USE OF TRACERS TO CONFIRM GROUND WATER FLOW

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Donald B. Aulenbach and Jeffrey H. Bull
Rensselaer Polytechnic Institute
and
Bradford C. Middlesworth
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Donald B. Aulenbach
Jeffrey H. Bull
Department of Chemical and Environmental Engineering
Rensselaer Polytechnic Institute
Troy, New York 12181

Bradford C. Middlesworth
The Research Corporation of New England
125 Silas Deane Highway
Wethersfield, Connecticut 06109

ABSTRACT

Both rhodamine WT and tritium were found to be satisfactory tracers to determine the direction and velocity of flow of the secondary treated effluent from the Lake George Village Sewage Treatment Plant which is applied to natural delta sand beds by the rapid infiltration technique. The average vertical velocity in the unsaturated portion of the sand bed was approximately 0.85 m/day (2.8 ft/day). The horizontal flow in the saturated aquifer reached between 10 and 12 m/day (33-40 ft/day). The velocity appeared to decrease with distance from the sand infiltration beds, although this may have been the result of a change in direction of the major portion of the ground water flow with the observation well not being in direct line of the direction of flow. Unfortunately, the dye could be traced only slightly less than half the distance from the sand infiltration beds to the seepage area adjacent to West Brook. Thus, a positive determination that the seepage consists primarily of sewage effluent and the ultimate time of flow to the seepage could not be determined in this study.

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INTRODUCTION

Lake George is a beautiful recreational lake located in the eastern portion of the Adirondack Park of eastern New York. (See Figure 1). The lake is used for recreational purposes such as swimming, boating, fishing, scuba diving, and water skiing and in addition is used as a drinking water supply for the Village of Lake George and many of the homes surrounding the lake. The lake has a special AA classification (1) which means the water can be utilized for public drinking supply with only chlorination to control any potential disease producing organisms. Many of the individual homeowners utilize the water directly from the lake with no treatment whatsoever.

In order to maintain the high purity of the waters of Lake George, special precautions have been taken. Septic tanks in the watershed are monitored to prevent any direct discharge to the lake. No discharges of any kind are permitted from boats within the waters of Lake George and special precautions are taken to provide for waste disposal on the public

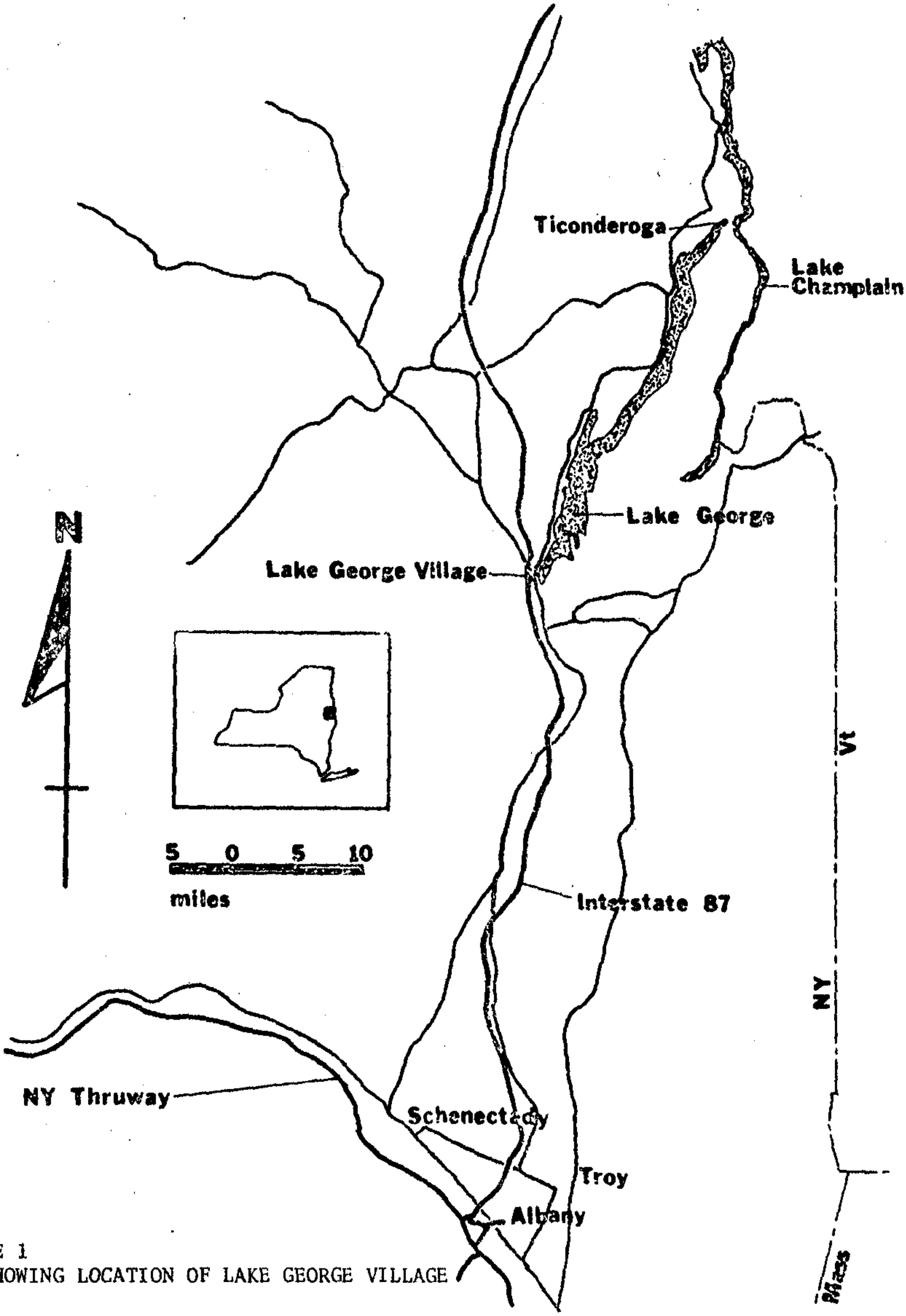


FIGURE 1
MAP SHOWING LOCATION OF LAKE GEORGE VILLAGE

camping islands. To assure the constant high quality of the waters of the lake, legislation has been passed (2) which prohibits discharge of any sewage or sewage effluent into the lake or into any tributary which flows into Lake George. In consideration of the high concentration of population at Lake George Village around the southern edge of the lake, a sewage collection system and treatment plant was put into operation to serve Lake George Village in 1939. The sewered area was expanded to include the adjacent Town of Lake George in 1965. The sewage is collected and conveyed by gravity to the lake level where at two different locations a pumping station is provided to lift the sewage through two separate force mains to the sewage treatment plant located approximately 1.6 km (1 mi) from the pumping station. The general relation of the sewage treatment plant and the Village and the lake is shown in Figure 2. The first part of the sewage treatment plant is quite conventional, consisting of two-compartment primary settling and sludge digestion tanks, two high-rate rotary and one fixed nozzle trickling filters, and secondary sedimentation. The plant was built in triplicate due to the fact that the summer flows during the tourist population peak are approximately 2 to 3 times the winter flows. During the summer the two high rate trickling filters are utilized, whereas during the winter only the fixed nozzle filter is used. This is covered with boards to prevent freezing of the filter bed during the extreme cold which is experienced during the winter in this area. The effluent from the secondary sedimentation tanks is placed upon sand beds which have been scooped out of the natural delta sand deposit on which the treatment plant was constructed. The original 6 sand infiltration beds have now been expanded to 21 with a total filter area of 2.15 hectares (5.3 acres). The preliminary portion of the treatment plant is considered to be designed

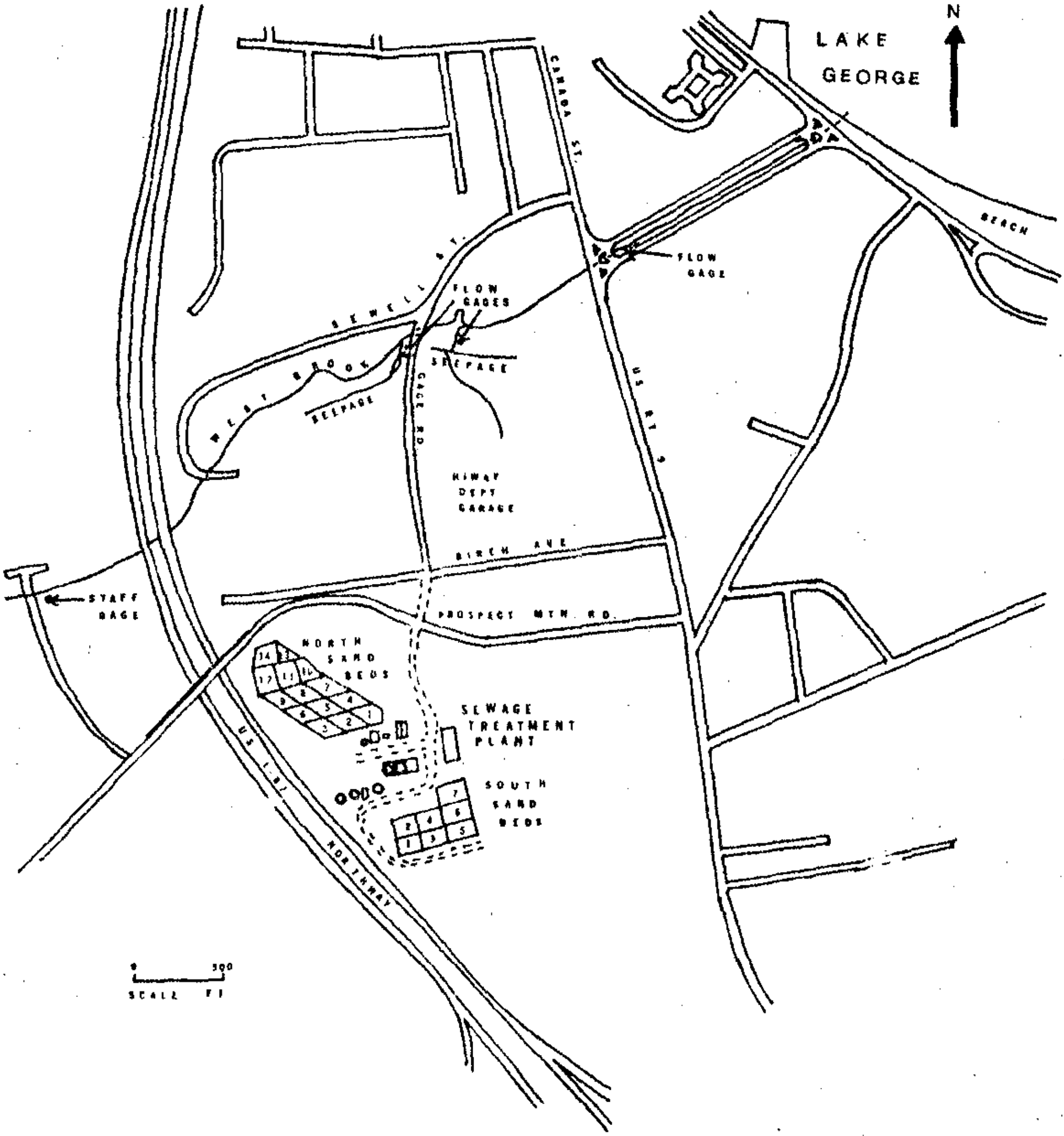


FIGURE 2
GENERAL AREA OF THE STUDY SHOWING THE RELATIONSHIP BETWEEN THE LAKE GEORGE VILLAGE SEWAGE TREATMENT PLANT AND LAKE GEORGE

for a flow of 1.75 mgd (6600 m^3/day). Maximum flows during the summer have been recorded at 1.25 mgd (4700 m^3/day). No chlorination is provided at the treatment plant. The general layout of the treatment plant is shown in Figure 3.

The normal operation of the sand beds is to dose one north and one south bed during the period from approximately 8 am to 4 pm and 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. During extremely high summer flows, additional beds are dosed as needed. Under normal operating conditions the beds drain dry in approximately 1 to 3 days. The beds are then allowed to dry as long as possible for aeration. With frequent dosing the beds slowly clog and the infiltration rate is decreased. Periodically, (approximately twice per year), the surface of the beds is scraped, a small amount of the sand is removed and the beds are raked and re-leveled and put back into service. The first few dosings after this cleaning procedure result in very high infiltration rates. Thereafter, they decrease somewhat to lower but more constant values.

As part of the overall concern for the introduction of nutrients into Lake George, questions were raised as to the efficiency of the treatment plant to prevent contamination of the lake from any potential nutrients which might pass through the treatment plant and the sand system, ultimately reaching Lake George. In the initial description of the treatment plant (3) it was stated that "the final effluent becomes ground water which in all probability seeps eventually, to some water course as a highly purified liquid which cannot be identified as a sewage effluent". However, there was no way to confirm this speculation since it was not known what became of the effluent after it infiltrated into the ground in the sand bed area.

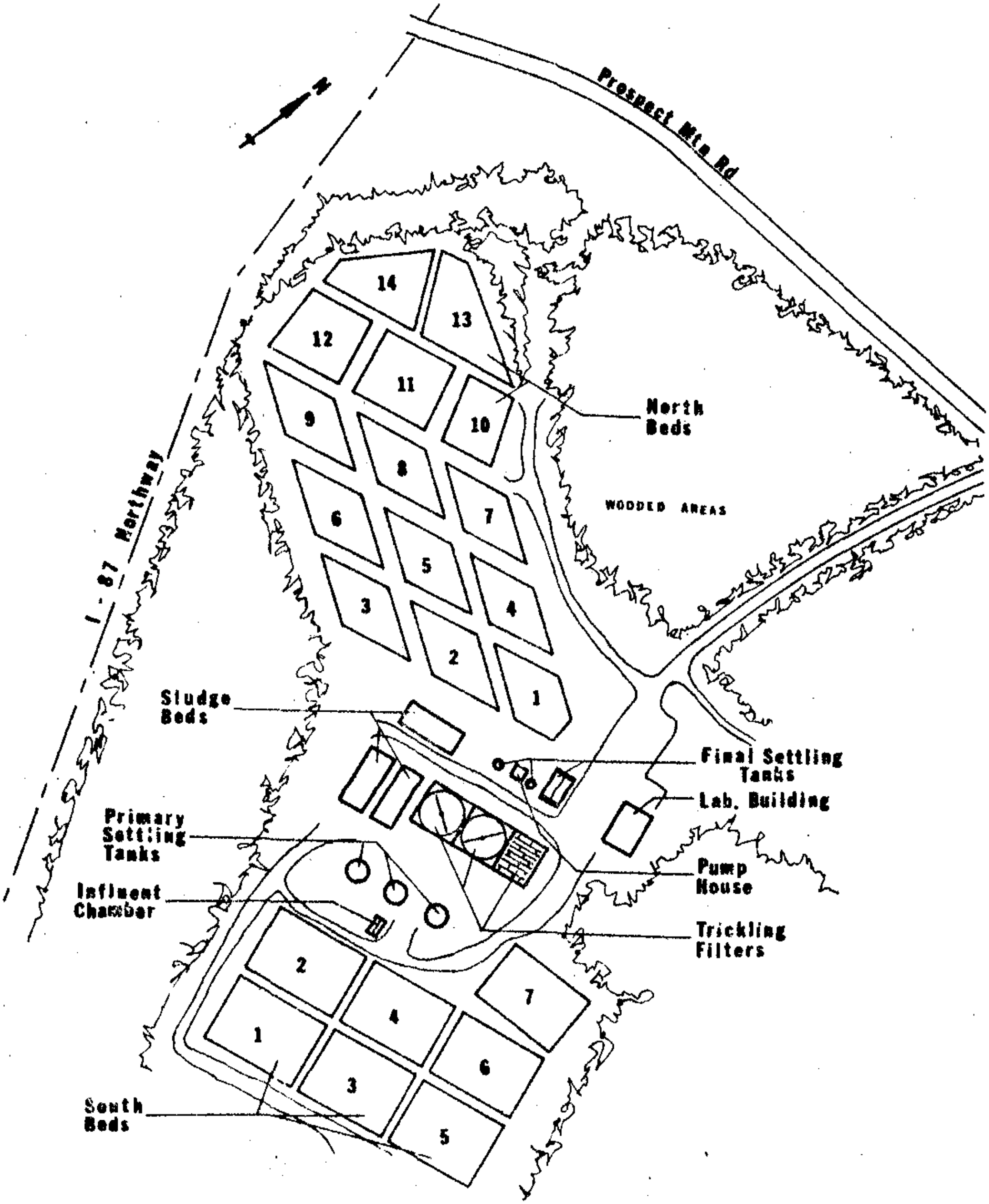


FIGURE 3
PLAN OF THE LAKE GEORGE SEWAGE TREATMENT PLANT

initial studies (4) in which Glavin and Romero tried to locate the presence of the sewage effluent in the ground water were unsuccessful. Further work by Fink (5) using a resistivity meter indicated a band of low resistivity ground water following a generally northerly direction along Gage Road toward West Brook (Figure 4). With this information at hand, a study was made on foot of the area along the south bank of West Brook both above and below Gage Road. A considerable amount of seepage was observed coming from the base of the hill which defines the flood plain of West Brook. The conductivity of the seepage showed highest values in the area very close to Gage Road with lower values in both a westerly and easterly direction from this location. The one exception was high values in the small drainage ditch which, it was found later, drains land on which the local highway department previously stored highway deicing salt for use during the winter. This has resulted in high conductivity measurement due to the sodium chloride which has gained access to the ground water. It was highly suspected that this seepage consisted at least in part of the effluent from the treatment plant.

Numerous studies (6-8) were conducted on the quality of the seepage in the area above and below Gage Road. These results showed that phosphorus levels in the seepage were about the same levels as the natural ground water in the area. However, nitrate levels in the order of 7-8 mg/l as N were observed in the seepage. The flow in West Brook is approximately 10 times the flow of the seepage; thereby reducing the nitrate nitrogen concentration in West Brook to approximately 0.8 mg/l. By the time this is diluted in Lake George there is no significant observable effect upon the lake. While the results indicated no adverse pollutional effects upon Lake George from the nutrients in the seepage, it remained

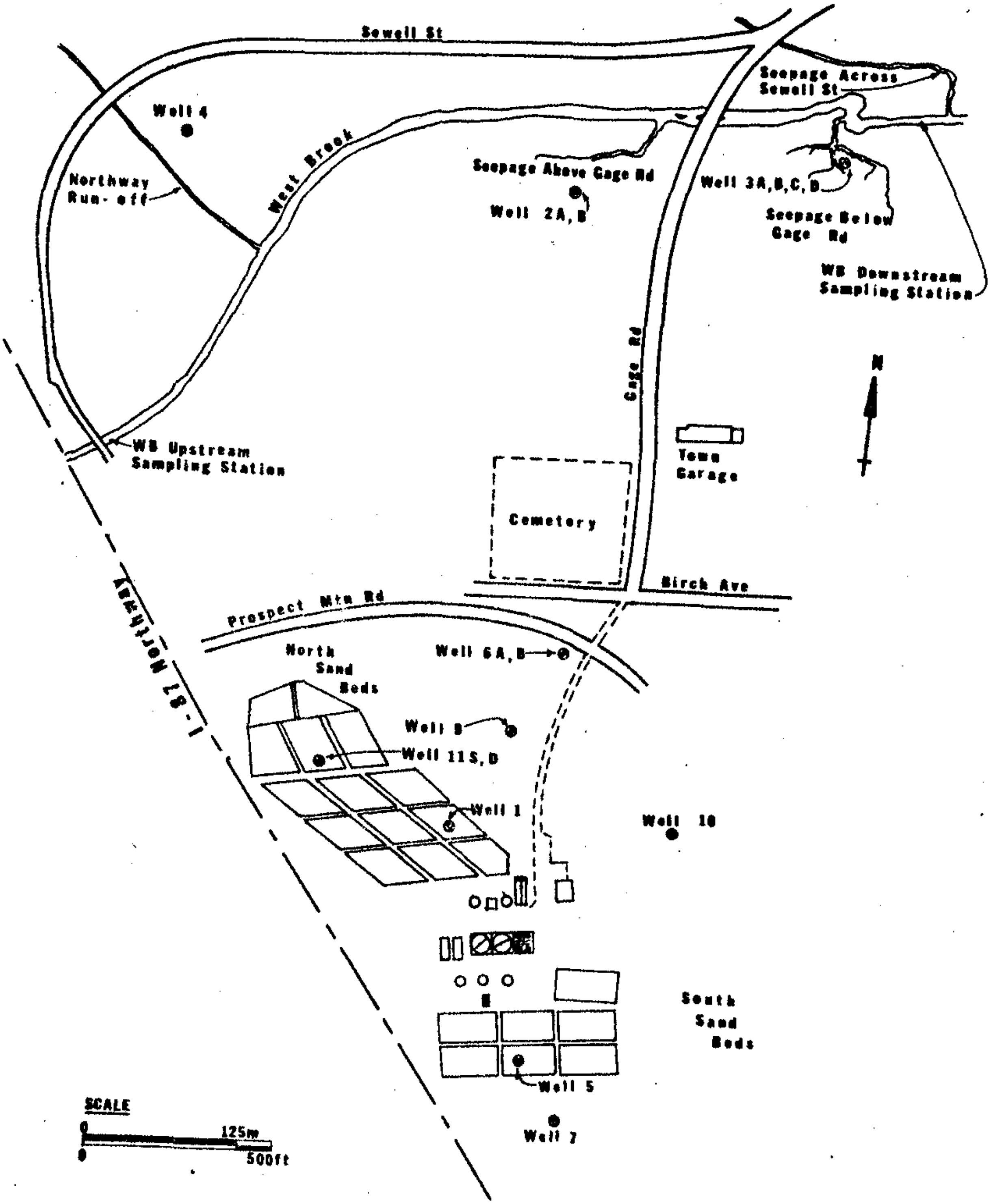


FIGURE 4
MAP OF THE GENERAL AREA OF THE STUDY SHOWING THE OBSERVATION WELLS AND OTHER SAMPLING POINTS USED IN THIS STUDY

to be proven that the liquid in the seepage positively was the effluent applied to the sand beds. Furthermore, information was needed regarding the time of flow from the sand beds to the seepage area. This would provide needed information in calculating rates of changes and the time required for any changes, and would provide information for the design of similar systems. In order to confirm the direct contact of the applied sewage effluent with the seepage and to obtain information on time of flow in this system, tracer studies were conducted.

VERTICAL TRANSPORT

All of the studies to determine the rate of vertical flow through the sand beds were conducted using north bed 11 (See Figure 3). This is a moderately rapid sand bed and probably indicates average results of all of the sand beds. In the earlier studies (4) rhodamine B dye was used as the tracer and the intensity of the dye was measured using a fluorometer. The results indicated a vertical percolation rate of approximately 8 m/day (27 ft/day) in the top 1.5 m (5 ft) of the sand bed.

In order to make more extensive studies and to follow the vertical transport to the ground water beneath the sand beds, additional well points, lysimeters, and pumping wells were installed in north bed 11 as shown in Figure 5. The well points were driven into the sand at depth intervals of 2 ft (0.6 m) from 2 to 14 ft (0.6 to 4.3 m). The porous cup lysmieters were installed at 5 ft (1.5 m) intervals from 5 ft (1.5 m) to 65 ft (20.8 m). Only 4 of these lysimeters (at depths of 3, 7, 11 and 18 m) proved to be functional. In addition, two wells with 6 in (0.15 m) casings were equipped with submersible pumps to obtain samples directly from the aquifer under bed 11. The penetration of these wells and lysimeters into the bed

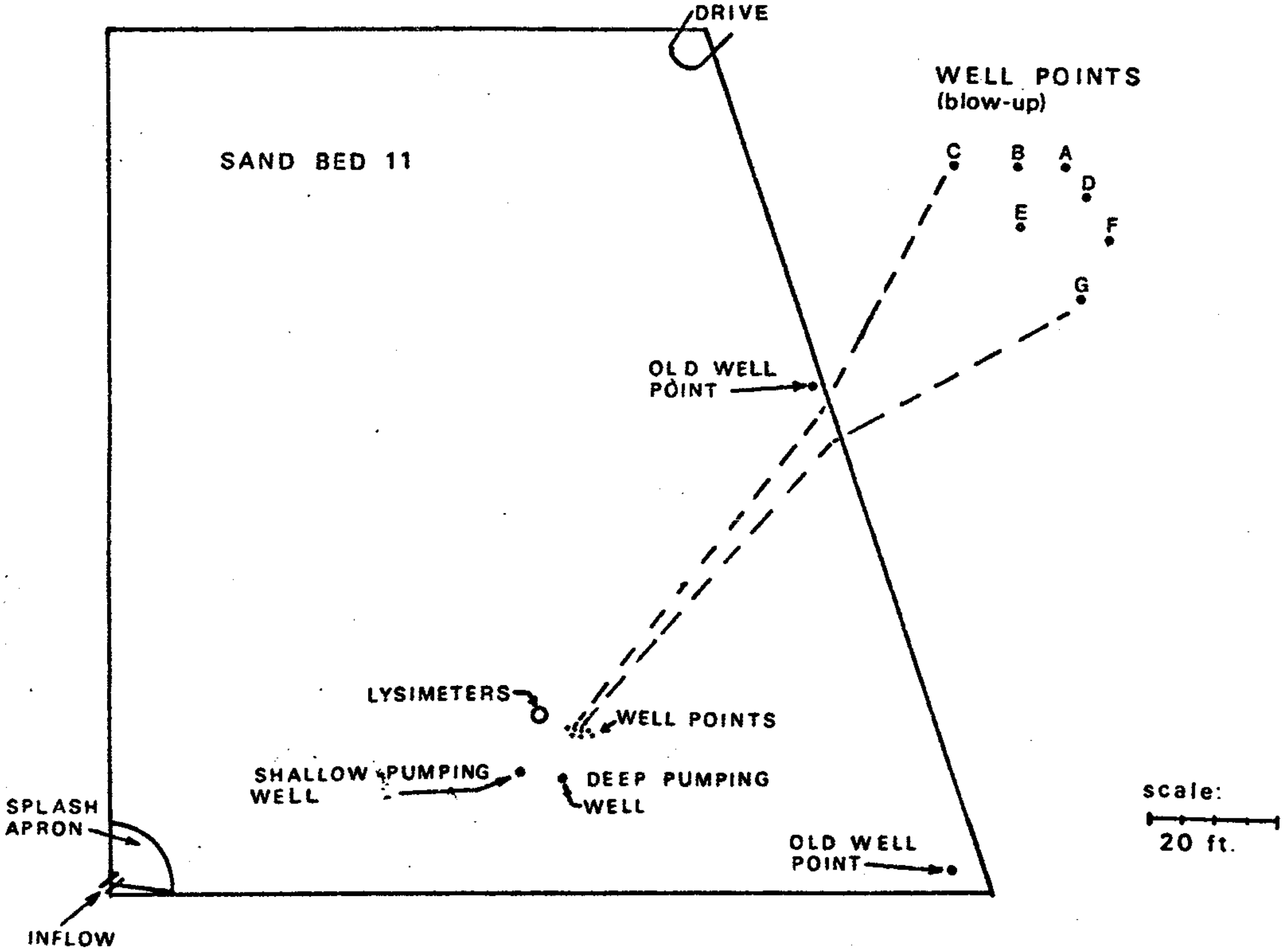


FIGURE 5
PLAN OF BED N11 SHOWING THE LOCATION OF THE DRIVEN WELL POINTS, THE LYSIMETERS AND THE SHALLOW AND DEEP PUMPING WELLS

are shown in Figure 6.

A preliminary dye study using rhodamine B was performed and found to be unsuccessful. The dye was not able to be recovered at even the 2 ft (0.6 m) driven well point. The study was then repeated using rhodamine WT which is less subject to adsorption onto the sand than rhodamine B. The results of this study are summarized in Figure 7. From the 10 to 60 ft depth the peak concentration showed approximately a straight line or a uniform flow through the sand bed. During the entire period of this study, the shallow well in the aquifer was pumped constantly and the first appearance of the dye in this well was observed 25 days after its addition to the bed. The pumping rate was purposely kept at a low value in order to reduce any effect of the drawdown on increasing the rate of flow from the surface of the ground water table to the location of the well screen.

The average velocity based on the peak concentration from the surface to the shallow pumped well was 0.7 m/day (2.32 ft/day). This is approximately 0.15 m/day (0.5 ft/day) less than the velocity calculated based on the first appearance of the dye in the ground water. The velocity of the liquid through the majority of the unsaturated zone was 0.55 m/day (1.8 ft/day). No dye was ever observed in pumping well 11D which was the deeper well in the aquifer.

HORIZONTAL FLOW IN THE SATURATED ZONE

It was hoped that the vertical flow study could be extended to measure the rate of horizontal flow within the saturated zone of the aquifer. However, complications with the test proved this to be unsuccessful. Therefore, additional studies were made to evaluate the horizontal flow

FIGURE 6
PROFILE OF BED N11 SHOWING THE DEPTHS OF THE DRIVEN WELL POINTS, THE OPERATIONAL LYSIMETERS AND THE SHALLOW AND DEEP PUMPED WELLS, THE LATTER TWO OF WHICH PENETRATE INTO THE SATURATED AQUIFER

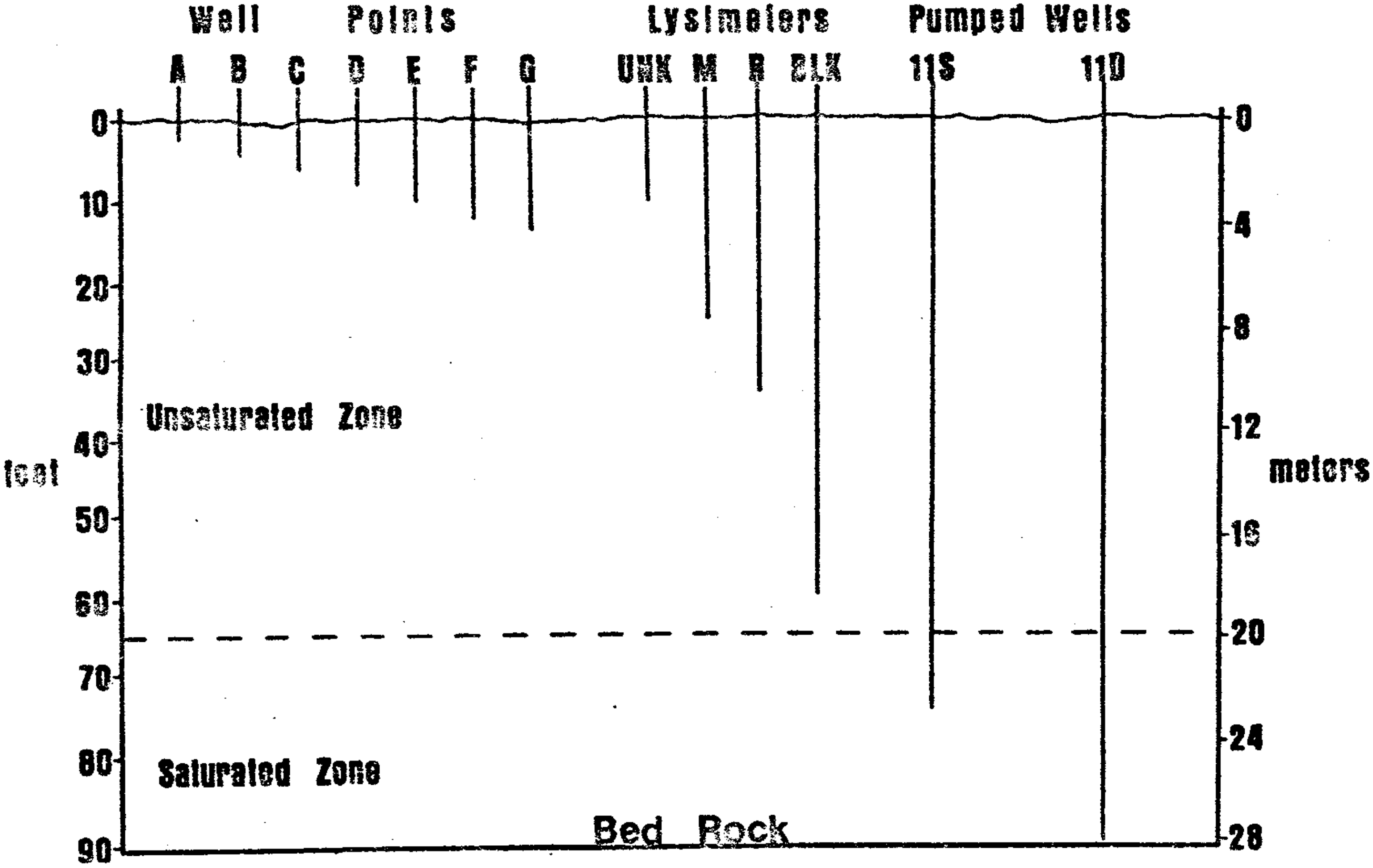
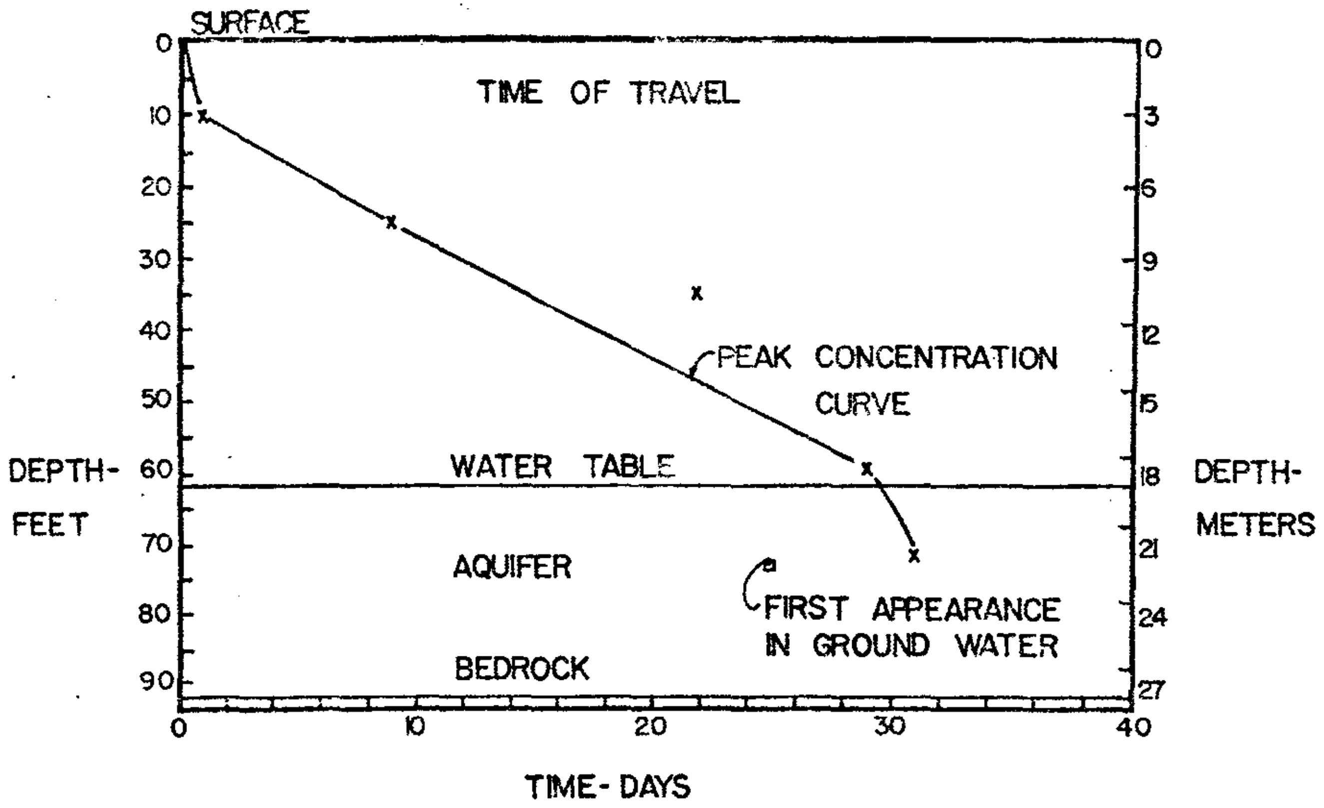


FIGURE 7
VERTICAL TRANSPORT OF RHODAMINE WT IN BED N11



within the saturated aquifer. In order to enhance the results it was decided that tritium would be the most desirable tracer for this portion of the study. Tritium reacts essentially the same as water and therefore flows through the soil system based on tritium measurements would reflect most accurately the actual flow of the water. Furthermore, it may be detected in very low concentrations and therefore its addition would not affect either ground water or surface water supplies into which it ultimately might flow. It was considered that a 0.1 Ci dose of tritium would be sufficient to be detected within the dilution of the treatment plant flow and the ground water. The one disadvantage of using tritium as a tracer is that it cannot be detected visually and must be measured by appropriate instrumentation. The instruments used in this study were both a Packard and a Beckman Liquid Scintillation Detector. In addition, to the tritium tracer, rhodamine WT was utilized as a secondary tracer, since this could potentially be determined visually and show when to concentrate the sampling for the tritium measurements.

In the first study, the tracers were placed in the ground water aquifer through well 11S, the shallower pumping well in the aquifer under bed N11. Unfortunately neither of the tracers could be detected in any of the observation wells in the area between bed N11 and West Brook (See Figure 4).

A second study was conducted also using 0.1 Ci of tritium and rhodamine WT by applying the tracers to the surface of bed N4 (see Figure 3). A new observation well, well 14 (see Figure 4) was installed specifically to recover the tracers very close to the edge of the sand infiltation beds. Again, this study proved unsuccessful as neither tracer was observed in any of the observation wells.

In view of the failure of the first two tracer studies, a new approach was used. In order not to lose the tracer by means of dilution it was decided to use the south sand beds where there is less distance to the ground water and also less ground water available for dilution. The bed chosen for the study was S3 (see Figure 3). This bed has only 5.5 m of sand above the bed rock and the water level was approximately 4.2 m from the ground surface, with the thickness of the aquifer approximately 1.3 m. Furthermore, there was an existing observation well (No. 5) located in this sand bed. In order to assure the tracer would be detected, a new ring of observation wells was installed to the north of bed S3 as shown in Figure 8. It was the intent to place alternate wells at the top of the aquifer and at the bottom or bedrock. In general, the thickness of the aquifer in this area was less than 2 m so that it made little difference whether the point was stopped as soon as ground water was encountered or whether the point was driven to the bedrock. At least 3 attempts were made to drive observation well 21. Unfortunately rock was struck in all instances prior to reaching ground water. Apparently there is a large rock in this area which actually splits the flow of the water from the south sand beds, causing the effluent to flow around this rock. This test was successful with the tritium and rhodamine being recovered in numerous observation wells. The recovery of the tritium and the rhodamine in the various observation wells is summarized in Figures 9 through 16. It may be seen that the results for the tritium and the rhodamine WT corresponded quite well. No results are shown for observation well 19 because between the time of installing this well and starting the study the ground water level dropped and no samples could be secured from this well. Also, no tracer was observed in any wells farther north than wells 6. Unfortunately at the

FIGURE 8
EXPANDED VIEW OF THE SOUTH SAND BEDS AND THE NEW OBSERVATION WELLS INSTALLED FOR THE TRACER STUDY

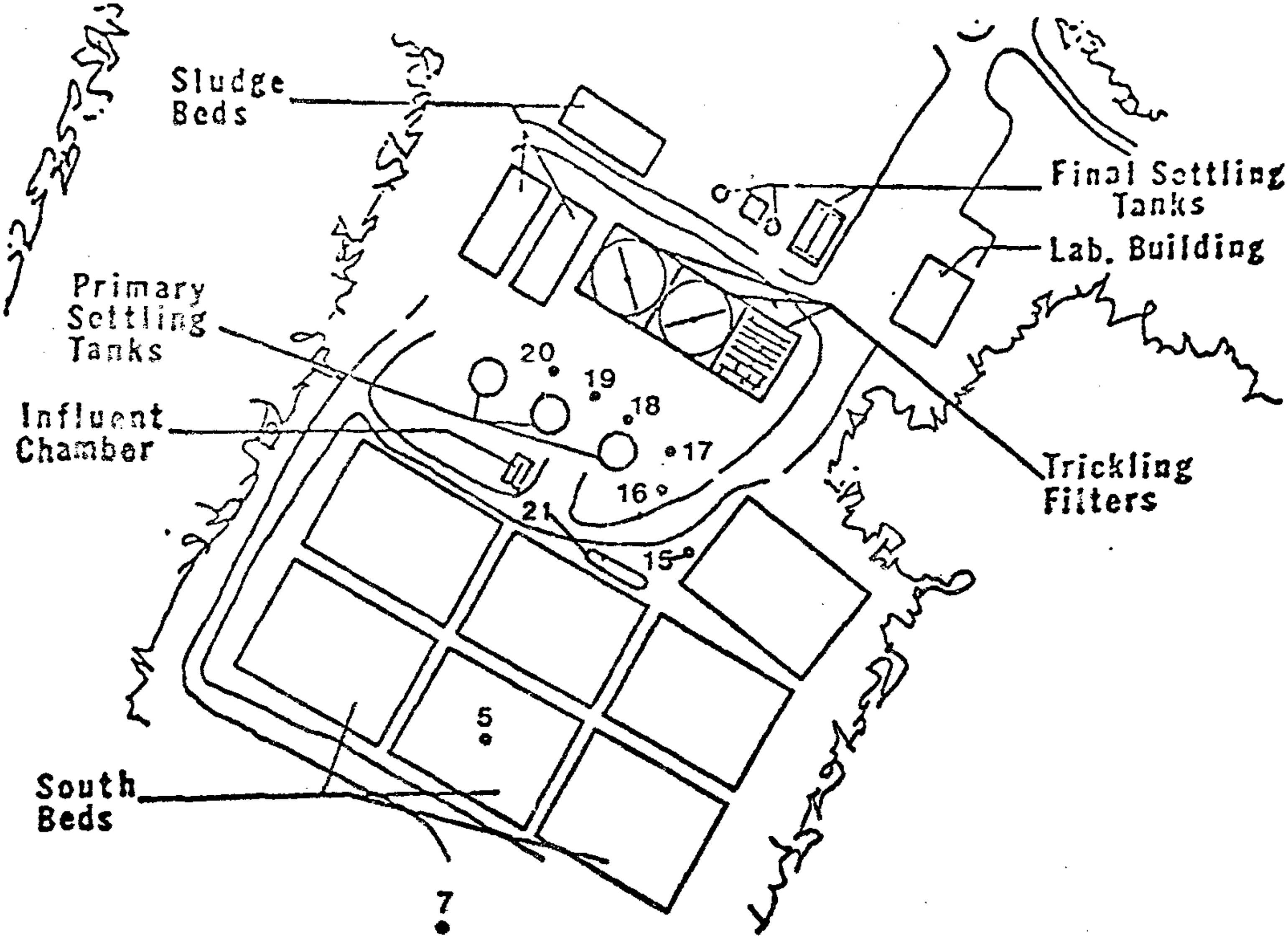


FIGURE 9
CONCENTRATION OF THE TRACERS WITH TIME FROM THE START OF THE TRACER STUDY IN OBSERVATION WELL 5

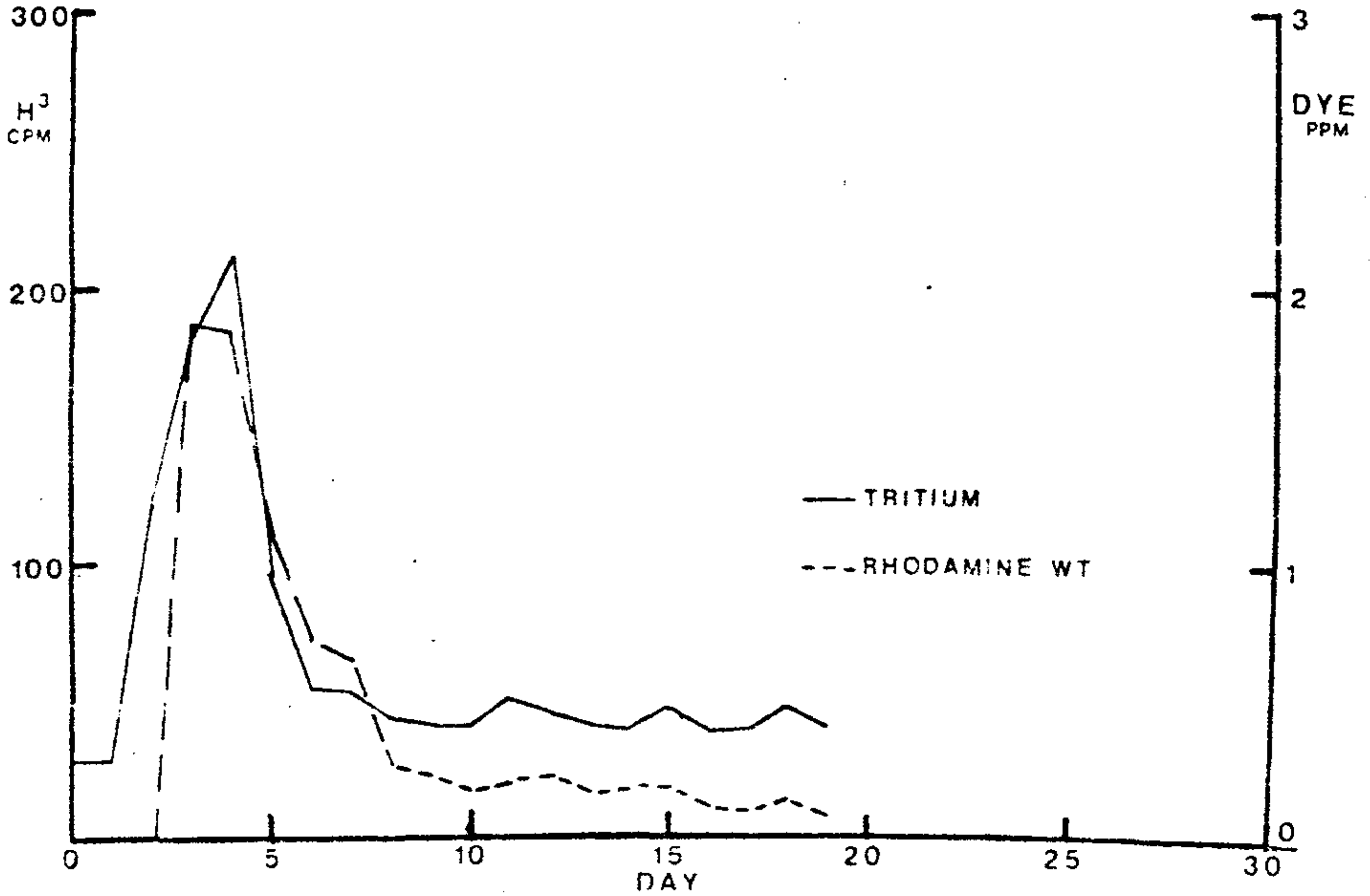


FIGURE 10
CONCENTRATION OF THE TRACERS WITH TIME FROM THE START OF THE TRACER STUDY IN OBSERVATION WELL 15

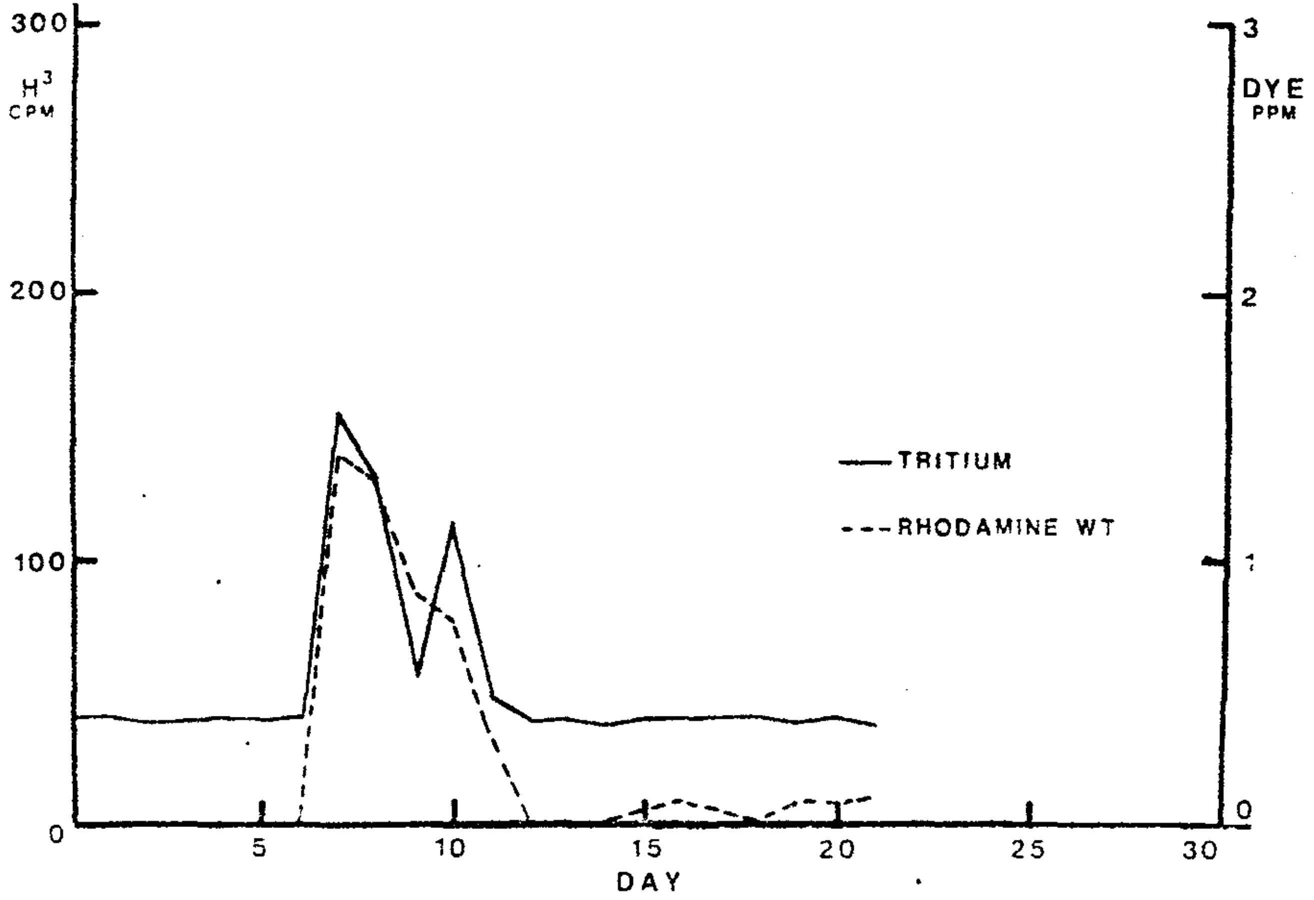


FIGURE 11
CONCENTRATION OF THE TRACERS WITH TIME FROM THE START OF THE TRACER STUDY IN OBSERVATION WELL 16

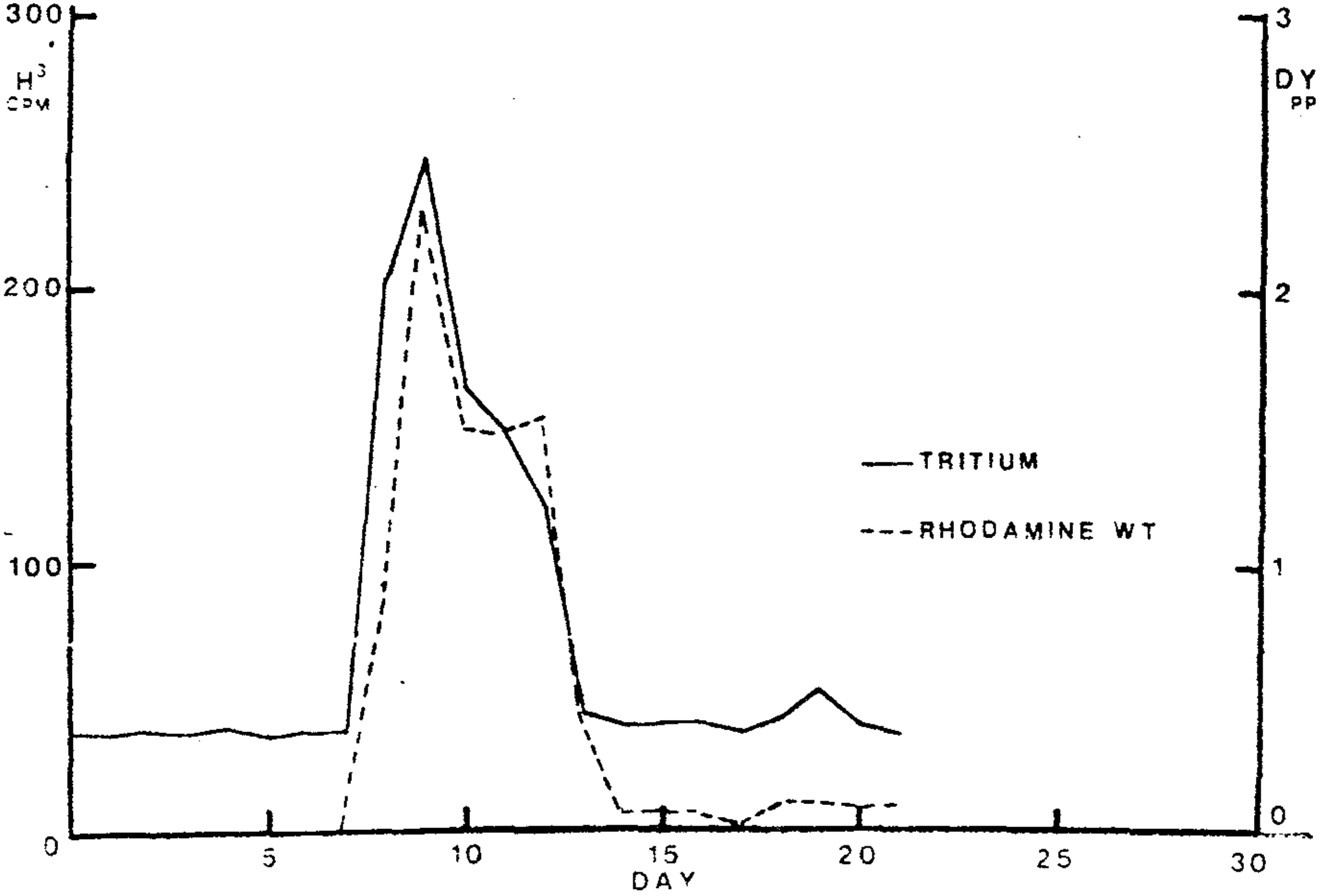


FIGURE 12
CONCENTRATION OF THE TRACERS WITH TIME FROM THE START OF THE TRACER STUDY IN OBSERVATION WELL 17

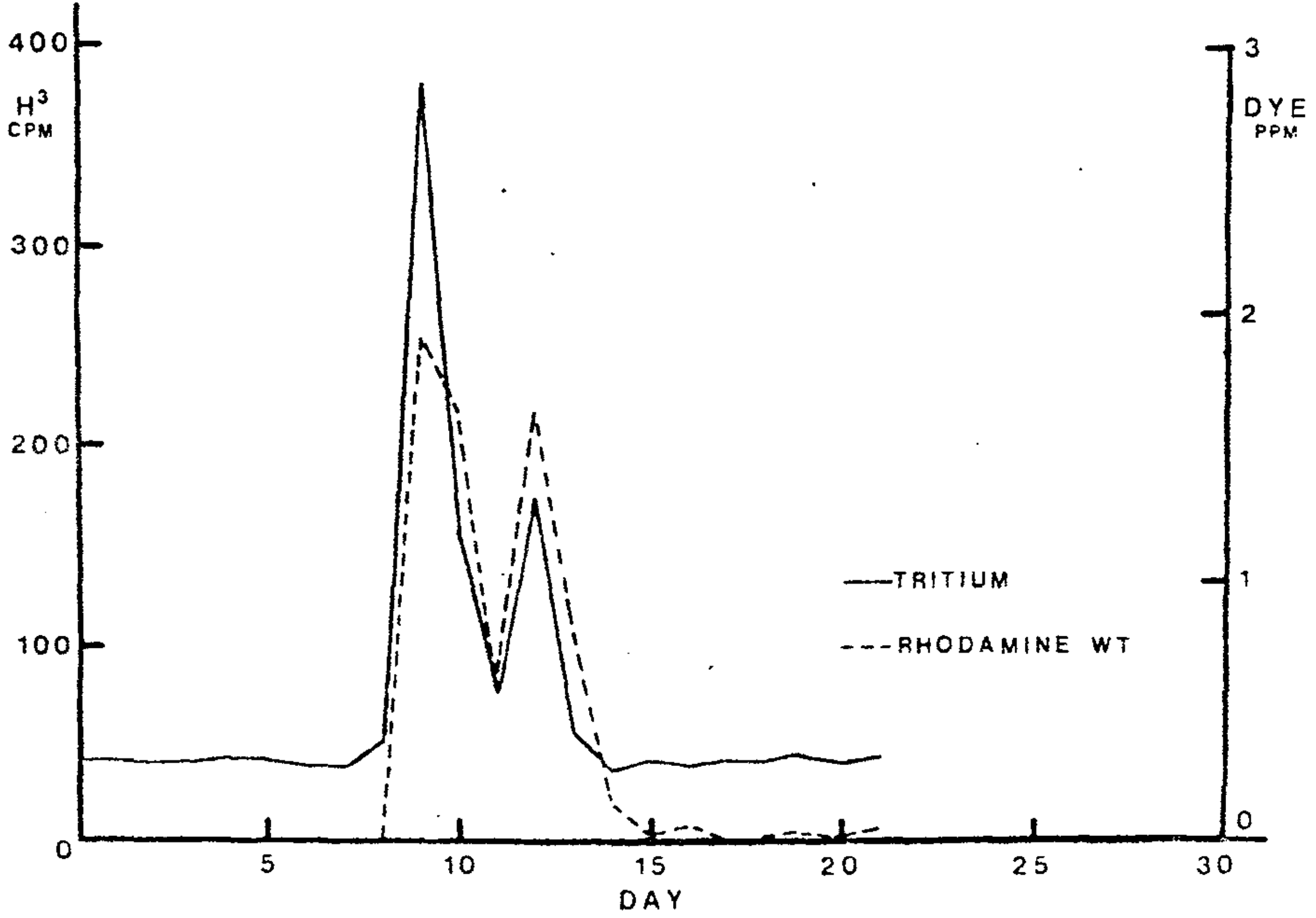


FIGURE 13
CONCENTRATION OF THE TRACERS WITH TIME FROM THE START OF THE TRACER STUDY IN OBSERVATION WELL 18

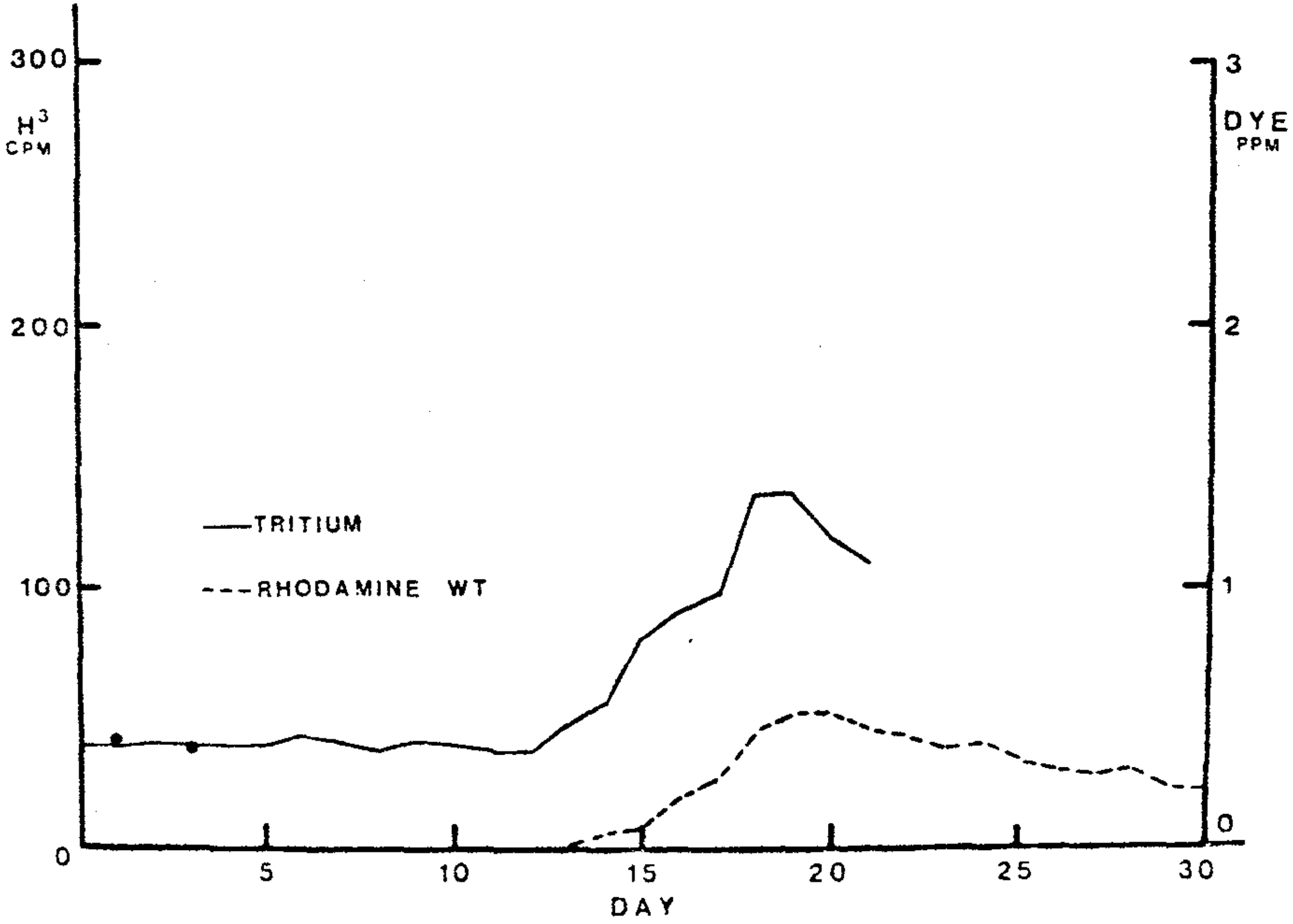


FIGURE 14
CONCENTRATION OF THE TRACERS WITH TIME FROM THE START OF THE TRACER STUDY IN OBSERVATION WELL 20

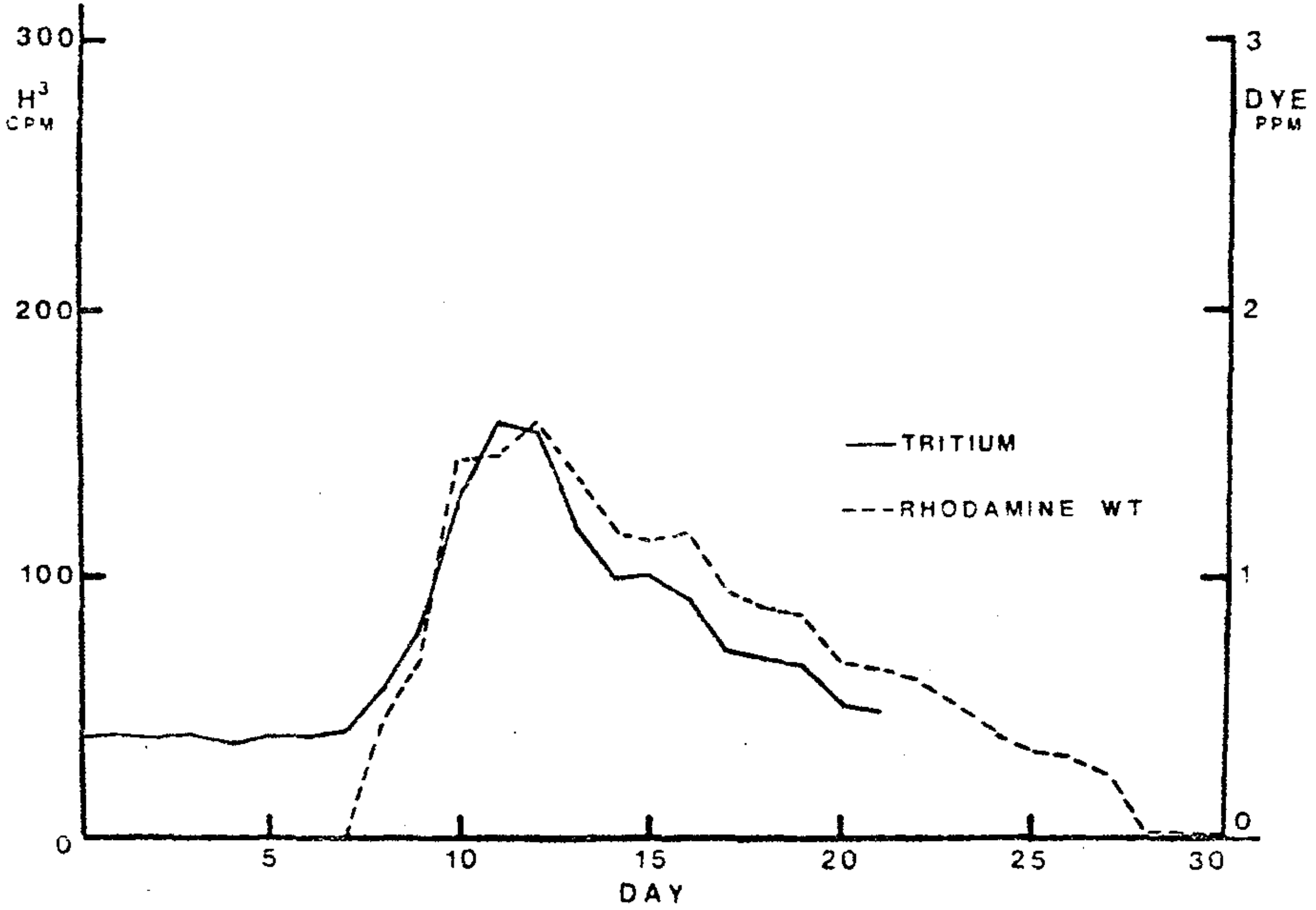


FIGURE 15
CONCENTRATION OF RHODAMINE WT WITH TIME FROM THE START OF THE TRACER STUDY IN OBSERVATION WELL 9

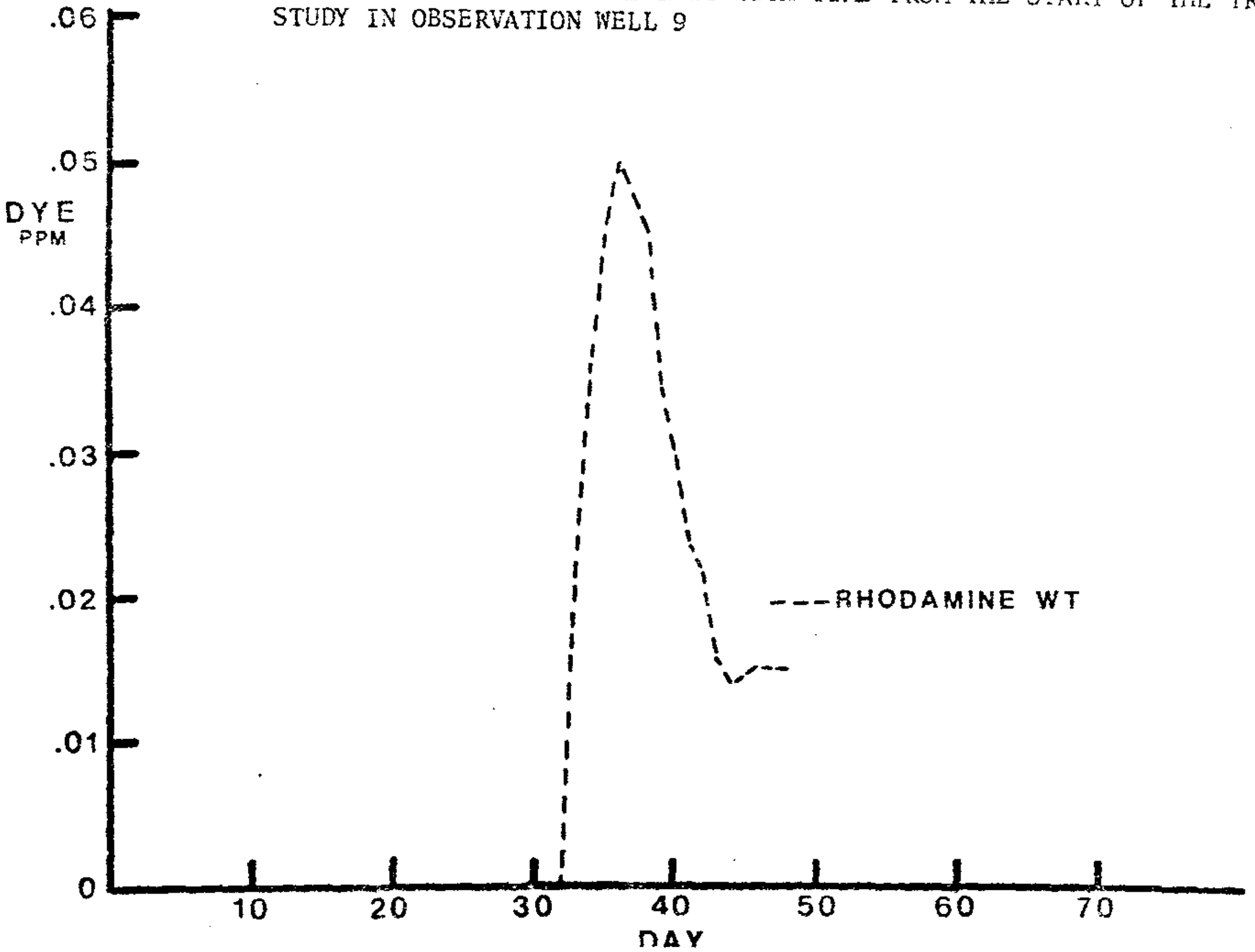
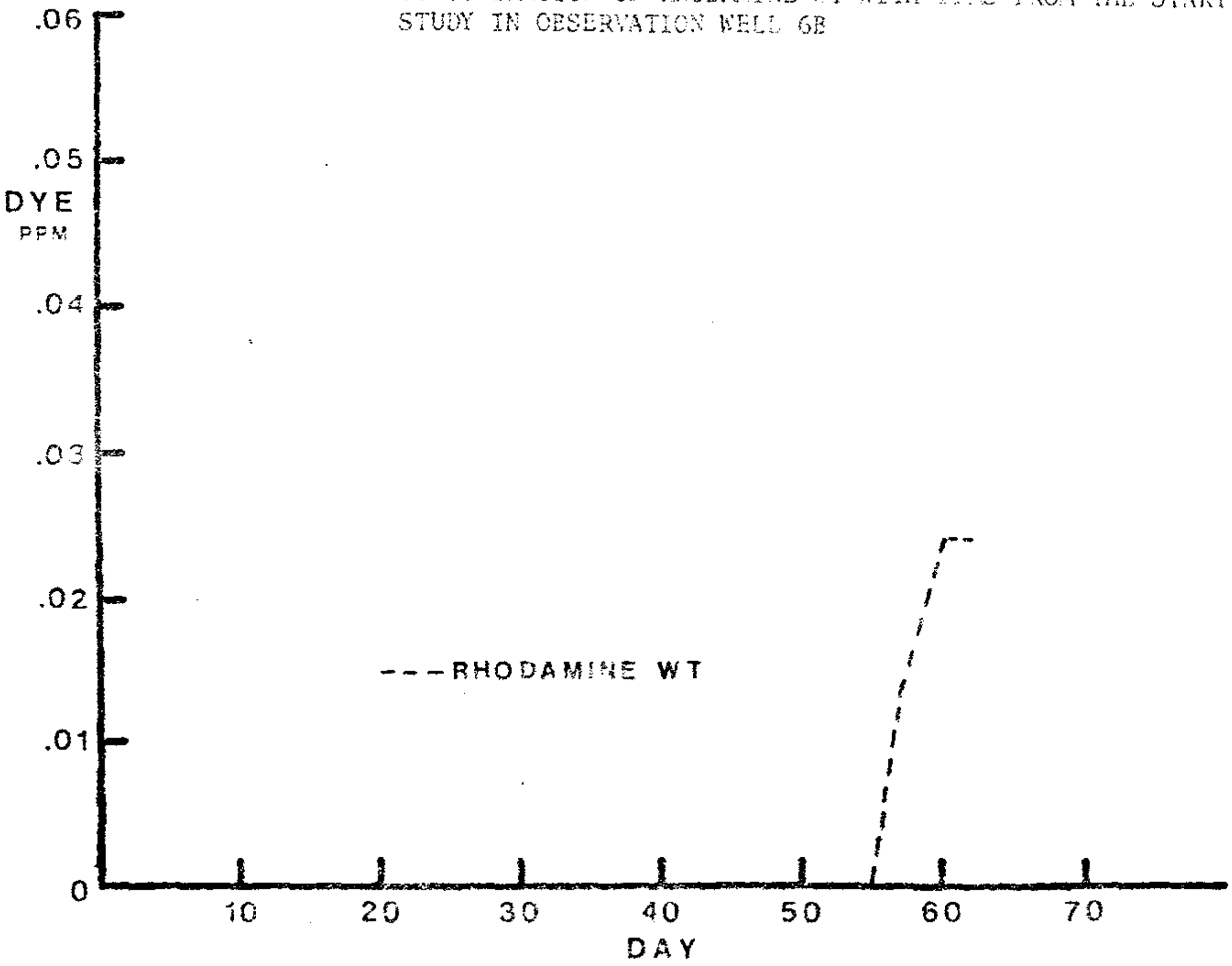


FIGURE 16
CONCENTRATION OF RHODAMINE WT WITH TIME FROM THE START OF THE TRACER STUDY IN OBSERVATION WELL 6B



time of the study, wells 12 were not operable; therefore, positive confirmation of the passage of the applied sewage effluent from the sand beds to West Brook could not be made. However, the velocity of flow in the various parts of the aquifer could be determined as summarized in Table 1. The velocity in the area immediately north of the south sand beds ranged between 10 and 12 m/day (33-40 ft/day). The lower value of 7 m/day (23 ft/day) to well 18 may be explained by the presence of the large rock noted to be present in that area. To reach observation well 18, the water had to flow around this rock. The velocity to well 9 averaged somewhat less at 8 m/day (26 ft/day), and the velocity to well 6 averaged about 6 m/day (20 ft/day). However, by determining the velocity between well 9 and well 6B, a lower velocity of only 3 m/day (10 ft/day) was observed. This lower velocity in this area could be due to a more gradual slope in the ground water or lateral dispersion of the water and tracers.

DISCUSSION

The results of this study showed that both tritium and rhodamine WT are suitable as tracers of ground water flow. Rhodamine WT has two advantages: one being that it may be detected visually and the other that it has no potential radioactive hazard. Rhodamine B is not suitable as a tracer of ground water flow.

The overall average velocity of vertical flow through an average sand bed at the Lake George Village Sewage Treatment Plant was approximately 0.85 m/day (2.8 ft/day). The velocity in only the unsaturated zone was 0.55 m/day (1.79 ft/day). This indicates a more rapid rate of flow in the saturated zone than in the unsaturated zone.

The flow in the saturated zone from the south sand beds ranged

TABLE 1. VELOCITY OF FLOW IN SATURATED ZONE

From	To	Distance, m	Time for Appearance, days	Rate m/day	Rate ft/day
Bed S-3	Well 15	50.60	5	10.12	33.2
Bed S-3	Well 16	62.64	6	10.44	34.25
Bed S-3	Well 17	69.72	6	11.62	38.12
Bed S-3	Well 18	75.90	11	6.90	22.64
Bed S-3	Well 19	76.50	-	-	-
Bed S-3	Well 20	72.34	6	12.06	39.56
Bed S-3	Well 9	249.63	31	8.05	26.42
Well 15	Well 9	199.03	26	7.66	25.12
Bed S-3	Well 6B	321.11	54	5.95	19.51
Well 9	Well 6B	71.48	23	3.11	10.20

between 10 and 12 m/day (33-40 ft/day). The velocity appeared to decrease in the area between well 9 and well6. This could be due to either slower rate of flow or more lateral dispersion to the latter sampling well. The velocity of flow is considered to be quite high and indicative of a rather coarse sand in the aquifer. This indicates why there is little mounding of the ground water in the area immediately beneath the sand beds. Based on the velocity of approximately 12 m/day in the saturated zone, it should have taken approximately 60 days for the tracer to travel the 600 m from the sand infiltration beds to West Brook. Sampling was continued for 8 months or approximately 240 days, but neither tracer was observed in additional wells or in the seepage. It is not certain whether the reason for not finding the tracers in the seepage was because of additional dilution or because the effluent from the treatment plant does not reach the seepage. From the general direction of flow and other data available, it is most likely that the applied sewage effluent does eventually reach the seepage areas of West Brook, and that additional dilution reduced the tracer concentrations below the detectable level.

CONCLUSIONS

The tracers were most useful in determining the velocity of flow in the sand in both the vertical and horizontal directions. The velocity of horizontal flow in the saturated aquifer was greater than the vertical flow in the unsaturated sand. Both tritium and rhodamine WT were found to be suitable tracers, but some advantages of the rhodamine WT were observed. It is essential to have observation wells located in the right places to observe the presence of the tracers. Apparently dilution by ground water (including sewage effluent) diluted the tracers to concentrations below detectable limits before they could be used to trace the flow all the way to the seepage at West Brook.

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