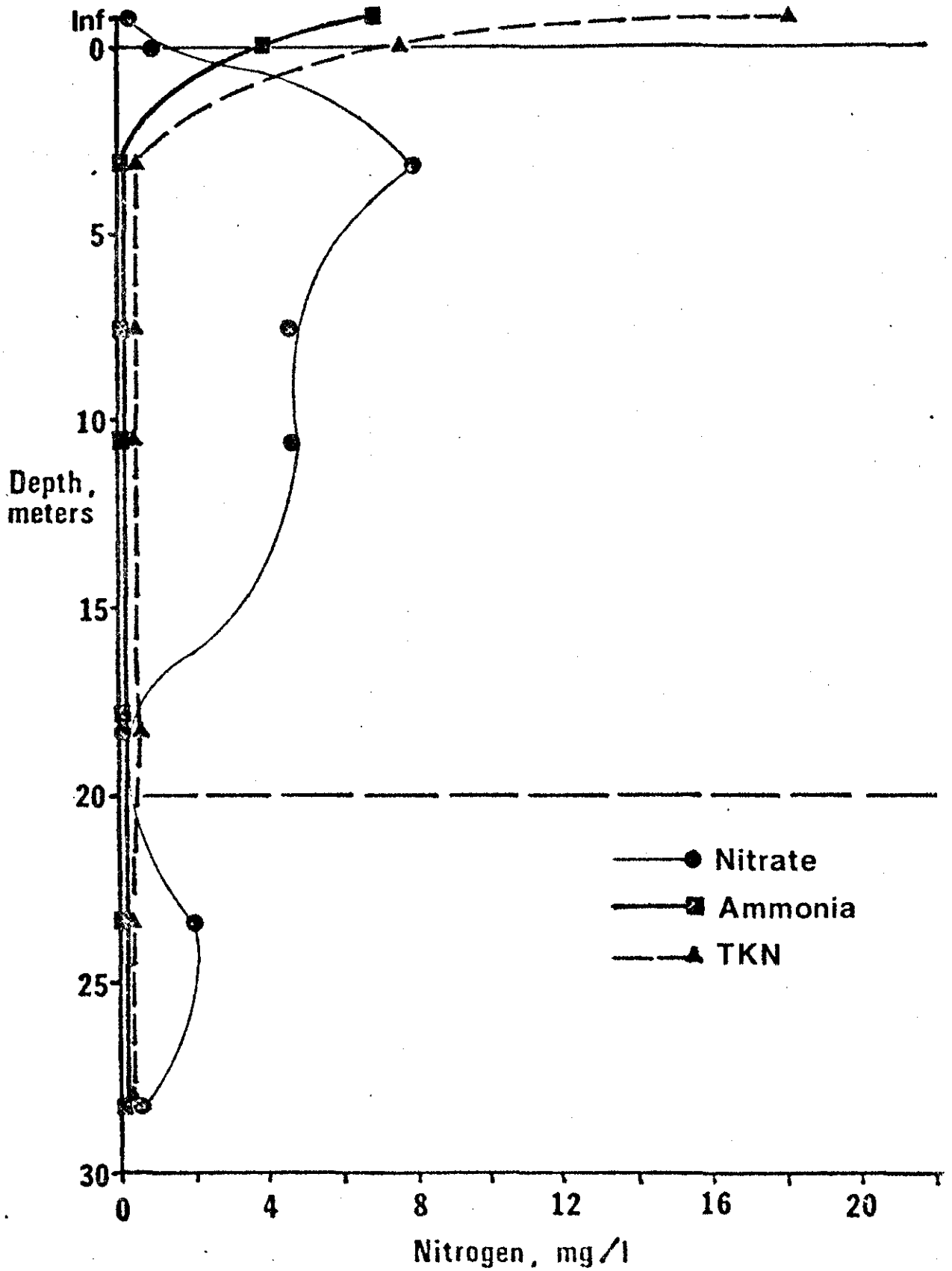
NITROGEN vs. DEPTH - FALL



of the sand bed with further reduction of this nitrogen to ammonia or organic nitrogen at a slightly greater depth. Since all forms of nitrogen showed significant reduction by the 18 m depth, there is apparently some loss of total nitrogen from the aqueous system. During the spring, the results (Figure 16) showed somewhat different trends. There was an increase in the nitrate content in the upper 3 m of the sand bed with a subsequent gradual reduction to less than 1 mgN/l at the 18 m depth. The nitrate and ammonia contents, however, dropped significantly to less than 1 mg/l at all depths of 3 m and greater. There was approximately 2 mg/l of nitrate in the shallow pumped well but all other values in both the shallow and deep pumped wells were less than 1 mgN/l. The results for spring indicate that there is an initial oxidation of the reduced nitrogen to nitrate with a possible subsequent reduction of the nitrate directly to nitrogen gas which escapes the aquatic system. It is not clear why during the summer and fall the reduction in nitrate resulted in a corresponding increase in the ammonia and kjeldahl nitrogen. It is also interesting to compare the nitrate content during the spring with the oxidation reduction potential measured during the same period as shown in Figure 12. The two curves are nearly identical in shape with the possible exception of slightly higher values of redox potential in the saturated portion of the aquifer. This supports the theory that oxidation to nitrate occurs in the upper 3 m of the sand bed with subsequent reduction of the nitrate to nitrogen gas in the lower portions of the sand bed. The one question which these results does not resolve is the relatively high concentration of 7 mg N/l of nitrate in the seepage adjacent to West Brook. Since the total nitrogen at the 18 m

FIGURE 16

# NITROGEN vs. DEPTH - SPRING



depth in bed N11, is usually less than this value, it is obvious that this nitrate does not originate from Bed N11. However, several of the sand beds, particularly the newer south beds are much less than 20 m deep. Thus, a bed 5 m deep would be likely to contain considerably more total nitrogen in the aqueous phase as the treated wastewater enters the saturated ground water zone. This may be the source of the high nitrate water found in some instances in the upper portion of the aquifer and at the seepage adjacent to West Brook.

The ortho- and total phosphate phosphorus are compared for the summer, fall and spring, in Figures 17, 18 and 19, respectively. Again insufficient data were secured during the winter to justify presentation of these results. In all cases, the orthophosphate was reduced to less than 0.1 mgP/l by the time the effluent reached the 10 m depth. In the summer and fall the total phosphorus was reduced significantly in the top 3 m followed by an increase in concentration at the 8 m depth. During the spring the concentration of total phosphorus was very similar to that of the orthophosphate. Slight amounts of total phosphorus were observed in the shallow pumped well during the summer and fall but during the spring and at the deeper pumped well the levels were consistently less than 0.1 mgP/l. During both the fall and spring, the sewage treatment plant accomplished a significant reduction in total phosphorus. During the spring there was also a reduction in orthophosphate in passing through the treatment plant, but during the fall there was a slight increase in orthophosphate, possibly indicating the conversion of polyphosphates to orthophosphates in the treatment system. In all instances, the orthophosphate was reduced to levels lower than could be achieved by con-

FIGURE 17

# PHOSPHORUS vs. DEPTH, SUMMER

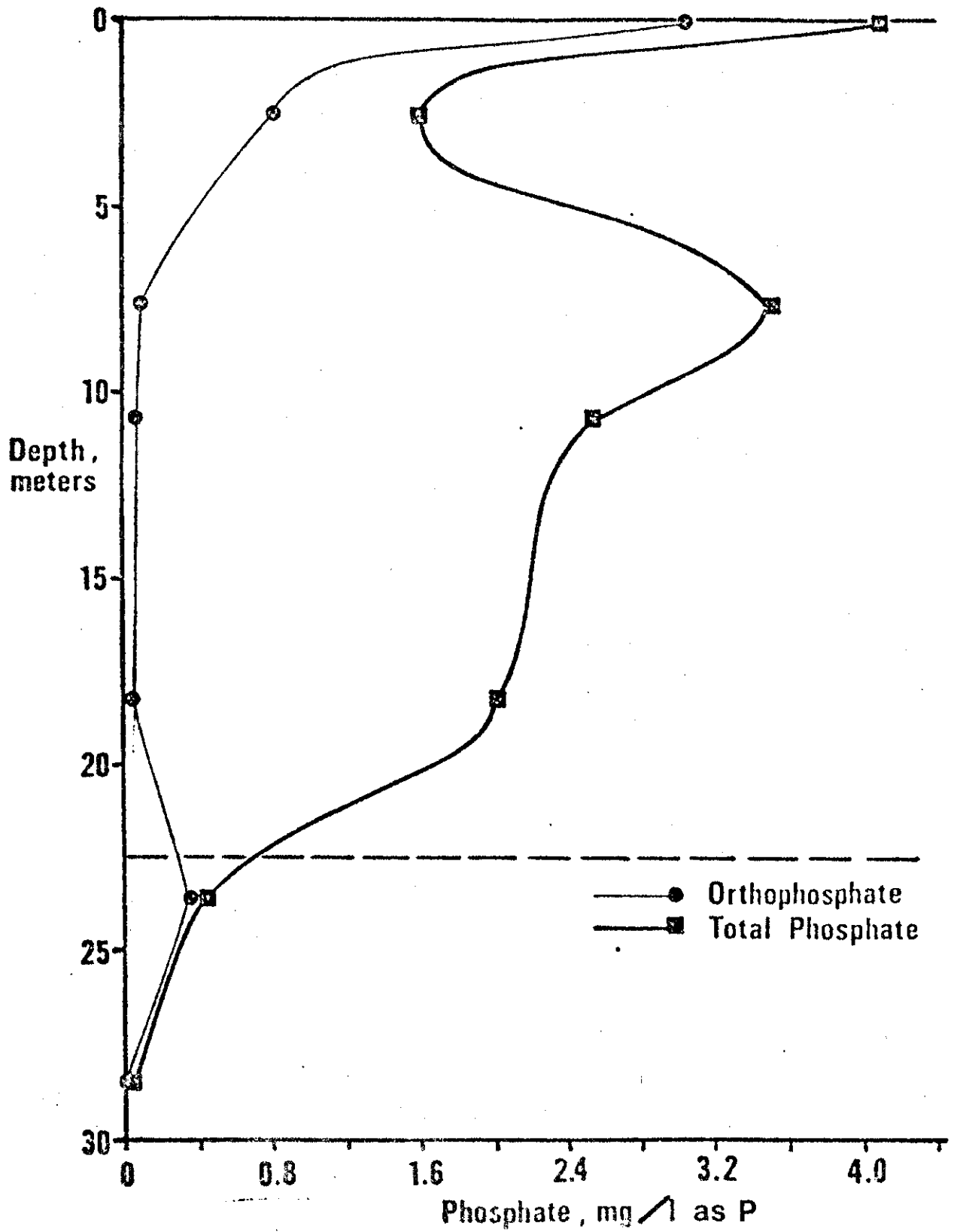


FIGURE 18

# PHOSPHORUS vs. DEPTH, FALL

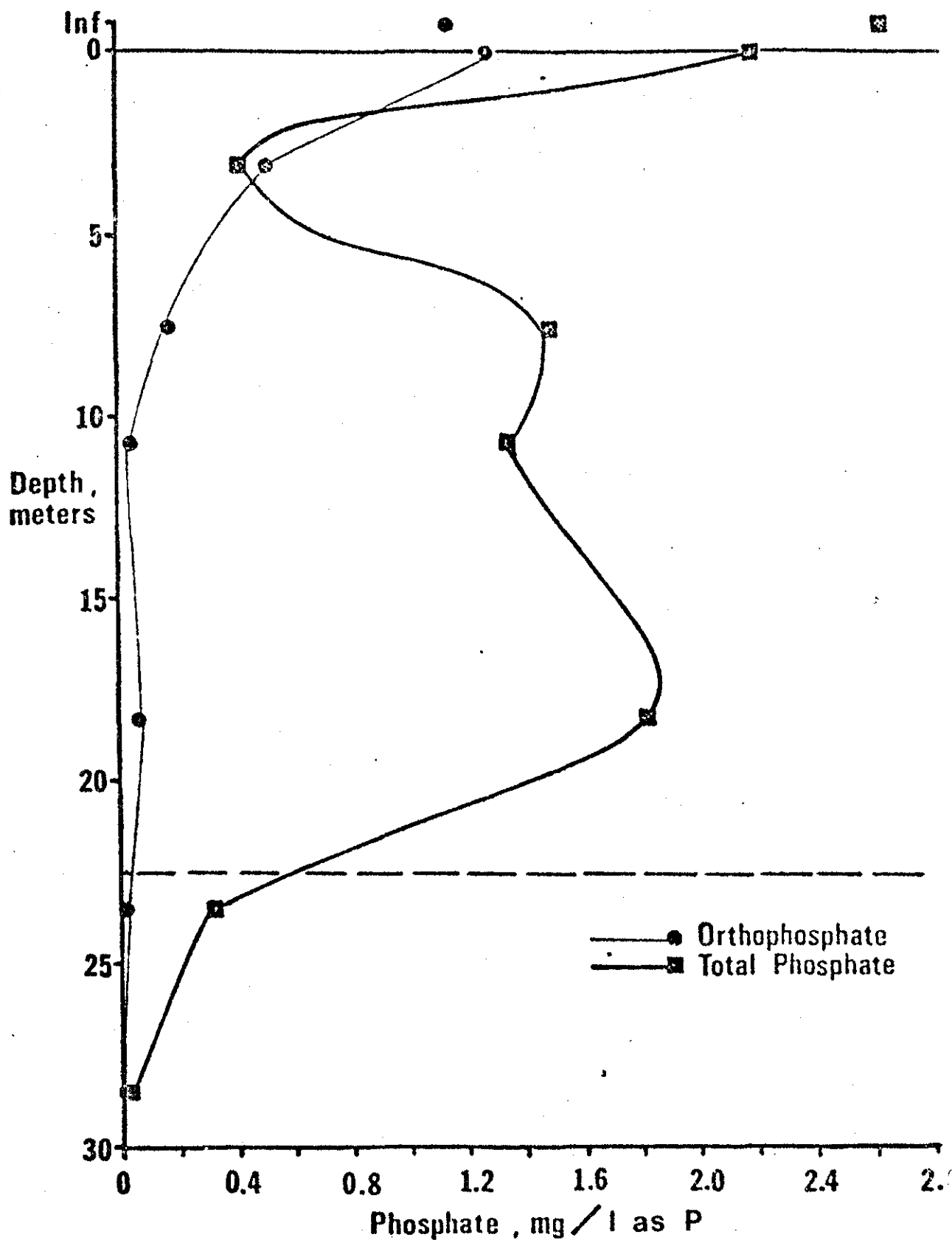
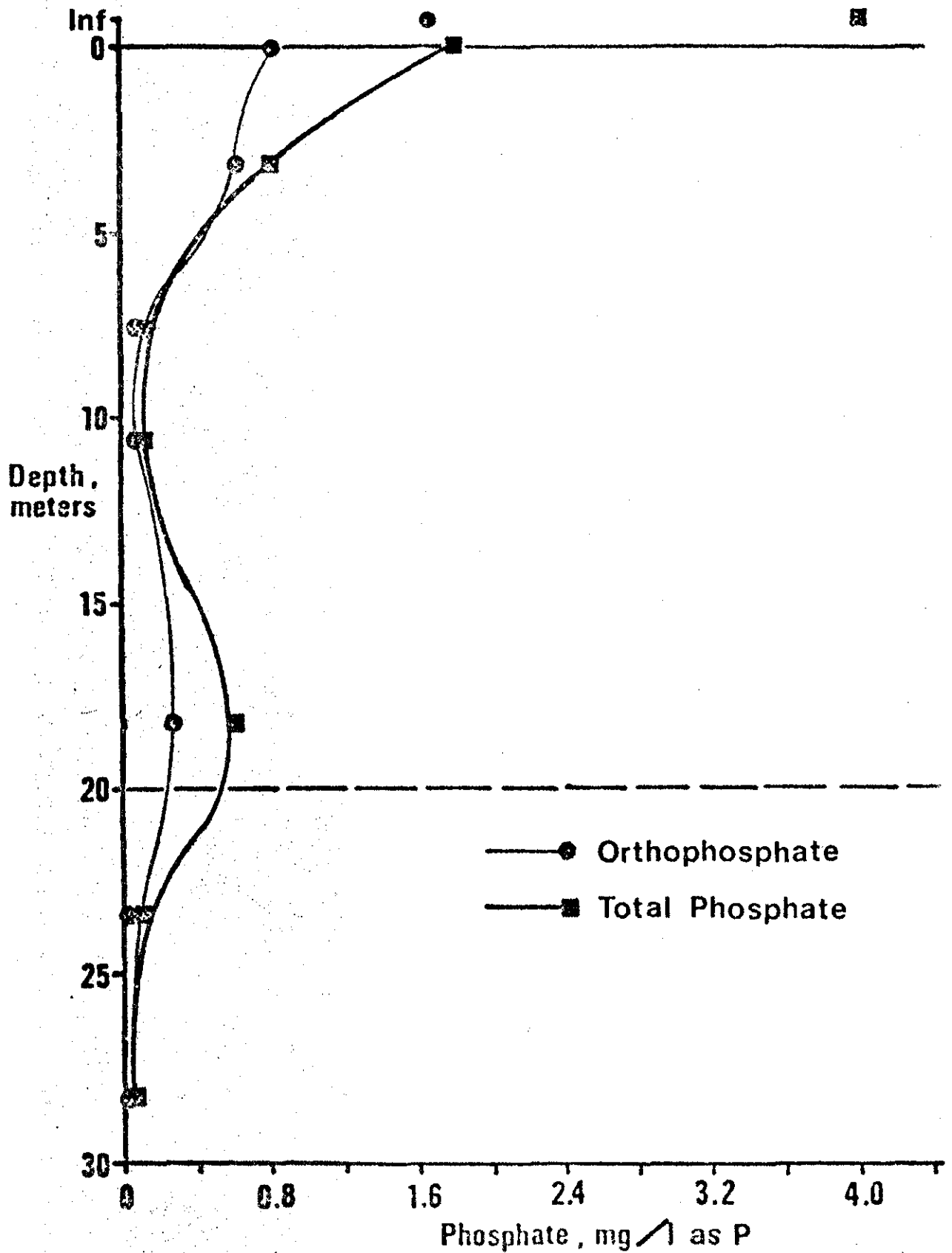


FIGURE 19

# PHOSPHORUS vs. DEPTH, SPRING



ventional physical-chemical treatment methods of phosphate removal by the time the liquid reached the 11 m depth sampling location. The approximately 0.4 mgP/l of total phosphorus observed in the shallow pumped well during the summer and fall was also less than could be achieved by normal removal techniques.

Additional determinations were made for calcium, magnesium, alkalinity, iron, sodium, potassium, potassium to sodium ratio and copper. A discussion of all of these results can not be included in this short paper. The concentrations of copper observed were always below the detectable limit of 0.05 mg/l by the atomic absorption technique. Measurements of BOD, COD and coliform are a part of a separate but related study.

#### CONCLUSIONS

A significant portion of the purification of the secondary effluent applied to the natural delta sand filters at the Lake George Sewage Treatment Plant is accomplished in the upper layers of the sand infiltration beds. Soluble non-reactive substances such as chloride pass directly through the sand system with little to no alteration. Oxidizable substances such as ammonia and organic nitrogen appear to be oxidized to nitrate in the top 3 m of the sand bed. There appears to be further reduction of this nitrate at greater depths with nearly a total removal of nitrate by the time the liquid passed through approximately 18 m of sand. Greater removals of all forms of nitrogen were observed during the spring. There appears to be a direct relationship between the nitrate concentration and the redox potential with depth. There is a measureable DO present at all depths within the sand bed, although the values recorded may be

somewhat high due to oxygenation during sampling. The orthophosphate is essentially all removed within the top 10 m of the sand bed, although there is less reduction in the total phosphorus with depth. A greater reduction in total phosphorus was observed during the spring sampling.

Thus it may be seen that the depth of sand required for a given degree of treatment will depend upon the substance of greatest concern. Significant reduction in total nitrogen requires approximately 18 m of depth; however, nitrate levels less than the 10 mg/l as N recommended as safe for a drinking water supply<sup>9</sup> are achieved below the 8 m depth. Satisfactory removal of orthophosphorous for nutrient control is achieved within the top 10 m of the sand bed.

The degree of treatment achieved by the Lake George Village Sewage Treatment Plant plays a significant role in the control of nutrients which would otherwise gain access to Lake George. A rapid infiltration sand system can be relied upon for many years to provide this desired degree of tertiary treatment.

#### ACKNOWLEDGEMENT

The cooperation of Harold Gordon, operator of the Lake George Sewage Treatment Plant and his staff in allowing the use of the facilities, adjusting bed dosings and working around our research installation is greatly appreciated. This study is was initiated with a small grant from the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory under Purchase Order BACA89-75-1265. However, continued funding was not provided and this project was completed with support by EPA Grant R-803452-01-0 and a significant contribution by Rensselaer Polytechnic Institute.

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