CHEMICAL INTERACTIONS IN A RAPID INFILTRATION SYSTEM ACCOMPLISHING TERTIARY TREATMENT OF WASTEWATER

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ABSTRACT

The settled trickling filter effluent from the Lake George Village Sewage Treatment Plant effluent is applied to natural delta sand beds by rapid infiltration. By means of wells and lysimeters within one of the sand beds and observation wells in the aquifer downstream from the infiltration beds, the degree and location of the purification process have been determined. Soluble constituents move through the sand system with little to no change in concentration. Oxidation of ammonia and organic nitrogen is correlated with the presence of DO and a positive redox potential. Most of the treatment was accomplished in the vertical transport through the unsaturated zone of the sand. The depth of sand required for removal of different constituents was variable. Nitrate was reduced to less than 1 mgN/l in the upper 8 m of the sand bed, whereas 18 m was required for significant total nitrogen removal. Orthophosphate was reduced to less than 0.1 mgP/l in the top 10 m of the sand. Coliforms required approximately 3 m for complete removal. Additional polishing of the effluent is achieved in the approximately 600 meters horizontal travel within the saturated zone of the aquifer. This final effluent has no deleterious effects on the quality of the water in Lake George.

CHEMICAL INTERACTIONS IN A RAPID INFILTRATION SYSTEM ACCOMPLISHING TERTIARY TREATMENT OF WASTEWATERS

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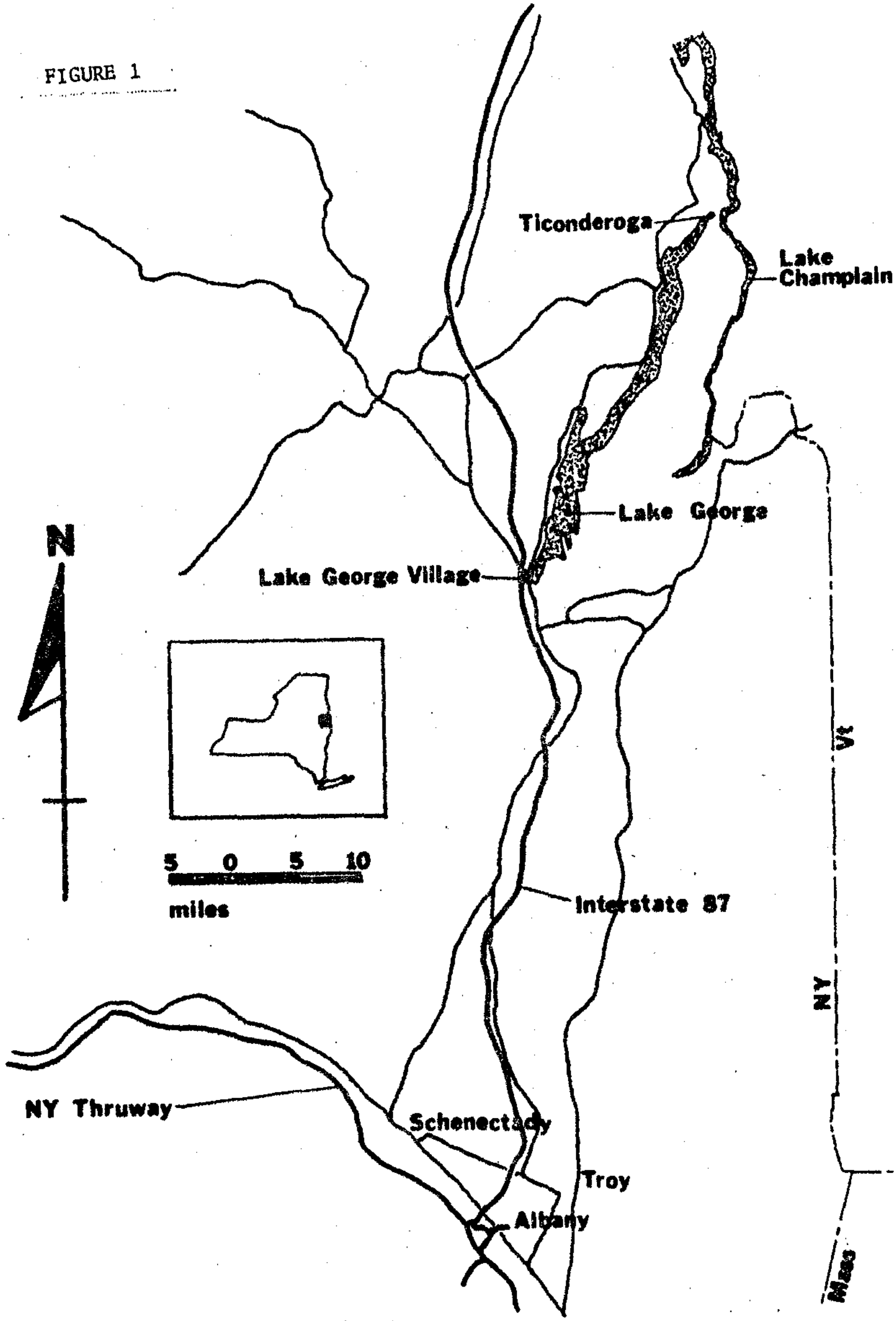
INTRODUCTION

Lake George is a beautiful recreational lake located in the eastern portion of the Adirondack Park of New York State (Figure 1). The lake is noted for its fine recreational facilities, its beautiful tree covered shoreline, and the clarity of its water.

As an indication of the quality of the waters of Lake George, the lake has been given a special class AA designation. This means that the water may be used for direct consumption with only chlorination required for public water supplies.[1] Many residents who live in cottages surrounding the lake secure their drinking water directly from the lake and consume it with no treatment whatsoever. In order to maintain the high quality of the lake water, regulations were passed [2] restricting the discharge of any wastewaters into the lake directly or into any stream which discharges into the lake. Properly operating sub-surface disposal systems such as septic tanks with seepage fields have been considered as adequate treatment provided there is no surface runoff of the leach field effluents into the lake or into any stream which flows into the lake. However, with the concentration of population at the southern tip of the lake it was decided that the number of septic tanks in that area would exceed the capacity of the soil to contain and purify the septic tank

FIGURE 1



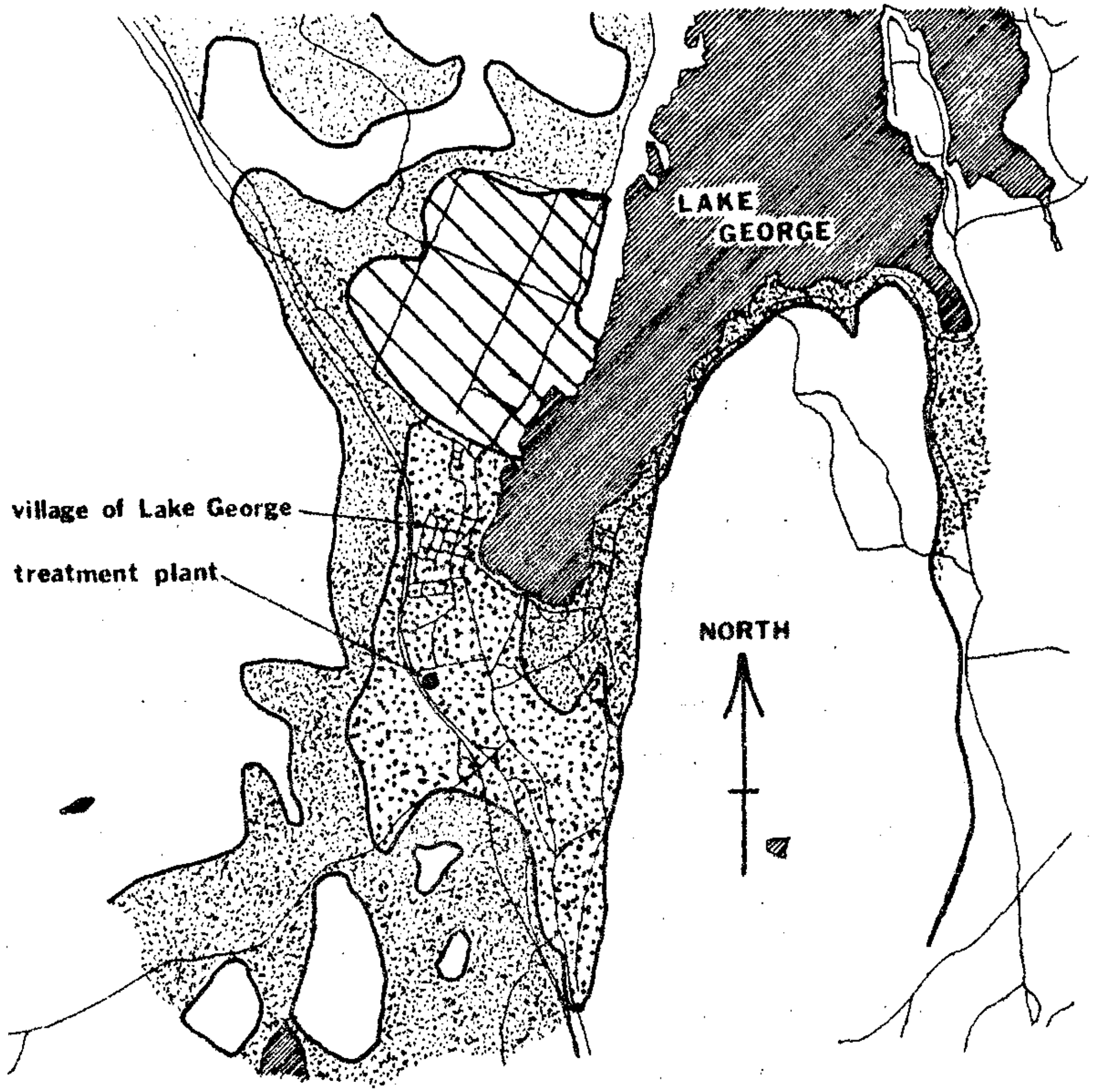
Ticonderoga
Lake Champlain
Lake George
Lake George Village
N
5 0 5 10
miles
Interstate 87
Vt
NY
NY Thruway
Schenectady
Troy
Albany
Mass

effluents adequately. Thus, in 1936 plans were made to construct a waste treatment plant for the Village of Lake George. The treatment plant consisting of secondary treatment by means of trickling filters and application of the final effluent onto natural delta sand beds was put into operation in 1939 and has been operating continuously since that time.

DESCRIPTION OF THE TREATMENT FACILITY

In the initial design of the treatment facility for the Lake George Village Sewage Treatment Plant consideration was taken of the presence of a large natural delta sand deposit off the southwest corner of Lake George as shown in Figure 2. Advantage was taken of this occurence since the discharge of any treated effluent to any surface stream is prevented due to the above stated law.[2] Thus, the design called for a relatively conventional domestic sewage treatment plant followed by the application of the final effluent onto sand beds in this natural delta sand formation.

The sewage from the Village is collected by gravity to a central location in a park adjacent to the lake. Here a pumping station assists in forcing the sewage approximately 55 m (108 ft) through a 1.6 km (1 mi) force main to the treatment plant. The pump house along the lake affords a resting place where individuals may obtain a beautiful view of the lake. A secondary lift station is located at an intermediate point, aiding in lifting the sewage to the treatment plant. The initial design of the plant was for a winter time flow of 0.15 mgd (600 m^3/day) and a summertime flow of approximately 3 times the winter flow, or 0.5 mgd (1,900 m^3/day). The plant itself was built in triplicate so that one third of the plant could be used for winter flows and the entire plant for summer flows. The treatment plant (Figure 3) consisted of three circular Imhoff tanks, three



LEGEND

- unclassified by Hill
- moraine sand, gravel, & boulders (Newland)
- delta deposits (Newland)
- lakes

SCALE

6000ft

FIGURE 2

GEOLOGY OF THE SOUTHERN LAKE GEORGE DRAINAGE BASIN

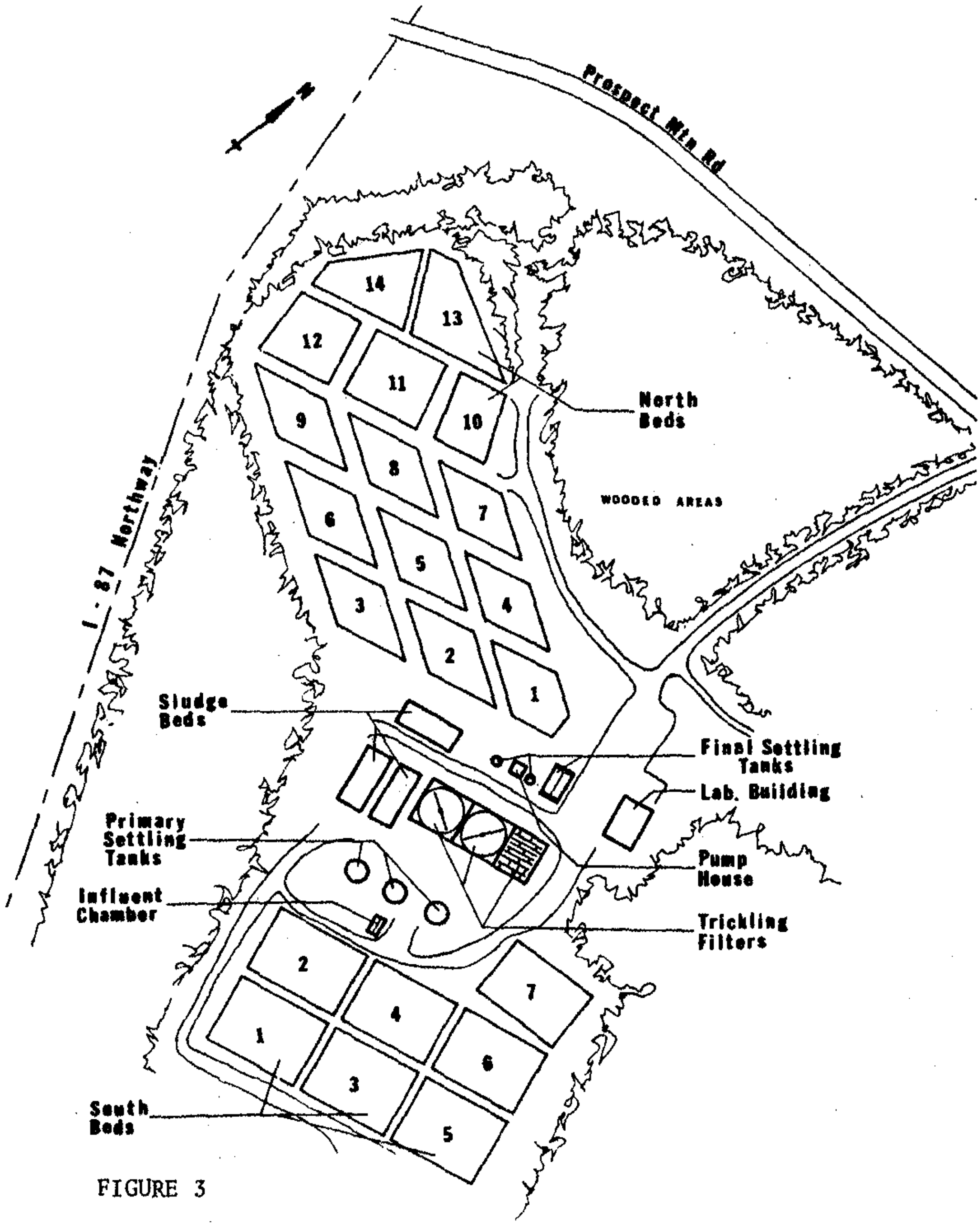


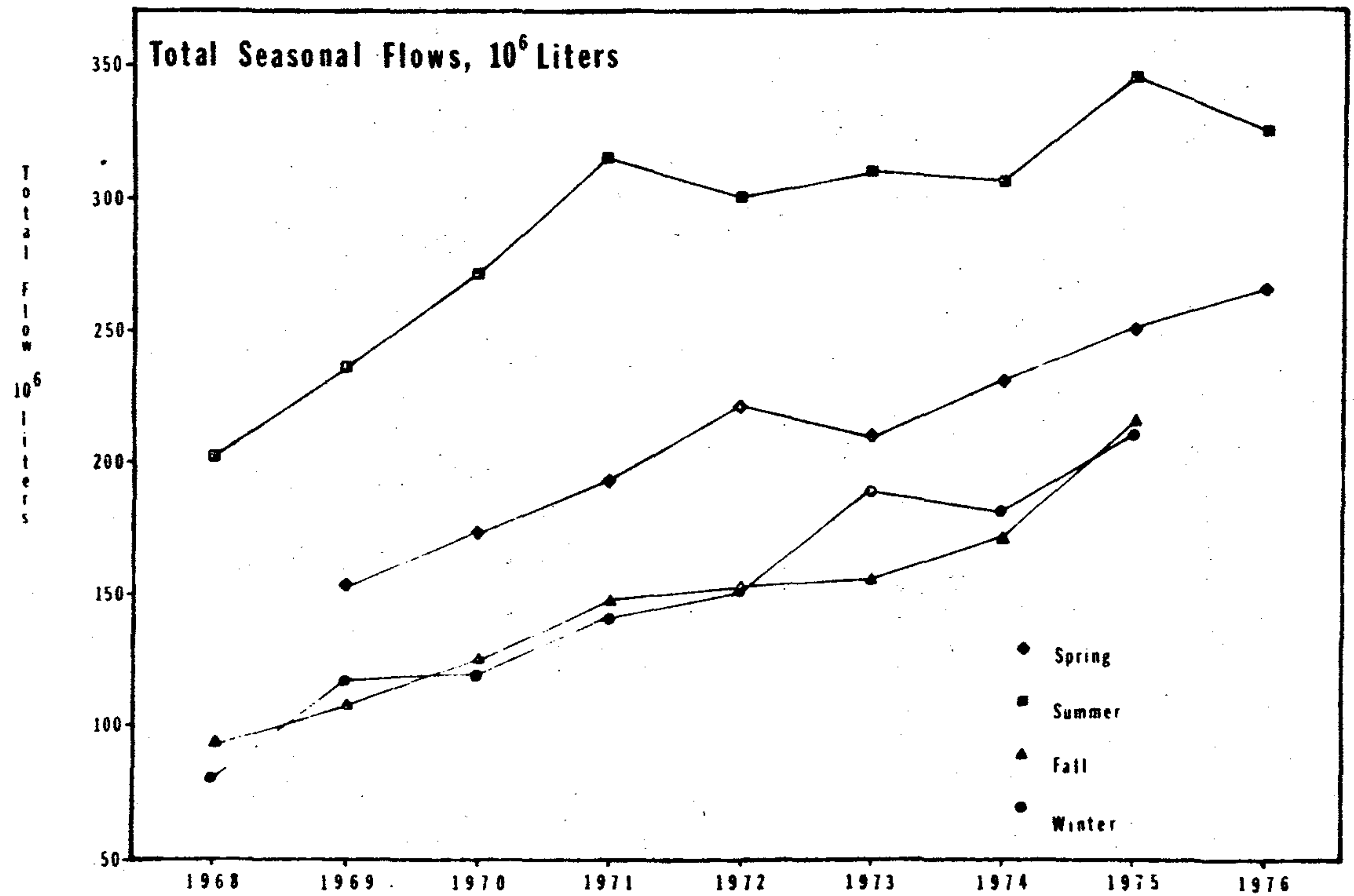
FIGURE 3

SEWAGE TREATMENT PLANT LAYOUT

dosing siphons, three trickling filters two of which have standard rotary arms and one of which has fixed nozzles, final claraification in two circular secondary tanks and the discharge of the final effluent without chlorination onto one of the six sand beds in the area. Since then two of the Imhoff tanks have been replaced by Clarigesters which still provide a separate compartment for sludge digestion. The fixed nozzle trickling filter is covered with boards on saw horses and is used exclusively during the winter. Although there is some ice buildup in the enclosure due to the extremely cold winters in the area, sufficient filter surface remains ice free to provide some degree of treatment throughout the winter. Two rectangular secondary settling tanks with continuous sludge scrapers have been added. The original six sand infiltration beds have now been expanded to 21 with a total filter area of 2.15 hectares (5.3 acres). The general layout of the present sewage treatment plant is shown in Figure 3. The preliminary treatment portion of the plant is considered to be designed for a flow of 1.75 mgd (6,600 m^3/day). Maximum flows observed on a summer weekend have reached 1.25 mgd (4,700 m^3/day). Recent average monthly flows are shown in Figure 4. For the sake of calculating seasonal averages, the data shown for the months stated begin with the 21st day of the previous month and carry through to the 20th day of the stated month. This is done since the summer period of high tourist population begins about June 21 and ends by September 20. At present the summer flows are approximately 2 times the winter flows.

The sand beds are normally operated by dosing one north and one south bed during the period from approximately 8 am to 4 pm and dosing another pair of north and south beds for the remaining 16 hours of the day. During a weekend two north and two south beds are dosed for a 24 hour period with

FIGURE 4



Total Seasonal Flows, 10^6 Liters
Total Flow 10^6 liters
350
300
250
200
150
100
50
1968
1969
1970
1971
1972
1973
1974
1975
1976
Spring
Summer
Fall
Winter

the new beds being put into operation approximately 8 am Saturday, Sunday and Monday. During the extremely high flows of a summer weekend additional beds are dosed as needed. Uner normal operating conditions the beds drain dry in approximately 1 to 3 days. The beds are allowed to remain dry as long as possible for aeration. With frequent dosing, the beds slowly clog and the infiltration rate is decreased. Periodically, which is in the range of twice per year, the surface of the beds is scraped. A small amount of the sand is removed and then the beds are raked and releveled prior to putting back into service. The first few dosings after this cleaning procedure result in very rapid infiltration rates. In 1973 approximately 1 ft (0.3 m) of the surface sand was removed from each of the sand beds to remove any fine sand grains, any surface clogging material and the sand which most likely had its phosphate removal capacity expended.

INFILTRATION RATES

Infiltration rates were estimated based on the amount of sewage applied to each sand bed, the time it takes for the sewage to drain through a bed, and the frequency of dosing. Since precise flow data to each sand bed are not available, it was assumed that half of the flow reaches the treatment plant during the period of 8 am to 4 pm and the other half of the daily flow occurs during the 16 hour night time period. Since two beds are being dosed simultaneously during each period, it is assumed that each bed receives approximately one quarter of the daily flow. This value may not be entirely accurate since the lower north beds are dosed by gravity and the upper south beds are dosed by means of a pump which is actuated by the depth of the water in a wet well. When the flow to the north beds exceeds a preset level, the excess overflows into the wet well and is then pumped to the upper south beds. Time and facilities were not available for the actual measurement of the flow to the upper beds or the time of operation of the pump to the upper beds. It if felt that dividing the flow equally between the north and south beds provides a reasonable estimate for calculation of the loading rates.

The estimated monthly loading rates over a full year are shown in Table 1.[3] It may be seen that the maximum loading rate occurred during the month of August with a loading of 4.83 gal/ft^2-day or 0.65 ft/day (1.37 m^3/ha-min or 0.2 m/day). It must be pointed out that this is not an infiltration rate. It represents the amount of liquid applied to the bed during this period including the resting period of the bed. It does, however, represent the amount of liquid that can be safely applied to the sand beds without exceeing the total infiltration capacity. It must be mentioned, however, that during the latter part of August 1975 and 1976, the sand beds were all completely loaded and the normal drying time between loading was either very short or non-existent. After the tourists departed after Labor Day, the flows diminished markedly and the sand beds were allowed to dry and were scraped, thereby increasing the infiltration capacity.

The actual infiltration rate was measured in several of the sand beds by installing a water level recorder in those beds. The rate of infiltration increased with the head of liquid on the sand bed as shown in Figure 5.[3] The lowest rates recorded with less than 1 ft (0.3 m) of liquid on the sand bed were in the range of 0.25 to 0.6 ft/day (0.08 - 0.18 m/day) under normal operating conditions. It may be seen that different beds have different infiltration rates, with bed S7 having a rate exceeding 1 ft/day (0.3 m/day) with a water depth on the bed of 2 ft (0.6 m). An infiltration rate exceeding 2 ft/day (0.6 m/day) was measured on a freshly scraped bed

TABLE 1

WASTEWATER LOADING RATES, LAKE, GEORGE, NEW YORK

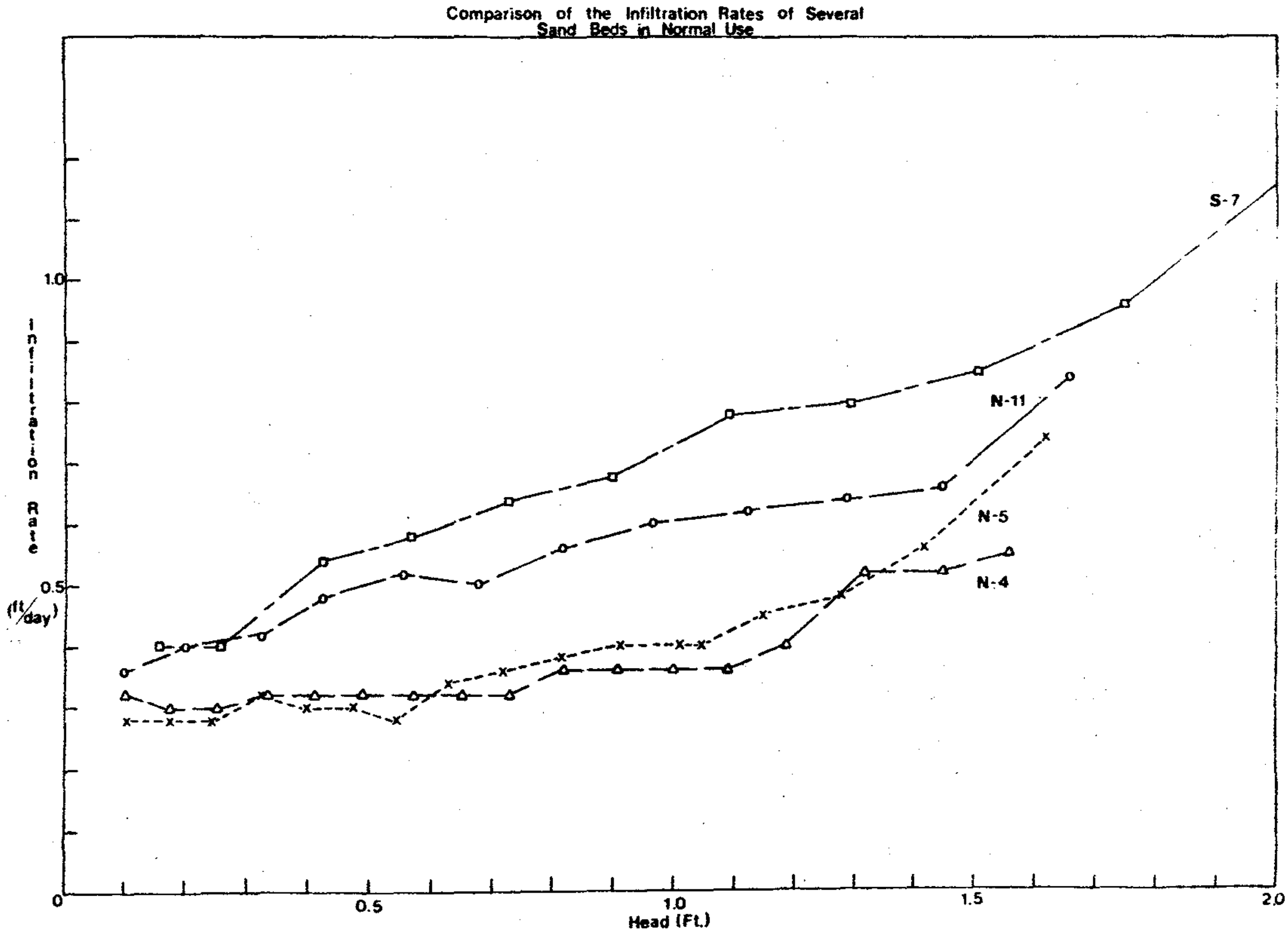
	Flow Mgal/d	Loading Rate $gal/ft^2 \cdot d$	ft/d
1974			
Sep	0.740	3.17	0.42
Oct	0.588	2.52	0.34
Nov	0.414	1.77	0.24
Dec	0.491	2.10	0.28
1975			
Jan	0.499	2.14	0.29
Feb	0.513	2.20	0.29
Mar	0.568	2.43	0.32
Apr	0.699	2.99	0.40
May	0.661	2.83	0.38
Jun	0.779	3.33	0.45
Jul	0.970	4.15	0.55
Aug	1.128	4.83	0.65
Average	0.67	2.87	0.38

1 Mgal/d = 43.8 L/s

1 $gal/ft^2 \cdot d$ = 0.283 m^3/ha-min

1 ft/d = 0.305 m/d

FIGURE 5


Comparison of the Infiltration Rates of Several Sand Beds in Normal Use
Infiltration Rate (ft/day)
1.0
0.5
0
0.5
1.0
1.5
2.0
Head (Ft.)
S-7
N-11
N-5
N-4

with a depth of water of 1 ft (0.3 m). With continued intermittent operation the flow rate decreased gradually to the values previously stated.

PURIFICATION OF APPLIED WASTEWATERS IN THE SOIL

Studies were made of the changes in water quality of the applied sewage effluent in both the vertical and horizontal transport through the soil. The soil in this case consists exclusively of delta sand deposits containing no observed quantities of clay. The quality changes during vertical transport were measured in north sand bed 11 and the quality changes during horizontal transport were measured in a series of well points installed between the infiltration beds and West Brook approximately 600 m (2,000 ft) north of the treatment plant. The ground water including the applied sewage effluent emerges from the ground as seepage along the south bank of the flood plain of West Brook. West Brook ultimately flows back into Lake George which is the drinking water supply for the area. All of the data are summarized on a seasonal basis to reflect the variations in flow in the treatment plant and temperatures within the ground.

Purification of Applied Wastewaters With Depth

North sand bed 11 was chosen for the quality changes with depth because it was one of the older beds and one in which earlier studies had been conducted to determine changes in water quality with depth.[4]. A series of well points was driven into the sand of bed 11 at intervals of 2 ft (0.6 m) from 2 - 14 ft (0.6 - 4.28 m). Porous cup lysimeters were installed at 5 ft (1.5 m) intervals from 5 ft (1.5 m) to 65 ft (20.8 m). Only four of these lysimeters proved to be functional but fortunately their distance distribution (3, 7, 11 & 18 m) was adequate to get a fairly uniform picture of changes in quality with depth. In addition, 2 wells with 6 in (15 cm) casing were equipped with submersible pumps to obtain samples directly from the top of the aquifer under bed 11. The location of these well points, lysimeters and pumping wells in Bed 11 is shown in Figure 6. The locations with depth in the bed are shown in Figure 7.

Samples for the study were secured on approximately a bi-weekly basis. Constrictions included the time for the sampling, the time for analysis of all the samples, and, as appropriate, the time required for the lysimeters to fill. 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 results of quality changes with depth in Bed 11 (Figures 8-19) the influent to the treatment plant is indicated at the top of the graph and the values shown at the zero depth represent the effluent from the treatment plant applied to the sand beds. The different or change between these two values represents the degree of treatment or change in passing through the conventional portion of the sewage treatment plant. The level of water in the saturated aquifer varied between 20 and 22.5 m from the surface. Thus, the (normally) two data points below this depth represent the quality of water within the saturated aquifer. In addition, in order to provide a reference point, the depth to the water and to the bedrock in well 5, which is located in south sand bed 3, is indicated in these figures.

Figure 8 shows the temperature fluctuations within Bed N-11 during a full year. In general the temperature increased with depth during the fall and the winter and decreased with depth during the spring and summer. The temperature of the water in the saturated aquifer was fairly constant throughout the year.

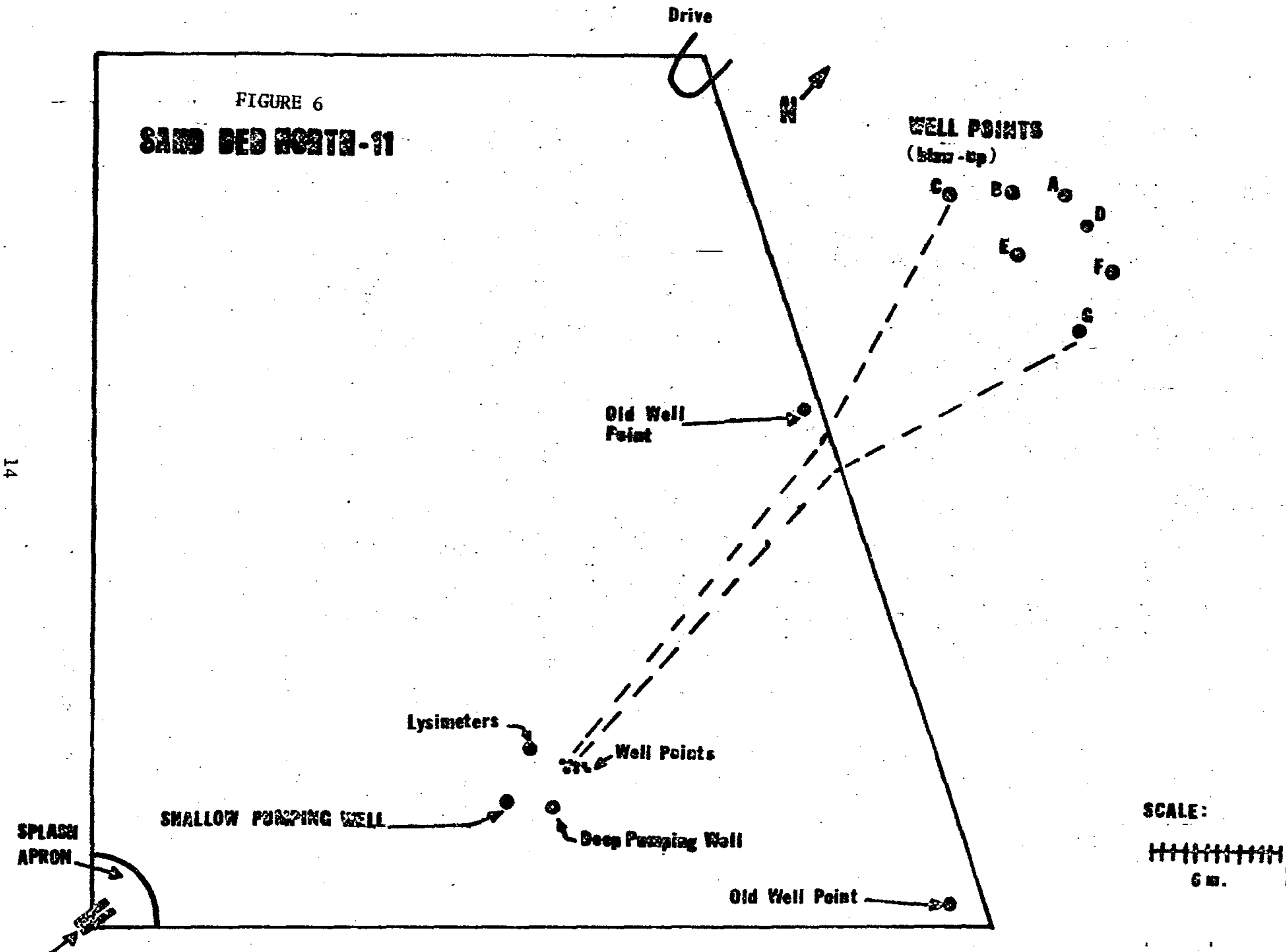


FIGURE 6

SAND BED NORTH-11

FIGURE 7

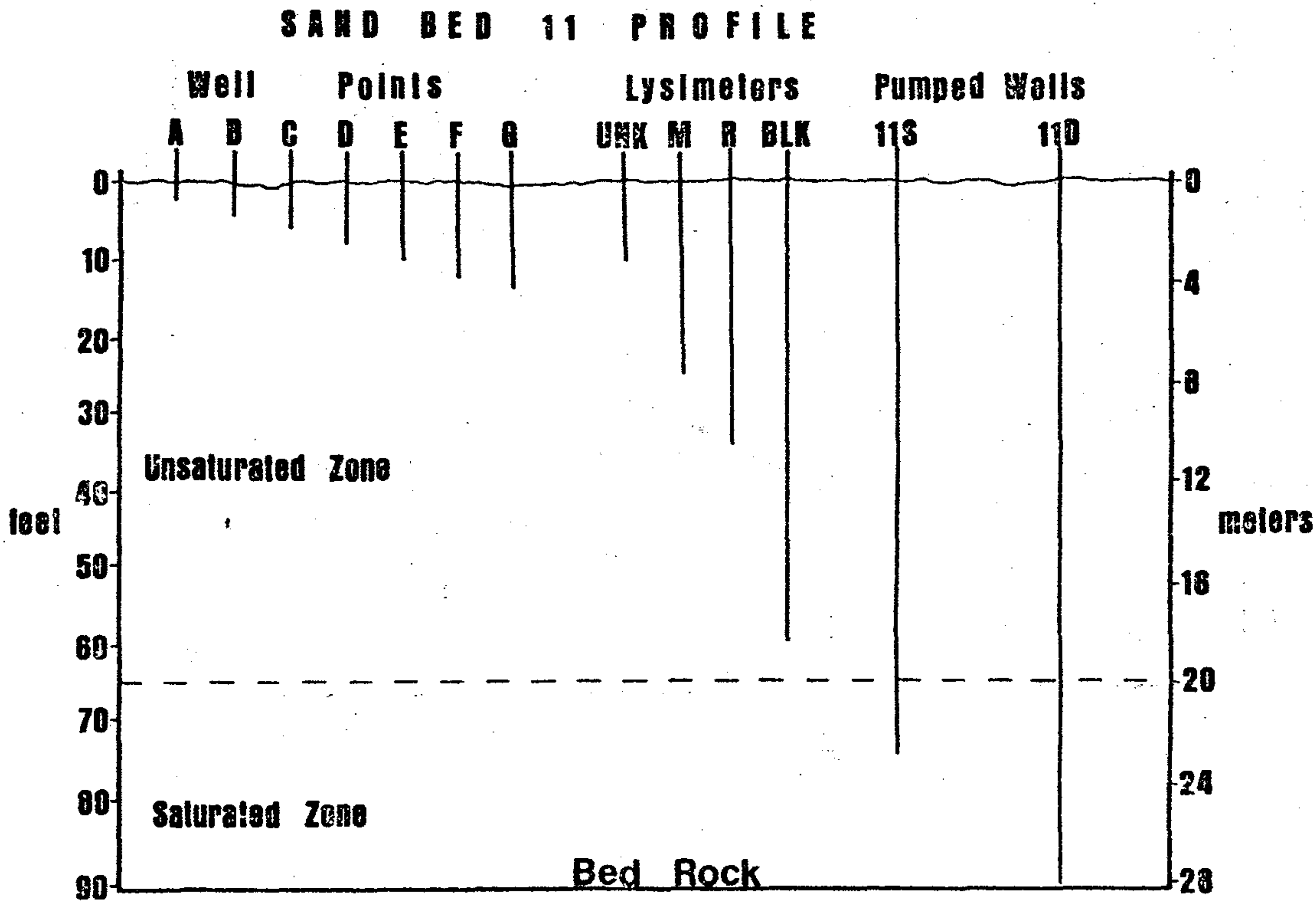
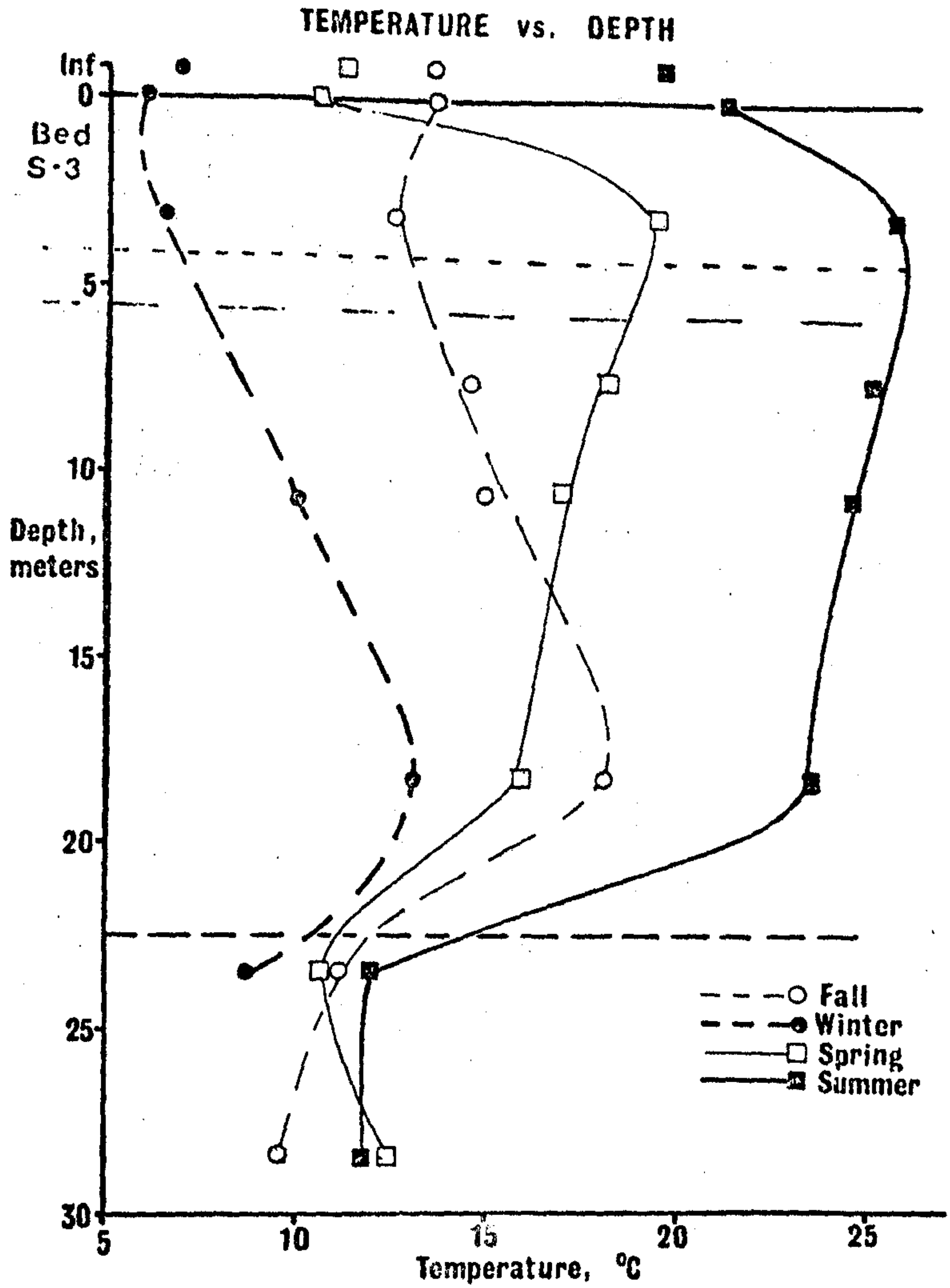

SAND BED 11 PROFILE
Well Points
Lysimeters
Pumped Wells
A B C D E F G
UNK M R BLK
11S 11D
0
10
20
30
40
50
60
70
80
90
feet
Unsaturated Zone
Saturated Zone
Bed Rock
0
4
8
12
16
20
24
28
meters

FIGURE 8



TEMPERATURE vs. DEPTH
Inf
0
Bed
S-3
5
10
Depth,
meters
15
20
25
30
5
10
15
20
25
Temperature, °C
Fall
Winter
Spring
Summer

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) show 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 the lower 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. The values measured within the well were lower than the pumped values. Thus, 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 during pumping.

The redox potential was determined during only the spring of 1976 after the required electrodes arrived (Figure 12). The treatment plant increased the redox potential markedly resulting in effluent values slightly on the positive side continuing in all samples except at the 18 m depth. There appears to be significant reduction at this depth within the sand

FIGURE 9

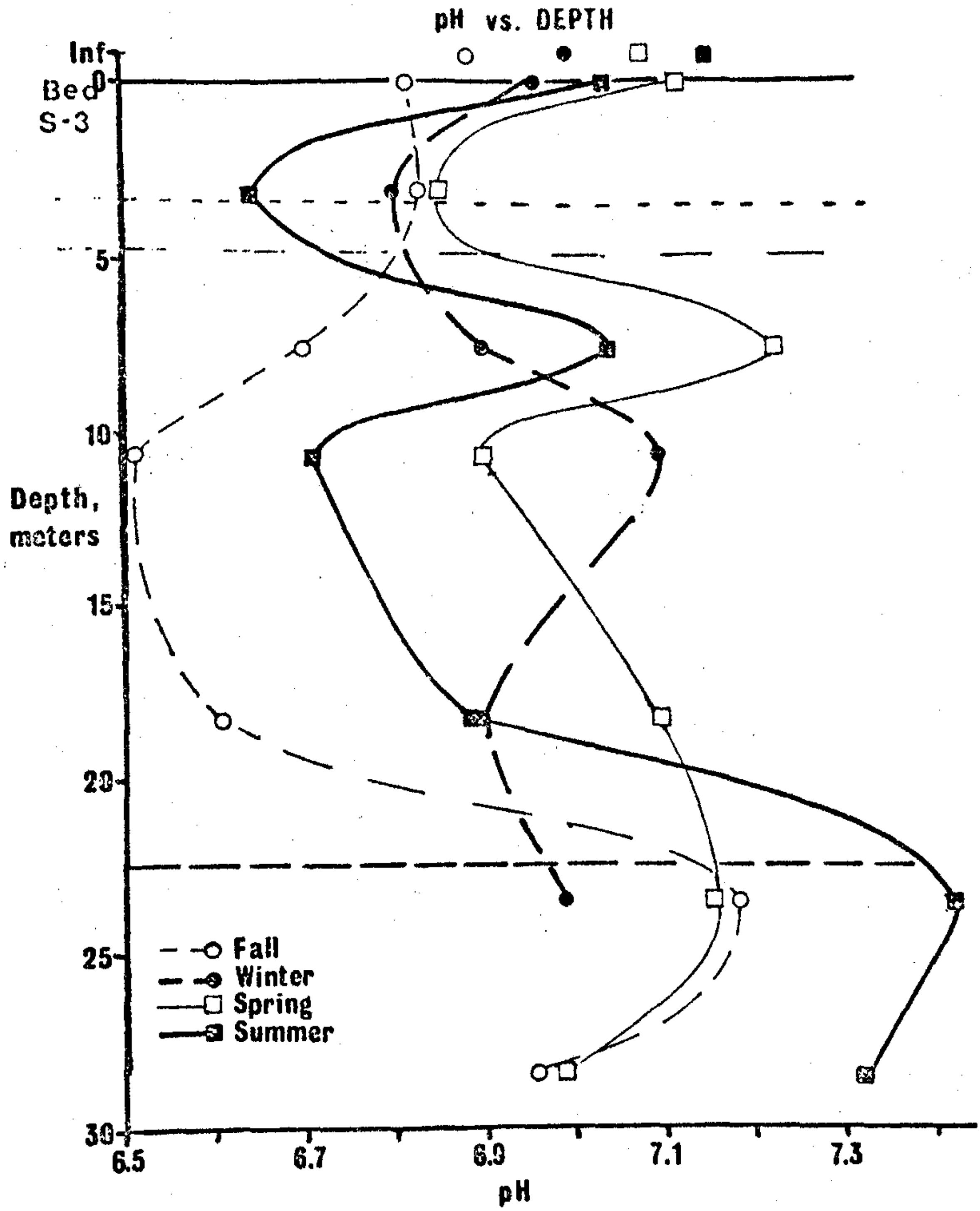

pH vs. DEPTH
Inf
Bed
S-3
0
5
10
15
20
25
30
Depth, meters
Fall
Winter
Spring
Summer
6.5
6.7
6.9
7.1
7.3
pH

FIGURE 10

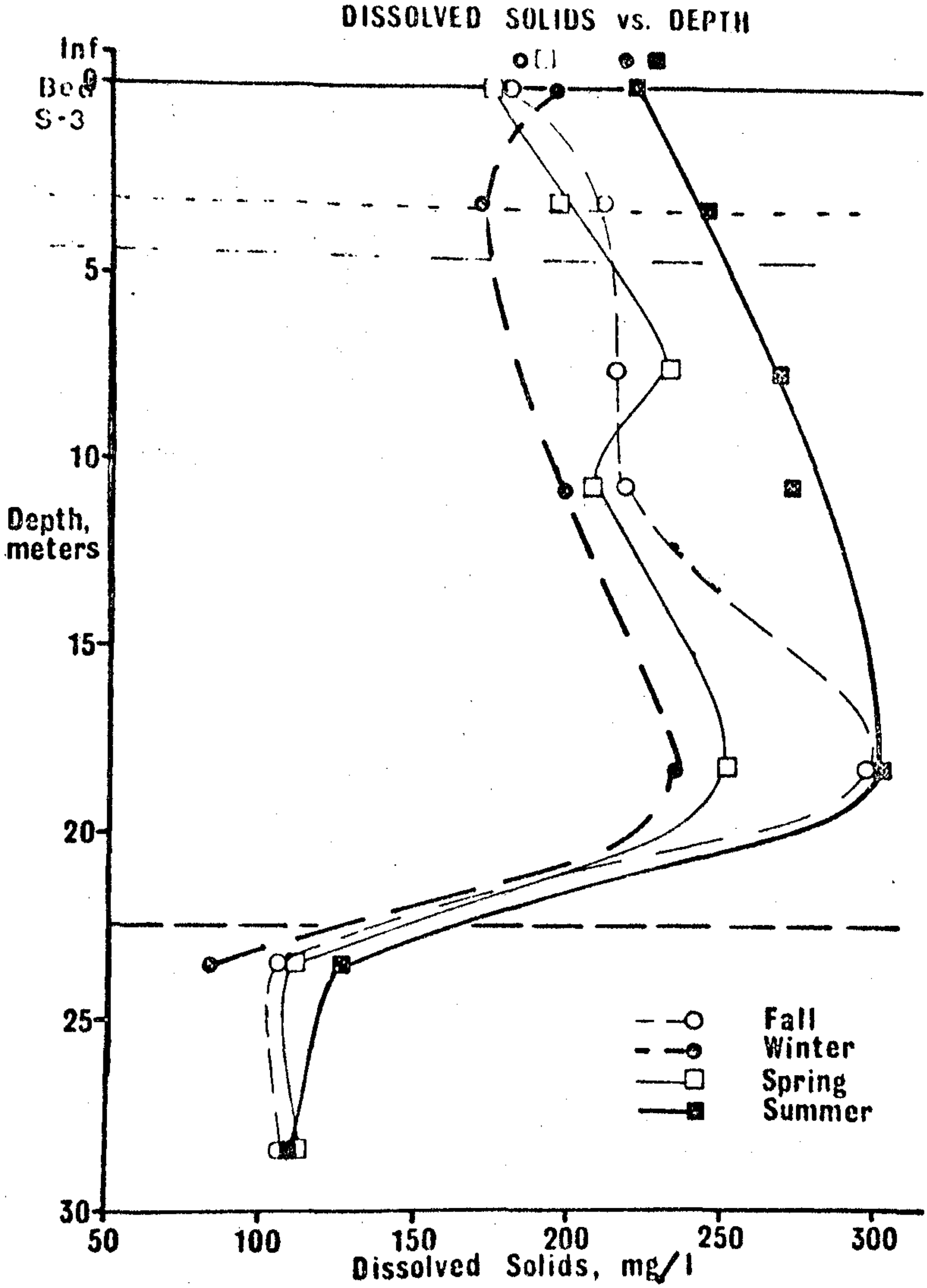

DISSOLVED SOLIDS vs. DEPTH
Inf
Bed
S-3
0
5
10
15
20
25
30
Depth, meters
50
100
150
200
250
300
Dissolved Solids, mg/l
Fall
Winter
Spring
Summer

FIGURE 11

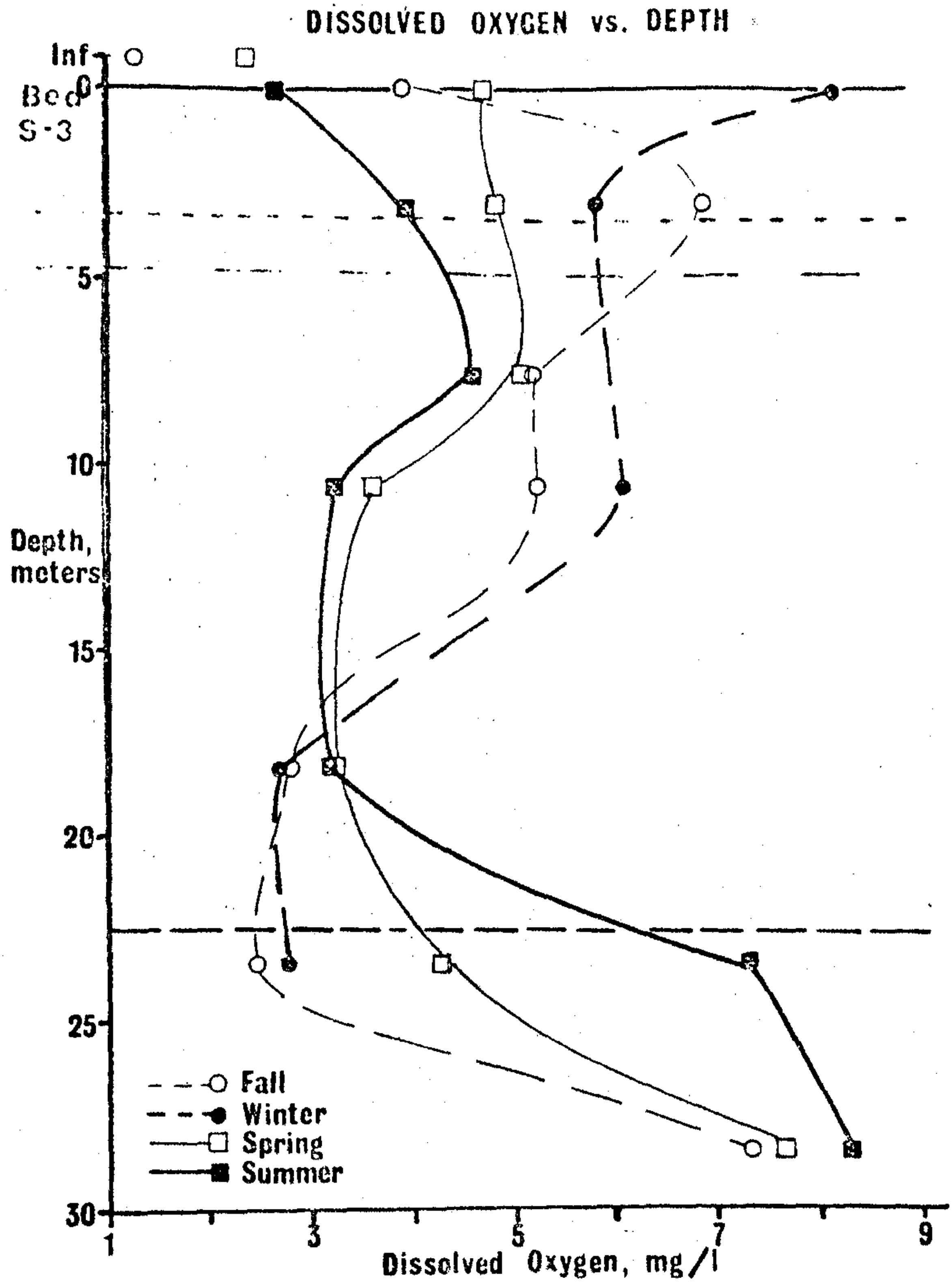
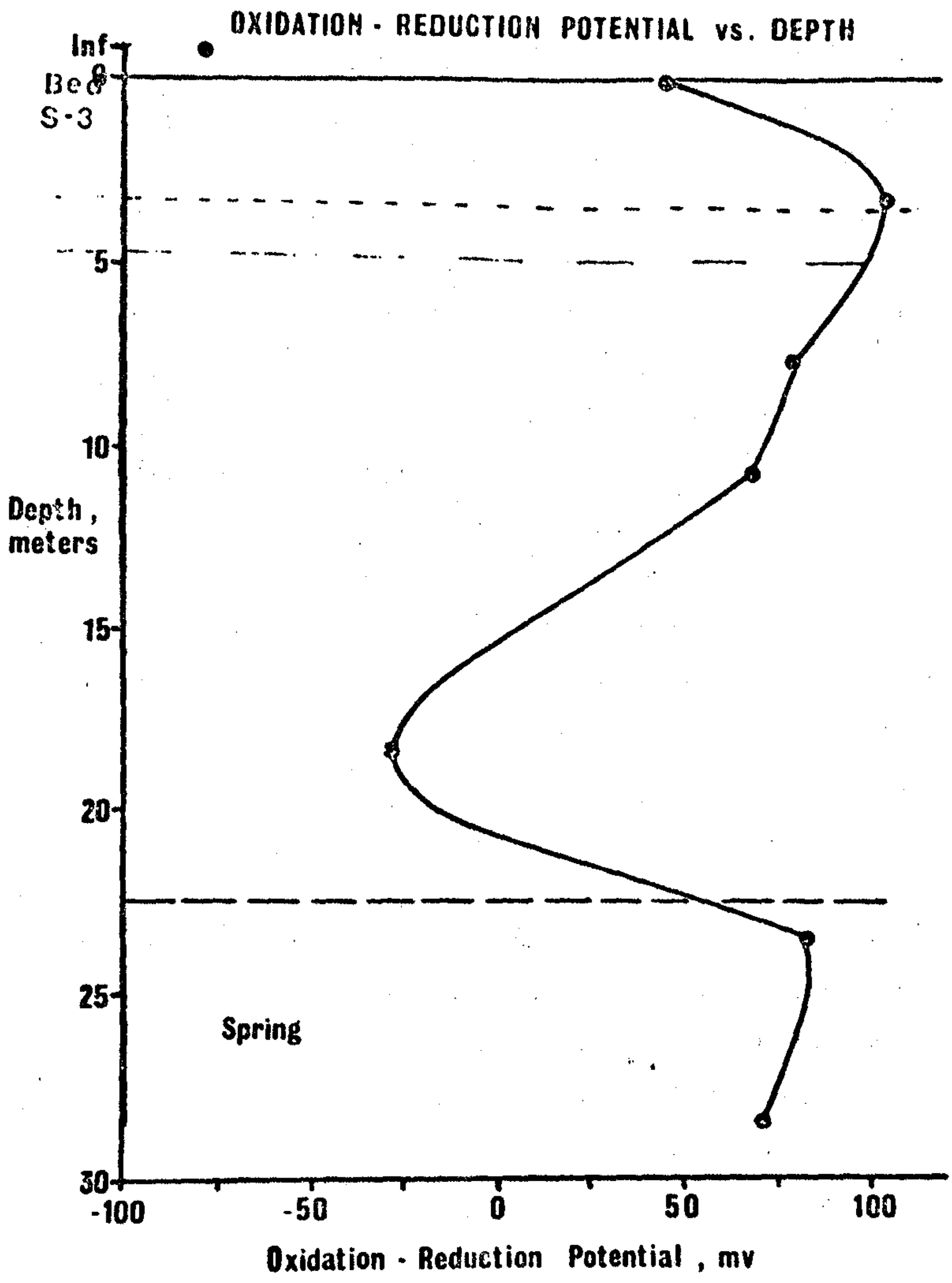

DISSOLVED OXYGEN vs. DEPTH
Inf
Bed
S-3
0
5
10
15
20
25
30
Depth, meters
1
3
5
7
9
Dissolved Oxygen, mg/l
Fall
Winter
Spring
Summer

FIGURE 12



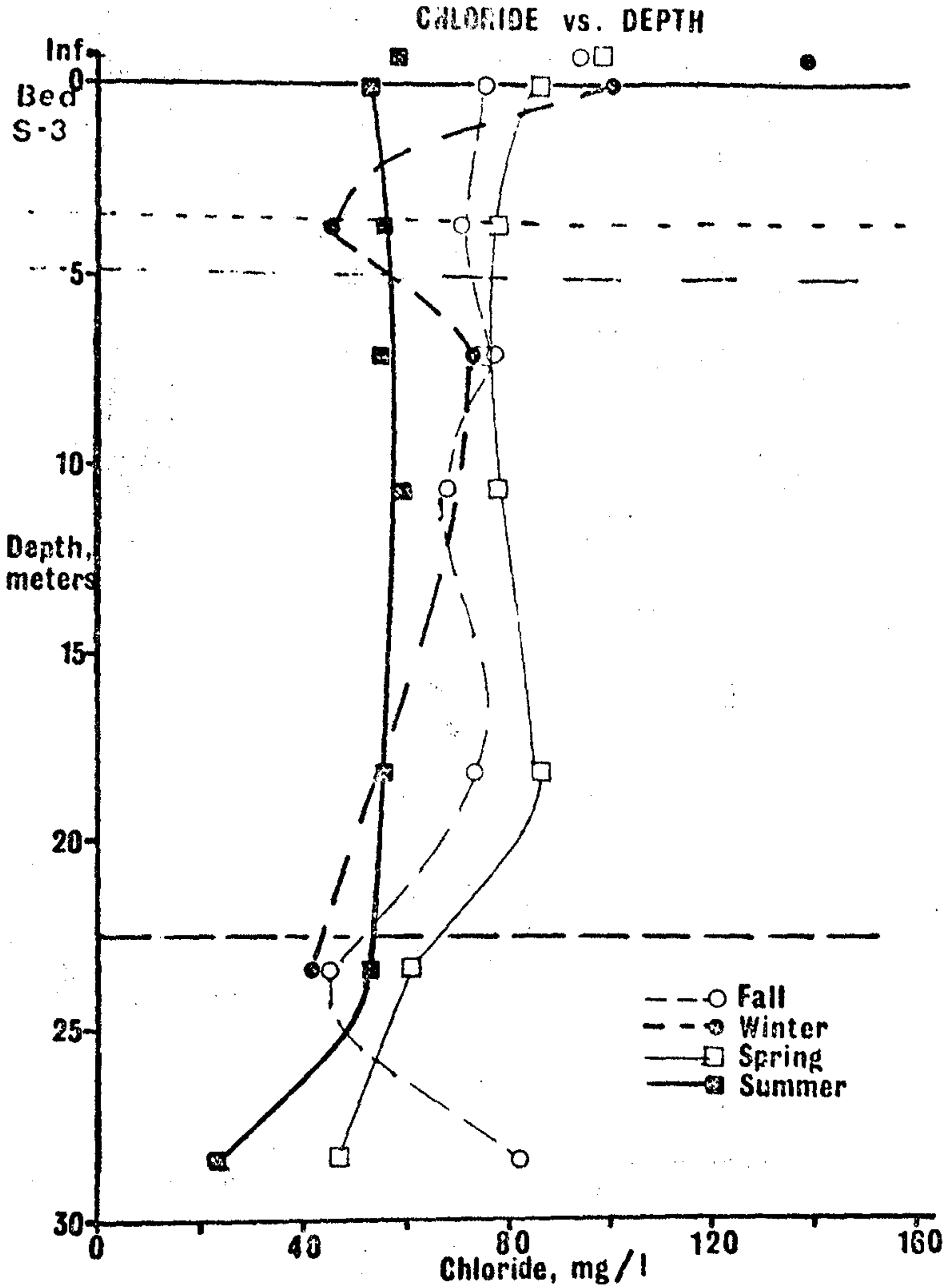
OXIDATION - REDUCTION POTENTIAL vs. DEPTH
Inf
Bed
S-3
0
5
10
15
20
25
30
Depth, meters
Spring
-100
-50
0
50
100
Oxidation - Reduction Potential, mv

bed, at least during spring. 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 wells.

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. 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 kjeldhal nitrogen as the liquid aproached 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 of the sand bed, with 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

FIGURE 13



CHLORIDE vs. DEPTH
Inf
0
Bed
S-3
5
10
Depth, meters
15
20
25
30
0
40
80
120
160
Chloride, mg/l
Fall
Winter
Spring
Summer

FIGURE 14

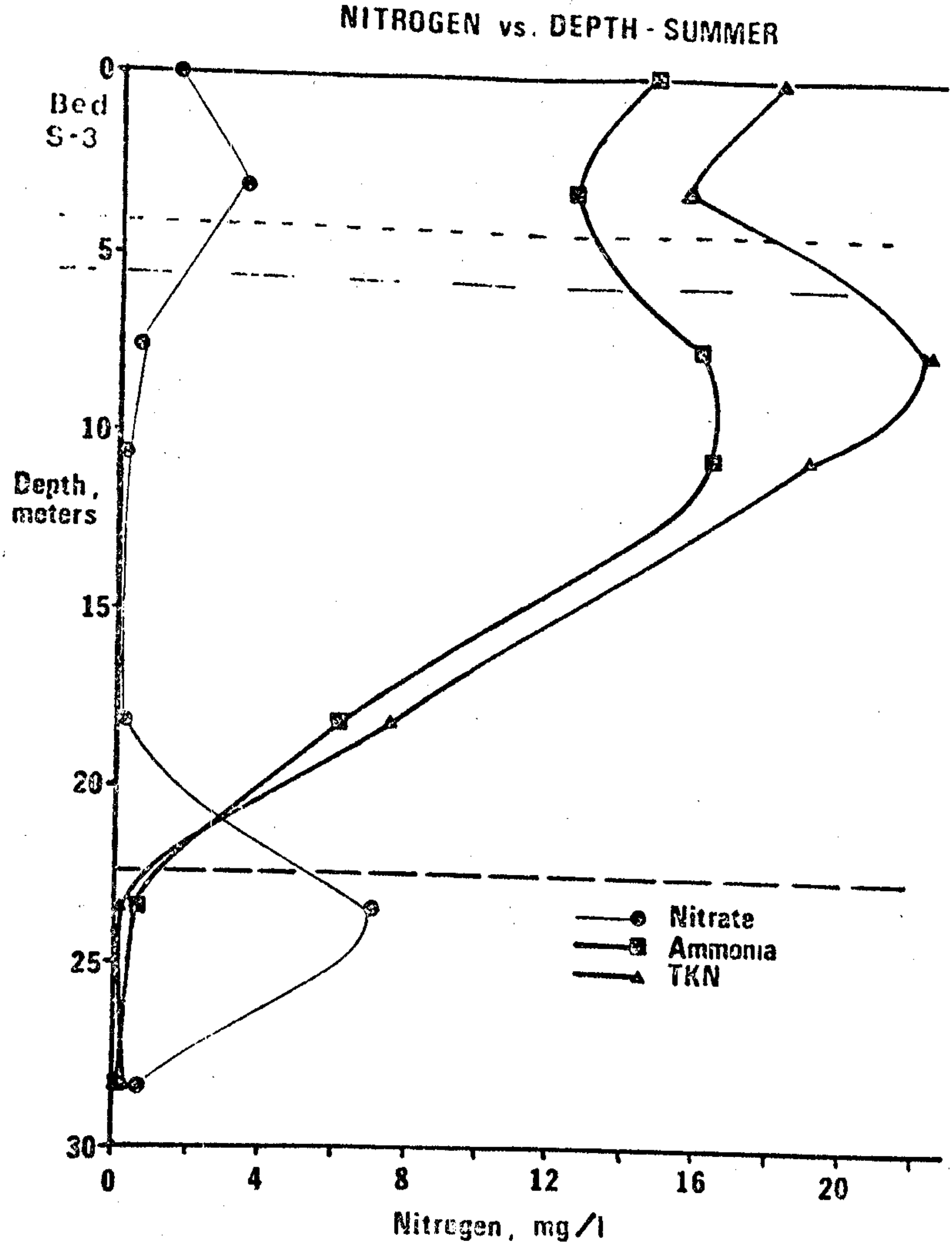

NITROGEN vs. DEPTH - SUMMER
Bed
S-3
Depth, meters
0
5
10
15
20
25
30
0
4
8
12
16
20
Nitrogen, mg/l
Nitrate
Ammonia
TKN

FIGURE 15

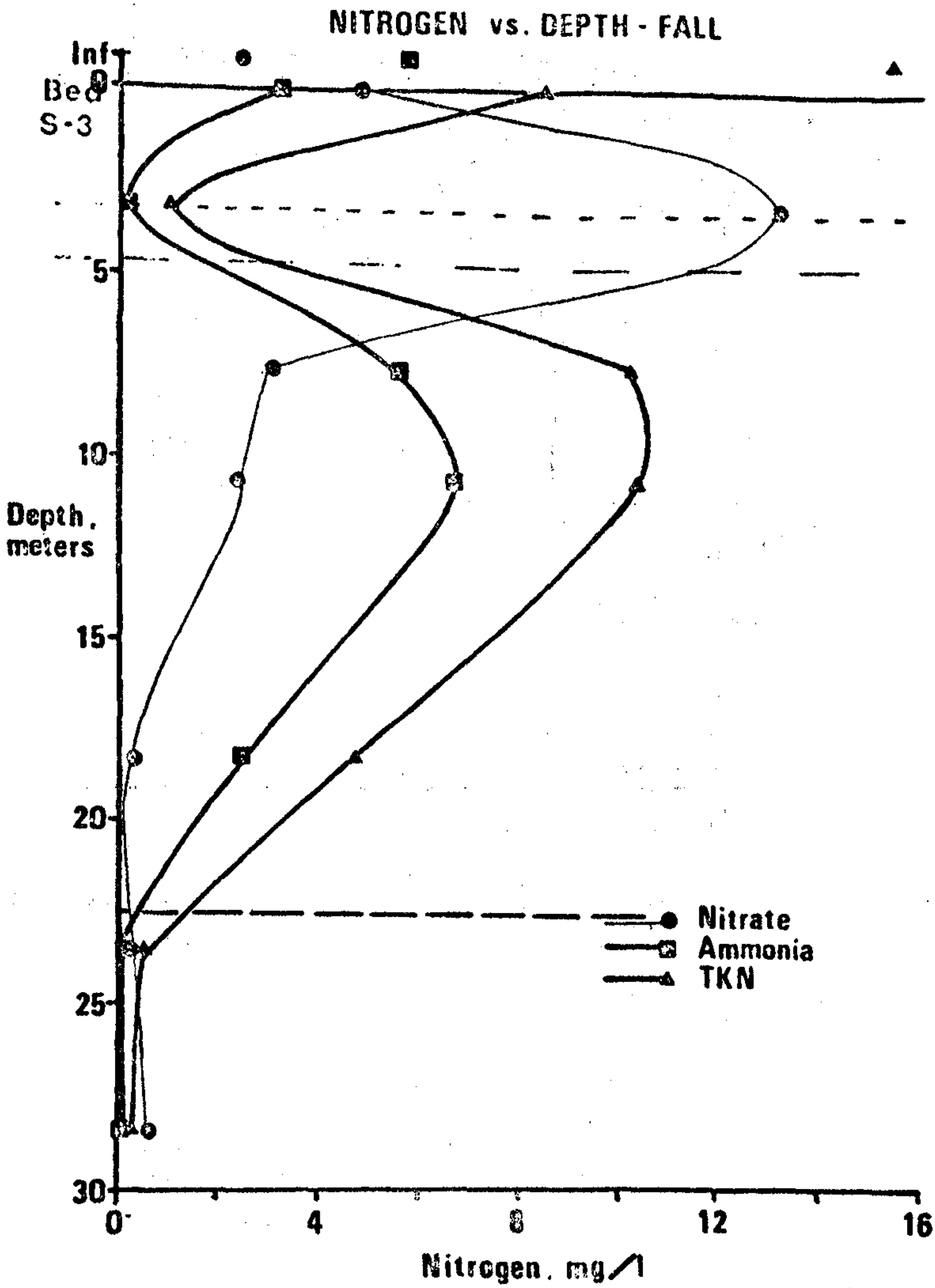
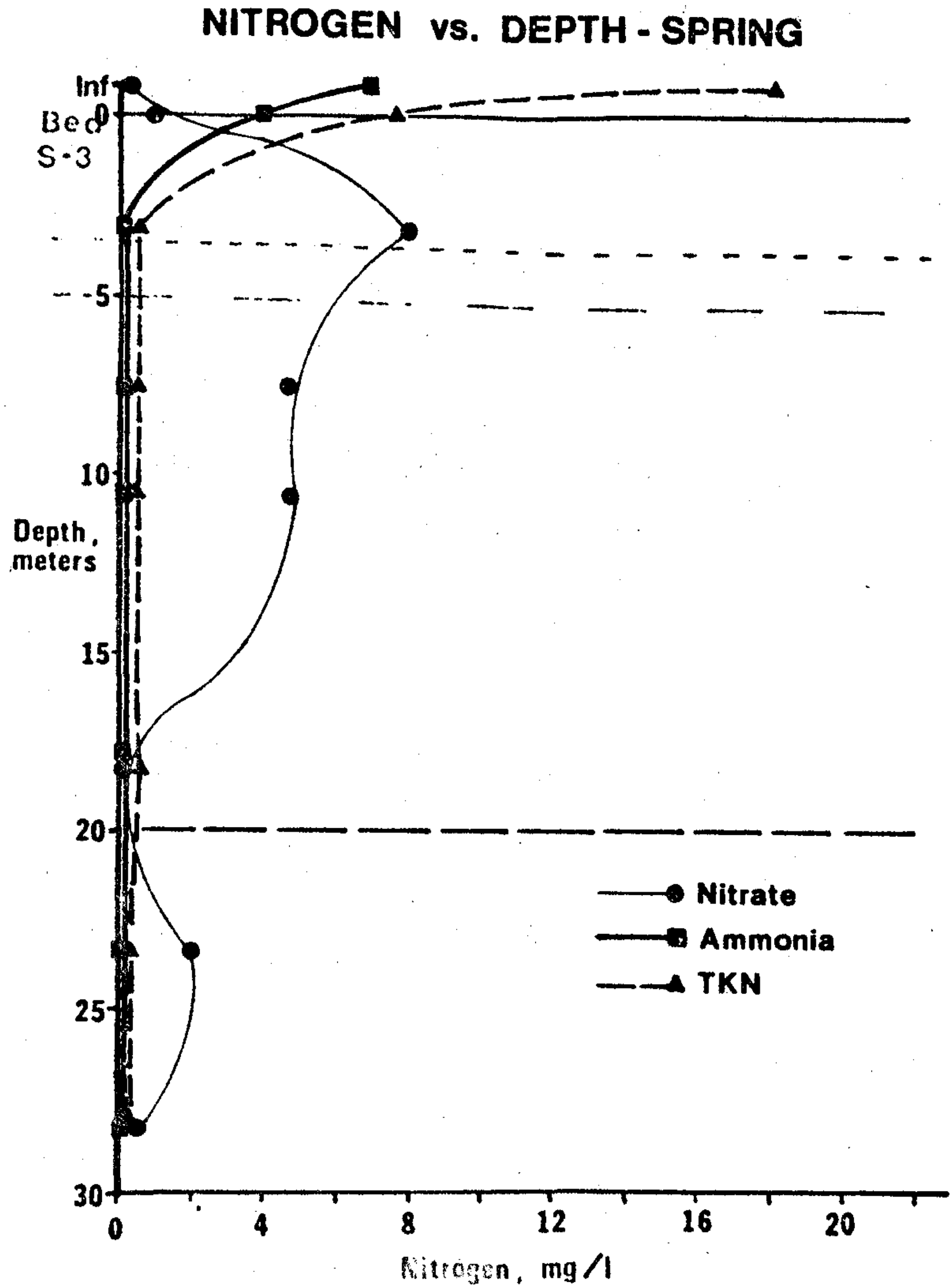

NITROGEN vs. DEPTH - FALL
Inf
Bed
S-3
0
5
10
15
20
25
30
Depth, meters
0
4
8
12
16
Nitrogen, mg/l
Nitrate
Ammonia
TKN

FIGURE 16

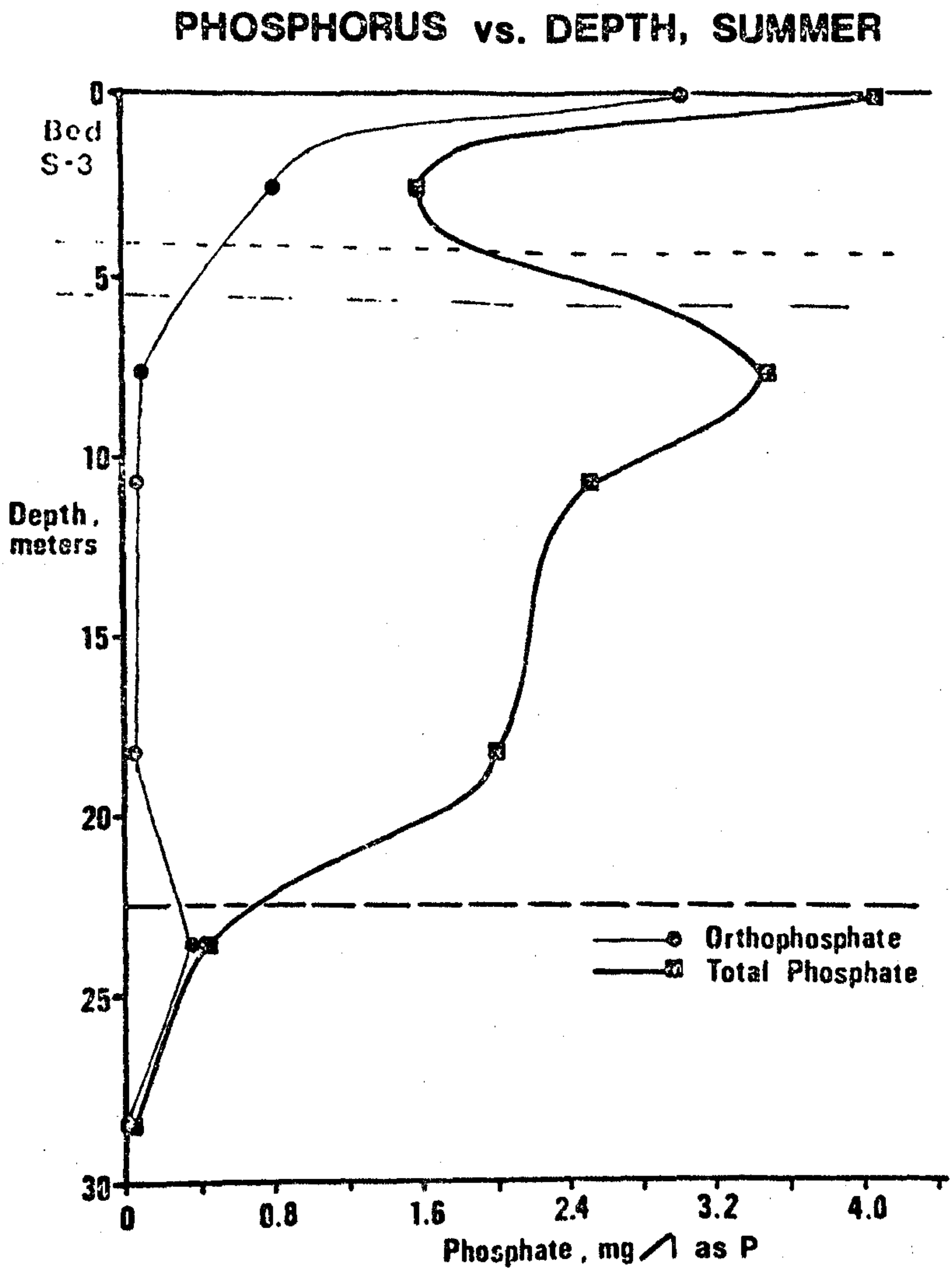


NITROGEN vs. DEPTH - SPRING
Inf
Bed
S-3
0
-5
10
15
20
25
30
Depth, meters
0
4
8
12
16
20
Nitrogen, mg/l
Nitrate
Ammonia
TKN

nitrate content in the upper 3 m of the sand bed with a subsequent gradual reduction to less than 1 mgN/1 at the 18 m depth. The nitrate and ammonia contents, however, dropped significantly to less than 1 mgN/1 at all depths of 3 m and greater. There was approximately 2 mgN/1 of nitrate in the shallow pumped well, but all other values in both the shallow and deep pumped wells were less than 1 mgN/1. 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.

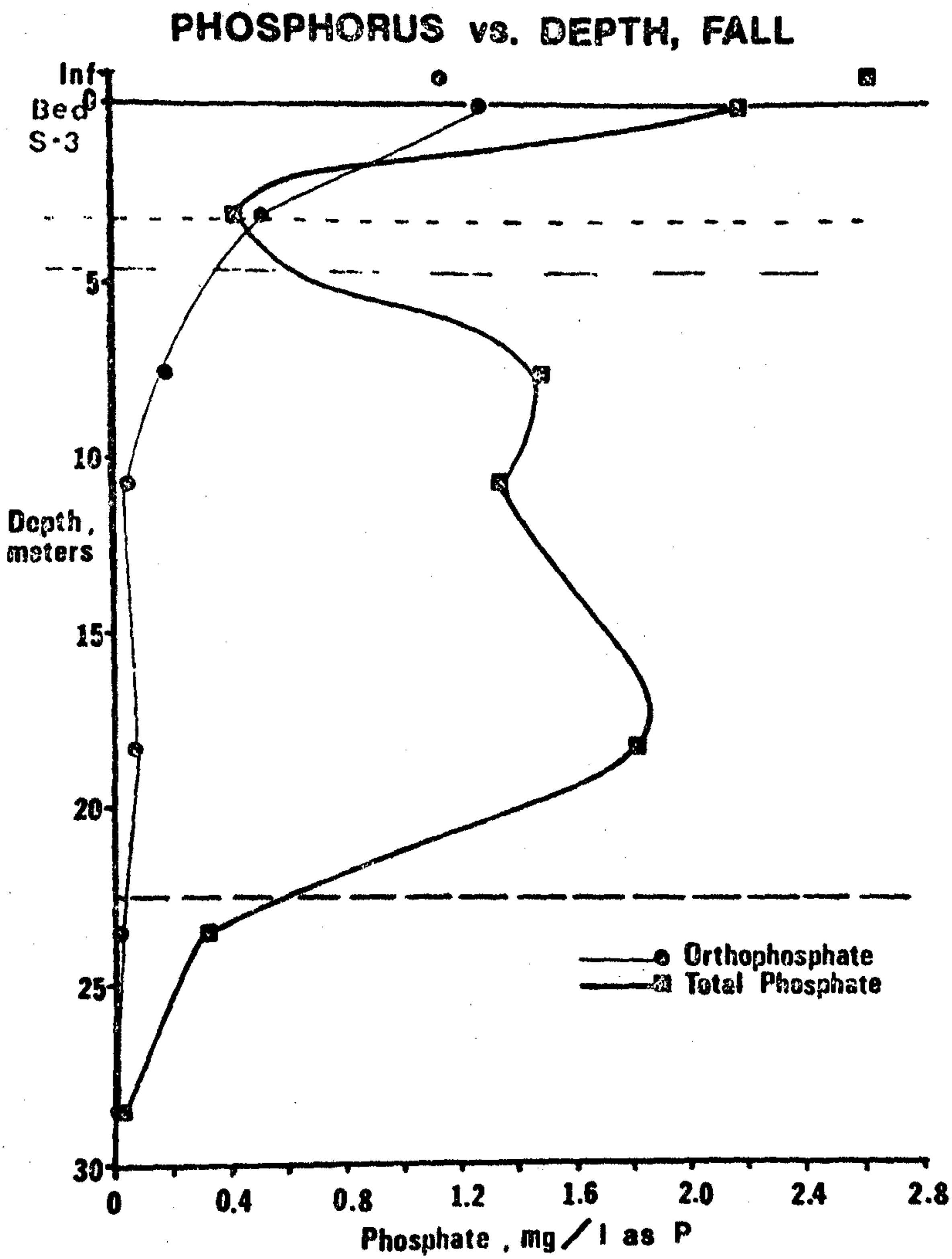
The ortho- and total phosphate phosphorus are compared for the summer, fall and spring, in Figures 17, 18 and 19, respectively. Again insufficient data were secured during the winter to justify presentation of these results. During both the fall and spring, the sewage treatment plant accomplished a significant 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 cases, the orthophosphate

FIGURE 17



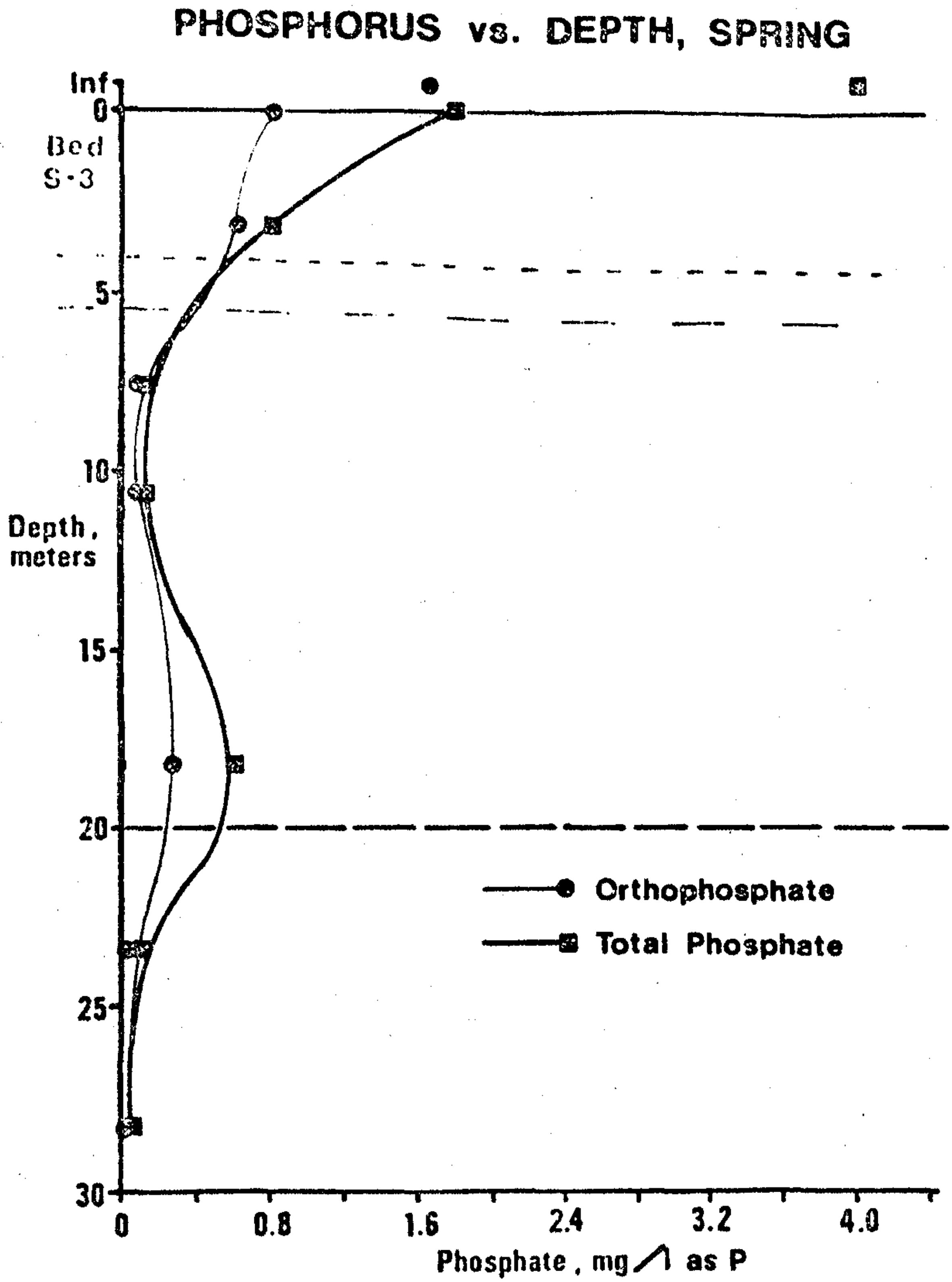
PHOSPHORUS vs. DEPTH, SUMMER
Bed
S-3
Depth,
meters
0
5
10
15
20
25
30
0
0.8
1.6
2.4
3.2
4.0
Phosphate, mg/l as P
Orthophosphate
Total Phosphate

FIGURE 18



PHOSPHORUS vs. DEPTH, FALL
Inf
Bed
S-3
0
5
10
15
20
25
30
Depth, meters
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
Phosphate, mg/l as P
Orthophosphate
Total Phosphate

FIGURE 19


PHOSPHORUS vs. DEPTH, SPRING
Inf
0
Bed
S-3
5
10
Depth,
meters
15
20
25
30
0
0.8
1.6
2.4
3.2
4.0
Phosphate, mg/l as P
Orthophosphate
Total Phosphate

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. The orthophosphate was reduced to levels lower than could be achieved by conventional 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.

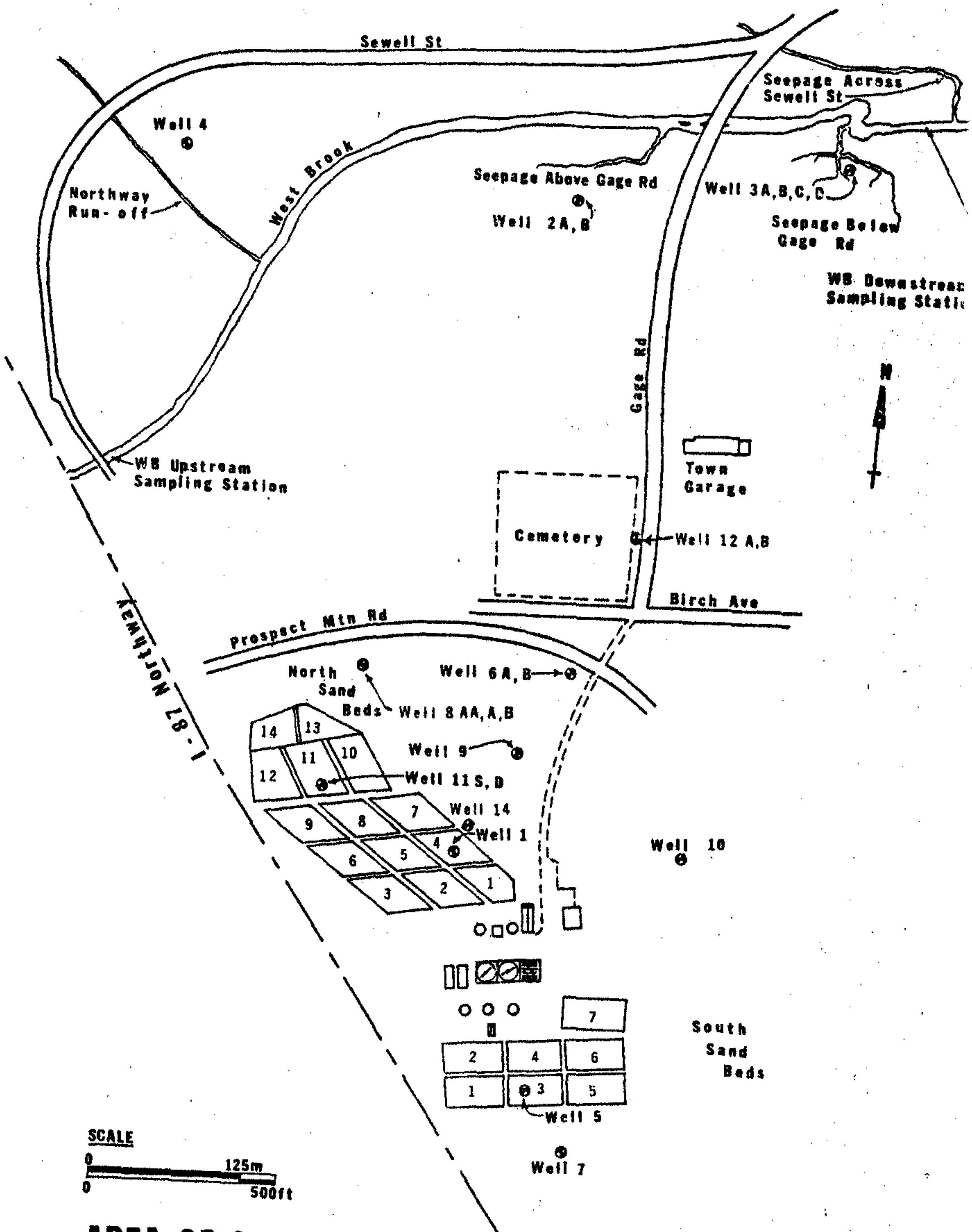
Additional determinations were made for calcium, magnesium, alkalinity, iron, sodium, potassium, potassium to sodium ratio and copper. A discussion of all of these results can not be included in this short paper. The concentrations of copper observed were always below the detectable limit of 0.05 mg/l by the atomic absorption technique. BOD, COD and coliforms were essentially completely removed in the top 3 m of the sand bed.

Change In Quality With Distance

After the applied sewage effluent travels vertically to the aquifer, the ground water including the sewage effluent travels in approximately a northerly direction toward West Brook. Tracer studies using tritium and rhodamine WT are presently being concluded confirming this direction of flow. The effluent reoccurs as seepage along the south banks of the flood plain of West Brook as shown in Figure 20.[5] This figure also shows the location of the sampling wells in the area between the infiltration beds and the seepage. Wells 4, 7, and 10 were intended to be controls not influenced by any of the applied sewage effluent. Also the sampling stations in West Brook upstream and downstream from the seepage indicate any influence upon West Brook of the seepages which enter West Brook between these two sampling locations. Wherever possible well points were driven to at least 2 different depths within the aquifer at the location of that well. The actual depth varied with the distance from the ground surface to the aquifer and the thickness of the aquifer. Consistently throughout the study, wells designated as A are the shallow wells, that is located near the top of the aquifer, and subsequent alphabetical letters indicate wells progressively deeper into the aquifer.

The figures representing changes in quality with distance (Figures 21-26) represent data secured from September 1975 to August 1976. The figures show data for the influent and effluent of the conventional portion of the sewage treatment plant to compare the changes in quality in the treatment plant with those in the soil. Where not specifically designated on the figures, the open symbols indicate the shallower wells, whereas the solid symbols represent the deeper wells. Where appropriate, separate lines were drawn to connect the shallower wells and the deeper wells. In all cases, Well 2 was connected to seepage above Gage Road (indicated as S, A on the figures). Similarly, the values from Well 3 were connected to seepage below Gage Road (indicated as S, B on the figures). This is due to the fact that the seepage above Gage Road is located adjacent to well site 2 and the seepage below Gage Road is located adjacent to well site 3 (see Figure 20). In addition, the values for the

FIGURE 20



AREA OF STUDY

West Brook upstream (WBUS) and West Brook downstream (WBDS) are indicated on the figures to show the effect of the seepage upon the quality of the water within West Brook.

There was little change in pH in the aquifer during the spring as shown in Figure 21A. However, during the summer there was a marked increase at Well 6 in both the shallow and the deeper sampling points. The highest seasonal value obtained was 8.8 in Well 6A during the summer. Thereafter, there was a gradual decrease in the pH in all the wells, but it remained higher than pH 7.0 which was the average value of the sewage treatment plant influent. In both the spring and the summer there was a slight decrease in the pH as West Brook passed the location of the inlet of the 2 seepages. During the fall (Figure 21B) there was a similar trend as during the summer but the values reached a maximum of only 7.67. There was little significant change in the pH with distance during the winter. During both fall and winter, there was a slight increase in the pH in West Brook in passing the area of the seepages.

The dissolved solids are shown in Figure 22A and B.[6] Quite consistently during all seasons the shallower wells indicated higher values of dissolved solids than the corresponding deeper samples. This indicates the potential for the sewage containing higher dissolved solids to remain nearer the surface of the aquifer, with the lower sampling points more representative of the normal ground water. The control for the dissolved solids analyses was Well 7 which showed values of 100 mg/1 during the fall and winter and 68 mg/1 during the spring. It must be pointed out here as with chloride analyses that above well site 3, which also represents seepage below Gage Road, there is a highway department garage which

FIGURE 21A

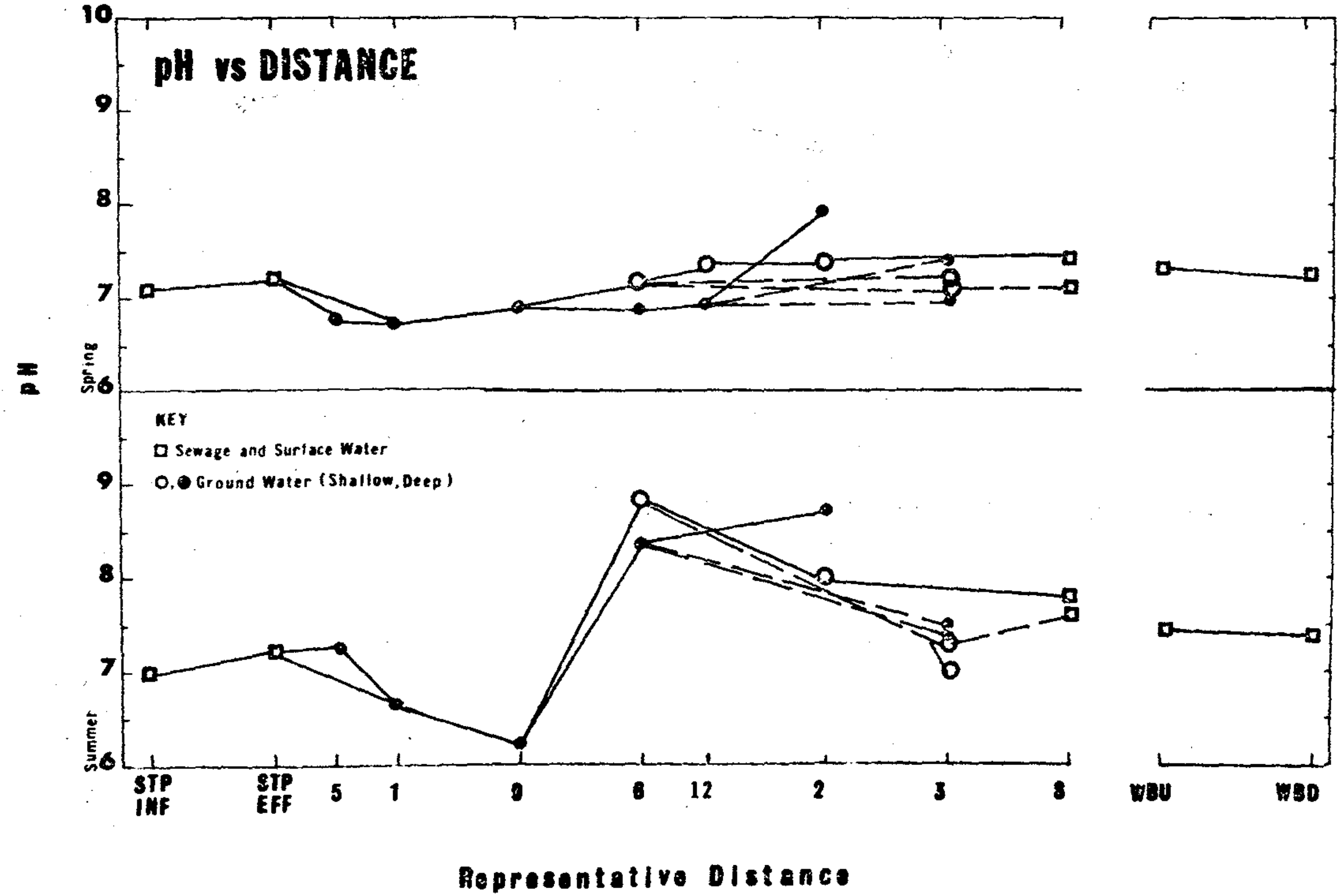
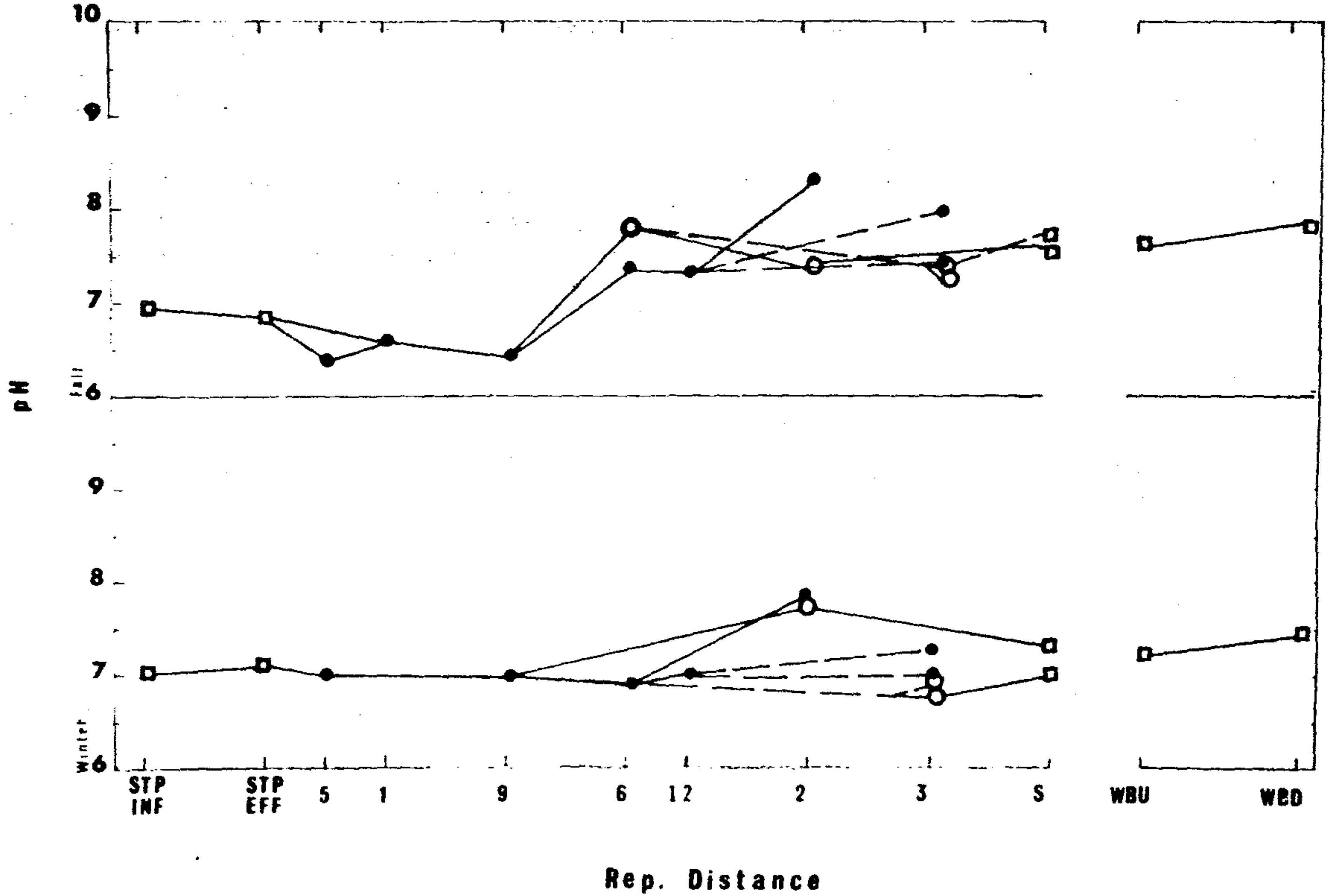

pH vs DISTANCE
10
9
8
7
6
pH
Spring
Summer
KEY
Sewage and Surface Water
Ground Water (Shallow, Deep)
STP INF
STP EFF
5
1
9
6
12
2
3
8
WBU
WBD
Representative Distance

FIGURE 21B



10
9
8
7
6
9
8
7
6
pH
Winter
STP INF
STP EFF
5
1
9
6
12
2
3
S
WBU
WBD
Rep. Distance

FIGURE 22A

VARIATIONS IN DISSOLVED SOLIDS WITH DISTANCE FROM THE LAKE GEORGE VILLAGE SEWAGE TREATMENT PLANT DURING FALL AND WINTER

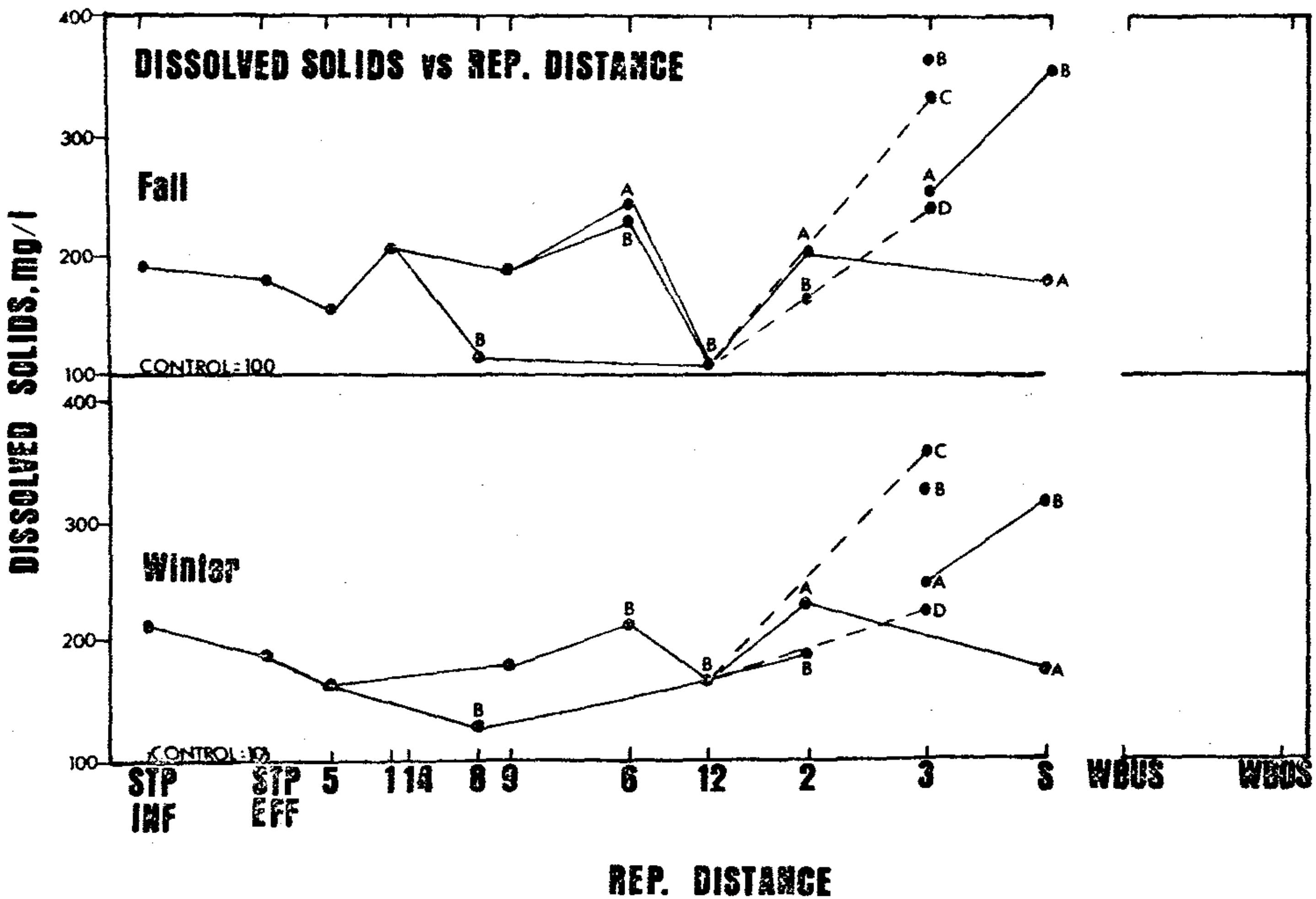
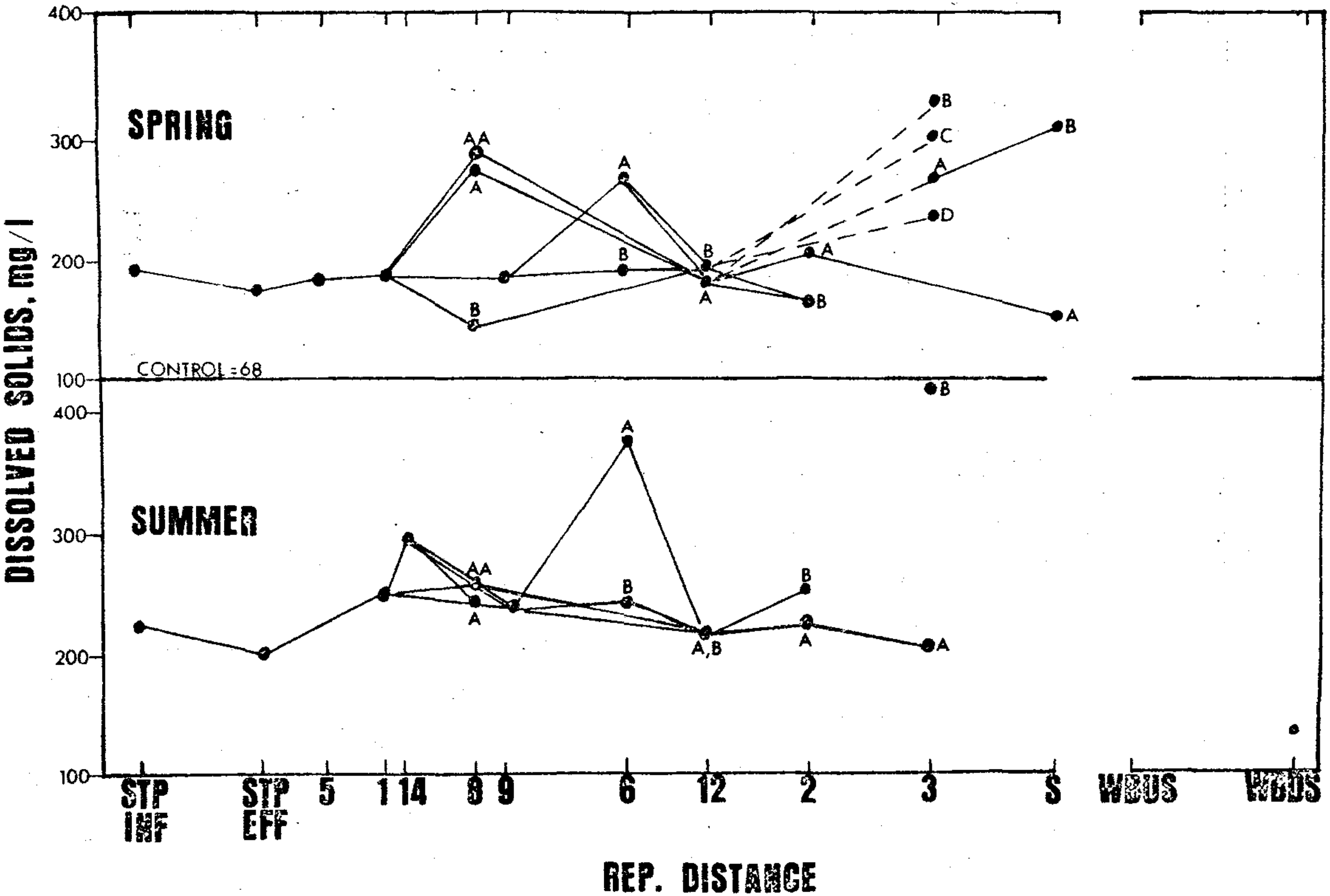


FIGURE 22B



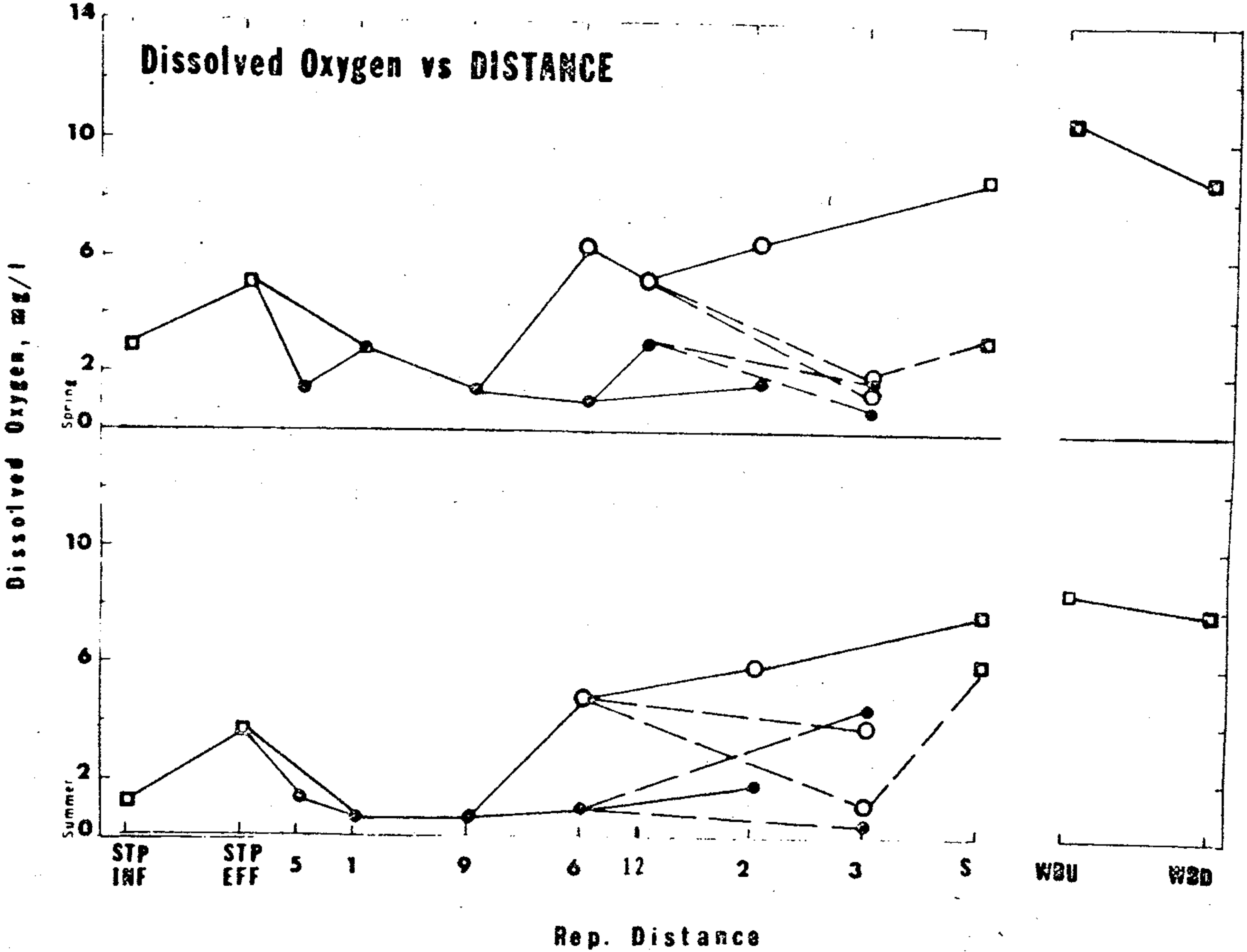
SPRING
SUMMER
CONTROL =68
DISSOLVED SOLIDS, mg/l
400
300
200
100
STP INF
STP EFF
5
1
14
8
9
6
12
2
3
S
WBUS
WBDS
REP. DISTANCE

formerly stored highway deicing salt in the open at this location. It becomes quite obvious that the salt has leached into the ground and affects the dissolved solids and chloride determinations at well site 3 and seepage below. Thus, these 2 locations are not representative of the effects of the sewage treatment plant effluent upon the ground water. Of particular note are the increases in dissolved solids during the spring and summer in both wells 8 and 6 at the shallower depths. Well 6 also indicated somewhat higher values during the fall and winter. A possible explanation could be runoff from highways containing salt used for deicing during the winter.

The shallower wells consistently maintained a higher dissolved oxygen (DO) content than the deeper wells as shown in Figures 23A and B. DO was measured at all times; the lowest values occurred during the summer with 0.5 mg/l being measured in wells 9 and 3D. There was a slight trend toward increasing DO levels with increasing distance from the sand infiltration beds. During all seasons there was a decrease in the DO content in West Brook as it picked up the discharges of the 2 seepages. This could in part be due to increase in the temperature resulting in a lower DO saturation value. The average seasonal increases in temperature in this stretch of West Brook were a minimum of 0.4^{o}C in spring and fall and a maximum of 1.4^{o}C in winter.

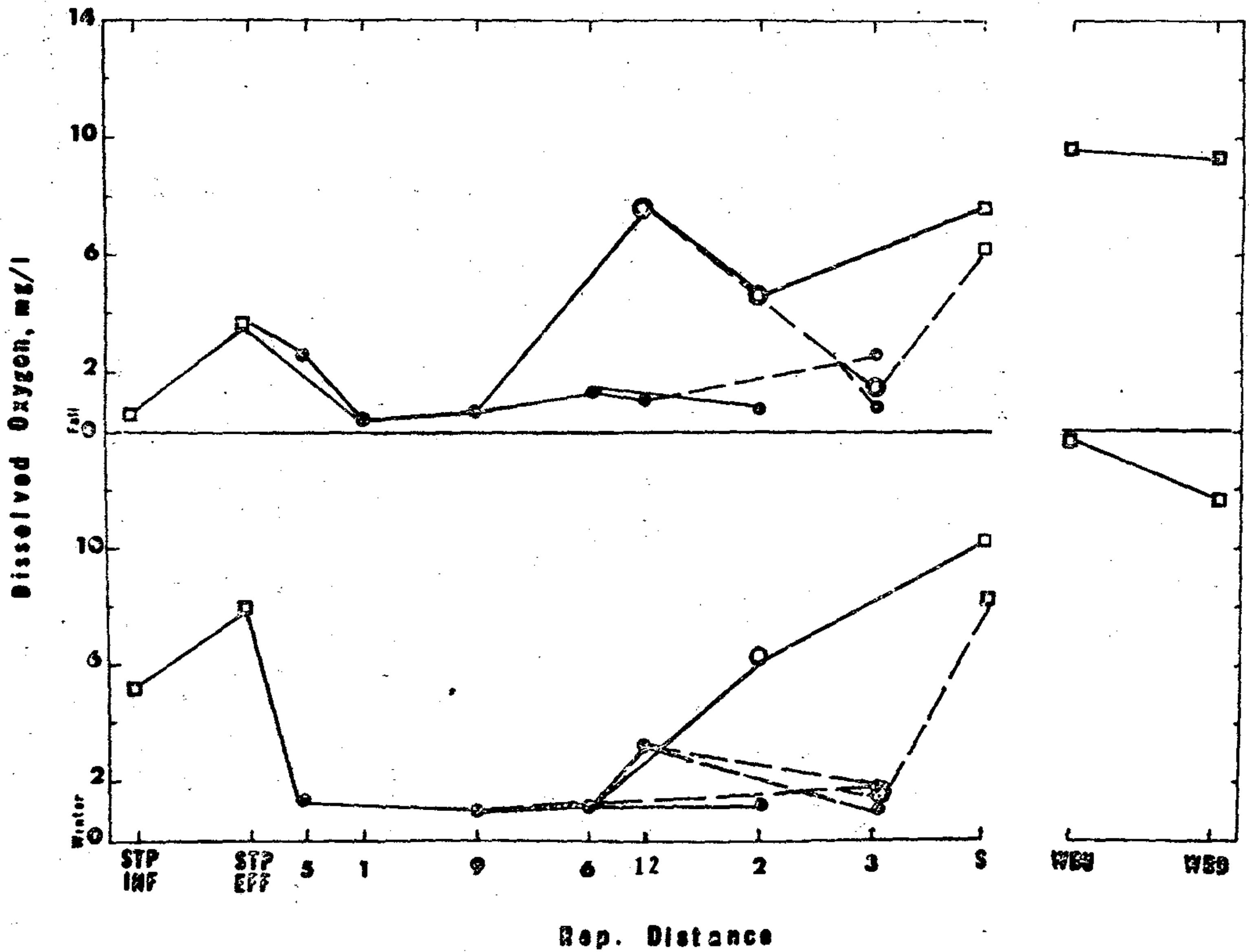
Redox potential data are available for only the spring of 1976 due to the late arrival of the appropriate electrodes. In general, the values varied between +100 and +150 mV with the highest value being +170 mV in Well 12B. Surprisingly the lowest values were observed in the test wells with a value of +55 mV at Well 10 and +65 mV in Well 4. The other control, Well 7, had a redox potential of +105 mV. There was an increase in West

FIGURE 23A



40

FIGURE 23B

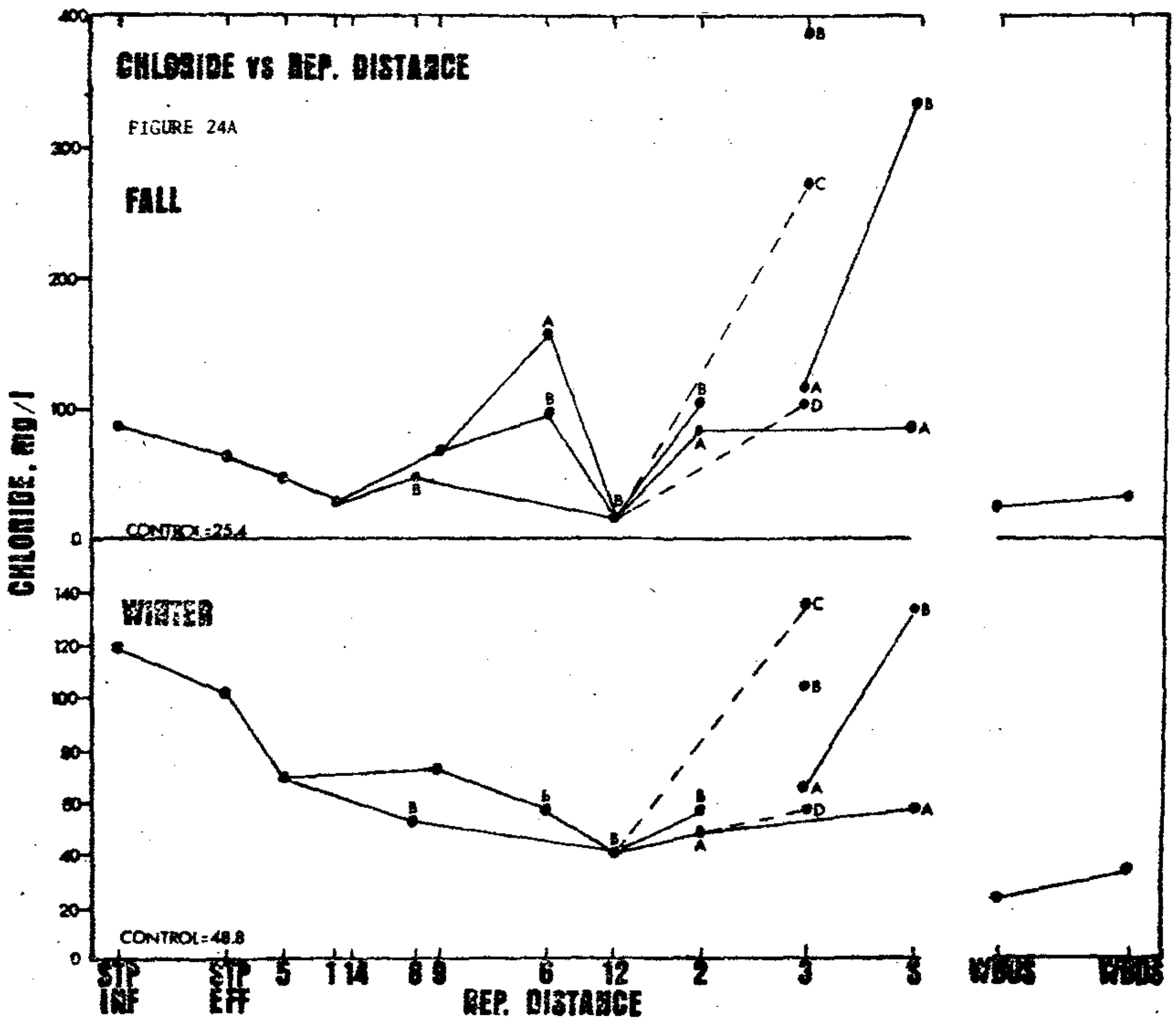


41

Brook from +90 mV at the upstream sampling to +107 at the downstream station.

Figures 24A and B show the results of the chloride concentration in the sampling wells.[6] With the exception of the samples from Well 6A during the summer and fall, there was a general trend of decreasing chloride versus distance from the treatment plant. Wells 3 and seepage below are high in chloride content reflecting the highway deicing salt which was stored at the local highway garage immediately above this location, as mentioned previously. In all cases, there was a slight increase in the chloride content of West Brook due to the seepage flows.

In order to show the inter-relationship between the various oxidized and reduced forms of nitrogen, these are plotted together for each season in Figures 25A through D. In general, there was a gradual reduction in the total Kjeldahl nitrogen (TKN) from about 6 mg/l in the applied sewage effluent to approximately 2 mg/l at Well 2. There was a much more significant reduction in the ammonium nitrogen from an average value of about 4 mg/l in the applied sewage effluent to values less than 0.1 mg/l at Well 2A. During the fall and spring there were higher values of ammonia nitrogen in Well 2B than in Well 12B, with values ranging between 0.3 and 0.5 mg/l. The nitrate values were approximately the inverse of the TKN and ammonia values. During the summer there was a marked reduction in the nitrate between Well 6 and Well 2, with values in Well 2B of approximately 0.6 mg/l. During the fall, winter and spring, the nitrate values at Well 2A ranged between 5 and 7 mg/l. This represents nearly a quantitative conversion of ammonia and TKN to nitrate within the system. During the summer, however, there appears to have been some loss of total nitrogen through the system. This is possibly due to the higher temperatures which enhance the denitrification reaction in which nitrate


CHLORIDE vs REP. DISTANCE
FIGURE 24A
FALL
WINTER
CONTROL=25.4
CONTROL=48.8
CHLORIDE, mg/l
REP. DISTANCE
STP INF
STP EFF
5
1 14
8 9
6
12
2
3
5
0
100
200
300
400
20
40
60
80
100
120
140
A
B
C
D

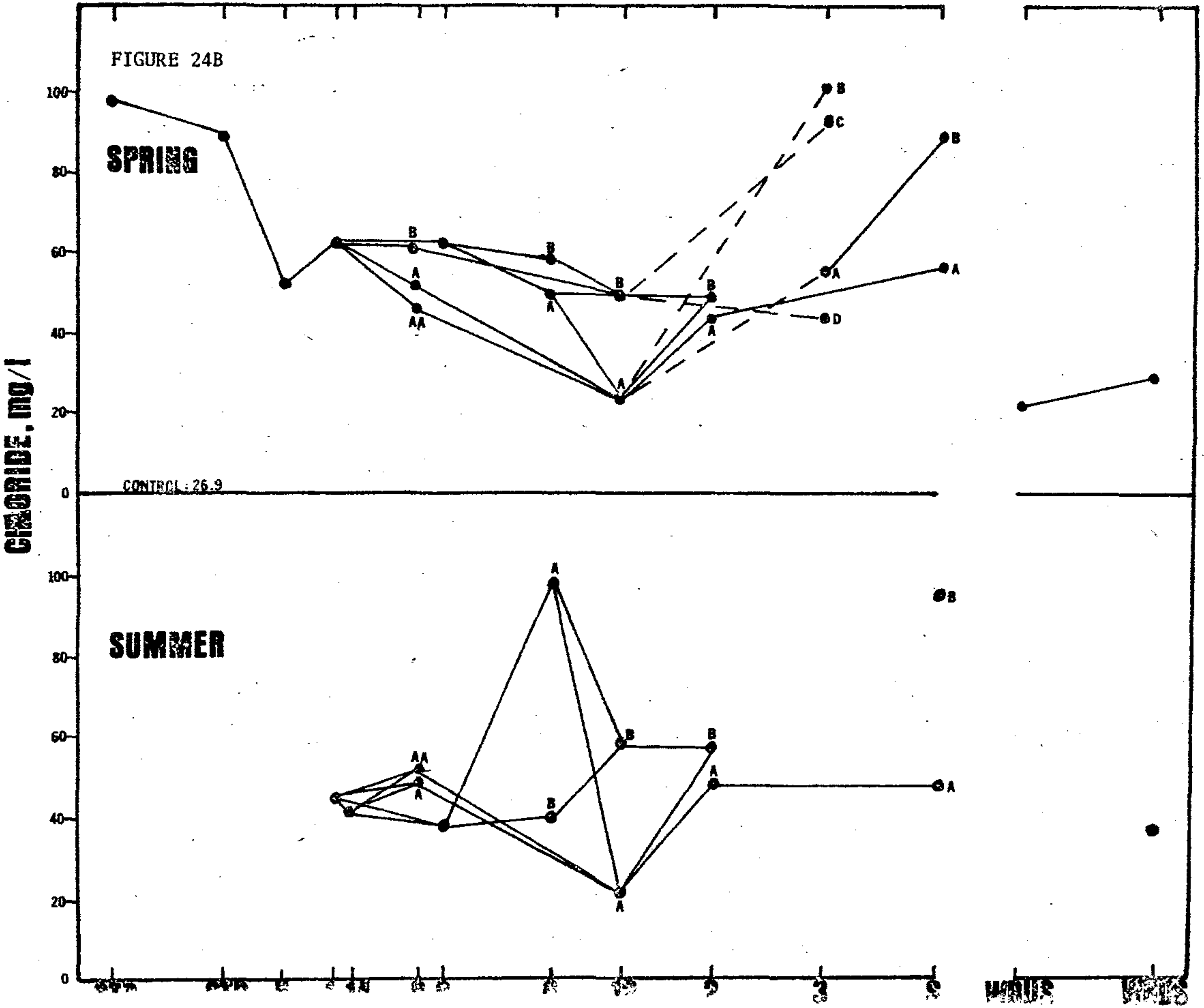
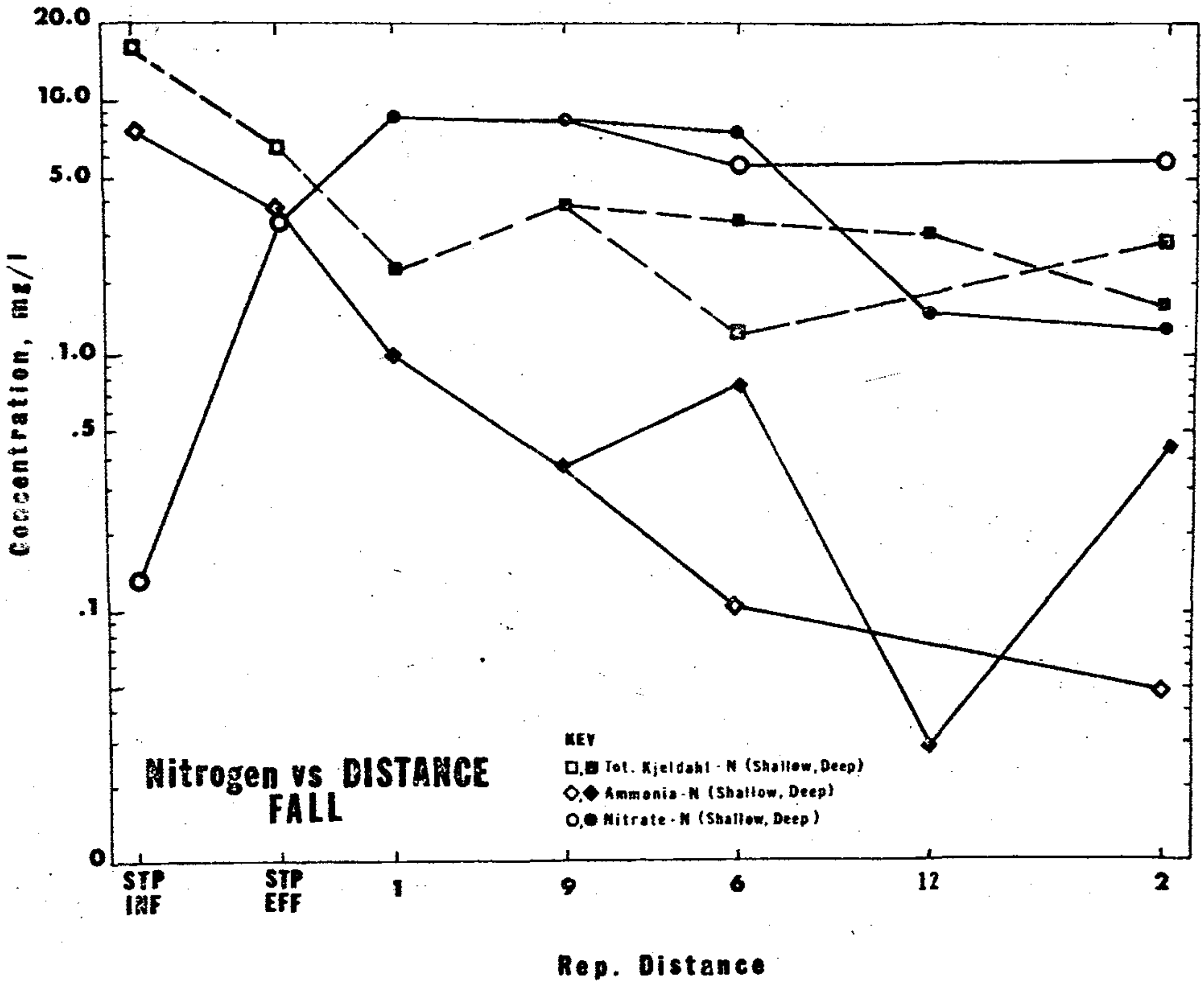


FIGURE 24B
SPRING
SUMMER
CHLORIDE, mg/l
CONTROL: 26.9
100
80
60
40
20
0
A
B
C
D

FIGURE 25A



20.0
10.0
5.0
1.0
.5
.1
0
Concentration, mg/l
STP INF
STP EFF
1
9
6
12
2
Rep. Distance
Nitrogen vs DISTANCE FALL
KEY
Tot. Kjeldahl - N (Shallow, Deep)
Ammonia - N (Shallow, Deep)
Nitrate - N (Shallow, Deep)

FIGURE 25B

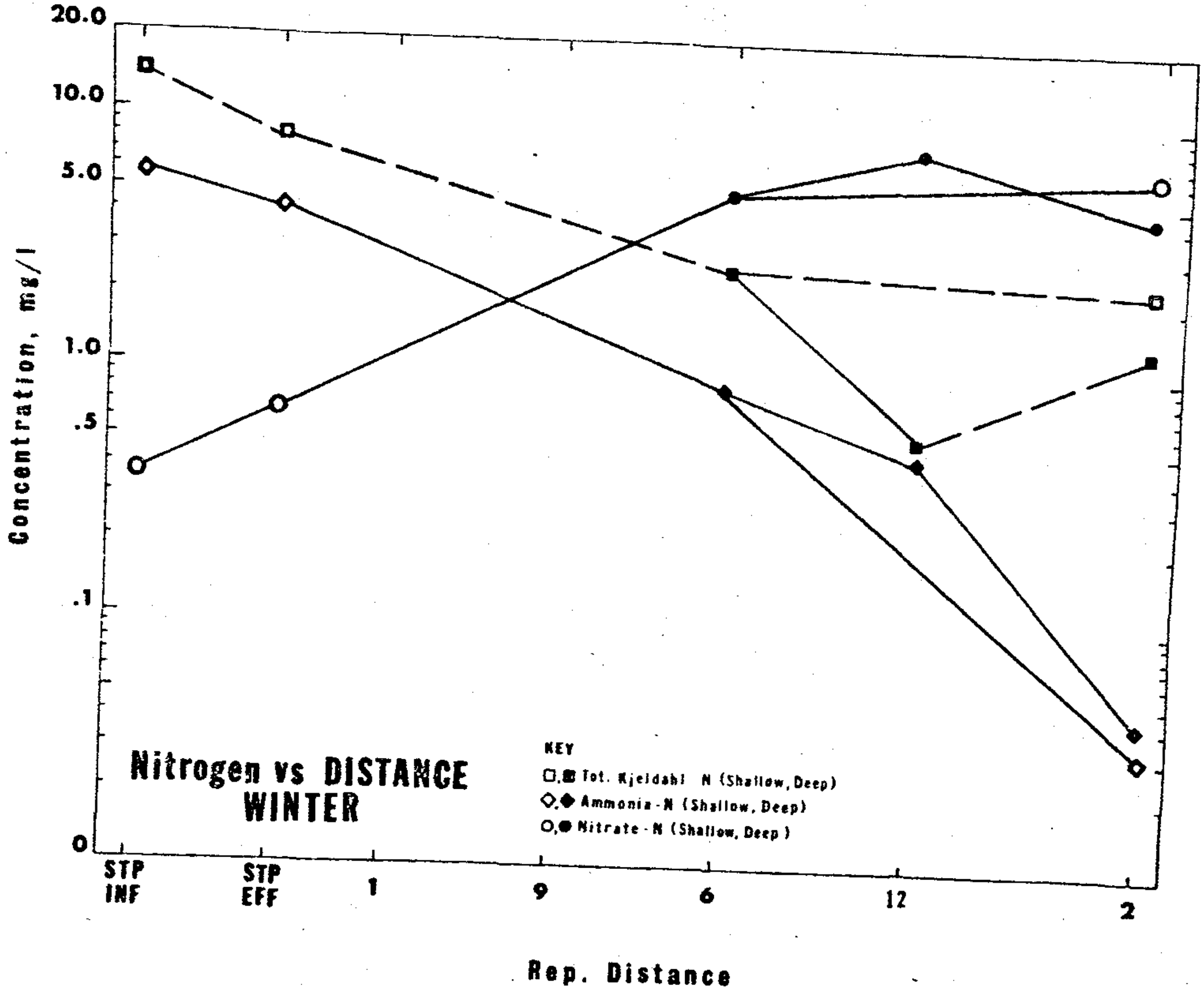

20.0
10.0
5.0
1.0
.5
.1
0
Concentration, mg/l
Nitrogen vs DISTANCE
WINTER
KEY
Tot. Kjeldahl N (Shallow, Deep)
Ammonia-N (Shallow, Deep)
Nitrate-N (Shallow, Deep)
STP INF
STP EFF
1
9
6
12
2
Rep. Distance

FIGURE 25C

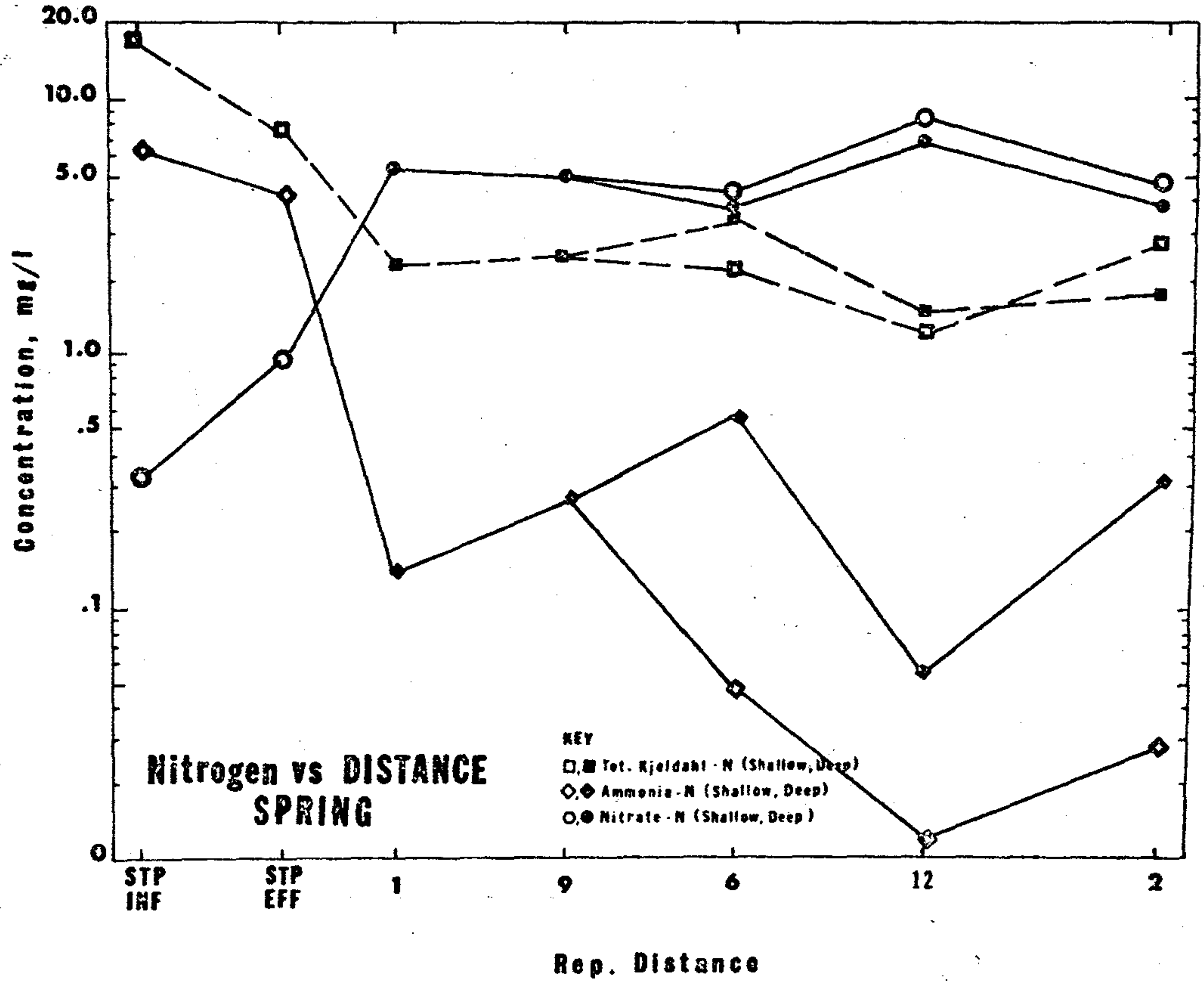
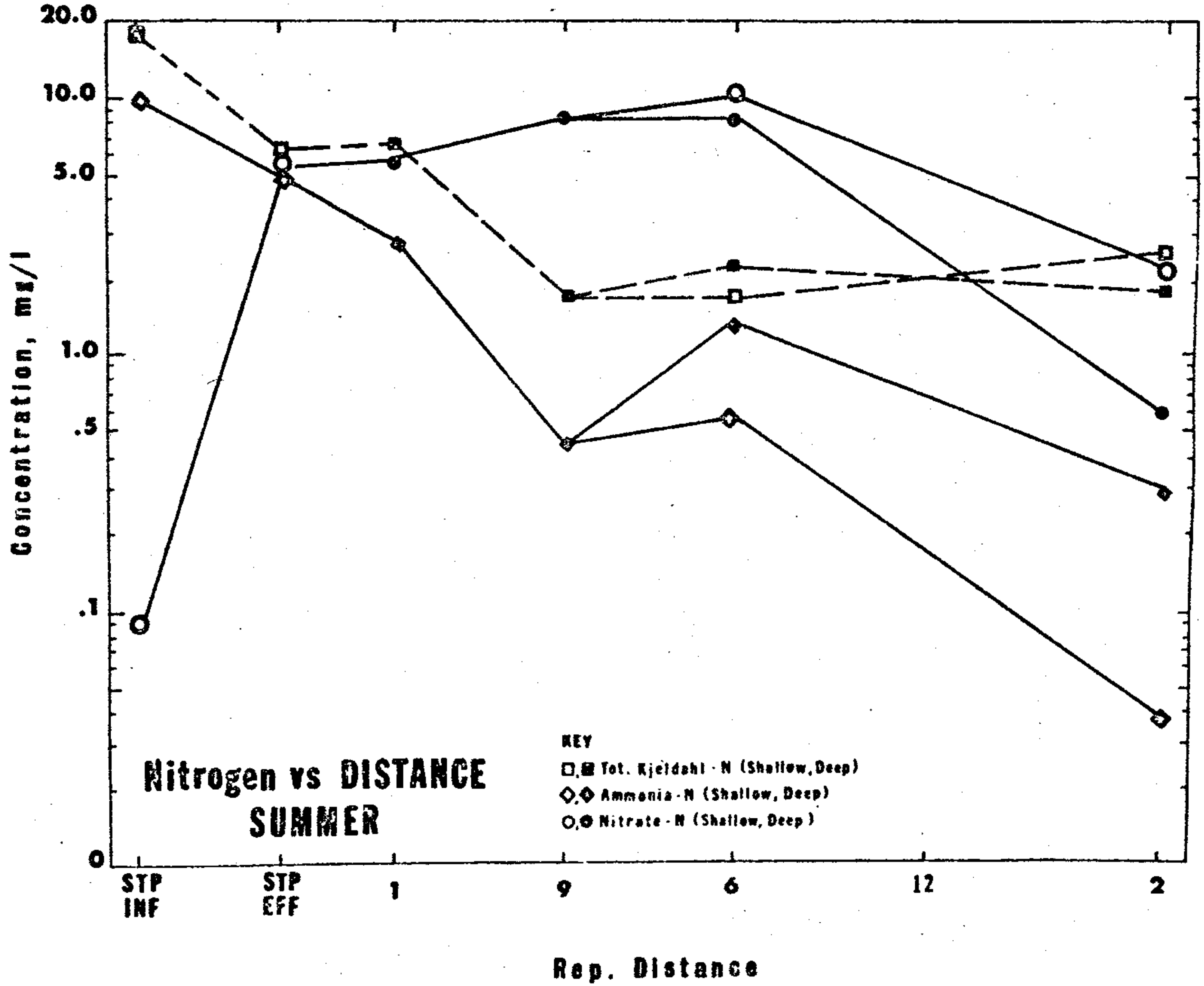

20.0
10.0
5.0
1.0
.5
.1
0
Concentration, mg/l
STP INF
STP EFF
1
9
6
12
2
Rep. Distance
Nitrogen vs DISTANCE
SPRING
KEY
Tot. Kjeldahl - N (Shallow, Deep)
Ammonia - N (Shallow, Deep)
Nitrate - N (Shallow, Deep)

FIGURE 25D


20.0
10.0
5.0
1.0
.5
.1
0
Concentration, mg/l
STP INF
STP EFF
1
9
6
12
2
Rep. Distance
Nitrogen vs DISTANCE
SUMMER
KEY
Tot. Kjeldahl - N (Shallow, Deep)
Ammonia - N (Shallow, Deep)
Nitrate - N (Shallow, Deep)

is reduced to nitrogen gas which then escapes from the aqueous system. During all seasons, the nitrate content was lower in Well 2B than in Well 2A. There is a slight correlation with the redox potential at these two locations since Well 2A had a redox potential of +108 mV whereas 2B had +102 mV. The other correlation is the quite high values of nitrate in Well 12. Well 12 has the highest redox potential of any of the observation wells.

The changes in total and soluble reactive phosphate as P with distance are shown in Figures 26A, B, C and D for the fall, winter, spring and summer seasons, respectively. In general the sand system lowered the total phosphorus concentration in the applied sewage effluent from an average of 3,000 ug/l (3 mg/l) to values generally less than 200 ug/l (0.2 mg/l). The only significant exception was in Well 3B during the spring at which time the average concentration was 450 ug/l (0.5 mg/l). The total phosphate at Well 2A was consistently nearly the same as in the applied sewage effluent; however, at Well 2B the values were reduced to 100 ug/l (0.1 mg/l) or slightly above. The soluble reactive phosphate (SRP) showed even more dramatic reductions. The poorest reductions were observed in Wells 5 and 1 both of which are located directly within the sand infiltration beds. The highest value in Well 5 was 3,800 ug/l (3.8 mg/l) occurring during the summer. In Well 1 the highest value was 2,000 ug/l (2.0 mg/l) occurring in the fall. All of the other observation wells with the exception of Well 3C showed SRP values on a seasonal basis of 10 ug/l or less. The lowest values of less than 0.2 ug/l (the minimal detectable limit of the method utilized) were found in Well 2B. In general it may be seen that the soil application system is doing an excellent job of removing the soluble reactive phosphate.

FIGURE 26A

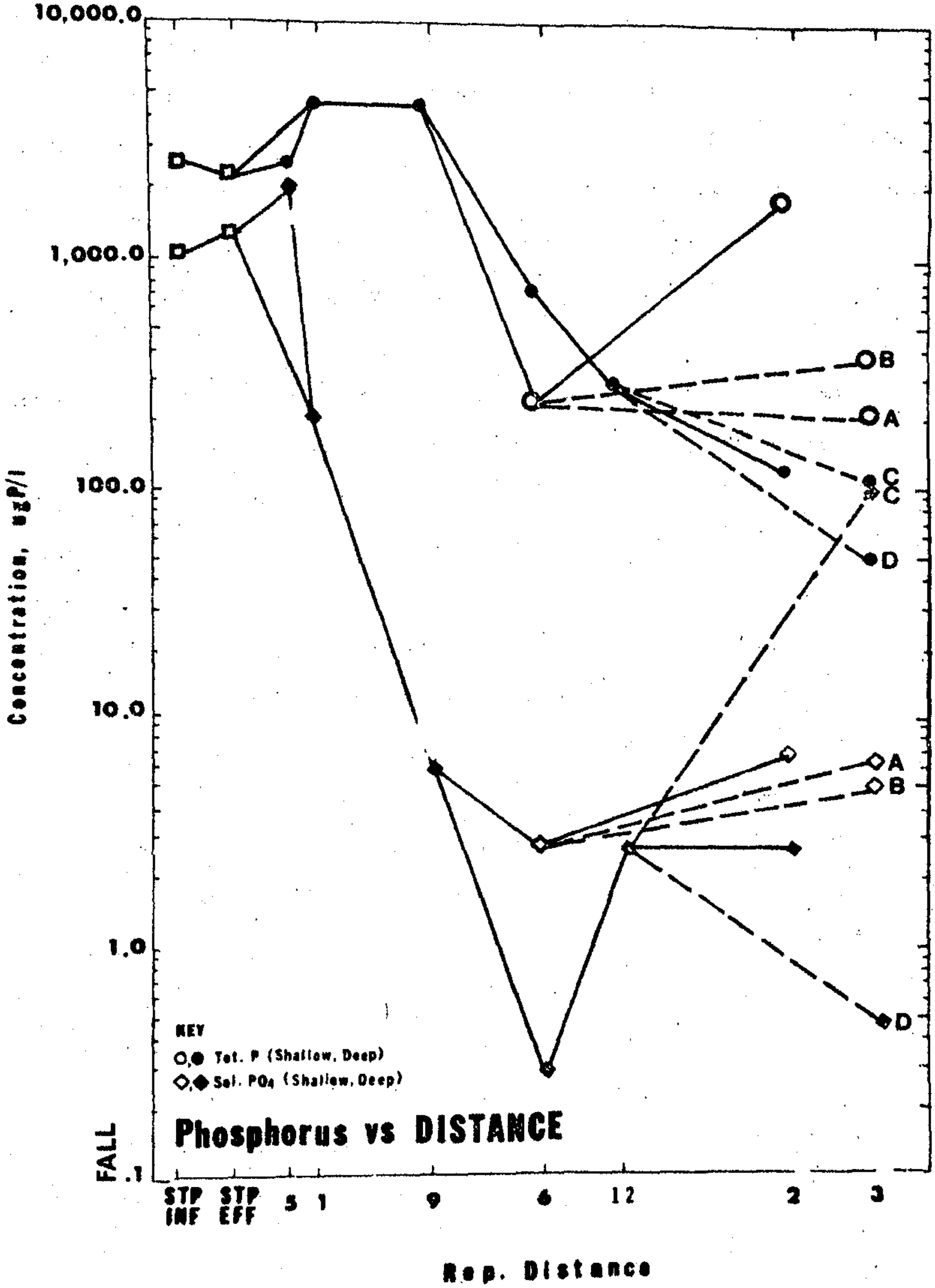

10,000.0
1,000.0
100.0
10.0
1.0
.1
Concentration, ugP/l
B
A
C
C
D
A
B
D
KEY
○,● Tot. P (Shallow, Deep)
◇,◆ Sol. PO4 (Shallow, Deep)
Phosphorus vs DISTANCE
FALL
STP INF
STP EFF
5
1
9
6
12
2
3
Rep. Distance

FIGURE 26B

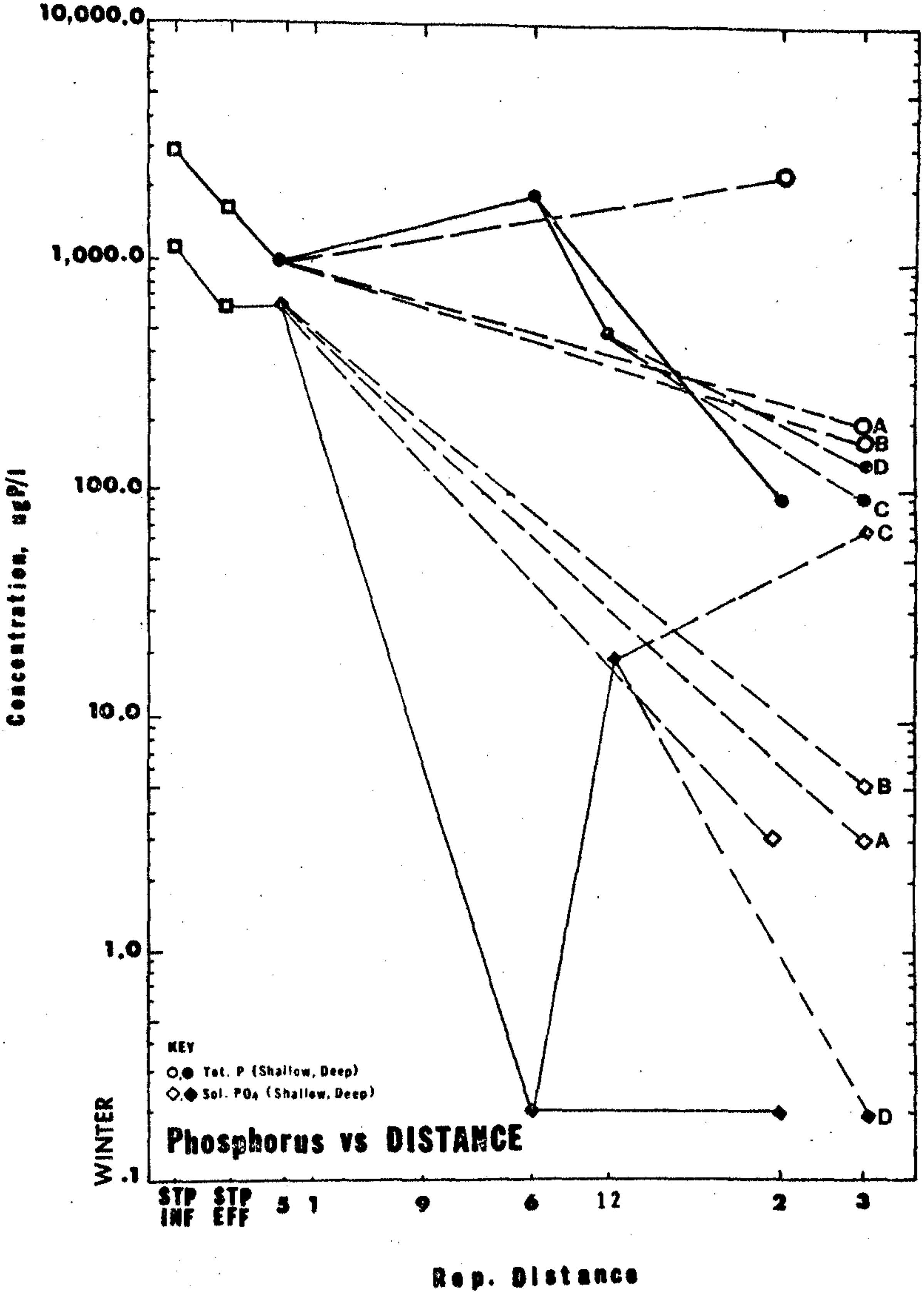

10,000.0
1,000.0
100.0
10.0
1.0
.1
Concentration, ugP/l
A
B
D
C
C
B
A
D
KEY
Tot. P (Shallow, Deep)
Sol. PO4 (Shallow, Deep)
WINTER
Phosphorus vs DISTANCE
STP INF
STP EFF
5
1
9
6
12
2
3
Rep. Distance

FIGURE 26C

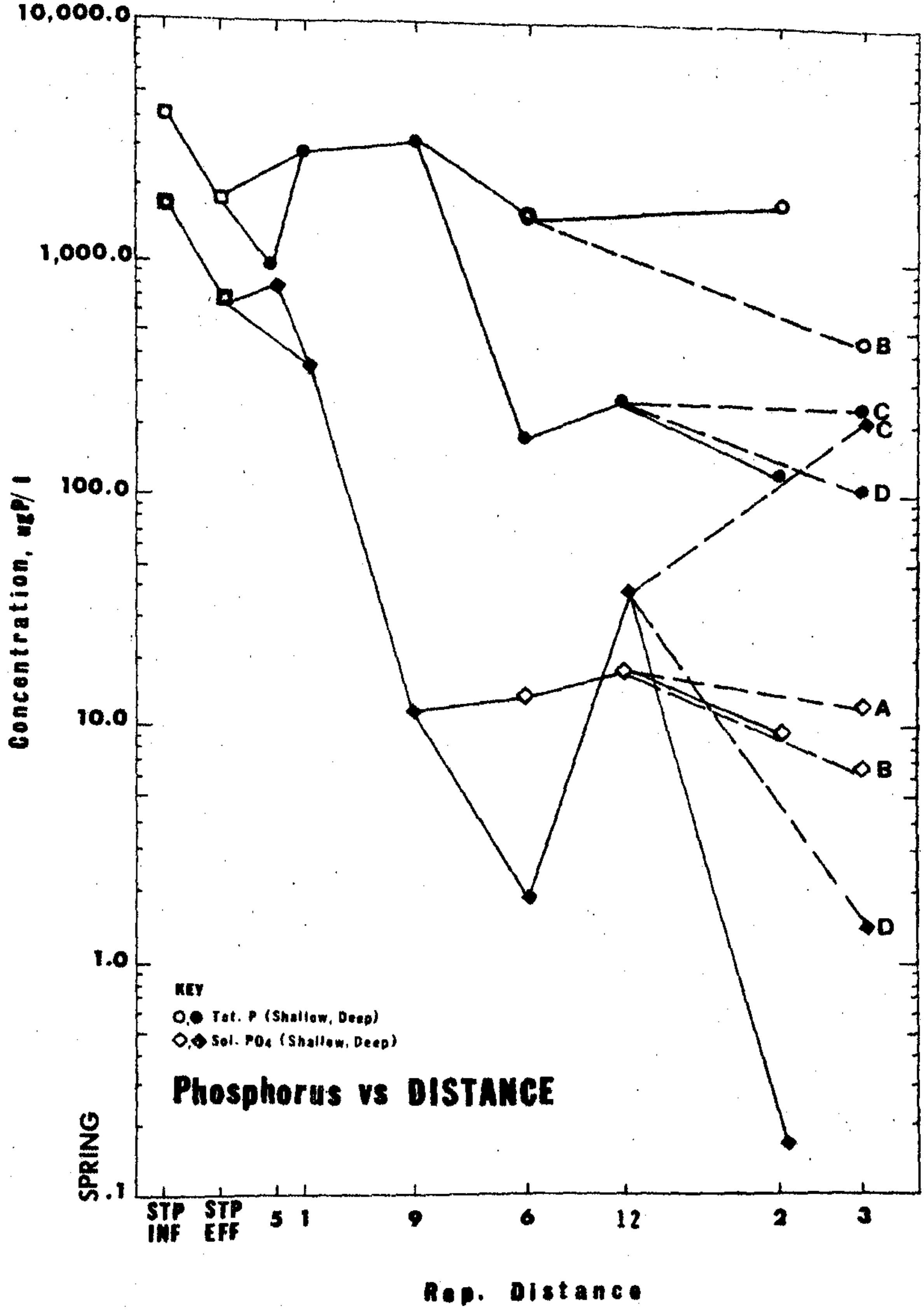
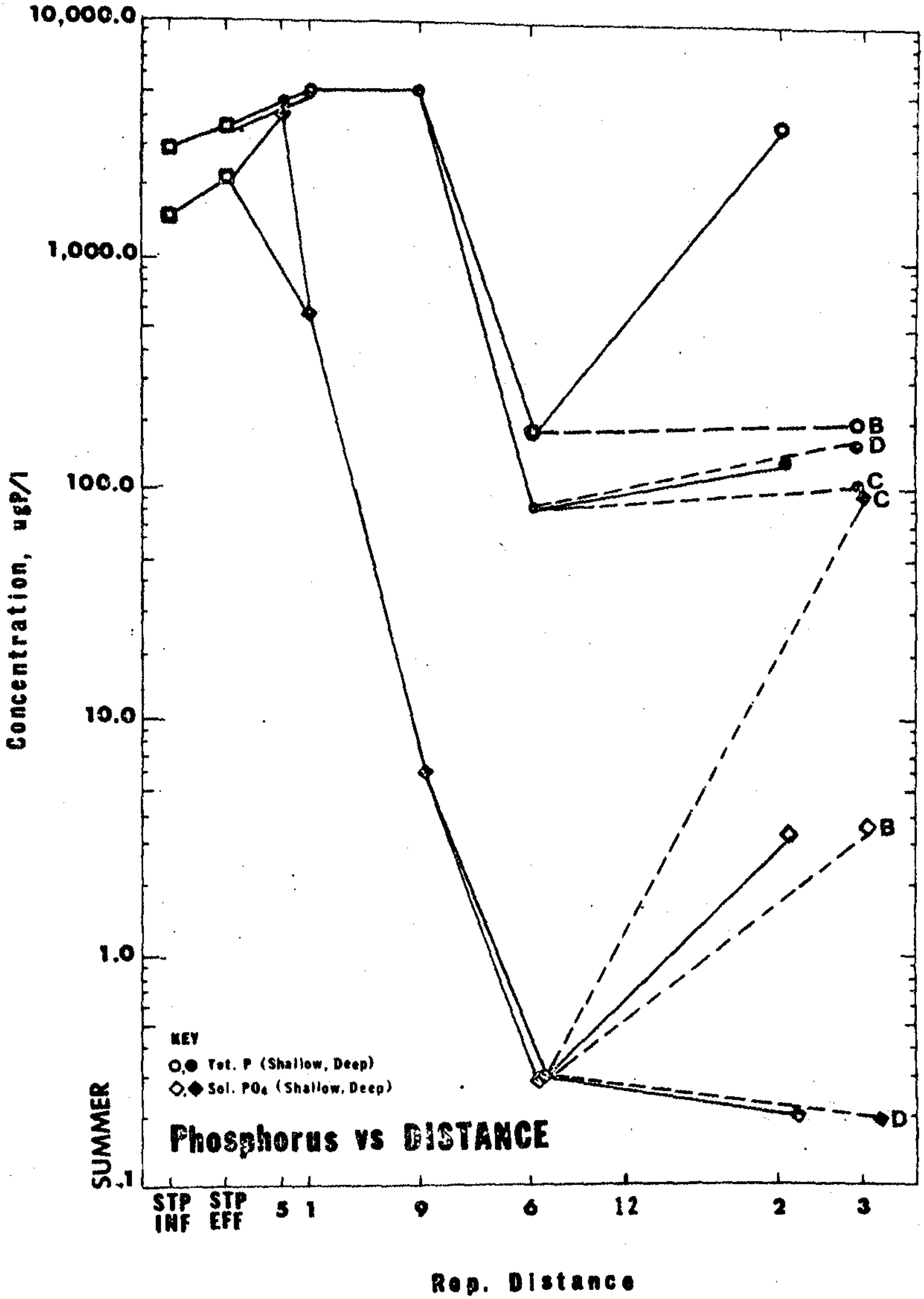

10,000.0
1,000.0
100.0
10.0
1.0
.1
Concentration, ugP/l
SPRING
B
C
C
D
A
B
D
STP INF
STP EFF
5
1
9
6
12
2
3
KEY
O,● Tot. P (Shallow, Deep)
◇,◆ Sol. PO4 (Shallow, Deep)
Phosphorus vs DISTANCE
Rep. Distance

FIGURE 26D



10,000.0
1,000.0
100.0
10.0
1.0
.1
Concentration, ugP/l
B
D
C
C
B
D
KEY
○,● Tot. P (Shallow, Deep)
◇,◆ Sol. PO_4 (Shallow, Deep)
SUMMER
Phosphorus vs DISTANCE
STP INF
STP EFF
5
1
9
6
12
2
3
Rep. Distance

DISCUSSION

The combined vertical and horizontal transport of the secondary treated effluent from the Lake George Village Sewage Treatment Plant through the sand achieves the production of a highly purified effluent. There are no significant adverse effects upon the ground water as indicated by the temperature, pH, alkalinity, coliforms, BOD, COD, or soluble phosphate. There is some increase in the total dissolved solids and the chloride content of the ground water but this is within acceptable limits.

The only parameter which approaches the limits for drinking water is the nitrate content of the water. The nitrate N values in the seepage approach 7 mg/l which is close to the recommended drinking water standard of 10 mgN/l.[7] Even this presents somewhat of an anomaly. Figures 14, 15 and 16 show the nitrate content in bed 11 at the 18 m depth to be less than 1 mg/l during all three seasons evaluated. Since all forms of nitrogen are low at this depth, it appears that there may be denitrification of the nitrate which was formed at shallower depths within this sand bed. The DO (Figure 11) and the redox potential (Figure 12) indicate the potential for reducing conditions to occur at this depth. Therefore, it is likely that the nitrates are reduced to nitrogen gas which escapes from the aqueous system. Figures 14, 15 and 16 show the greatest nitrate concentration to be at the 3 m depth which is the depth of the highest redox potential.

Observing the low nitrate content in bed 11 at the 18 m depth appears at first to contradict the relatively high nitrate N concentration at the seepage and Well 2A of approximately 7 mg/l. It must be pointed out, however, that not all of the sand beds are as deep as bed 11. This may be seen be refering to Table 2 which shows the vertical distances to the aquifer and to the bed rock at each of the observation wells. The difference between these two distances represents the thickness of the aquifer at each location. Wells 1, 5 and 11 are located within a sand infiltration bed. A cross section of the soil and ground water conditions in the area of the sewage treatment plant are shown in Figure 27.[8] It may be seen that there is much less vertical distance of travel in Well 5 which is in south sand bed 3 as compared with Wells 1 and 11 which are located in north sand beds 4 and 11, respectively. It is for this reason that the depth of sand bed S3 was superimposed on the vertical transport data shown in Figures 8 to 19 for the purification with vertical distance in bed N11. Since there is only 3.8 m vertical distance of travel in bed S3, it might be expected that this is the quality of the water which reaches the aquifer. Thus, since this is the depth at which the maximum nitrification occurs, it might further be expected that this nitrate would be carried in the horizontal transport through the soil to the seepage with little to no further removal. Thus, there is a slight water quality degradation with respect to nitrate in the ground water.

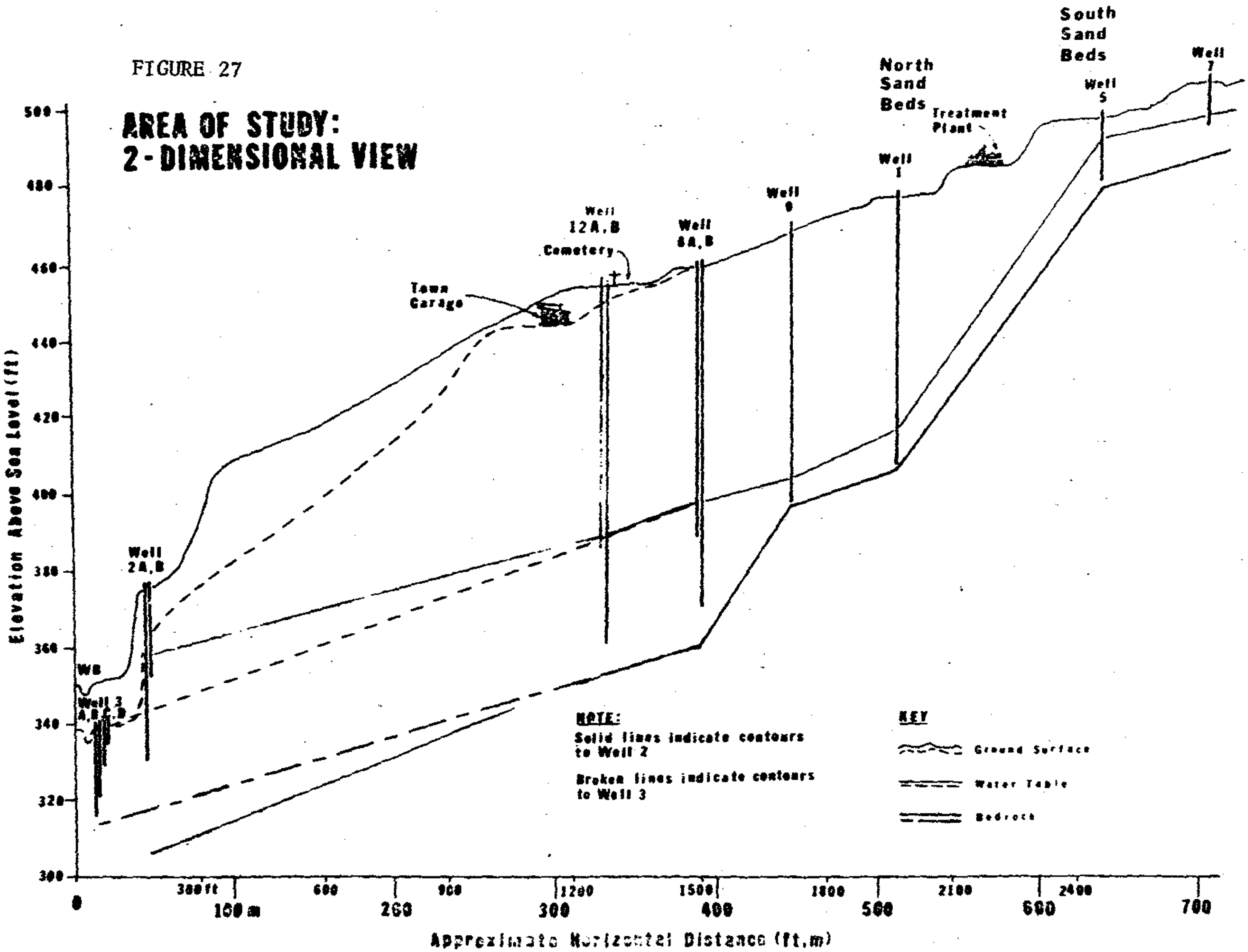
Application of secondary treated effluent onto natural delta sand beds at the Lake George Village Sewage Treatment Plant has successfully been achieving the equivalent of tertiary treatment of the wastewaters since 1939. This has gone a long way to protect the quality of the water of Lake George which is used for recreational purposes as well as for a drinking water supply.

TABLE 2

VERTICAL DISTANCES TO AQUIFER AND BEDROCK
AND AQUIFER THICKNESS AT WELL LOCATIONS, METERS

Well Number	Depth of Sand to Top of Aquifer	Depth to Bedrock	Thickness of Aquifer
1	18.3	21.3	3.0
2	5.2	21.2	16.0
3	0.1	7.9	7.8
4	0.0	1.9	1.9
5	3.8	5.5	1.7
6	19.0	30.0	11.0
7	1.0	2.1	1.1
8	21.2	24.9	3.7
9	19.3	21.8	2.5
10	6.4	7.3	0.9
11	20.0	28.0	8.0
12	18.7	26.6	7.9
14	18.0	19.8	1.8

FIGURE 27


AREA OF STUDY:
2-DIMENSIONAL VIEW
Elevation Above Sea Level (ft)
Approximate Horizontal Distance (ft,m)
South Sand Beds
North Sand Beds
Treatment Plant
Well 7
Well 5
Well 1
Well 9
Well 8A,B
Well 12A,B
Cemetery
Town Garage
Well 2A,B
WB
Well 3 A,B,C,D
NOTE:
Solid lines indicate contours to Well 2
Broken lines indicate contours to Well 3
KEY
Ground Surface
Water Table
Bedrock

REFERENCES

1. "Official Code Rules and Regulations of the State of New York," Part 830, Title 6, Item 48, Water Index No. C-101-T367, Class AA.

2. "The Environmental Conservation Law", Chapter 664, Sec. 17, Title 17, Art 1709.

3. Beyer, S. M., "Flow Dynamics in the Infiltration-Percolation Method of Land Treatment of Wastewater", M.S. Thesis, Rensselaer Polytechnic Institute, Troy, N.Y. (May 1976).

4. Aulenbach, D.B., Glavin, T.P. and Romero-Rojas, J. A., "Protracted Recharge of Treated Sewage into Sand: Part I, Quality Changes in Vertical Transport Through the Sand", Ground Water 12, 161 (1974), FWI Report 74-1.

5. Chiaro, P. S., "Hydraulic and Water Quality Aspects of a Municipal Land Application Wastewater Treatment System", M.E. Thesis, Rensselaer Polytechnic Institute, Troy, N.Y., (Dec. 1976).

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7. Environmental Protection Agency, "Interim Primary Drinking Water Standards", Federal Register 40, No. 51, 11990 (March 14, 1975).

8. Hajas, L., "Purification of Land Applied Sewage Within the Ground Water", M.S. Thesis, Rensselaer Polytechnic Institute, Troy, N.Y. (Dec. 1975).