SEASONAL VARIATIONS IN THE PURIFICATION OF TREATMENT PLANT EFFLUENT IN NATURAL SAND DEPOSITS

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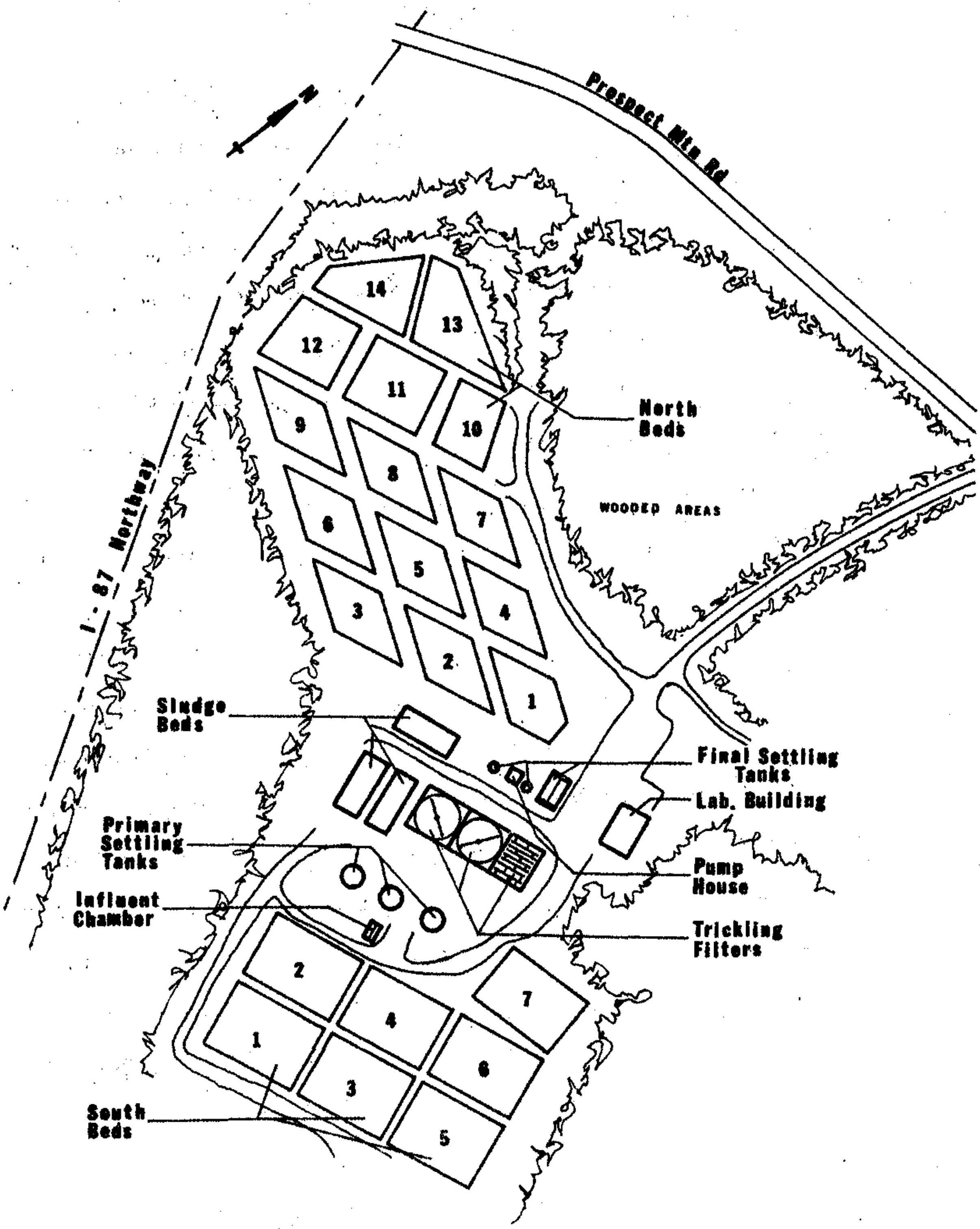
Since 1939, the Lake George Village Sewage Treatment Plant has been providing efficient tertiary treatment of the municipal wastewaters from the Village of Lake George. However, it was only recently, with the concern for the potential addition of nutrients to Lake George, that investigations were performed which confirmed that the treatment plant was doing an adequate job. [1,2,3,4,5,6,7,8,9,10] Of further concern was whether or not the treatment plant was continuing this high degree of treatment of the wastewaters and the nutrient removal throughout the course of a full year. Thus studies were performed and the data broken down to show the differences in quality of the final treated effluent over the course of the four seasons of the year.

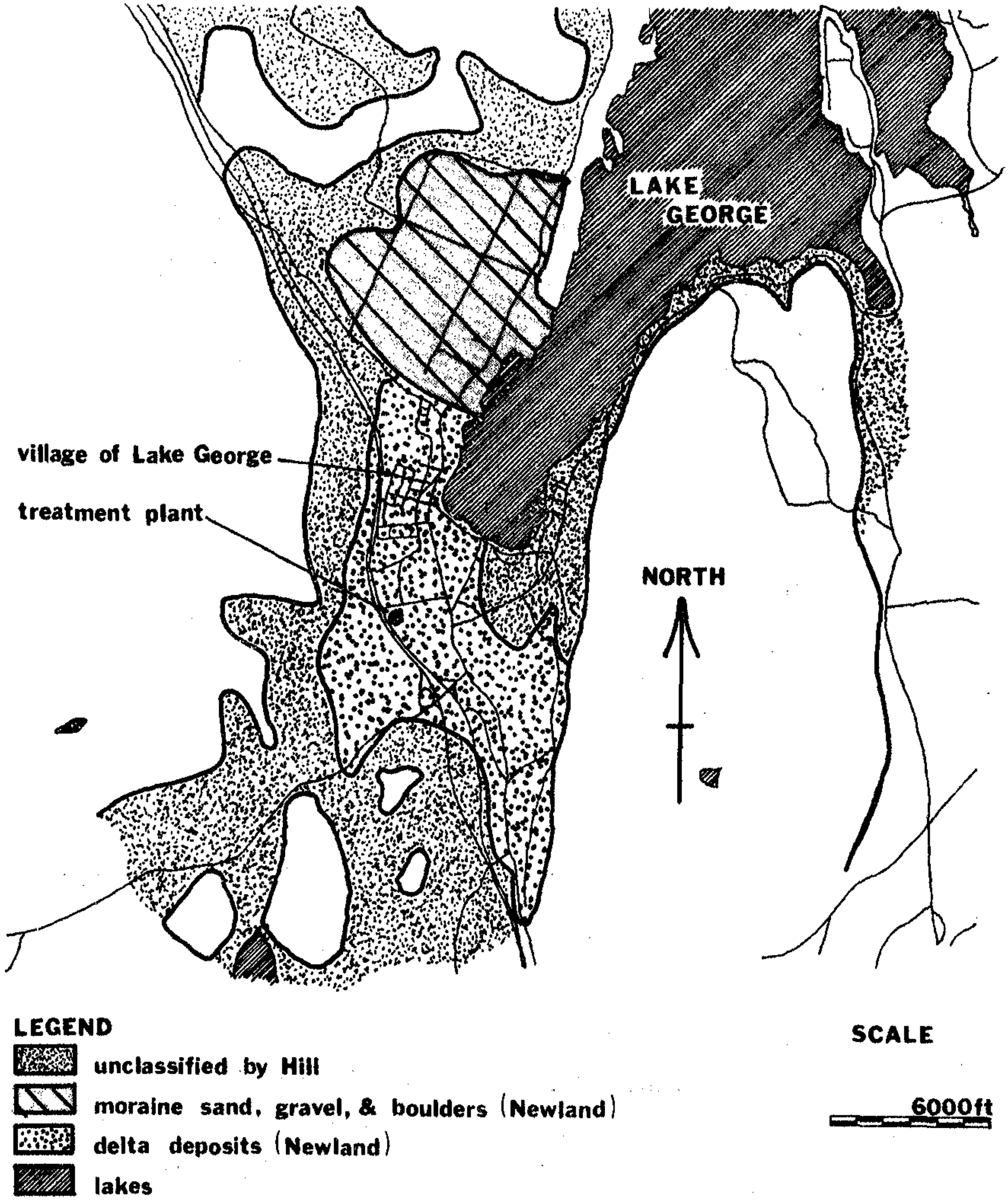
The original Lake George Village Sewage Treatment Plant design consisted of primary sedimentation with Imhoff type sludge digestion, trickling filters, secondary sedimentation and discharge of the secondary effluent onto natural sand beds. Originally there were only six sand beds. The present number is twenty-one consisting of 2.15 ha (5.3 acres) of actual sand infiltration area. The layout of the sewage treatment plant is shown in Figure 1. The main feature of the treatment plant is the good fortune of finding some natural delta sand deposits as shown in Figure 2 around the sound end of Lake George. It is this deep natural sand deposit which accomplishes the tertiary treatment for the Lake George Village Sewage Treatment Plant effluent.

One of the main features enabling this study is the fact that the treated sewage effluent has been identified seeping from the ground near



SEWAGE TREATMENT PLANT LAYOUT

FIGURE 1.



GEOLOGY OF THE SOUTHERN LAKE GEORGE DRAINAGE BASIN

FIGURE 2

south bank of West Brook as shown in Figure 3. The distance from the ltration beds to the edge of the flood plain of West Brook is approxi- ly 600 meters (2,000 feet). Although, West Brook is primarily fed by ind water, the two areas of seepage above and below Gage Road have been itified as containing significant amounts of the treated sewage effluent. s felt that essentially all of the treatment plant effluent re-emerges the ground along with additional ground water at these two locations.

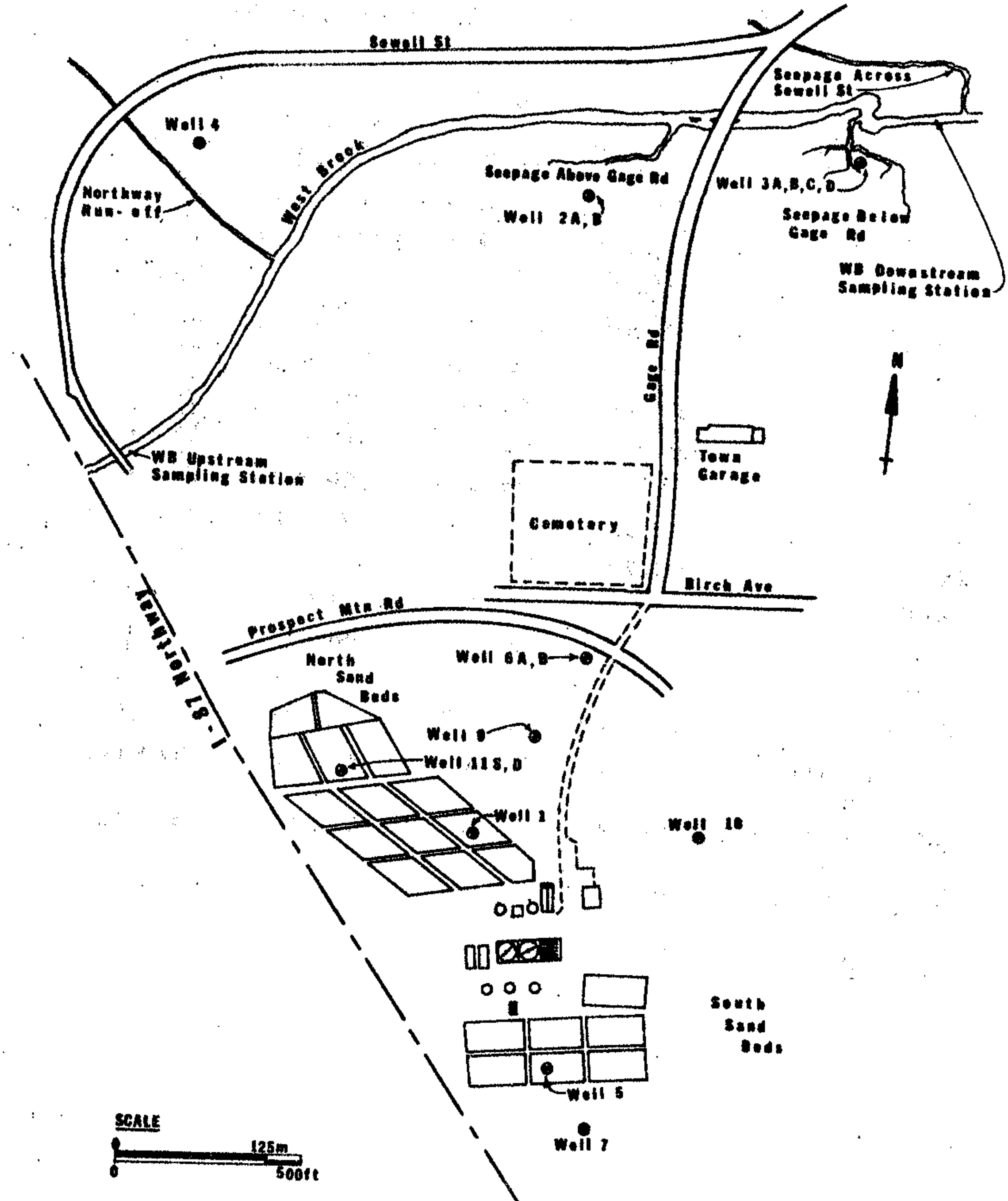
As an aid in studying the quality of the ground water as it passes the treatment plant area to West Brook, wells have been installed ughout the area as shown in Figure 3. Wells 4, 7 and 10 are used as rol wells with well 10 being the one referred to as a control well his study. Wells 1, 5 and 11 are located within the sand seepage beds. other wells in order of their distance from the sand beds are 9, 6, id 3. In several instances well points were placed at several depths in the aquifer at a well location. For purposes of identification, shallowest point at any location is always indicated as well A and the est as the lowest needed letter in the alphabet (well 3D being the est of four wells at this location). With the exception of wells 11S D all of the wells are points with screens located at the depth ified. Wells 11S (shallow) and D (deep) are pumping wells which tain submersible pumps in a 6 inch (15 cm) casing penetrating shallow deep within the aquifer. The actual depths of the individual wells shown in Figure 4 with detailed numbers of the depths of the wells wn in Table 1. A representative cross section of the area from well 7 West Brook is shown in Figure 5. It may be seen that there is a slope the ground from the treatment plant towards West Brook with a rather

TABLE 1

Well Data

Elevations in Ft. Above Mean Sea Level

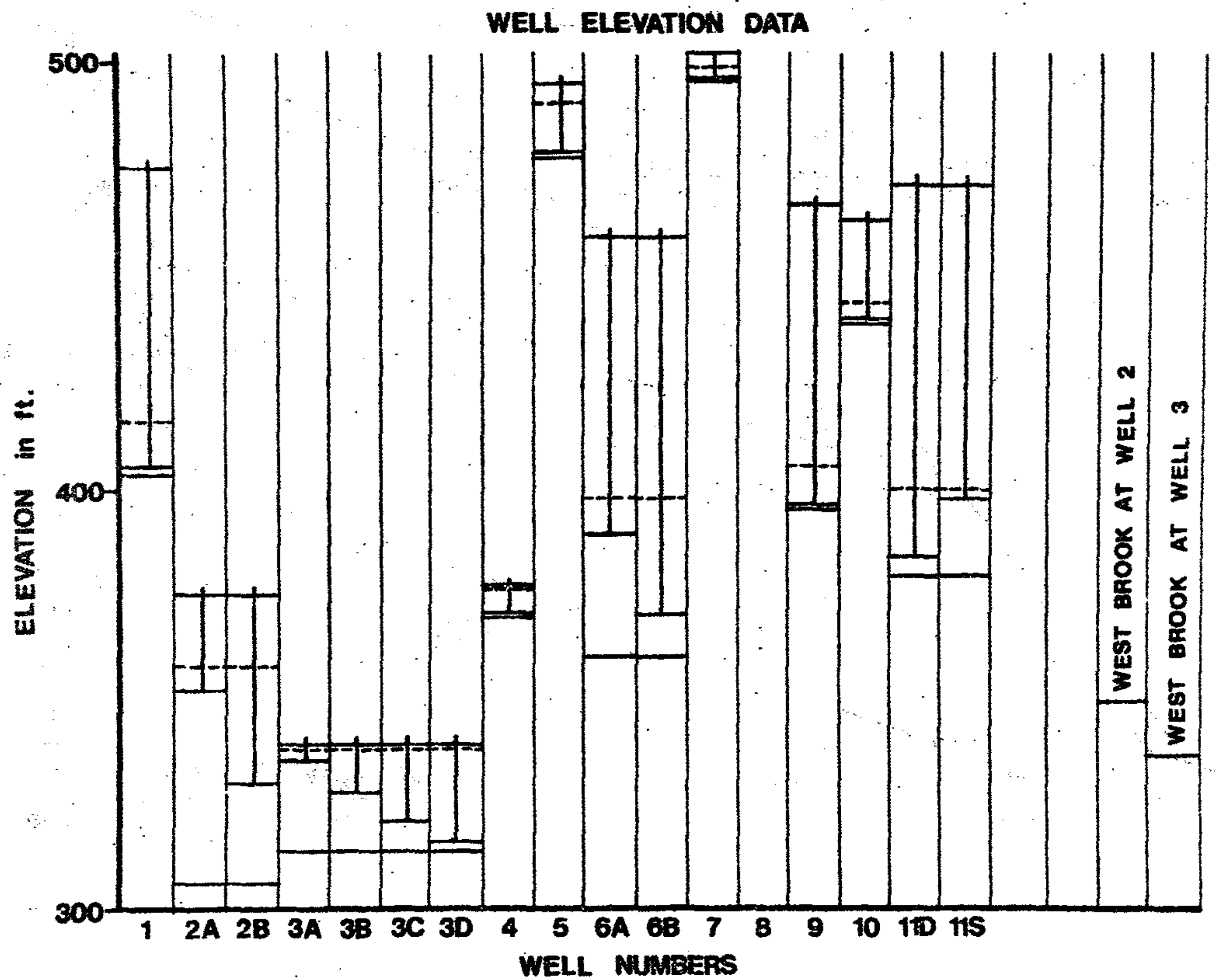
Location	Surface	Approx. Ground Water	Bottom of Point	Bedrock
Well 1	475.0	415.66	407.80	405.0
Well 2A	375.40	359.22	352.13	306.0
Well 2B	375.40	359.2	330.35	306.0
Well 3A	339.90	339.74	336.44	314.0
Well 3B	339.90	340.01	329.06	314.0
Well 3C	339.90	340.08	321.23	314.0
Well 3D	339.90	340.0	315.64	314.0
Well 4	376.63	375.62	369.48	369.48
Well 5	495.37	490.98	479.40	477.40
Well 6A	458.7	397.6	388.13	360.0
Well 6B	458.7	397.6	370.63	360.0
Well 7	504.33	496.53	496.54	-
Well 9	467.02	405.39	395.51	395.51
Well 10	462.73	441.7	438.91	438.91
Pumped Well 11 (Deep)	471.60	400.0	384.60	379.60
Pumped Well 11 (Shallow)	472.73	400.0	397.73	379.60
West Brook at Well 2	348.0	-	-	-
West Brook at Well 3	334.9	-	-	-

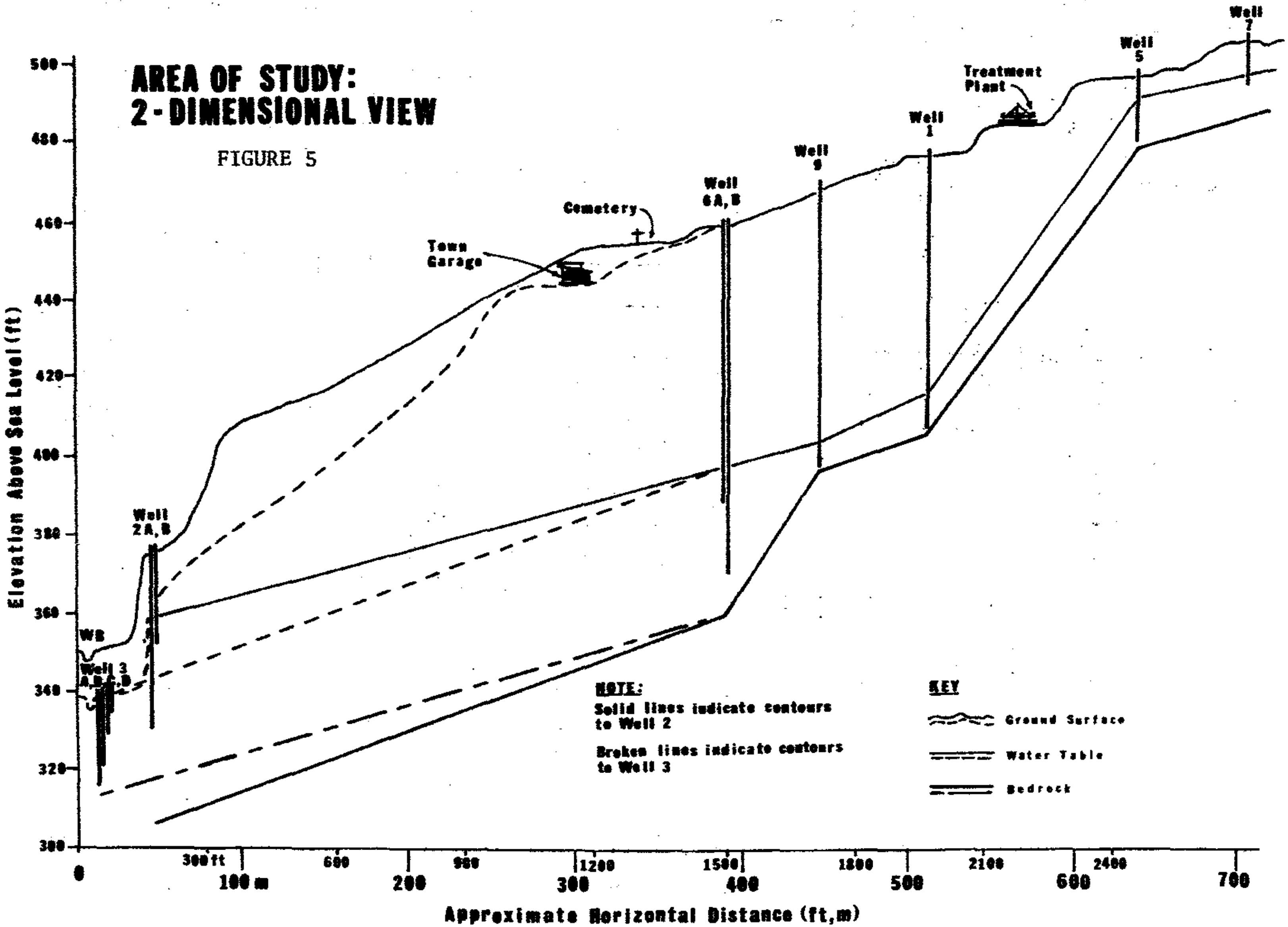


AREA OF STUDY

FIGURE 3

FIGURE 4


WELL ELEVATION DATA
500
400
300
ELEVATION in ft.
1
2A
2B
3A
3B
3C
3D
4
5
6A
6B
7
8
9
10
11D
11S
WEST BROOK AT WELL 2
WEST BROOK AT WELL 3
WELL NUMBERS


AREA OF STUDY:
2-DIMENSIONAL VIEW
FIGURE 5
Elevation Above Sea Level (ft)
500
480
460
440
420
400
380
360
340
320
300
Well 7
Well 5
Treatment Plant
Well 1
Well 9
Well 6A, 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
0
300 ft
600
900
1200
1500
1800
2100
2400
100 m
200
300
400
500
600
700
Approximate Horizontal Distance (ft, m)

8

steep hill near the banks of the flood plain of West Brook. The bed rock slopes at an even greater angle and the aquifer becomes thicker as it approaches West Brook. An attempt to depict a three dimensional view of the location of the treatment plant and of the wells is shown in Figure 6. This figure shows the physical relationships between the most important wells in this study, and the bedrock and ground water depths at each well location.

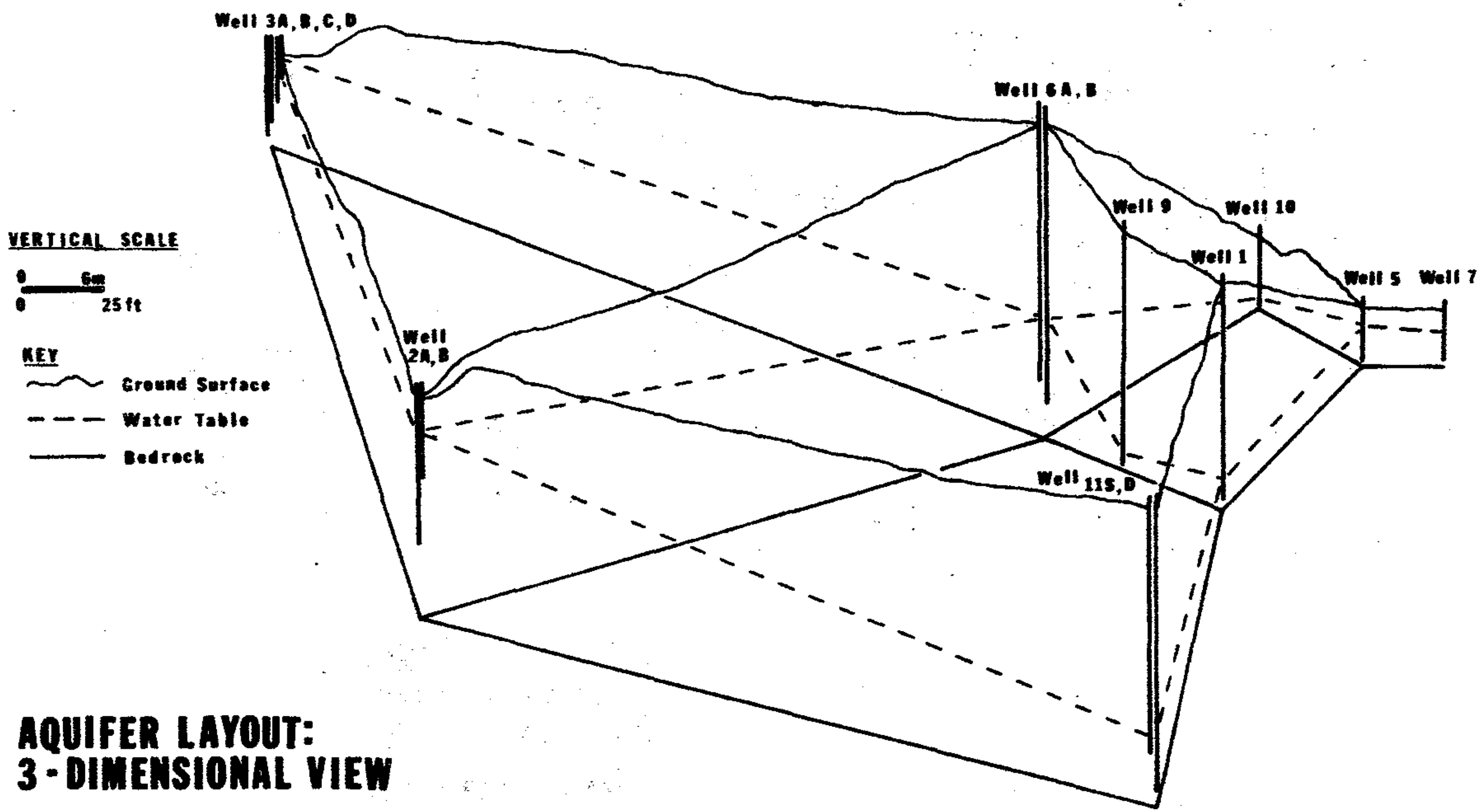
Except for the results from the two seepage areas, all the data included in the averages are from the beginning of the intensive study of the system or from the time the sampling site (as a well) was established, through September 27, 1975. In the case of the seepage samples, the first results included in these averages were in November of 1974. The dates of the first samples included in this study for each sampling site are shown in Table 2. This gives an indication of the different lengths of time the various sites were sampled.

There is always concern about how efficiently a treatment plant works under adverse conditions. In the case of the Lake George Village Sewage Treatment Plant, one adverse condition occurs during the winter when temperatures reach a low of $-35^{o}C$ ($-30^{o}F$). Another critical time is during the summer when increased flows are created by a large influx of tourists into the area. The original design of the treatment plant was based on the summer flow being approximately three times the winter flow. That this still is approximately true is shown in Figure 7. In order to show any differences in efficiency of the treatment plant or the treatment by the soil system, the data were broken down seasonally. Actual seasons beginning June 21st through September 20th, etc. were chosen, primarily on the basis

TABLE 2

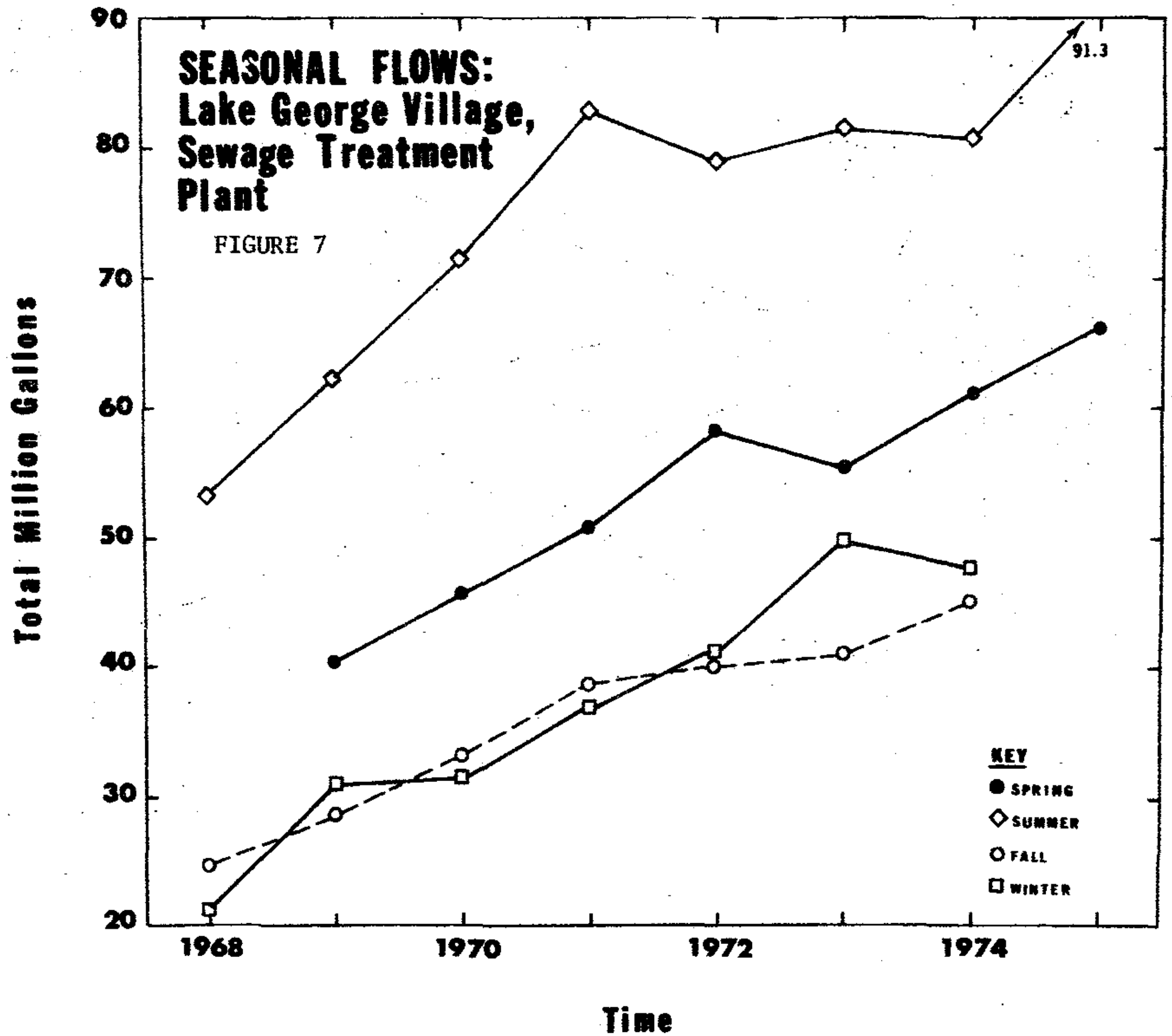
DATE OF FIRST SAMPLING INCLUDED IN THIS REPORT FOR EACH SAMPLING SITE

Location	Date of First Sample
Sewage Treatment Plant Influent	6/26/73
Sewage Treatment Plant Effluent	4/19/73
Well 1	6/07/73
Well 2A	6/07/73
Well 2B	10/17/73
Well 3A	6/07/73
Well 3B	6/07/73
Well 3C	6/07/73
Well 3D	6/23/73
Well 4	3/27/75
Well 5	7/25/73
Well 6A	10/17/73
Well 6B	7/08/73
Well 9	3/28/75
Well 10	7/11/73
Well 11 Deep	3/13/75
Well 11 Shallow	3/13/75
Seepage Above	11/01/74
Seepage Below	11/15/74
West Brook Upstream	4/17/73
West Brook Downstream	4/17/73



**AQUIFER LAYOUT:
3-DIMENSIONAL VIEW**

FIGURE 6

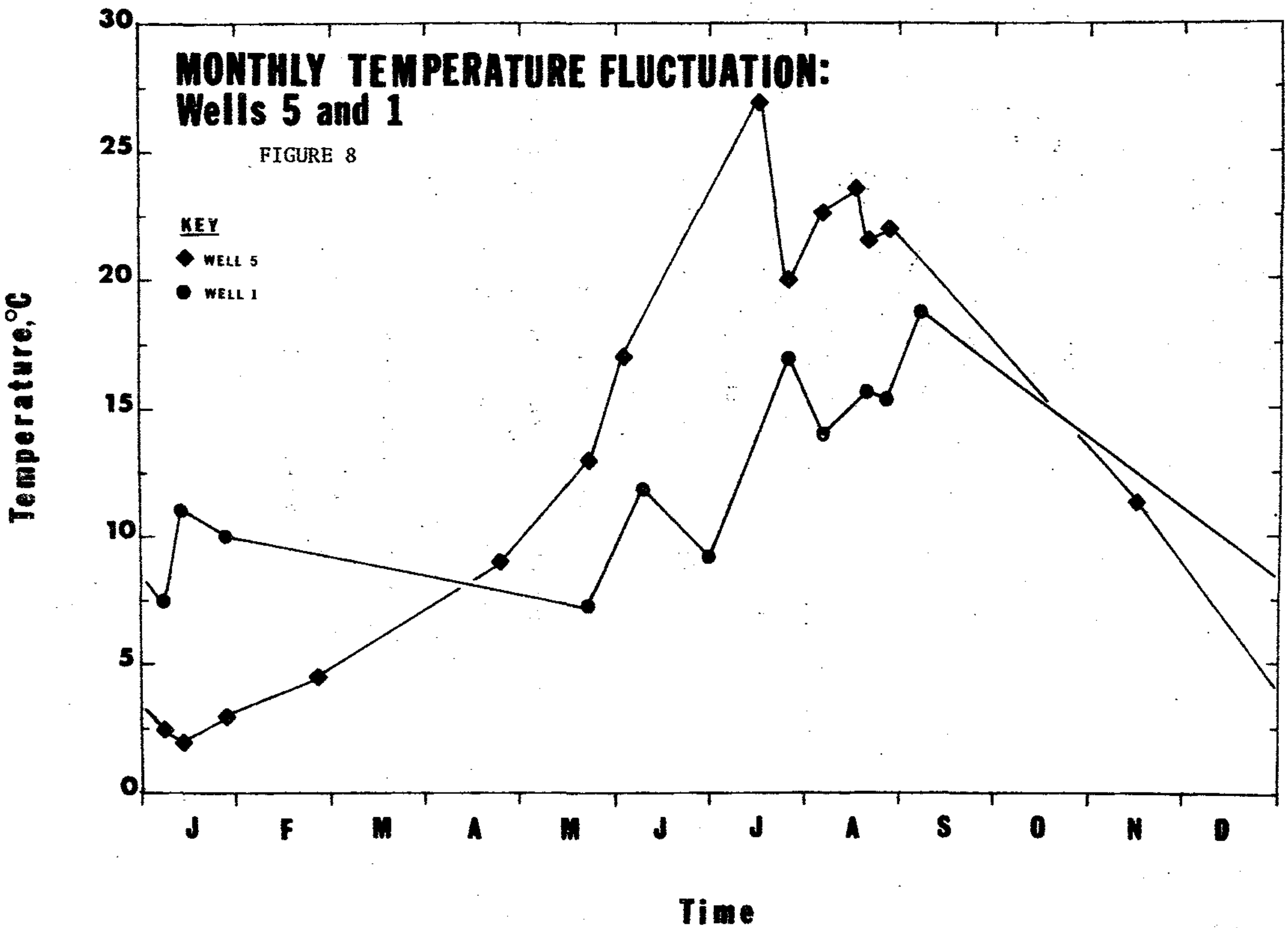


SEASONAL FLOWS:
Lake George Village,
Sewage Treatment
Plant
FIGURE 7
91.3
90
80
70
60
50
40
30
20
Total Million Gallons
1968
1970
1972
1974
Time
KEY
SPRING
SUMMER
FALL
WINTER

of the fact that this encompasses adequately the prime summer tourist season time. There is less of a definite difference between flow flucuations during the other seasons; however, the spring season represents the high flows due to melting of winter snow and ice which does come generally during the period from March 21st through June 20th. Thus this breakdown is used for studying the results.

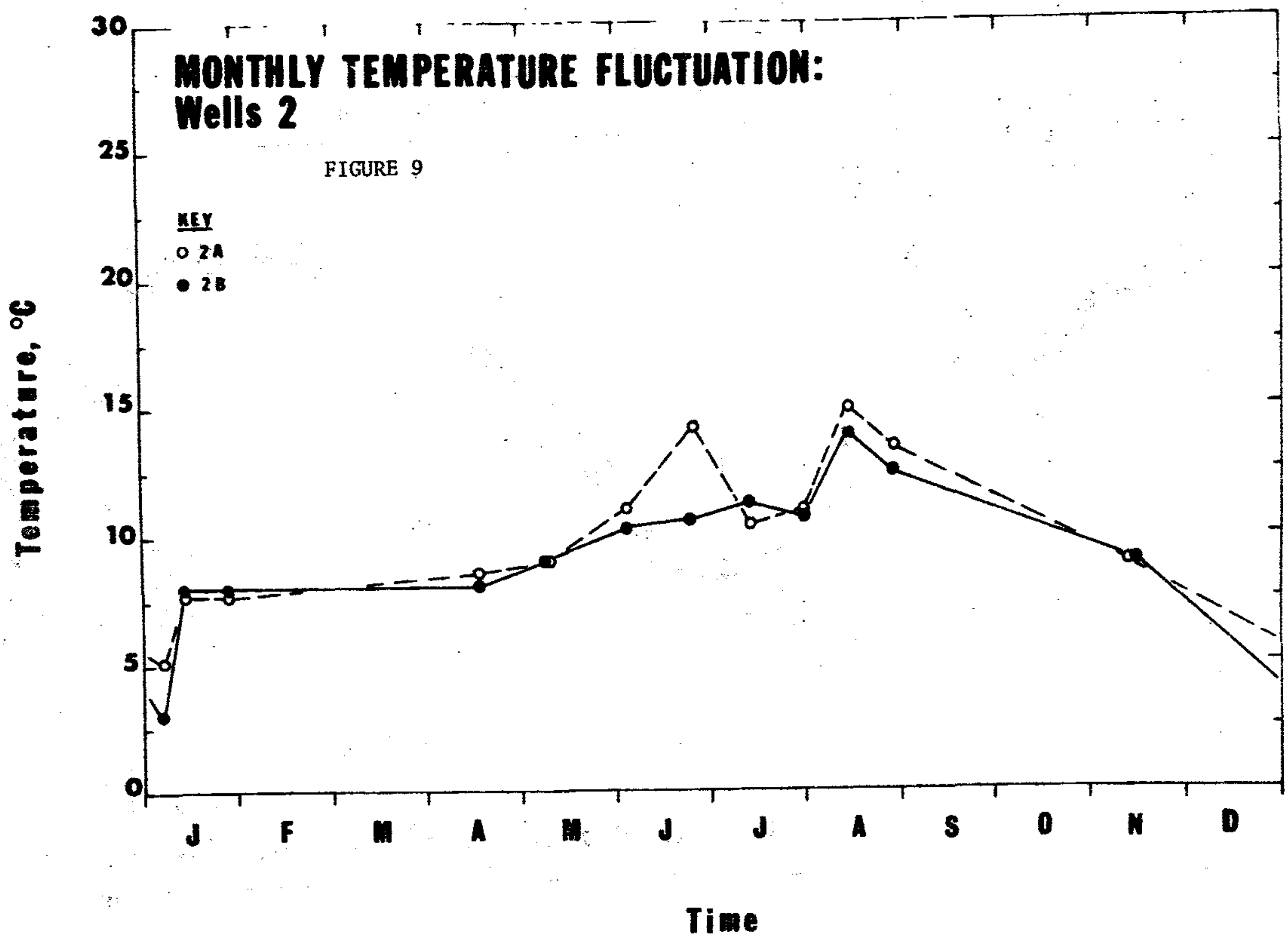
As shown in Figure 7 there is little difference between the flows during fall and winter. Increased flows during spring represent primarily increased run-off and infiltration into the sewer system. The high flows during summer represent the peak flows during the tourist season. It may be seen that in all cases the flows have been increasing during the period covered from 1968 when the Caldwell sewer district was added to the Village treatment plant through the summer of 1975 when the highest flows ever recorded were received at the plant. The flows are recorded separately; one for the Village sewers and one for the Caldwell or town sewers, by means of Parshall flumes using separate recording meters. The maximum daily flows during the summer of 1975 exceeded 1 mgd (3.8×10^6 liters per day), whereas the design capacity of the plant is 1.75 mgd (6.6×10^6 liters per day).

The temperature of the water in each test well was determined _in situ_ by means of a YSI temperature-DO probe. The average monthly temperature for selected list of representative wells is shown in Figures 8, 9 and 10 The wells were separated into several categories according to their similarities. Wells 1 and 5 are both located in sand beds, with well 1 being quite deep in the sand bed and well 5 being in a shallow sand bed. As shown in Figure 8 the flucuations in temperature varied considerably

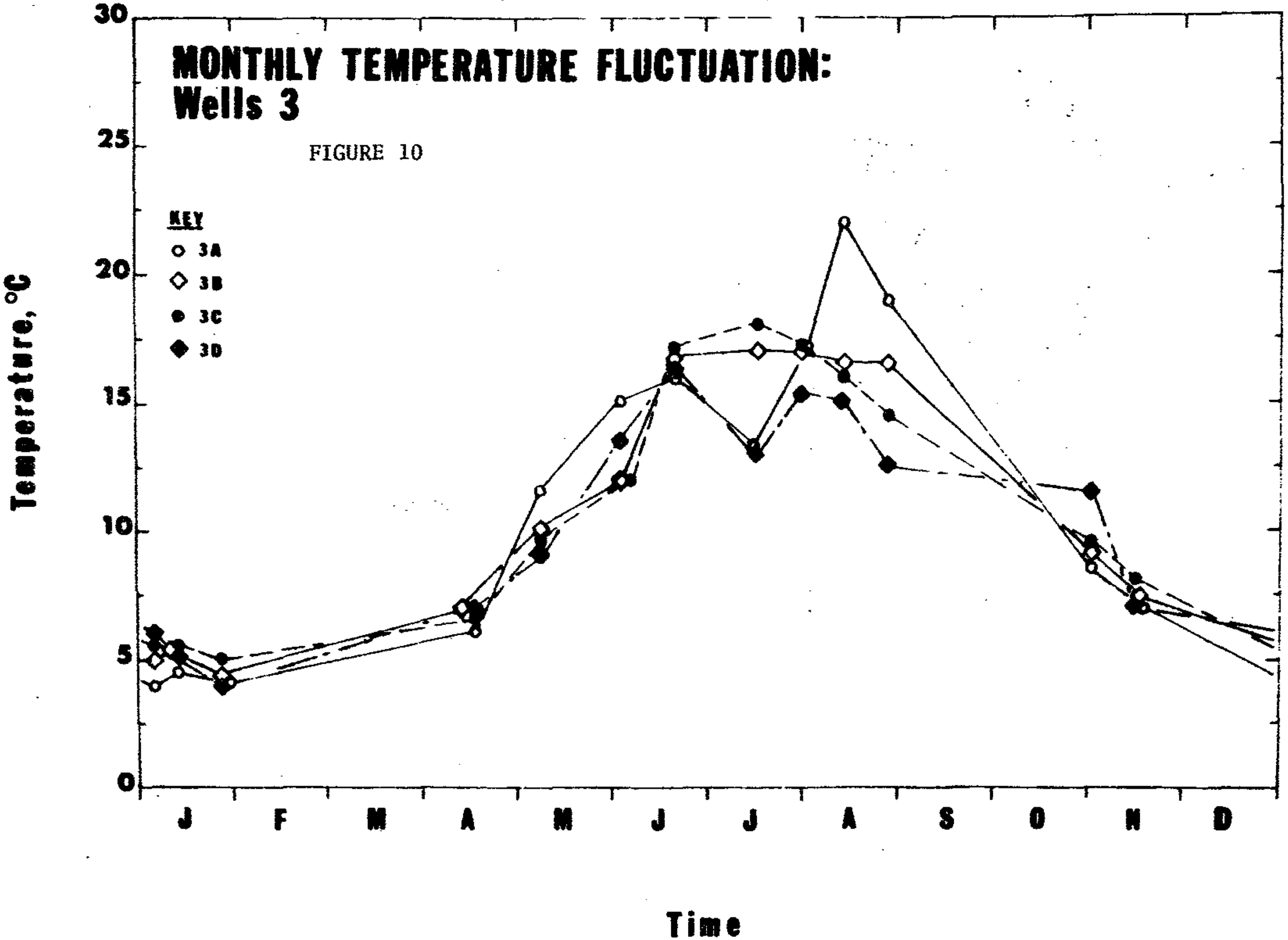


MONTHLY TEMPERATURE FLUCTUATION:
Wells 5 and 1
KEY
WELL 5
WELL 1
Temperature,°C
30
25
20
15
10
5
0
J
F
M
A
M
J
J
A
S
O
N
D
Time

FIGURE 8



MONTHLY TEMPERATURE FLUCTUATION:
Wells 2
FIGURE 9
KEY
2A
2B
Temperature, °C
30
25
20
15
10
5
0
J
F
M
A
M
J
J
A
S
O
N
D
Time


MONTHLY TEMPERATURE FLUCTUATION:
Wells 3
FIGURE 10
KEY
3A
3B
3C
3D
Temperature, °C
0
5
10
15
20
25
30
J
F
M
A
M
J
J
A
S
O
N
D
Time

in both of these wells primarily due whether or not the bed was being dosed at the time of the sampling. Unfortunately a sufficient number of samples is not available to separate the temperatures when the beds were being dosed from those when the beds were not being dosed. There was a greater flucuation of temperature between summer and winter in the shallower well 5, primarily due to the influence of the temperature of the air above the sand bed during the various seasons. At well 2 (Figure 9) which is quite a distance from the sand beds, there was much less flucutation in temperature over the year. There was a slightly greater flucutation in the shallower well 2A then in the deeper well 2B. There are four well points at location 3 and in general the aquifer is close to the surface at this location. There was a significant difference in temperature between the summer and the winter with the highest temperature during the summer in the shallowest well 3A (Figure 10). During the other three seasons there is little significant difference between the four wells located at different depths within the aquifer.

The remainder of the data presented here are broken down into seasonal categories with representative distances indicated on the ordinate scale. In all these figures when there are points at two different depths at the same location the open marks indicate the shallower wells and the solid marks the deeper wells. For well 3 which has points at four different depths, these are identified as A, B, C and D. The seepages above and below Gage Road are indicated as A and B, respectively. Since flow from well 6 could be toward either wells 2 or 3, the flow from well 6 to well 2 is indicated by a solid line and the flow from well 6 to well 3 is indicated by a broken line. The flow is from well 2 to the seepage above Gage Road which is connected by a solid line and from well 3 to the seepage below Gage Road which is represented by a broken line. In all cases where more than one depth is sampled, the lines connect well points of similar depths. Also shown in these figures are the conditions in West Brook upstream from all of the seepages involved in this study and downstream from these locations, thus including any influences due to the sewage seepages discharging into West Brook. These are labled as WBU (West Brook Upstream) and WBD (West Brook Downstream). What is significant in this case is any change which occurs between these two locations, indicating the influence of the seepage discharges on the quality of the water within West Brook. It must be noted that West Brook flows into Lake George approximately one-half mile from this sampling location and thus the concern that the quality of West Brook as affected by the seepage will not be deleterious to the quality of water in Lake George. In all of the figures the control is represented by well 10.

The seasonal fluctuation in pH versus distance is shown in Figures 11A and B. In all cases the pattern is similar. There is a decrease in the pH in flowing through the treatment plant and further decreases in wells 5 and 1 with the lowest values being found in well 5. When data were available for spring and summer, well 9 was slightly higher in pH than the control and the highest pH values were generally found in well 6, with significantly higher pH values in the deeper well points during the spring and fall. During the fall and winter there were slight increases in the pH at the deeper wells from well 6 to wells 2 and 3. In all cases the pH of the seepage was between 7.5 and 8. It may be seen that there is a slight influence to raise the pH in West Brook as it flows past this seepage area.

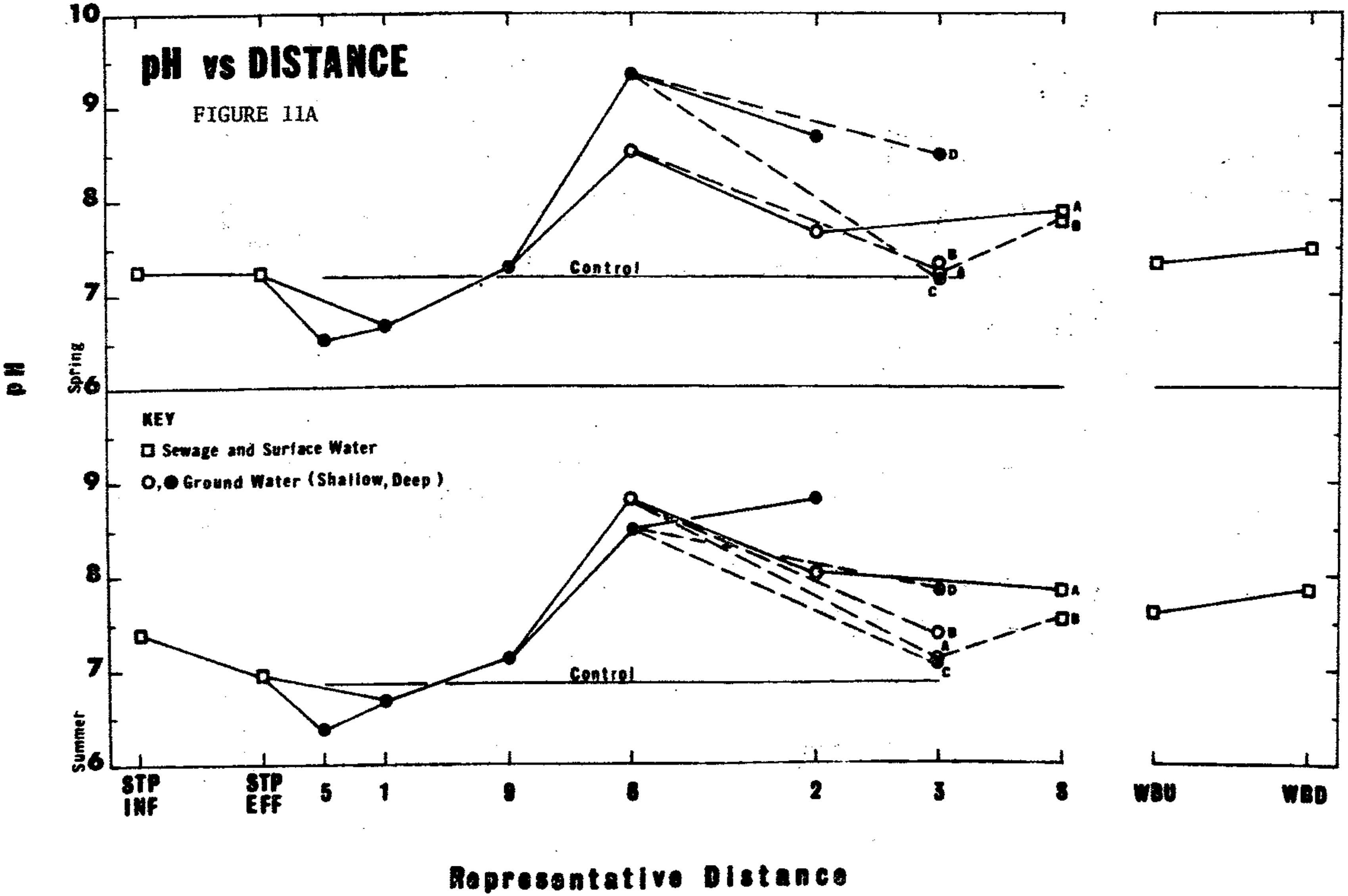
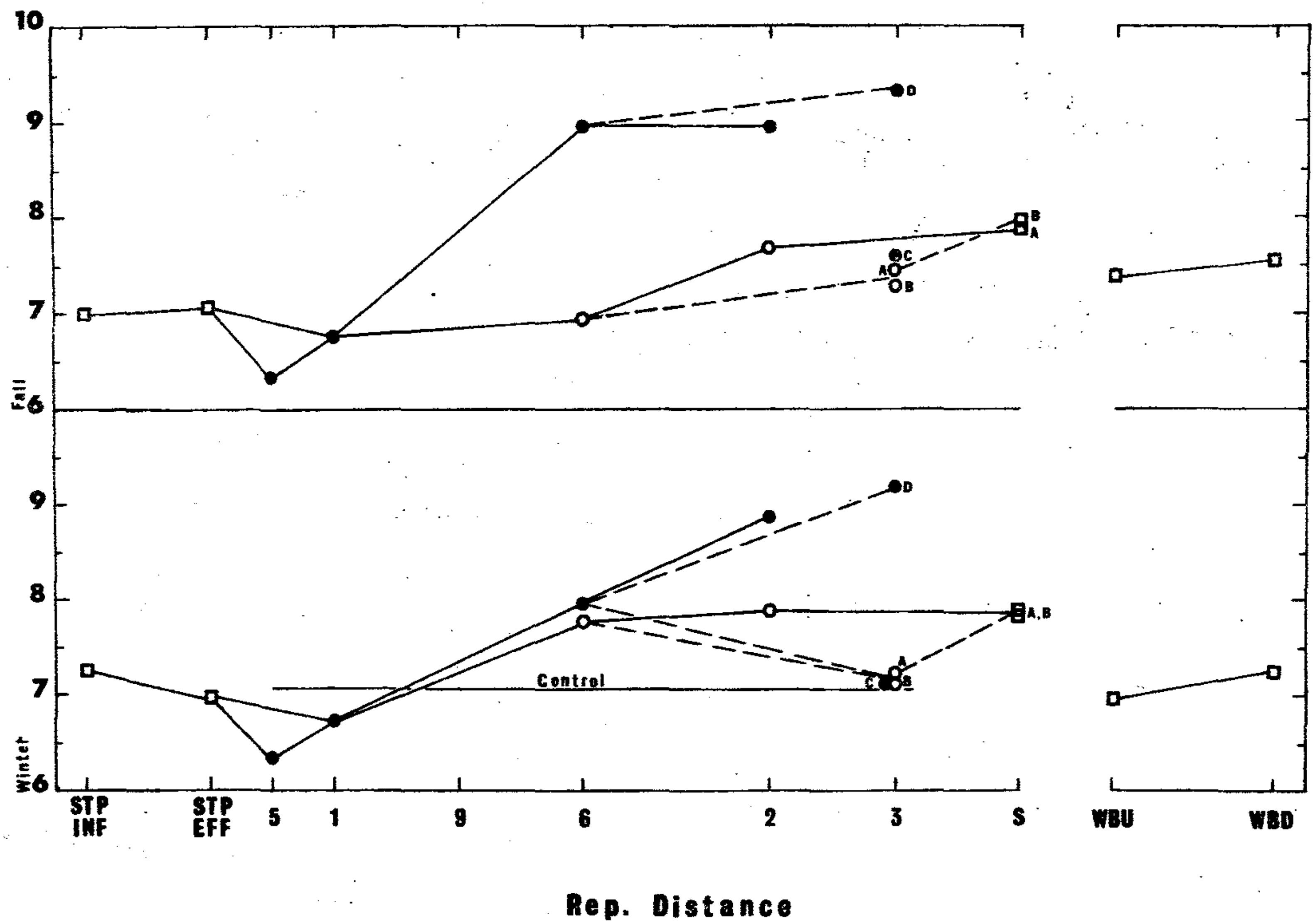

pH vs DISTANCE
FIGURE 11A
pH
Spring
Summer
Control
KEY
□ Sewage and Surface Water
○,● Ground Water (Shallow, Deep)
10
9
8
7
6
A
B
C
D
STP INF
STP EFF
5
1
9
6
2
3
8
WBU
WBD
Representative Distance

FIGURE 11B



10
9
8
7
6
pH
Fall
Winter
D
C
A
B
A,B
Control
STP INF
STP EFF
5
1
9
6
2
3
S
WBU
WBD
Rep. Distance

With the exception of well 3 during spring, summer and winter, there was little significant difference in the alkalinity concentrations at the various sampling wells as shown in Figures 12A and B. Well 3 generally had higher alkalinity values, which may be attributed in part to the influence of highway deicing salt which was stored on the hill above well 3. The seepage below also reflects this influence from the deicing salt. West Brook does indicate a measureable increase in alkalinity due to the influence of the seepage from this area.

In all cases, the chloride content is significantly higher than that in the natural ground water as shown in Figures 13A and B. Well 3 consistantly has a higher chloride content which may be attributed to the influence of the former storage of the highway deicing salt immediately above the location of well 3. It is unfortunate that this salt interferred with the test, as, otherwise, chloride could have been used as a tracer to identify the sewage effluent. The high content at well 3 is also reflected in the high chloride content in the seepage below Gage Road, which in all cases was even higher than the chloride content of the wells at location 3. In all other sampling sites, there was little significant difference in the chloride content with either season or distance, with the possible exception of well 6A during the spring period which seemed to be rather low in chloride content. Comparing West Brook downstream with West Brook upstream it may be seen that there is a measureable increase in chloride content of the stream as it passes by the area where the seepage enters the stream.

The dissolved solids as shown in Figures 14A and B is quite similar to the chloride content. Again the influence of the highway deicing salt is shown in the higher dissolved solids content of wells 3 and the seepage

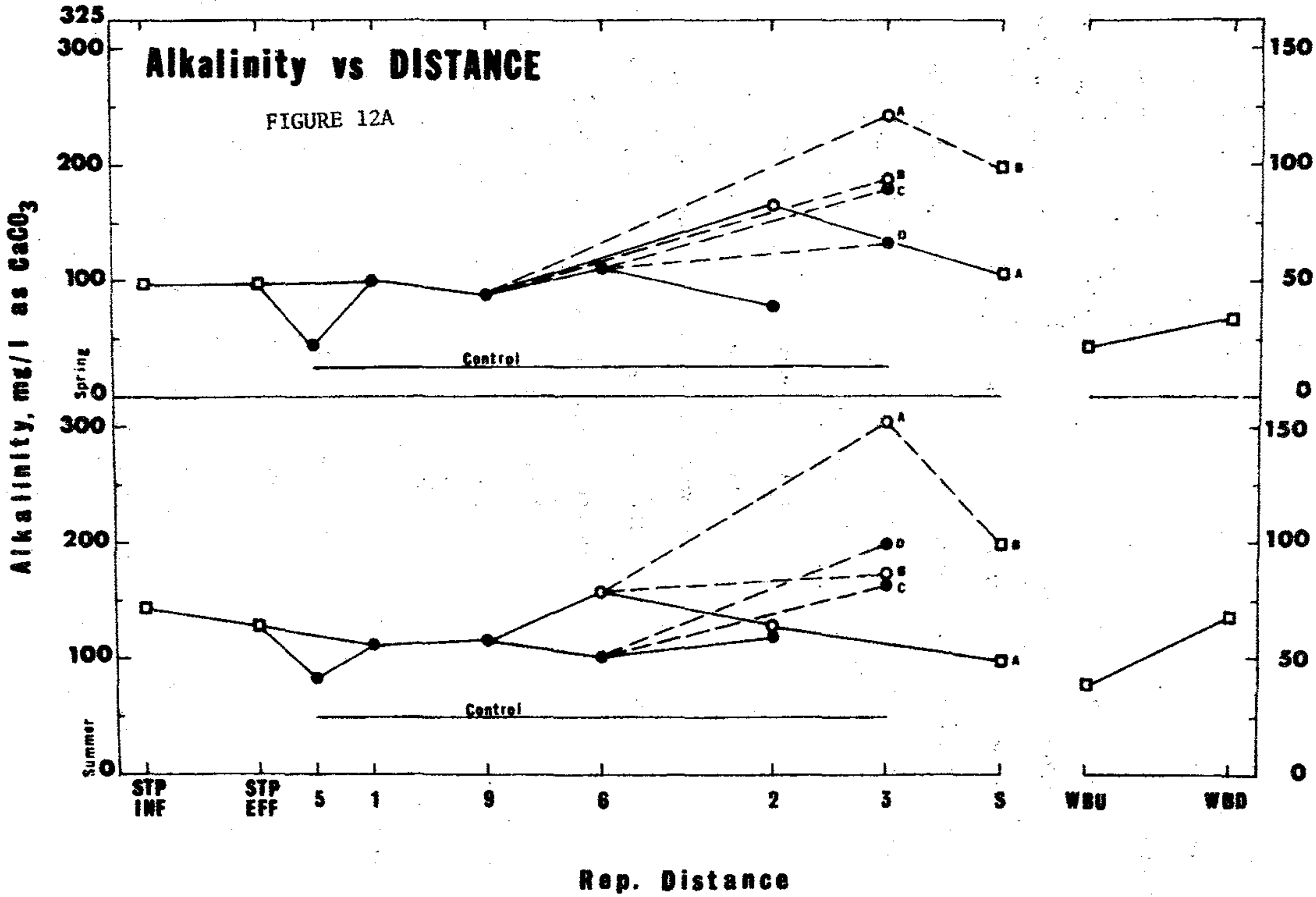
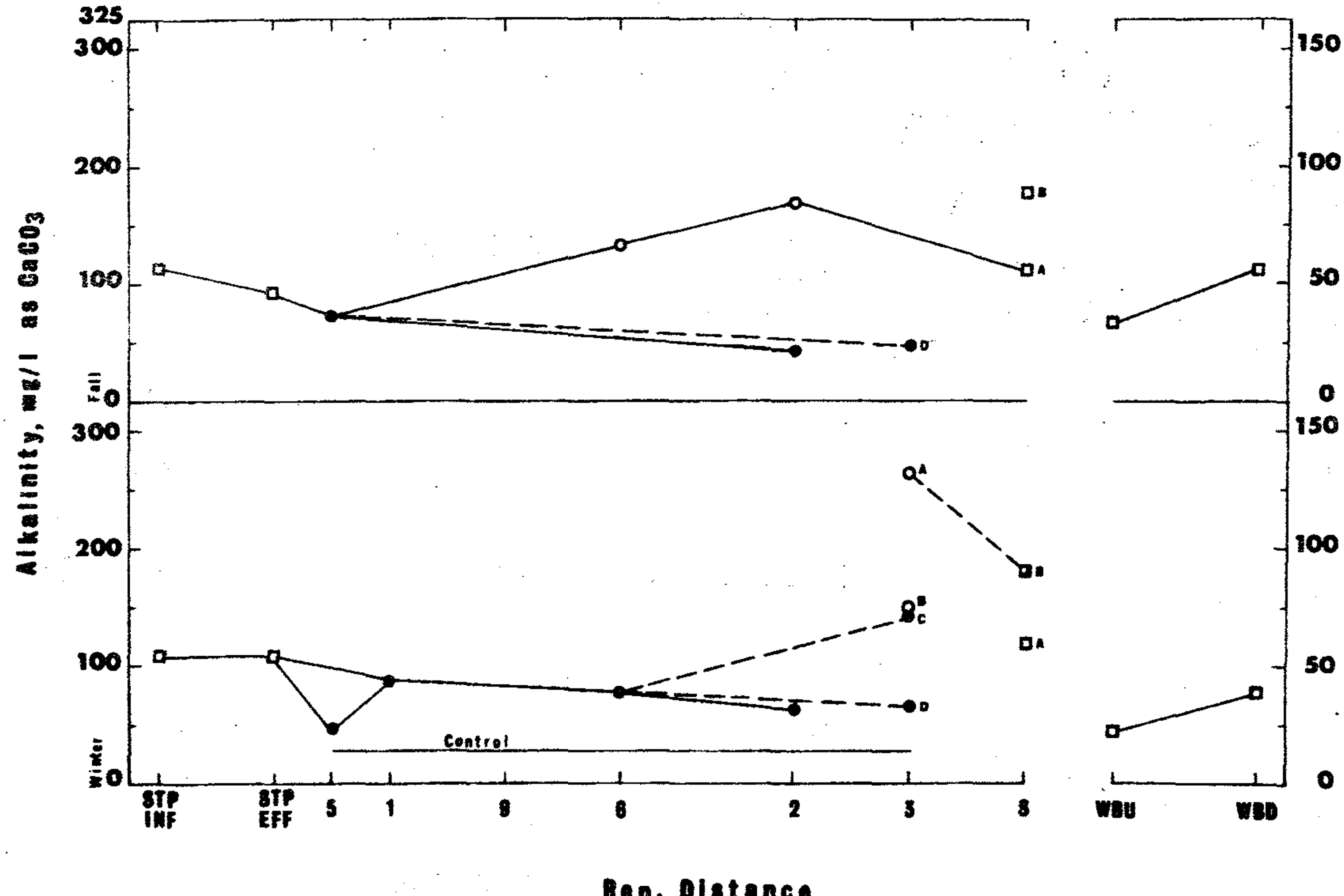

Alkalinity vs DISTANCE
FIGURE 12A
Alkalinity, mg/l as $CaCO_3$
Spring
Summer
Control
325
300
200
100
0
150
100
50
0
A
B
C
D
STP INF
STP EFF
5
1
9
6
2
3
S
WBU
WBD
Rep. Distance

FIGURE 12B



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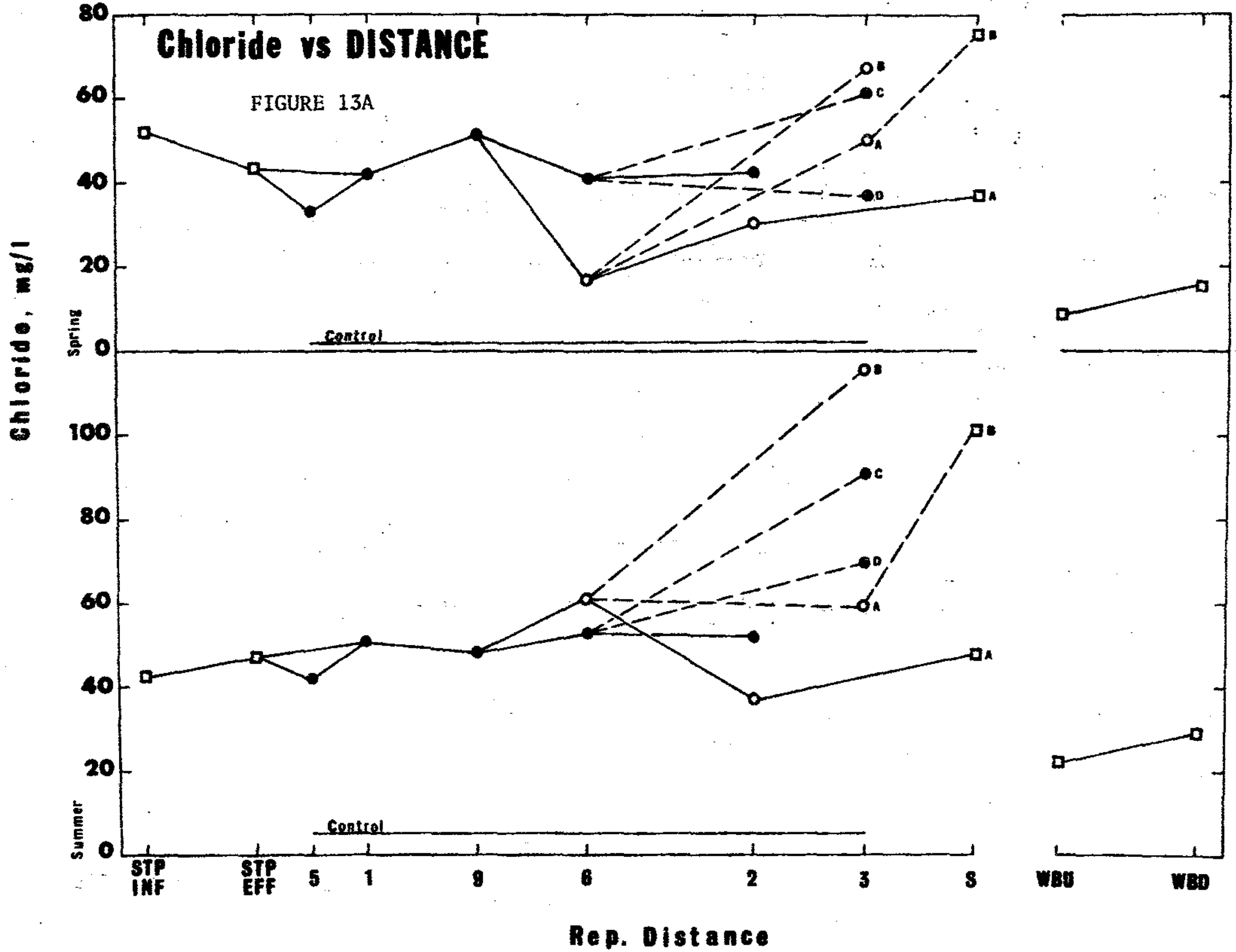
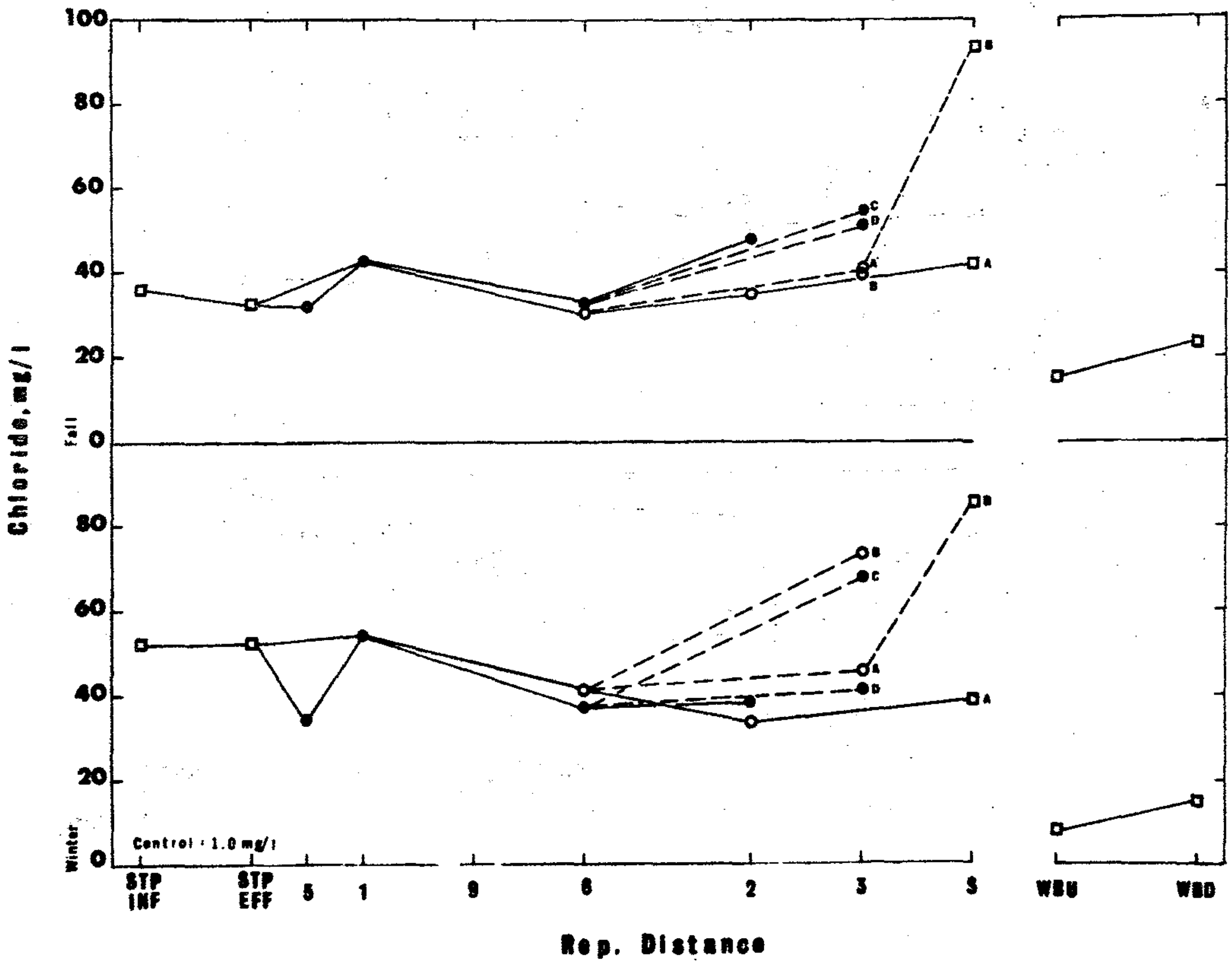


Chloride vs DISTANCE

FIGURE 13A

FIGURE 13B


100
80
60
40
20
0
Chloride, mg/l
Fall
Winter
Control : 1.0 mg/l
A
B
C
D
STP INF
STP EFF
5
1
9
6
2
3
S
WBU
WBD
Rep. Distance

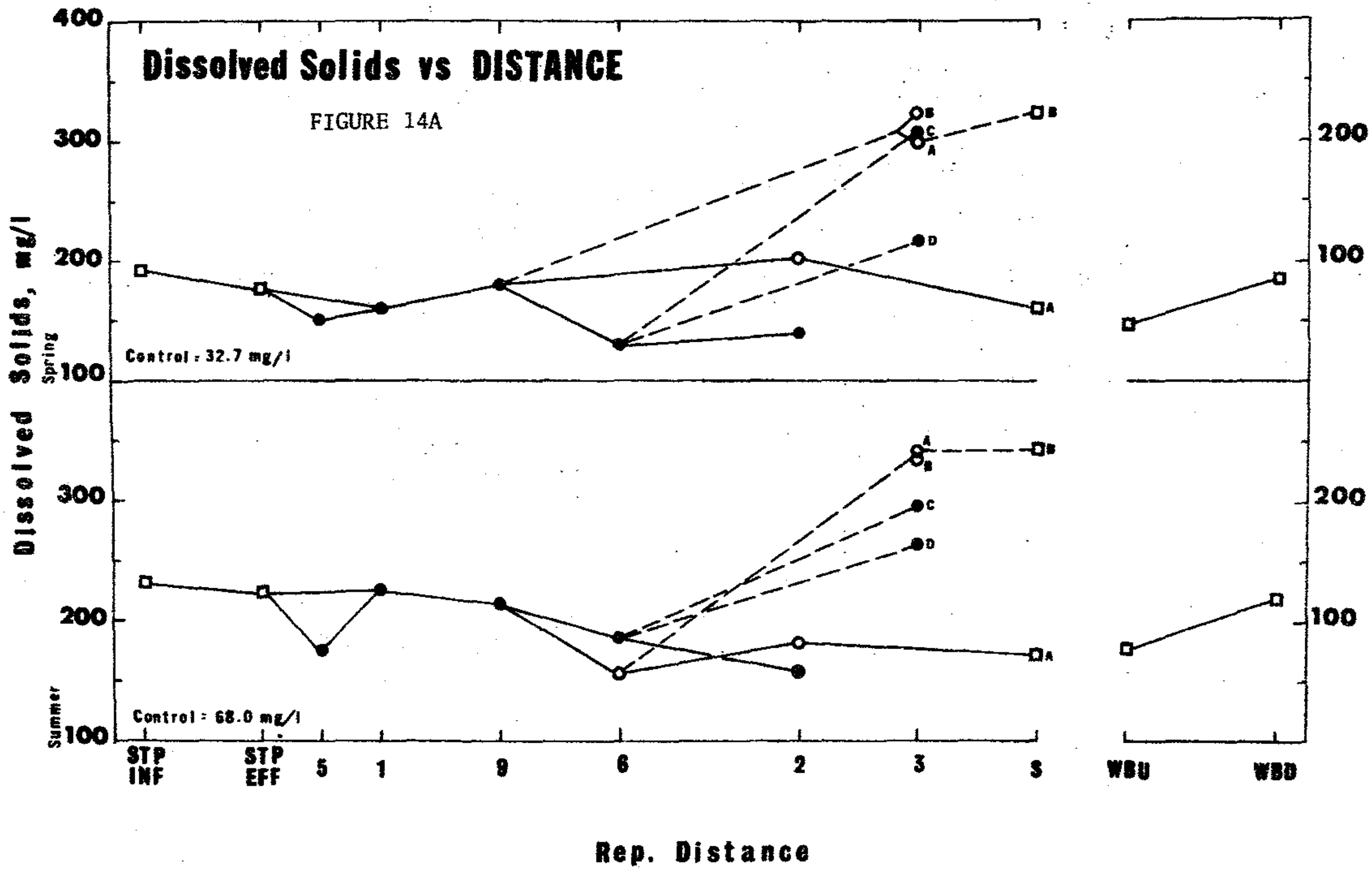
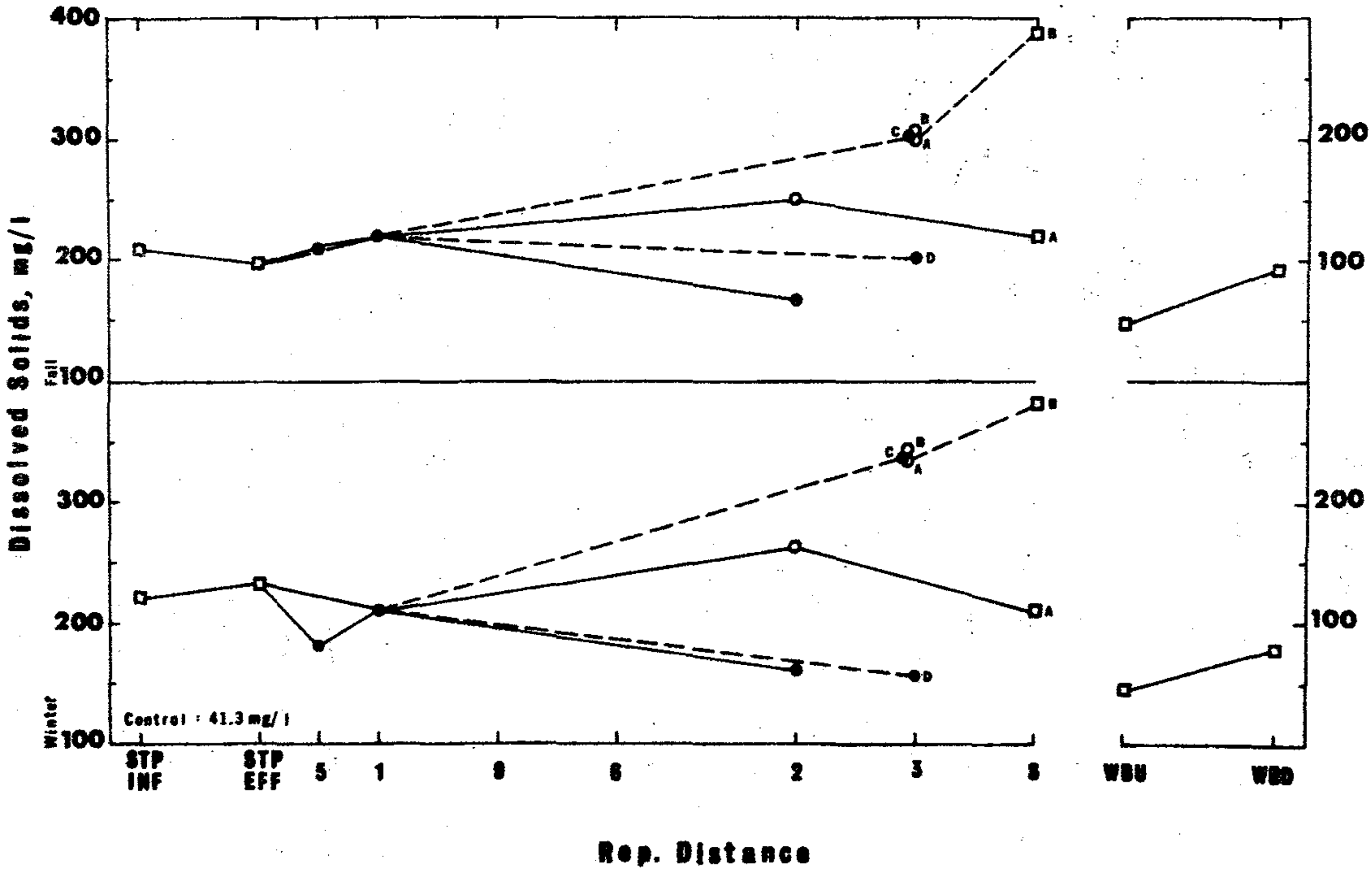

Dissolved Solids vs DISTANCE
FIGURE 14A
Dissolved Solids, mg/l
Spring
Summer
Control : 32.7 mg/l
Control : 68.0 mg/l
400
300
200
100
STP INF
STP EFF
5
1
9
6
2
3
S
WBU
WBD
A
B
C
D
Rep. Distance

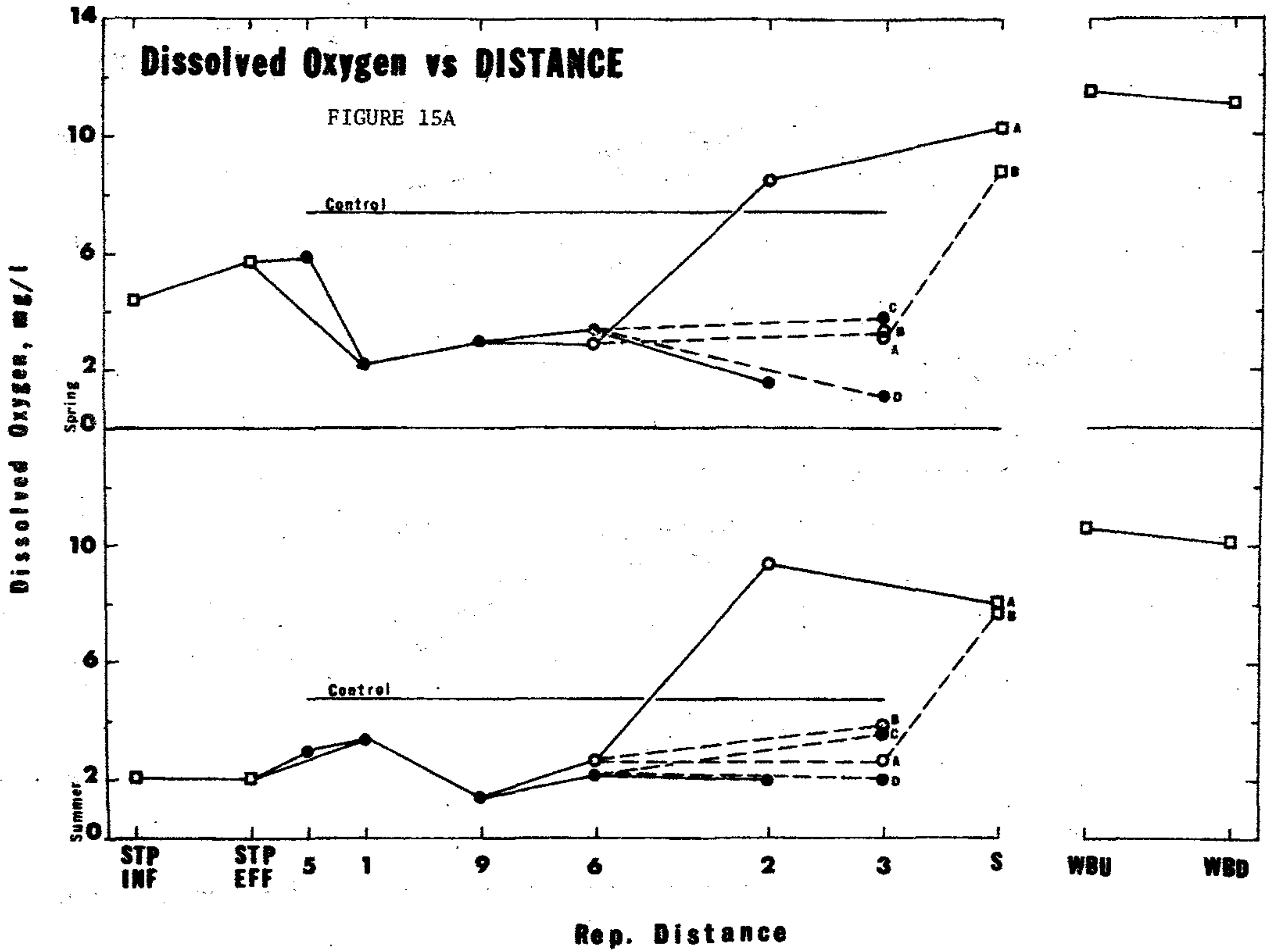
FIGURE 14B


Dissolved Solids, mg/l
Fall
Winter
400
300
200
100
Control : 41.3 mg/l
STP INF
STP EFF
5
1
8
6
2
3
S
WBU
WBD
Rep. Distance

below Gage Road. What is interesting to note is the fluctuation of the dissolved solids of the control which had a value during the summer twice that of the value during the spring. This may represent dilution by snow melt during the spring season at which time the water level at this location is higher. West Brook definitely shows an increase in dissolved solids as it passes by the two seepage areas.

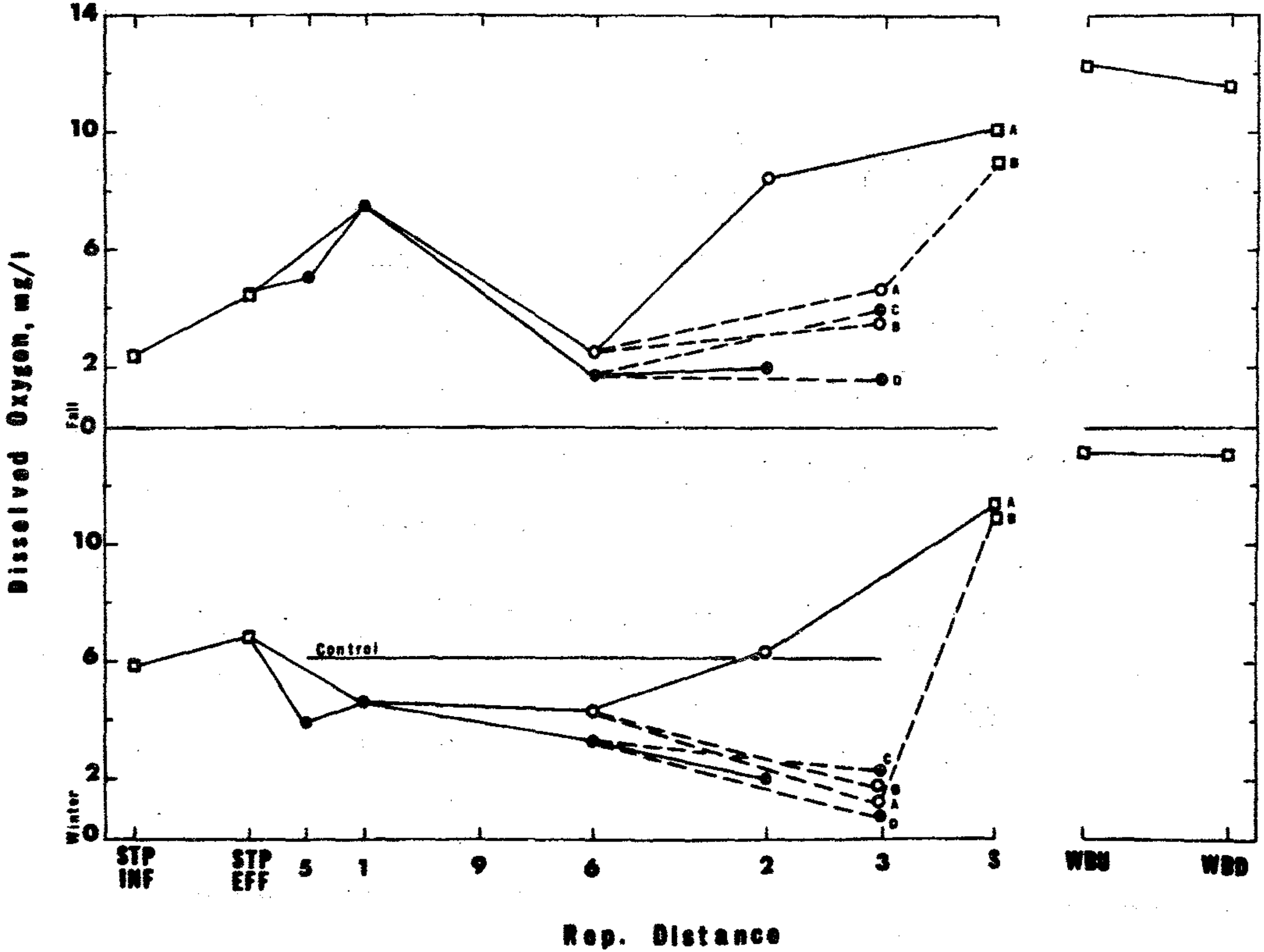
The seasonal dissolved oxygen changes are shown in Figures 15A and B. It may be noted that there was dissolved oxygen present in the saturated ground water at all times and in all seasons. The lowest dissolved oxygen level of approximately 1 mg/l was observed at well 3D during the winter and spring periods. Well 2A always had significantly more dissolved oxygen than the deeper well 2B. The seepage was generally high in dissolved oxygen and there was a very slight decrease in dissolved oxygen in West Brook in flowing past the point where the two seepages discharge into the stream. In general the dissolved oxygen in levels of all sampling locations were lower during the summer than in the other seasons.

Inspection of the data showed there was little significant seasonal variation in the levels of the nitrogen components in the entire system. What was more significant was the inter-relationship between the various forms of nitrogen in passing through the system. These are shown in Figure 16 which was plotted with the concentration on a log scale in order to portray the very low concentrations of certain forms of nitrogen. In general, the total Kjeldahl nitrogen (TKN) generally decreased through the treatment plant and the soil system. However, there was a significant increase at well 6B. The ammonia nitrogen on the other hand decreased rapidly through the treatment plant to well 9 and then increased at well 6

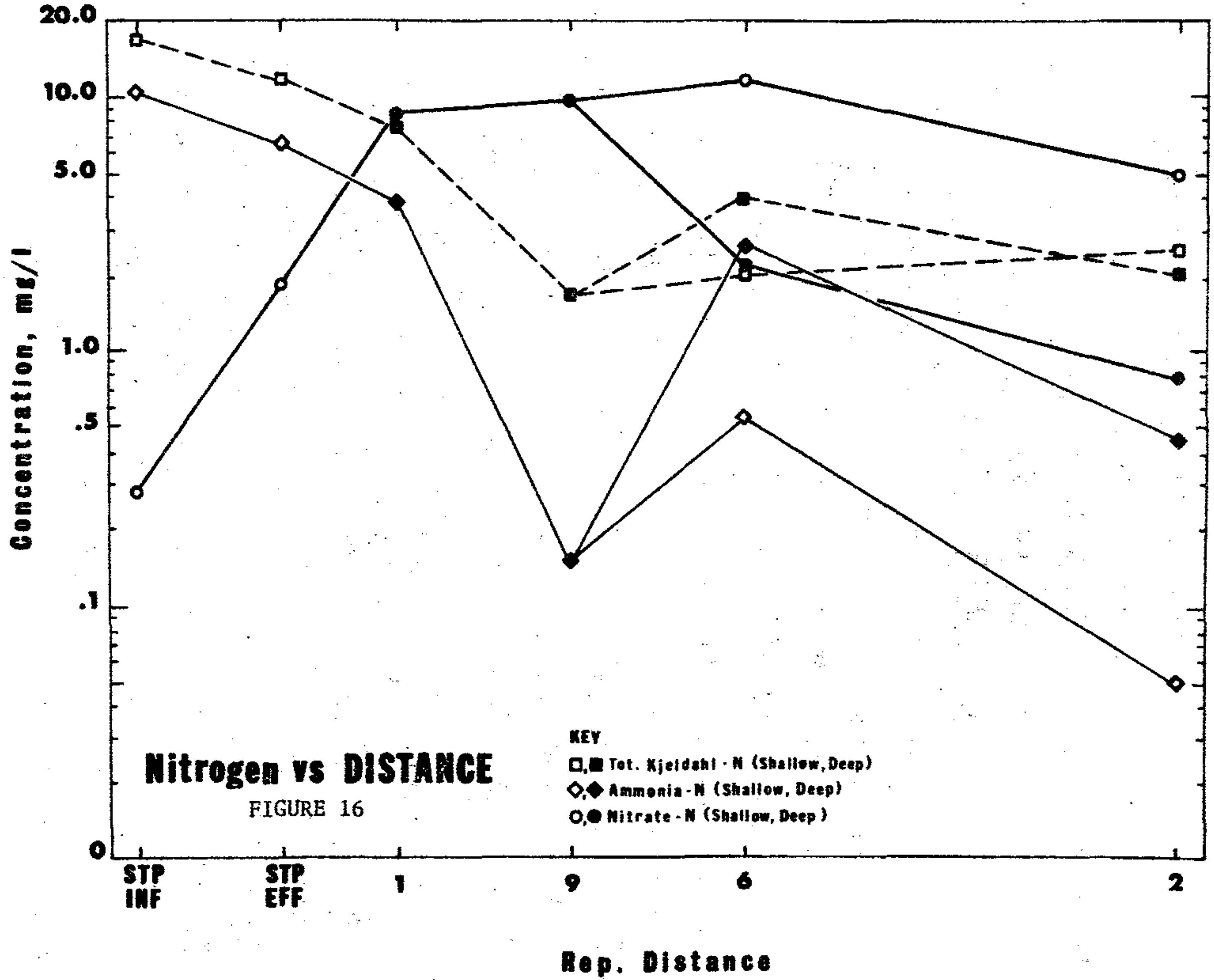


Dissolved Oxygen vs DISTANCE
FIGURE 15A
Control
Control
14
10
6
2
0
10
6
2
0
Spring
Summer
Dissolved Oxygen, mg/l
A
B
C
D
STP INF
STP EFF
5
1
9
6
2
3
S
WBU
WBD
Rep. Distance

FIGURE 15B



14
10
6
2
0
10
6
2
0
Fall
Winter
Dissolved Oxygen, mg/l
Control
A
B
C
D
STP INF
STP EFF
5
1
9
6
2
3
S
WBU
WBD
Rep. Distance

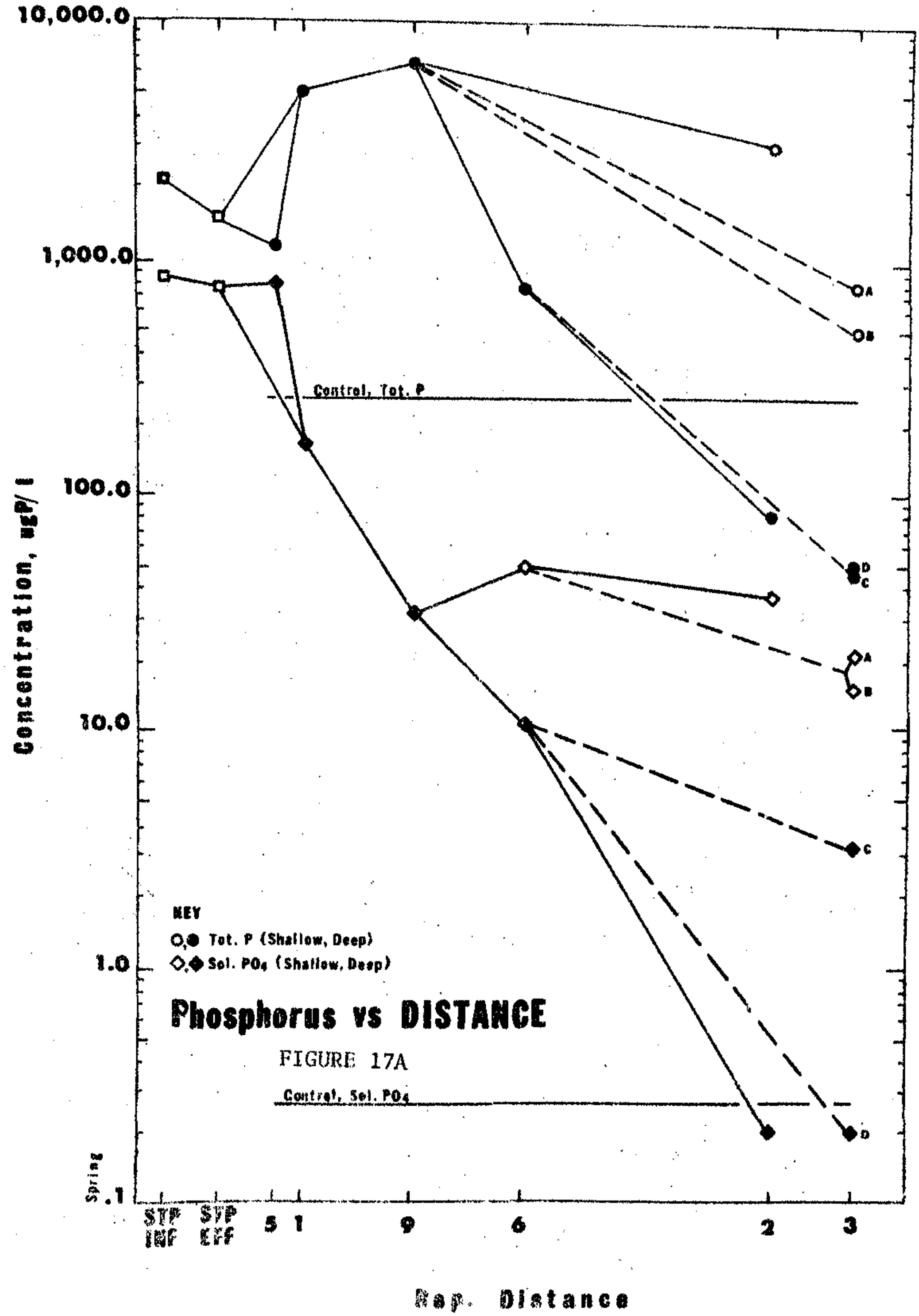


Nitrogen vs DISTANCE

FIGURE 16

and to a greater degree in the deeper well 6B. Thereafter,to well 2 there was further reduction in the ammonia nitrogen. Conversely, as the TKN and the ammonia nitrogen decreased the nitrate nitrogen increased. There was, however, a significant reduction in the nitrate content at well 6B and a still further reduction at well 2B. No explanation is available at the present time as to the reasons for the decrease in nitrate and the increase in the ammonia content at well 6B. The results indicate the reduction in nitrate to ammonia but no information is available on the possible production of nitrogen gas. In general there is a slight reduction in the total nitrogen through the entire treatment system, indicating some form of nitrogen removal in the system.

The total phosphorous and the ortho-phosphate for the samples through the treatment system are shown in Figures 17A, B and C for the spring, summer and winter, respectively. The ortho-phosphate represents ortho or reactive phosphate in filtered samples. The total phosphorous represents acid digestible and particulate phosphate. In some instances the amount of particulates in the well samples is significant. Insufficient data were available during the fall to calculate a representative average value. With the exception of the summer ortho-phosphate values, there was a reduction in both the total phosphates and the ortho-phosphorous in the sewage treatment plant. The levels in the sewage treatment plant effluent range from approximately 0.5 to 5 mg/l (note: again the log scale for phosphorous concentration). The concentrations of phosphorous were higher during the summer, possibly caused by the greater number of persons contributing to the flow and the lower infiltration rates during this drier season of the year. In all cases the concentrations of phosphorous in



Phosphorus vs DISTANCE

FIGURE 17A

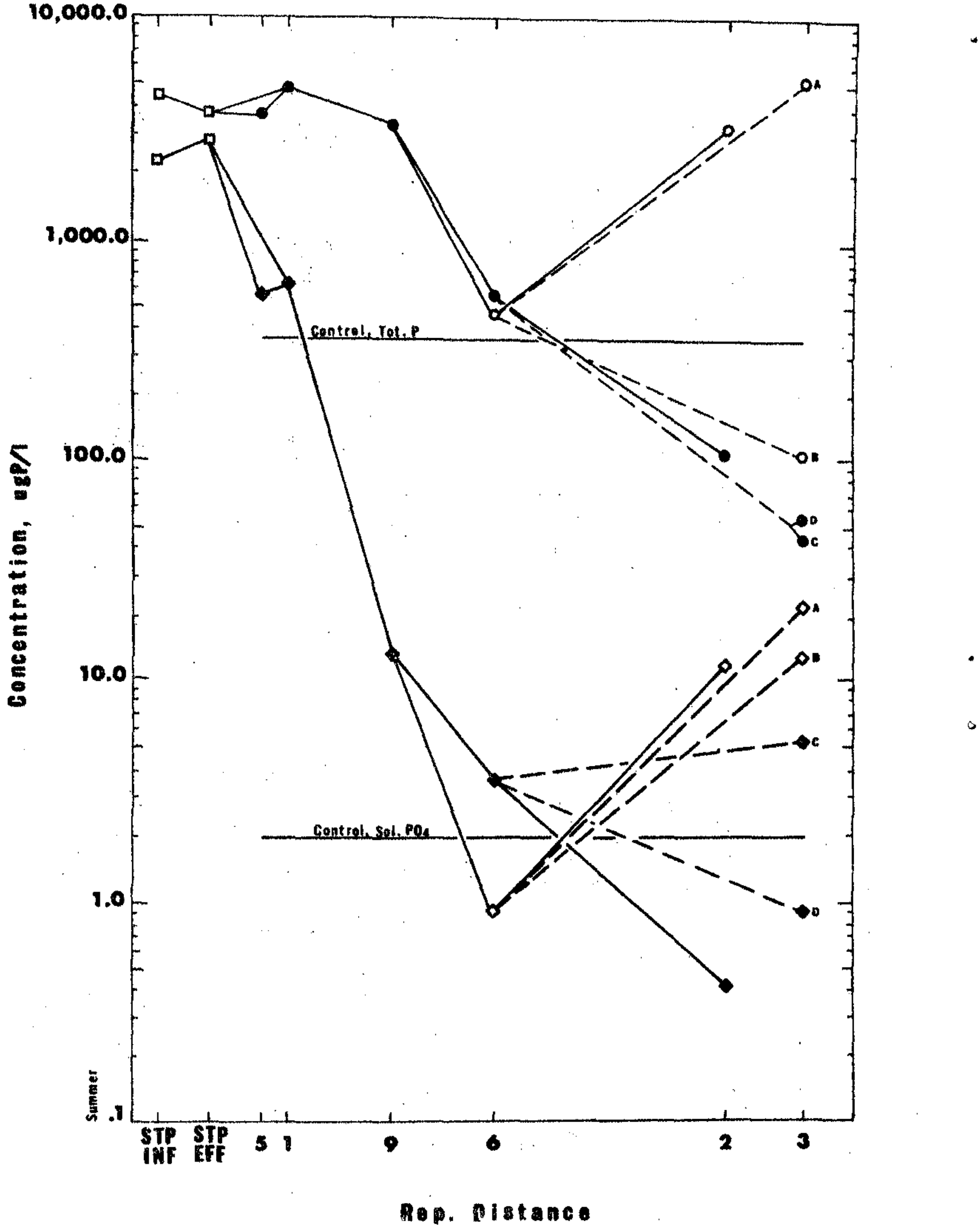
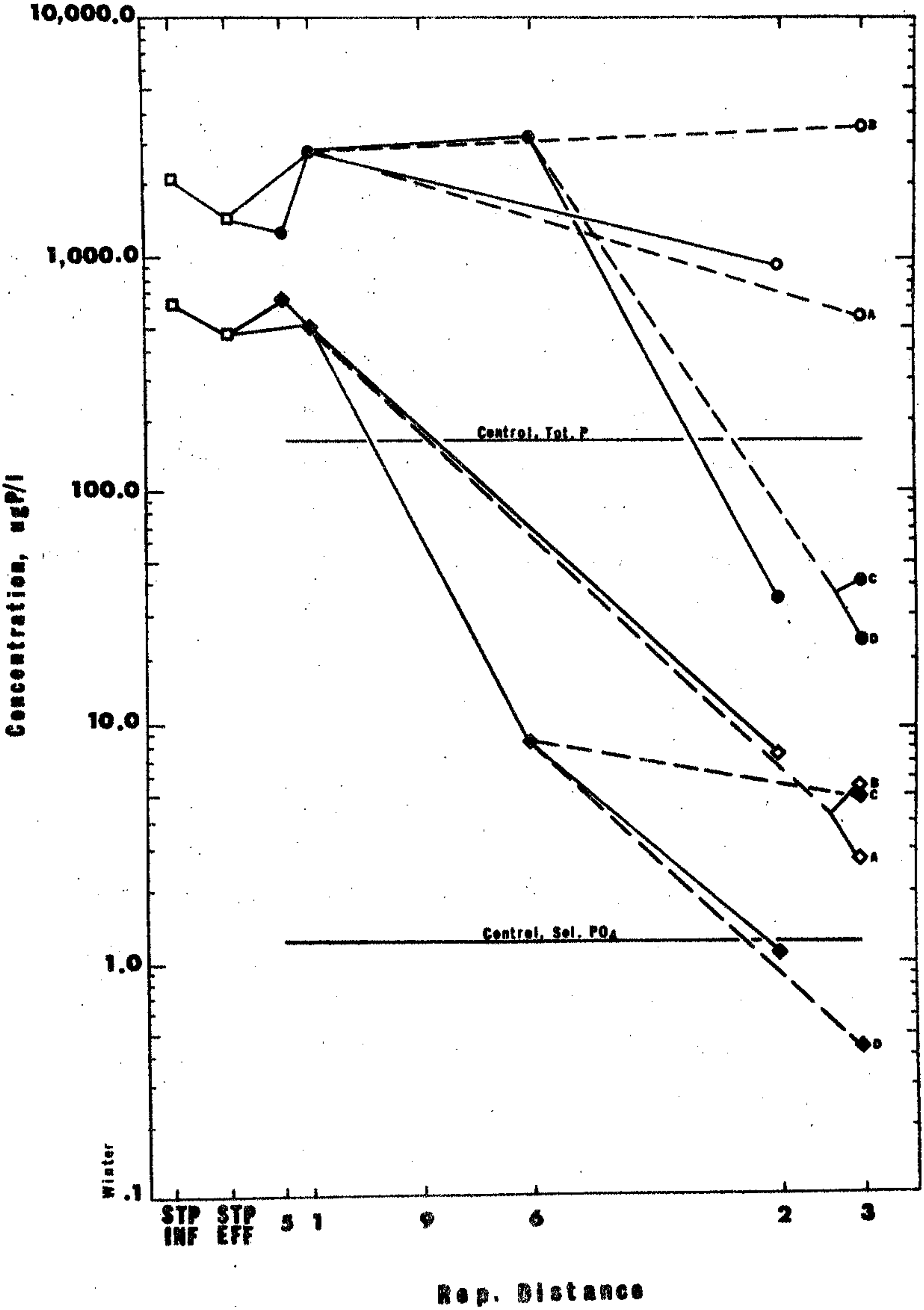

10,000.0
1,000.0
100.0
10.0
1.0
.1
Concentration, ugP/l
Control, Tot. P
Control, Sol. PO4
A
B
C
D
Summer
STP INF
STP EFF
5
1
9
6
2
3
Rep. Distance

FIGURE 17C



10,000.0
1,000.0
100.0
10.0
1.0
.1
Winter
Concentration, ugP/l
Control, Tot. P
Control, Sol. PO_4
B
A
C
D
B
C
A
D
STP INF
STP EFF
5
1
9
6
2
3
Rep. Distance

well 5 in the upper (south) sand bed were lower than in the sewage treatment plant effluent. However, at well 1 in the lower (north) sand beds the concentration of total phosphorous was consistently higher than in the sewage treatment plant effluent, whereas the ortho-phosphate values were lower during spring and summer. During the spring well 9 exhibited the highest total phosphorous content although here again the ortho-phosphate continued to be reduced during the spring and winter, although there was a slight increase at wells 2 and 3 during the summer. The concentrations of both total and ortho-phosphate were reduced to values equal to or below the respective values in the control well 10. It must be noted, particularly for the ortho-phosphate, that the concentrations were reduced to values below 10 ug/l. The increases in total phosphorous throughout the year at wells 1 and 9 and also at well 6 in winter, while there was a corresponding decrease in ortho-phosphate at these locations and times, suggest a mechanism for phosphorous removal. The ortho-phosphate may be converted to soluble organic forms, or precipitated, in which form it accumulates in the sand system. Whether the increase in total phosphorous at well 6 in the winter is a function of greater distance of transport, temperature, and/or biological activity, is a point which warrants further study. Since the winter results preceded the spring and summer results, it may be concluded that the appearance of the high phosphorous concentration in well 6 during the winter is not the result of phosphorous breakthru on a long term basis.

It may be seen that the complete treatment system at the Lake George Village Sewage Treatment Plant including the preliminary secondary treatment and the final treatment through the sand system is providing an adequate degree of treatment during all seasons. This includes the periods of stress during the summer caused by the large tourist population which results in increased flows and concentrations of constitutents, and the winter period during which time biological degradation is retarded due to the lower temperatures. By the time the liquid reappears as seepage along West Brook in the area of Gage Road, the dissolved oxygen level is high, the nitrogen has been mostly oxidized to nitrate and the phosphorous is reduced to levels equal to or below those in the natural ground water. Increases in alkalinity, chlorides and dissolved solids are apparent in the seepage and produce measureable increases in West Brook as it collects the seepage from this area. Other measurements made included those for coliforms and BOD. In both cases, these levels were extremely low (essentially non-existent). It may be stated that the seepage as it appears along the bank of West Brook is of satisfactory drinking water quality and could be used as a drinking water supply. There is a moderately elevated nitrate content in the order of 7 to 8 mg/l which is within the drinking water standards of 10 mg/l. [11,12] By the time this is diluted by a factor of approximately 10 in West Brook, there is no significant degradation of the quality of the water within West Brook. The phosphorous levels are reduced to values in the range of 1 ug/l of ortho-phosphate and 100 ug/l of total phosphorous. These are not seen to be harmful to either West Brook or Lake George. By the time the seepage is diluted with the waters of West Brook the concentration of total phosphorous is less than the 10 micrograms per liter suggested for control of excessive algae growths. [13] Thus it can be concluded that the Lake George Village Sewage Treatment Plant is not creating any excessive strain upon the quality of the water in Lake

George. Furthermore the studies indicate that the disposal of sewage treatment effluent onto the soil can provide the equivalent of tertiary treatment, particularly from the standpoint of phosphorous removal, and do it at a minimum cost reliably for a period of well over 35 years. These studies suggest that the disposal of sewage into the soil may prove to be a valid means for controlling nutrient inputs to lakes and streams. Further studies will have to be made to determine the effectiveness of septic tank systems in achieving a similar degree of nutrient removal. Continued use of the Lake George Village Sewage Treatment Plant can be expected to provide adequate protection of the quality of the water of Lake George from wastewaters generated in Lake George Village.

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REFERENCES

1. Aulenbach, Donald B., Glavin, Thomas P. and Romero Rojas, Jairo A., "Protracted Rechardge of Treated Sewage into Sand: Part I - Quality Changes in Vertical Transport Through the Sand", Ground Water, 12, 161 (1974) (RPI FWI Report 74-1).

2. Fink, William B. and Aulenbach, Donald B., "Protracted Recharge of Treated Sewage into Sand: Part II - Tracing the Flow of Contaminated Ground Water with a Resistivity Survey", Ground Water 12, 219 (1974) (RPI FWI Report 74-4).

3. Aulenbach, Donald B., Clesceri, Nicholas L., Ferris, James J., and Tofflemire, T. James, "Protracted Recharge of Treated Sewage into Sand: Part III - Nutrient Transport Through the Sand", Ground Water, 12, 301 (1974) (RPI FWI Report 74-5).

4. Aulenbach, Donald B., Clesceri, Nicholas L., and Tofflemire, T. James, "Water Renovation by Discharge into Deep Natural Sand Filters". Proceedings of the Second National Conference on Complete WateRuse, AIChE, Chicago, May 4-8, 1975 (RPI FWI Report 74-20).

5. Aulenbach, Donald B., Clesceri, Nicholas L., and Tofflemire, T. James, "Thirty-five Years of Continuous Discharge of Secondary Treated Effluent Onto Sand Beds", P. II-25 in Environmental Impact and Linkages, edited by David W. Eckhoff, Assoc. of Environ. Eng. Professors, (1974) (RPI FWI Report 74-19).

6. Aulenbach, Donald B., Clesceri, Nicholas L., Ferris, James J., and Tofflemire, T. James, "Thirty-five Years of Use of a Natural Sand Bed for Polishing a Secondary Treated Effluent", pp. 227-240 in Water Pollution Control in Low Density Areas, edited by William J. Jewell and Rita Swan, University Press of New England, Hanover, N.H. (1975) (RPI FWI Report 73-15).

7. Aulenbach, Donald B., and Tofflemire T. James, "Thirty-five Years of Continuous Discharge of Secondary Treated Effluent onto Sand Beds", Ground Water, 13, 161 (1975).

8. Aulenbach, Donald B., Tofflemire T. James, Clesceri, Nicholas L., Beyer, Steven and Hajas, Louis, "Water Renovation Using Deep Natural Sand Beds", Proceedings of the 30th Industrial Waste Conference, Purdue University, Engineering Extension Series No. , (1975) (RPI FWI Report 75-2).

9. Aulenbach, Donald B., Clesceri, Nicholas L., Tofflemire, T. James, Hajas, Louis and Beyer, Steven, "Tertiary Treatment by Soil at Lake George Village Sewage Treatment Plant". Presented at Joint Meeting of New England and New York Water Pollution Control Associations, Lake Placid, N.Y., June 8-11, 1975 (RPI FWI Report 75-5).

10. Aulenbach, Donald B., Clesceri, Nicholas L., Tofflemire, T. James, Beyer, Steven and Hajas, Louis, "Water Renovation Using Deep Natural Sand Beds", AWWA 67, 510 (1975).

11. U.S. Public Health Service, Drinking Water Standards, 1962, U.S. Dept. of Health, Education and Welfare.

12. Environmental Protection Agency, Interim Primary Drinking Water Standards, (40 CFR Part 141) (FRL 343-8) Federal Register 40, No. 51, p. 11990, March 14, 1975.

13. Vollenweider, R. A., Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters with Particular Reference to Nitrogen and Phosphorous as Factors in Eutrophication, OECD, Directorate for Scientific Affairs, Paris, (1968).