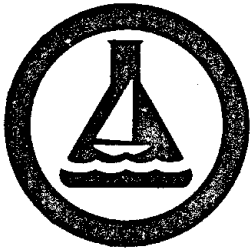


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EVALUATION OF TRACERS FOR FOLLOWING GROUND WATER FLOW

By

D. B. Aulenbach, J. H. Bull, and B. C. Middlesworth

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Rensselaer Polytechnic Institute

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EVALUATION OF TRACERS FOR FOLLOWING GROUND WATER FLOW

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ABSTRACT

With greater emphasis being placed on land application as a method for treatment and disposal of wastewaters, methods for monitoring the possible effects of these wastewaters on the ground water must be applied. However, monitoring is ineffective if information is not available as to the direction of flow of the waters within the ground. Positive proof must be shown that the ground water being monitored did originally come from the applied sewage effluent. In order to confirm this ground water flow, various tracers are available to follow the flow within the ground. Studies were made utilizing sodium chloride, potassium chloride, rhodamine B, rhodamine WT, and tritium. The potential merits of each are discussed. In actual studies conducted at the Lake George Village Sewage Treatment Plant which discharges its final secondary effluent into coarse sand, rhodamine WT was found to be the most effective tracer. It was followed for a distance of 300 m and was easily detected by means of a fluorometer. Tritium also appeared to be a fairly effective tracer; however, the amount added in these studies produced a concentration insufficient for detection in the same distance as the rhodamine WT. In two case studies rhodamine WT

was found to be an effective tracer to prove that leachate from a highway deicing salt storage area reached adjacent wells which provided the drinking water supply for individual homes. In all cases, rhodamine WT was found to be the most effective tracer to follow the flow of water within the ground.

INTRODUCTION

The flow of surface streams is easy to follow. The flow of water in the ground is difficult to observe. Methods for measuring ground water flow are desirable in order to follow the flow of recharge water to trace possible ground water contamination.

The recent increase in public concern over how its tax dollars are spent has caused environmental engineers to search for more cost effective methods of treating municipal wastewater. One of these methods, land application, is an alternative to conventional secondary treatment which has become increasingly important since a recent Environmental Protection Agency (EPA) memorandum requiring all preliminary design studies of municipal treatment systems to explore the feasibility of land application [2] and since the passage of PL95-217.

In examining land application as an alternative method, the environmental engineer must define the maximum hydraulic loading of the soil, and provide assurance that the wastewater will not contaminate local drinking water supplies after it infiltrates the soil. The hydraulic loading can be estimated by determining the soil's permeability and porosity. However, these tests are limited as they depend upon samples from limited areas to describe the nature of all the surrounding soil. Another method which describes more precisely the soil hydraulics and also aids in determining the probability of contaminating water supplies is the tracer study. This provides the design engineer with actual infiltration rates, percolation velocities of the ground water, and direction of flow. In addition it is useful in confirming continuity of flow from one location to another.

The most important element of a tracer study is choosing the best tracer for the study at hand. The "ideal" tracer has the following characteristics: [1,5,6,11]

1. Must act physically and chemically like water.
2. Must not change appreciably the characteristics of water, the transmission characteristics of water, or the transmission

characteristics of the media.

2

3. Must not precipitate, filter out, or settle out.
4. Must be highly soluble in water.
5. Must not be adsorbed onto the media or exchanged with ions present in the media -- 100 percent recovery must be possible.
6. Must be easily detected at very low concentrations with a minimum amount of laboratory equipment and laboratory knowledge.
7. Pose no health hazard due to contamination of ground water.
8. Must be nearly absent from the ground water source being studied.
9. Must be inexpensive.
10. Must be readily available.

Tracers, by their nature, fall into four (4) categories: (1) chemical, (2) chemical-color, (3) radioactive, and (4) biological. Chemical tracers include all non-radioactive ions whose presence is determined by chemical tests or electrical resistance. Chemical color tracers include all dyes and other compounds whose presence is determined by color analysis. Radioactive tracers are those ions measured by radiation detection equipment. Biological tracers include active and inactivated organisms which can be detected by various means including culture.[9]

In recent research conducted by the authors, various tracers falling into three categories were used to determine the hydraulics of an existing land application treatment system and the contamination of ground water supplies from highway deicing salt operations. This paper describes the tracers and examines the performance of each.

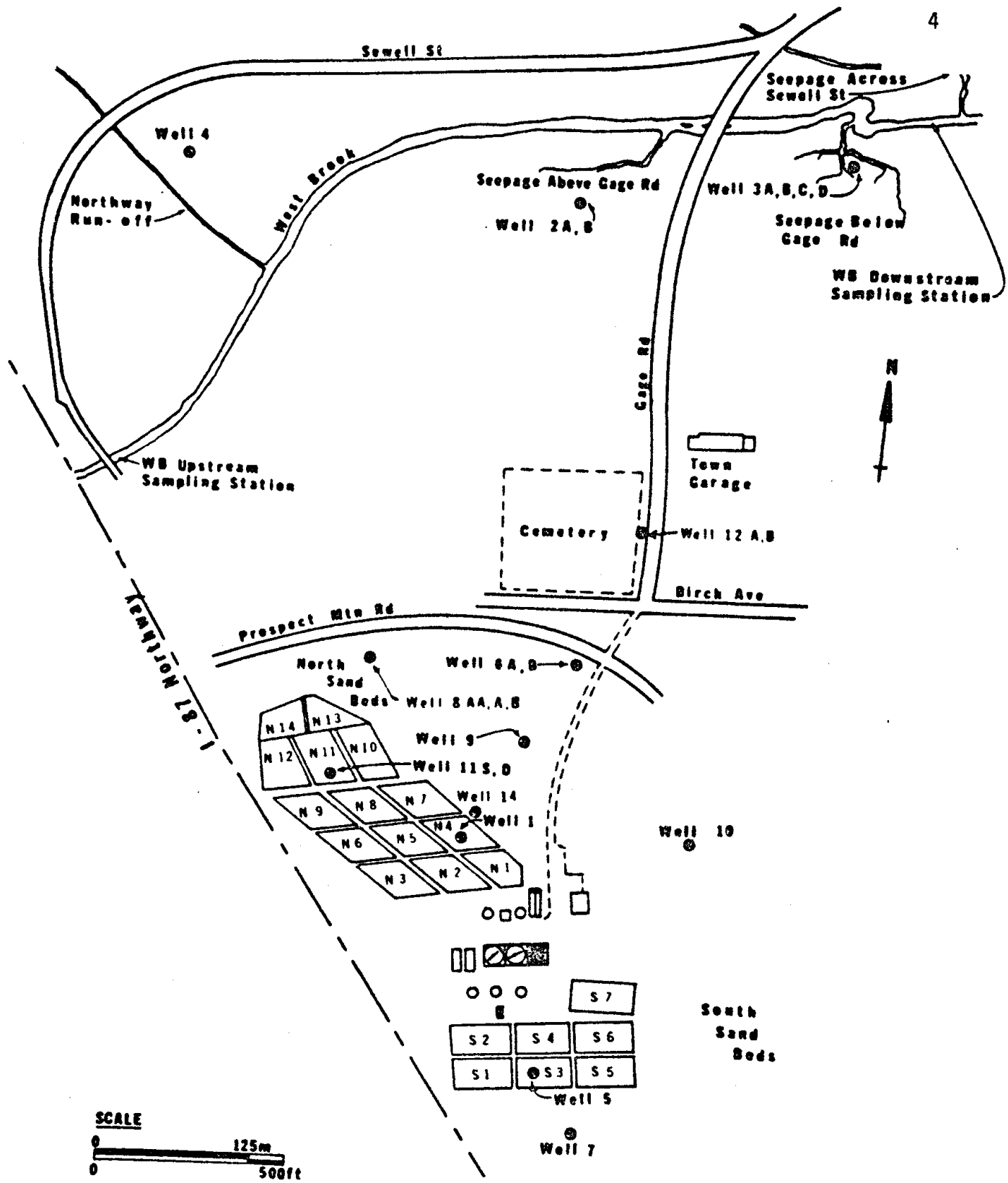
TRACERS EMPLOYED

The chemical tracers employed included sodium chloride (NaCl), and potassium chloride (KCl). Both compounds ionize in water to release chloride as a tracing element plus either sodium or potassium. The

concentration of chloride in the sample can easily be determined by either wet chemistry using the Argentometric Method or the Mercuric Nitrate Method, or by using a specific ion electrode.[10] Measurement of both sodium and potassium requires the use of an atomic adsorption spectrophotometer. Chloride has been used as a ground water tracer with varied success [3,18]. Potassium and sodium have met with less success as these ions tend to be exchanged within the soil for calcium and magnesium. At the Lake George site the use of sodium chloride as a tracer was complicated by the former storage of highway deicing salt in an open pile at the nearby Town highway department garage (See Figure 1).

Two chemical color tracers, rhodamine WT and rhodamine B were tested. Both of these fluorescent red dyes are produced by DuPont Chemical Corporation. Concentrations of rhodamine B and WT have been easily determined to a minimum concentration of 0.1 ppm using a spectrophotometer and 0.1 ppb if a fluorometer is employed. These dyes have been approved as posing no public health hazard other than coloring the water.

Tritium was the only radioactive tracer used. Tritiated water, HTO, has been described as the "ideal" tracer because it differs very little either chemically or physically from natural water. Tritium is very easy to detect at low concentrations using conventional liquid scintillation techniques. The long half-life of 12.26 years eliminates the need for decay calculations in short term studies, but it could potentially pose some problems to public health because it would not quickly disappear. Recently there has been some skepticism as to tritium being an "ideal" tracer. This is because several investigators [7,11,12] have shown that tritium can react and exchange with tightly bound water associated with clays. However, the amount of exchange is thought to be insignificant, approximately 1 percent.



AREA OF STUDY

FIGURE 1

RESULTS OF TRACER STUDIES

An intensive investigation took place at the Lake George Village Sewage Treatment Plant (Figure 1). The treatment plant is situated on coarse delta sand deposited by a receding Pleistocene glacier [4]. The soil characteristics are shown in Table 1.

In the first tracer study rhodamine B was placed in seepage bed N-11 while it was being flooded. The intent was to locate the dye in lysimeters placed within the unsaturated zone of the sand bed as well as in 2 pumped wells located in the aquifer immediately below this bed. This study failed due in part to a problem involving the Turner Model #111 Fluorometer used to detect the fluorescent rhodamine B. An attempt to observe the dye visually in the lysimeters also failed.

In the second tracer study rhodamine WT was applied to the same bed N-11. Its presence was detected in four of the lysimeters in the unsaturated zone as well as the shallower pumping well within the aquifer (Figure 2). Although actual concentrations of the dye were not determined, a visual examination of all samples indicated that the concentration of the dye decreased as it percolated through the soil.

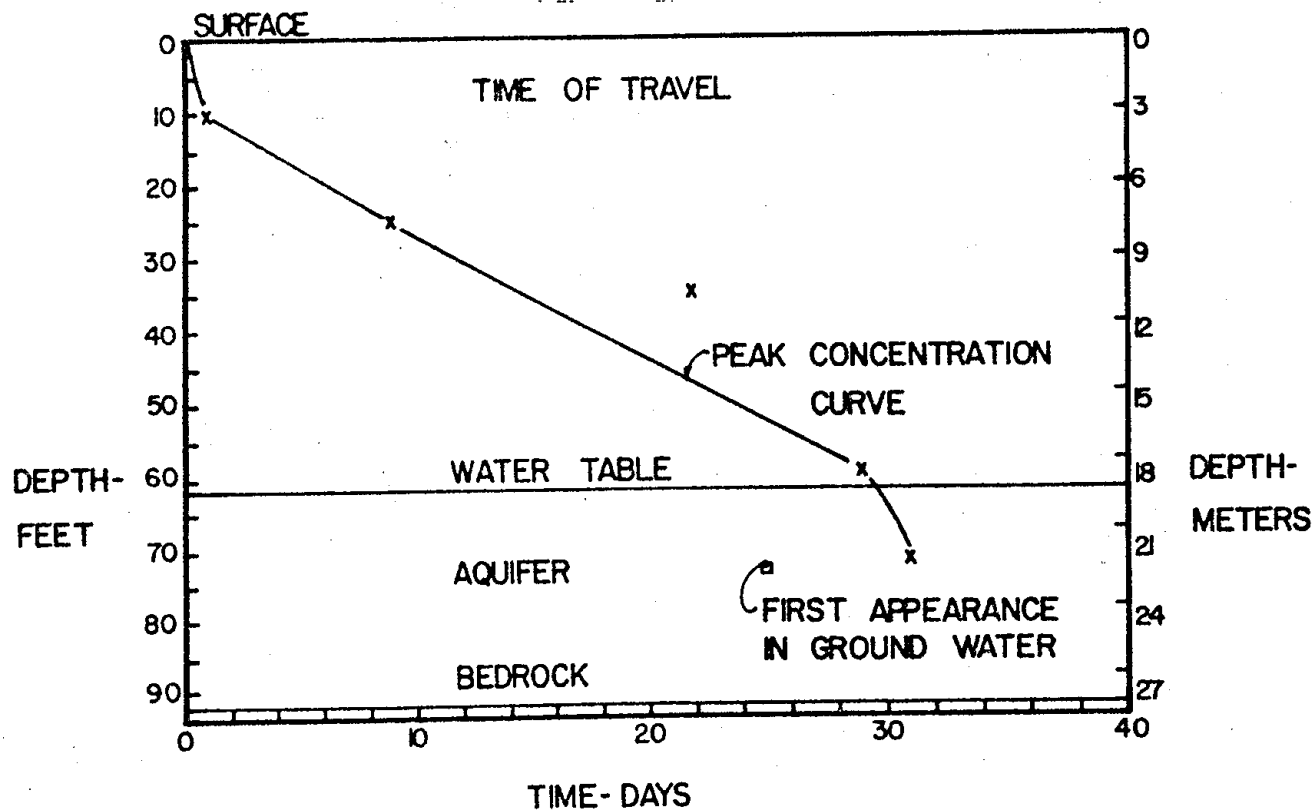
The third study took place below bed N-11. In this study 0.1 Ci of tritium and 11.2 kg of 20 percent rhodamine WT were directly introduced into the aquifer via the shallow pumping well approximately 3 m (10 ft) into the aquifer. The tracers were flushed out of this well by pumping water into it from the deep pumping well 5 m (approximately 15 ft) below it for a period of three weeks. It was the intent to locate the tracers in downstream wells 2, 3, 6, 8, 12 and the seepage areas near West Brook (Figure 1). Each of the wells was sampled prior to introducing the tracer to determine background concentrations of tritium. Analyses for

TABLE 1
SAND ANALYSIS

In Aquifer	Well 1	Well 2	Well 3	Well 5	Well 6
Effective Size, mm	0.08	.37	0.15	0.12	0.15
Mean Size, mm	0.15	1.40	0.27	0.30	0.38
Uniformity Coeff.	2.13	4.32	2.53	2.83	2.93
"S" Shape Curves	?	Yes	No	Yes	Yes
Gravel %	1	16	20	8	1
Fine Sand %	94	13	62	73	58
Coarse Sand %	6	72	18	19	41
Permeability					
m/day	8.5	19.5	--	--	4.6
ft/day	28	64	--	--	15.1

FIGURE 2

VERTICAL TRANSPORT OF RODAMINE WT IN BED N11



tritium were performed using a Packard Model 3003 TriCarb Scintillation Spectrometer. Samples of the wells taken daily for a period of 48 days thereafter failed to show the presence of either of the tracers.

Seepage bed N-4 was used for the next tracer study. A new well, Well 14, was placed at the edge of bed N-4 (Figure 1) in what appeared to be the direction of flow to insure recovering the tracer. In addition to 0.1 Ci of tritium and 11.2 kg of 20% rhodamine WT, 108 kg of rock salt as a chemical tracer intended to double the normal chloride content of the applied effluent was placed in the seepage bed during flooding. The rock salt was dissolved prior to dosing. Samples were taken daily and analyzed as before using the fluorometer, liquid scintillation counter, and a chloride specific ion electrode. This study also failed to produce any results within 56 days of continuous monitoring.

For the last tracer study at the Lake George Village Sewage Treatment Plant bed S-3 was used (Figure 1). The main difference between bed S-3 and the previously studied areas was the distance between the soil surface and the aquifer. The aquifer is approximately 4 m under bed S-3 whereas it is 20 m under beds N-11 and N-4 (Figure 3). Additional wells were installed around bed S-3 to insure tracer recovery (Figure 4). As in the previous two studies 11.2 kg of 20 percent rhodamine WT and 0.1 Ci of tritium were used. Potassium chloride, KCl, was the chemical tracer chosen using 22.5 kg of technical grade KCl. The dose of KCl was calculated to double the normal K content of the applied effluent. All three tracers were applied to the bed during the same dosing period. Rhodamine WT was observed in well 5 (located in bed S-3), the ring of wells (wells 15, 16, 17, 18, and 20 [75.9 m downstream from the seepage bed]), well 9 (249.6 m downstream) and well 6B (321.1 m downstream from the seepage bed), whereas tritium was recovered in only wells 5, 15, 16, 17, 18 and 20 as shown

FIGURE 3

**AREA OF STUDY:
2-DIMENSIONAL VIEW**

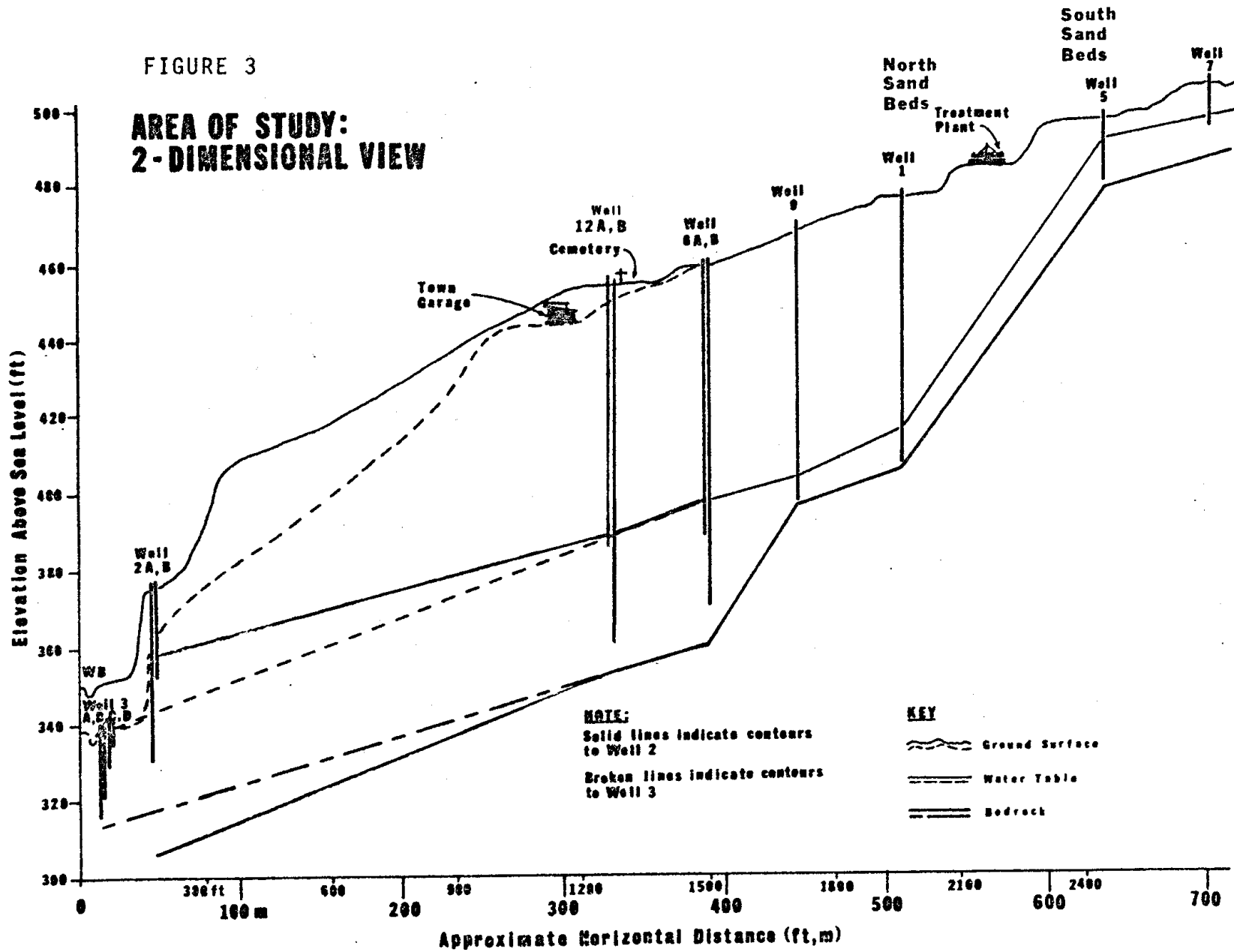
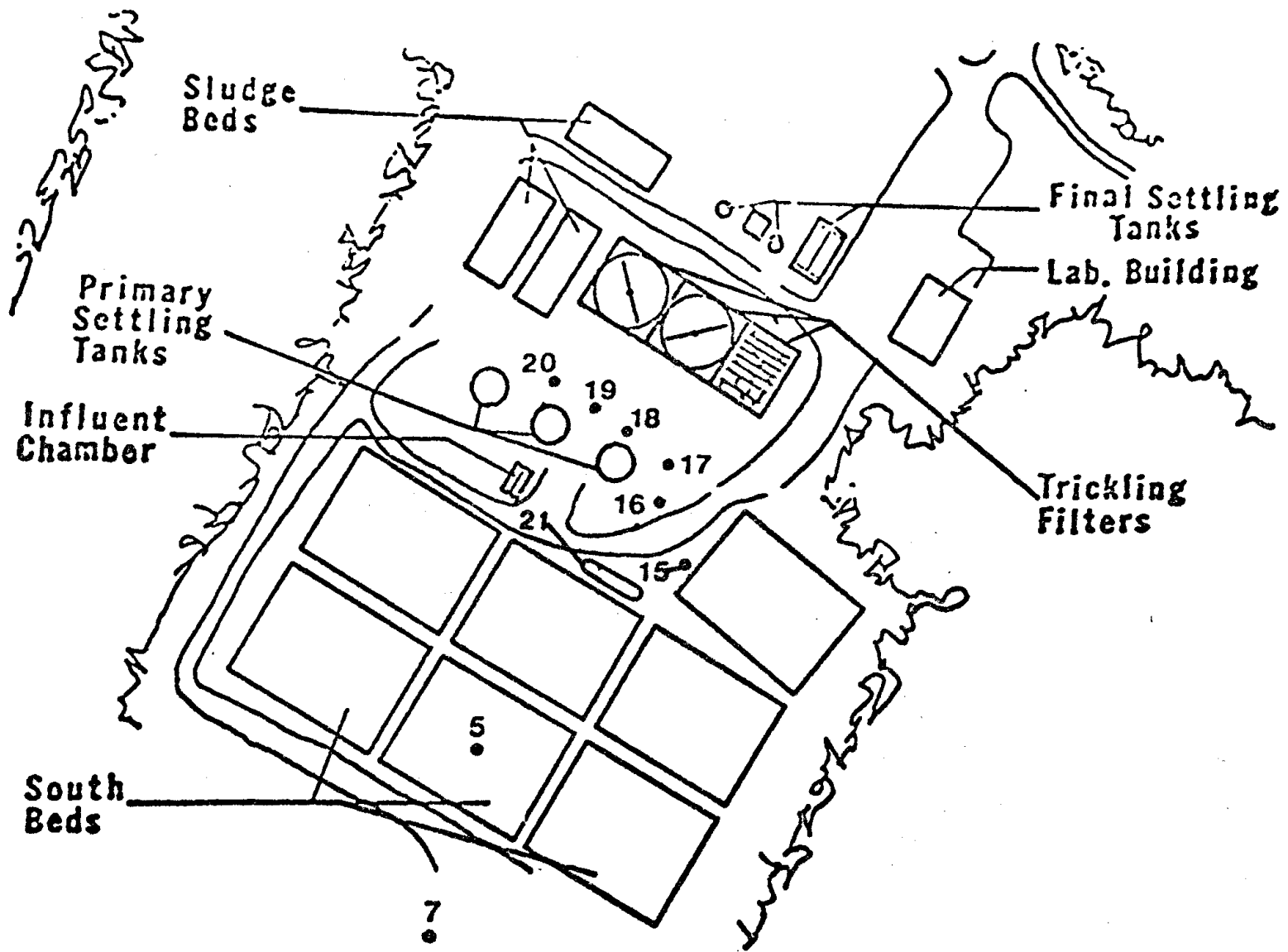


FIGURE 4



in Figures 5 through 12. Discernible peaks in concentration of either potassium or chloride were not detected in any of the wells monitored.

DISCUSSION OF RESULTS

In evaluating a tracer's performance, no direct conclusion can be made unless the tracer is recovered in an observation well. This is because the tracer is only a single part of the complex tracer study. So much of a tracer's success is also dependent upon the mechanics of the study such as well location and method of applying the tracer. This limits the discussion to the two successful tracer studies conducted at the Lake George Village Sewage Treatment Plant and two of the three studies relating to the contamination of drinking water supplies.

The first successful study at Lake George involved using the chemical color tracer rhodamine WT. The tracer was observed in 4 of the lysimeters in the unsaturated portion of the soil and the shallow pumping well within the aquifer. As the dye percolated through the unsaturated soil, it appeared to be removed from the water as evidenced by the lower concentration of tracer observed in the deeper lysimeters. The method of removal, whether it is adsorption, absorption, exchange, or chemical decomposition has not been established.

When rhodamine B was used at the same site no tracer was recovered so no conclusion can be made. However, due to rhodamine WT's success it would be indicated that rhodamine WT is a better chemical color tracer than rhodamine B in the sand system studied. This could possibly be due to rhodamine B being removed from the water to a higher degree as it percolates through the unsaturated zone.

In the other successful tracer study conducted at the sewage

FIGURE 5
TRACERS: WELL 5

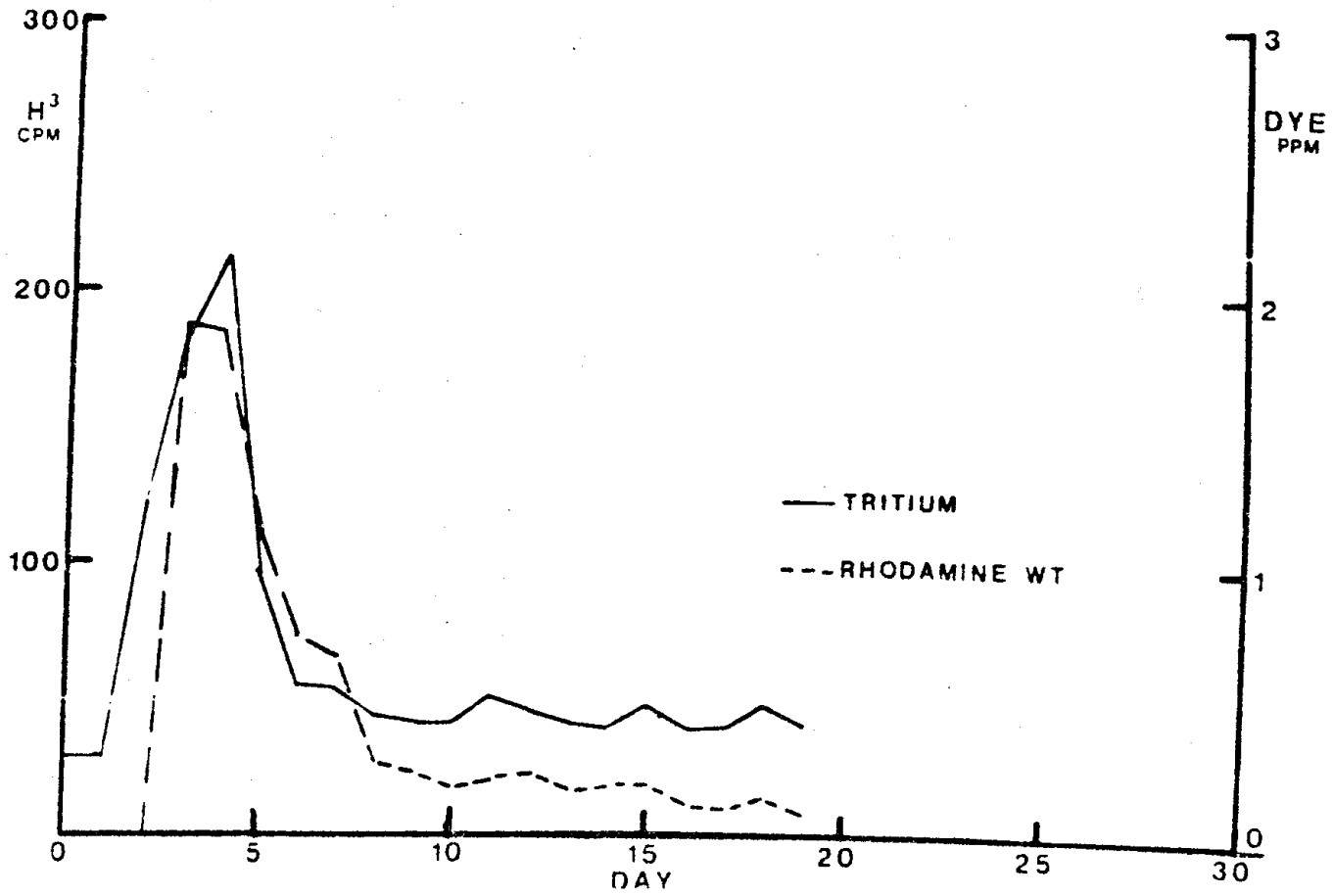


FIGURE 6
TRACERS: WELL 15

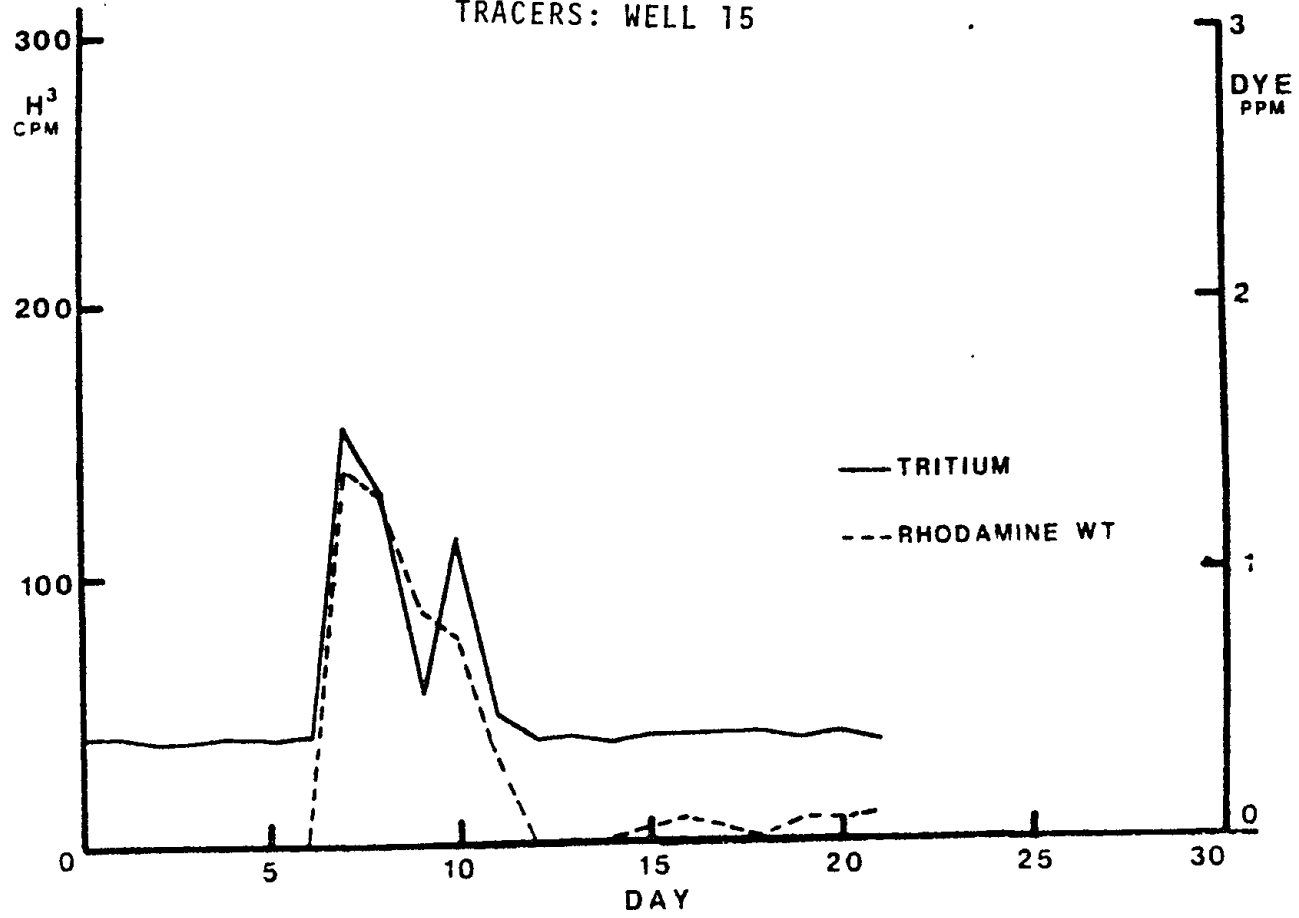


FIGURE 7
TRACERS: WELL 16

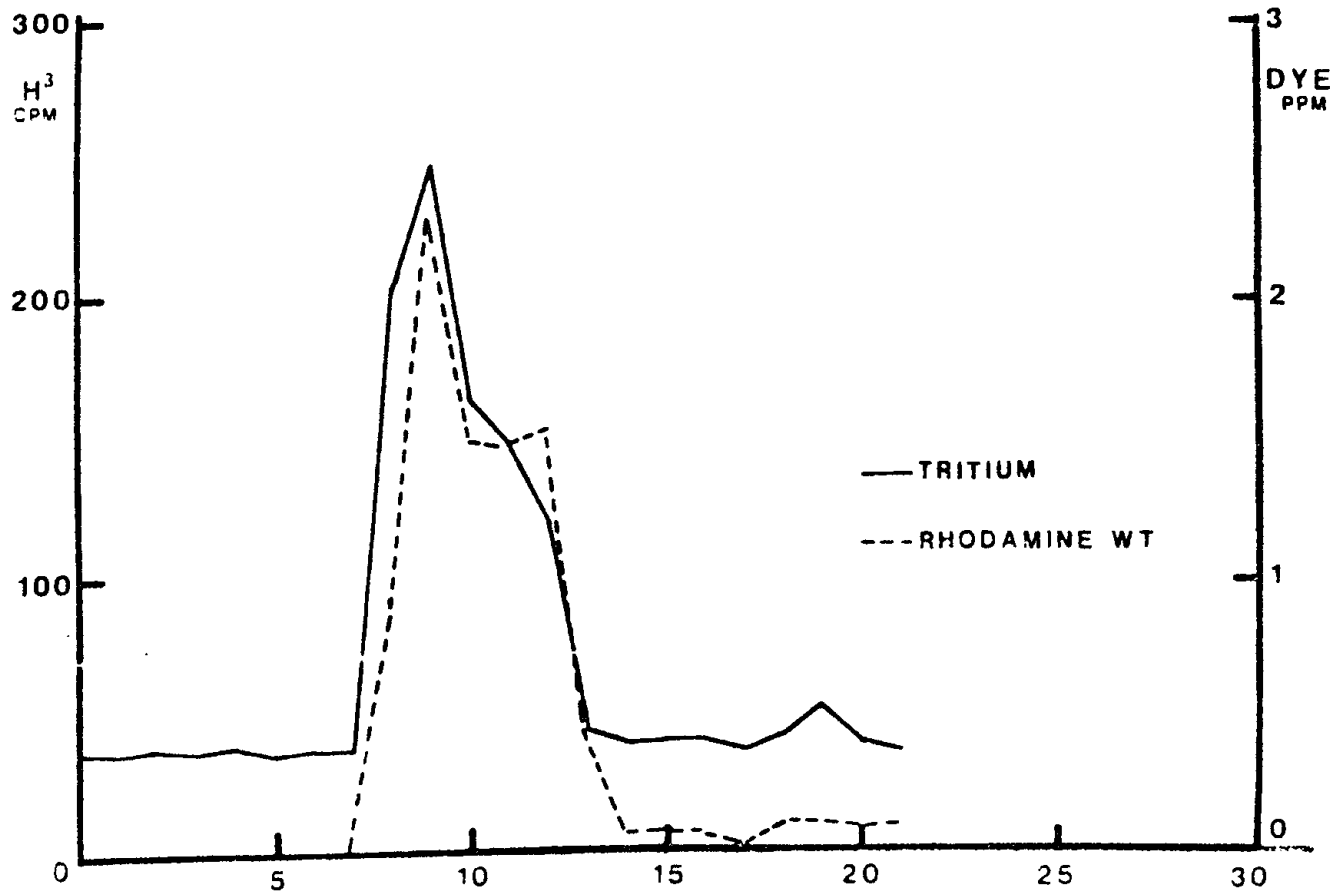


FIGURE 8
TRACERS: WELL 17

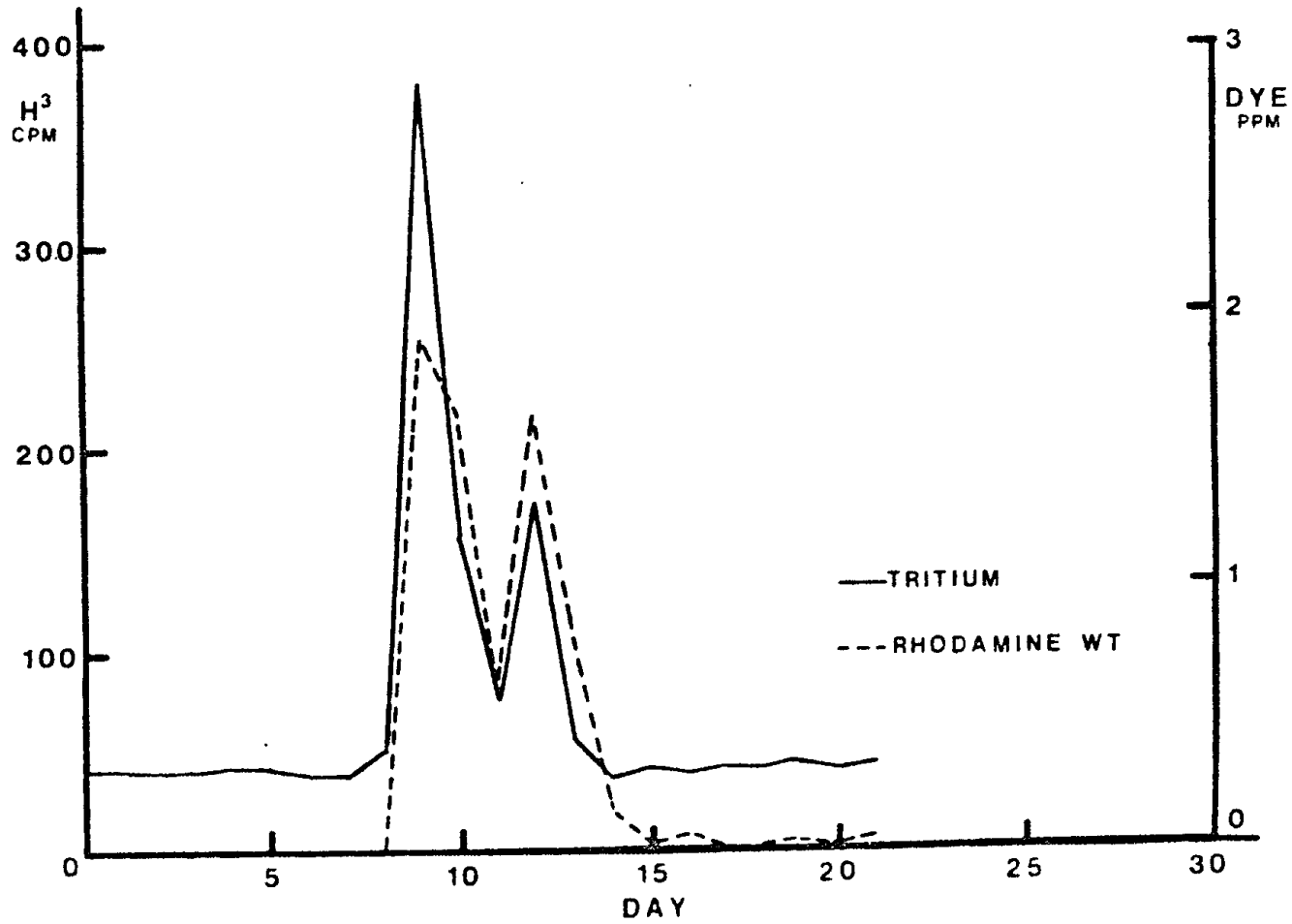


FIGURE 9

TRACERS: WELL 18

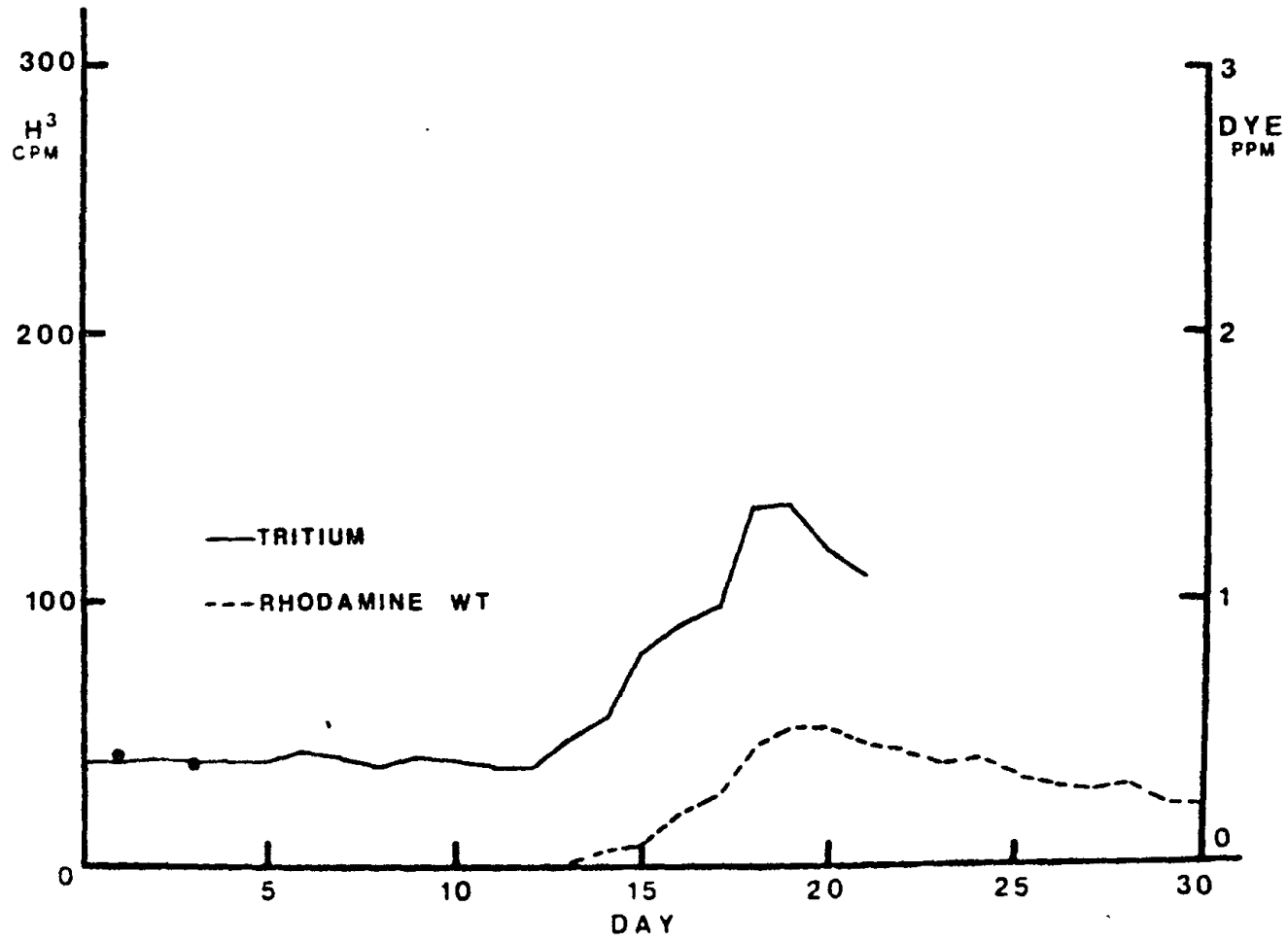


FIGURE 10

TRACERS: WELL 20

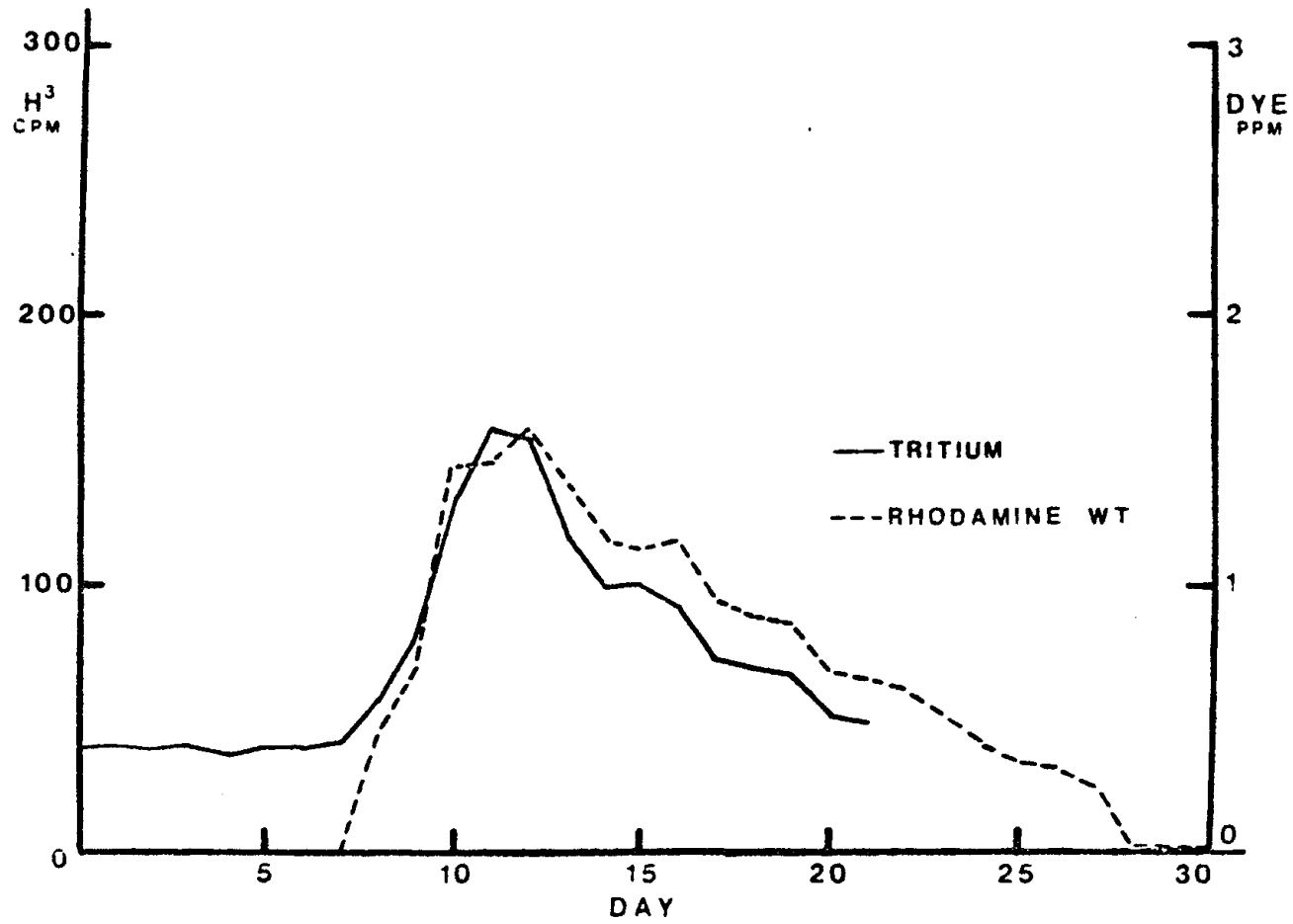


FIGURE 11
TRACER; WELL 9

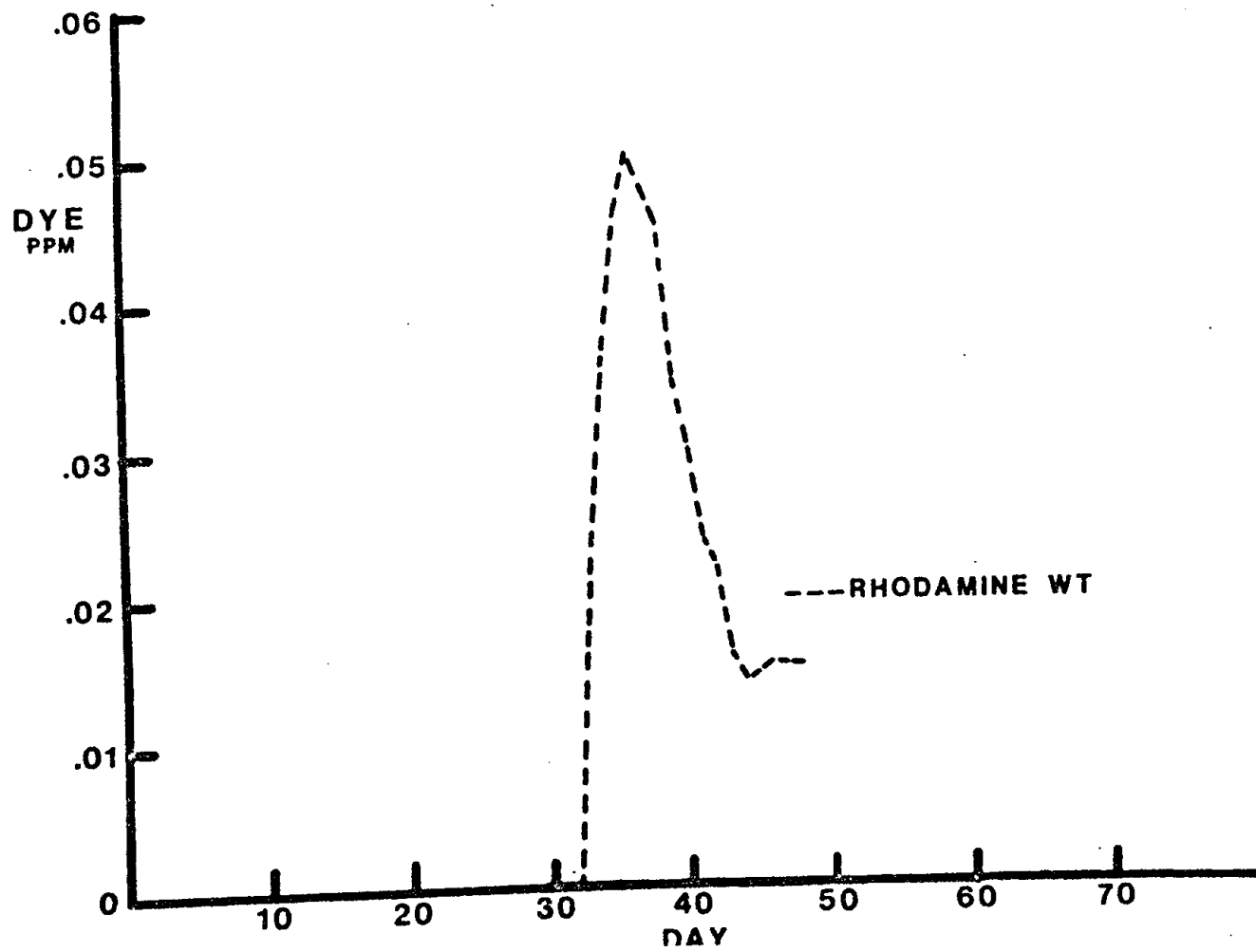
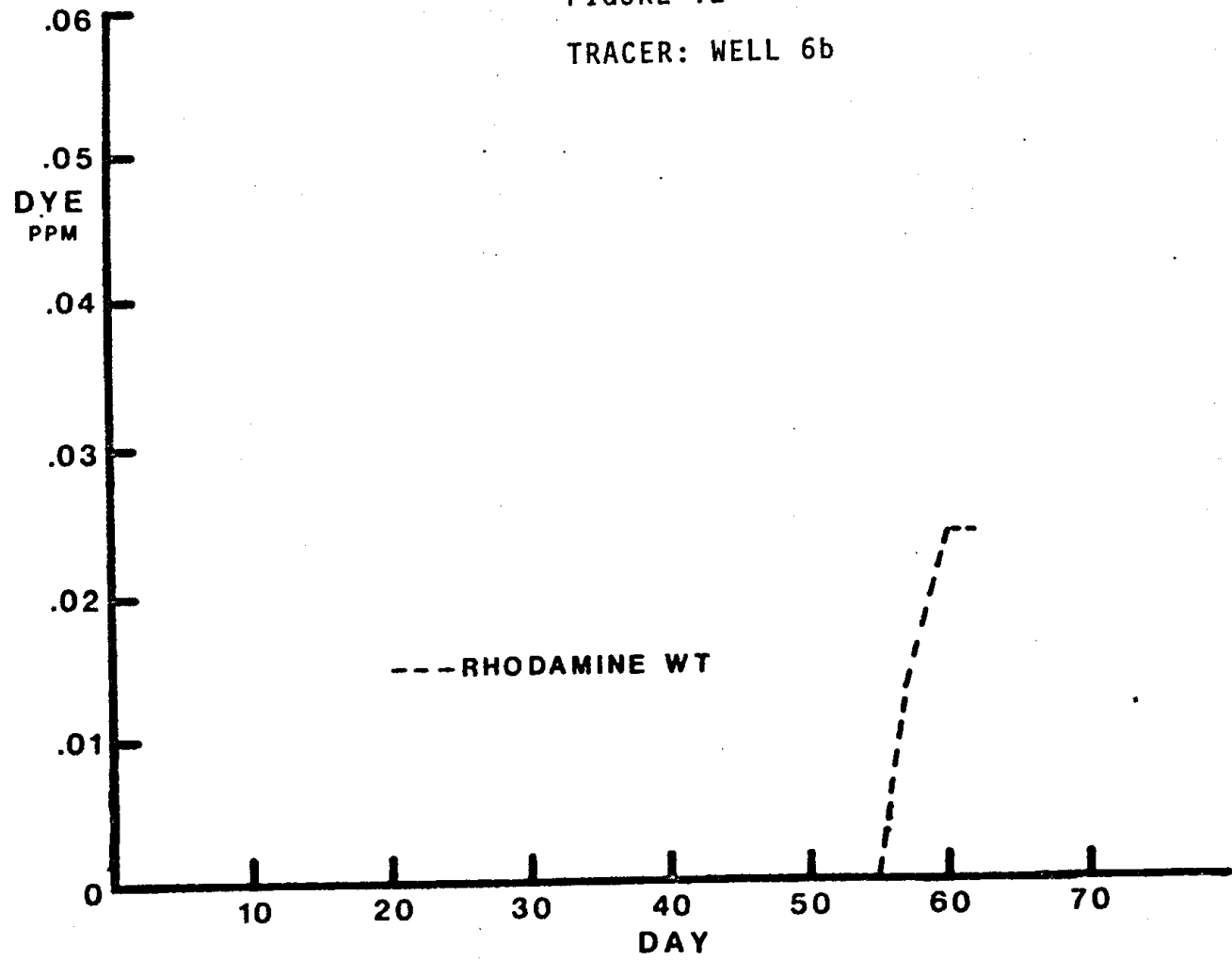


FIGURE 12
TRACER: WELL 6b



of tritium the New York regulatory agencies allowed to be used in the study. This is confirmed by the concentration ratios of the two tracers at various wells (Table 2). The concentration ratios were calculated by integrating the areas under the curves and comparing the results at the various wells.

All decreases in tritium were attributed to dilution and dispersion. Based on this, any additional decrease in rhodamine WT is attributed to sorption and/or decomposition. The concentration of tritium decreased by a factor of 6.8 during infiltration and percolation vertically from the surface of the seepage bed to well 5 located within the seepage bed at a depth of 4 m, while the rhodamine WT concentration decreased by a factor of 14.4. This indicates that rhodamine WT was adsorbed in the unsaturated zone by a factor of 2.1 assuming the reduction due to dilution and dispersion was 6.8.

No further decrease in either tritium or rhodamine WT was seen from well 5 to the ring of wells (15, 16, 17, 18, and 20) located 75 m downstream from the edge of the seepage bed. This indicates that once rhodamine WT reached the saturated aquifer no more appreciable adsorption took place. It is also possible that a significant portion of the reduction in rhodamine WT occurred while it was standing on the surface of the sand bed exposed to the sunlight before it infiltrated the sand.

Rhodamine WT was also recovered in well 9, 249.6 m from the seepage bed. The dye concentration decreased by a factor of 36.7 from well 17 to well 9. That tritium was not recovered in well 9 may be explained by assuming that the decrease in concentration of tritium would be the same as that for rhodamine WT. The highest concentration of tritium in well 17 was 380.7 cpm. Decreasing this by a factor of 36.7 leaves a concentration of 10.4 cpm which is not statistically greater than the

TABLE 2
CONCENTRATION RATIOS

Location:Location	Tritium Concentration	Tritium Ratio	Rhodamine Concentration	Rhodamine Ratio
Bed S-3:Well 5	914:134	6.8:1.0	15.9:1.1	14.4:1.0
Well 5:Well 17	134:149	1.0:1.1	1.1:1.1	1.0:1.1
Well 17:Well 9	---	---	1.1:0.03	36.7:1.0
Well 9:Well 6B	---	---	0.03:0.02	1.5:1.0

treatment plant, tritium, rhodamine WT and potassium chloride were used. Tritium was recovered up to 76 m and rhodamine WT was recovered in wells up to 321 m from the seepage bed. Neither added potassium nor added chloride was recovered in any of the observation wells. It was the initial intention to tag the water with enough chloride to observe a peak of approximately 100 ppm above background. The background concentration in the well located directly under the seepage bed was 50 ppm. Although a general increase in chloride was observed, no discernible peak of chloride appeared. Since chloride is assumed not to be adsorbed, exchanged, or chemically decomposed within the soil; an explanation for not observing the chloride peak would be dilution and dispersion of the tracer. This is verified by comparing the tritium concentration to the chloride concentration. Tritium, also, is not adsorbed or exchanged to any appreciable amount. Thus, any decrease in the concentration of tritium would be caused by dilution and dispersion. The concentration of tritium decreased by a factor of 6.8 from the surface to well 5 located in the seepage bed 4 m below the soil surface. Assuming the same decrease for chloride, a peak concentration of 14.8 ppm above background would be expected. This concentration is too low to detect significantly.

Comparing the recovery of the tritium and rhodamine WT, it becomes apparent from the graphs that the concentrations versus time are almost identical for each tracer at each well. This indicates that both tracers travelled at the same velocity and experienced similar dispersion and dilution.

Significant concentrations of rhodamine WT were observed as far downstream as well 6B, 321 m from the seepage bed. Tritium, however, was last detected in well 18, 75.9 m from the seepage bed. The absence of tritium in wells 9 and 6B is attributed to the limited amount, 0.1 Ci,

background of 40 cpm. Had the requested dose of 1 Ci of tritium been approved, there would most likely have been sufficient present to detect at subsequent wells. Also the results indicated that greater dilution of the tracers occurred than was anticipated.

GROUND WATER CONTAMINATION CASE STUDIES

Dyes may be used as tracers of ground water contamination other than from sewage or septic tank effluents. In the colder areas of our country salt is used for deicing of roadways, culverts, gutters, etc. Whereas salt spread on highways can cause minor contamination of local ground and surface waters, the greatest potential hazard in terms of concentration is the salt storage areas. Traditionally, local highway departments have stored deicing salt in the open on the bare ground the garage area with no concern for the salts dissolving in rainwater or penetrating into the soil beneath the pile. Due to the salt, the ground beneath the salt pile seldom freezes, thereby allowing the rainfall and dissolved salt to soak into the ground. Although it appears obvious that major salt contamination in a well in an area where there is otherwise no salt in the ground is most likely from stored or spread deicing salt, in a court case positive proof must be made that ground water can flow from a salt storage area to the offended water supply. It is in this area that the use of the dye as a tracer of the ground water is very useful.

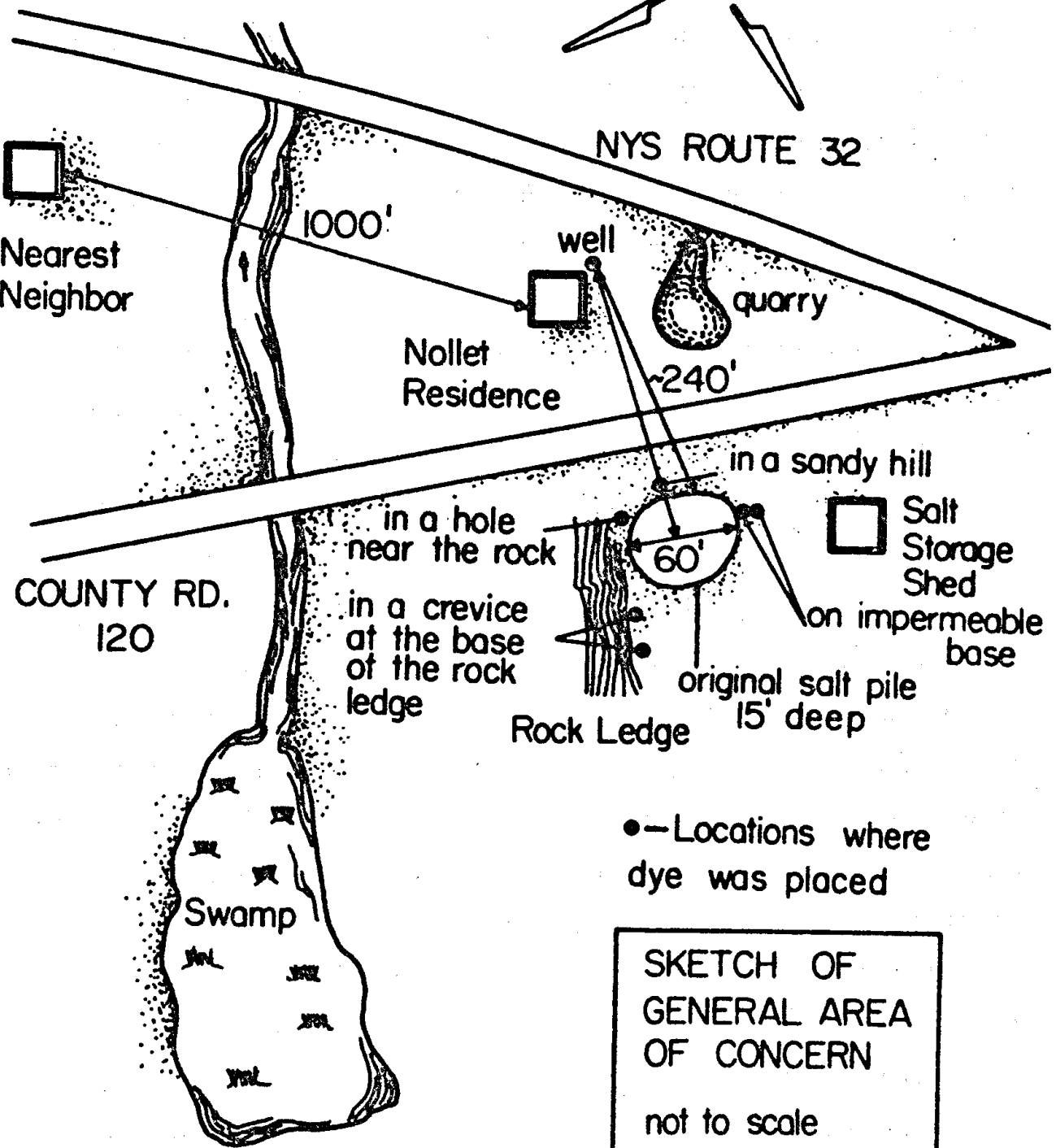
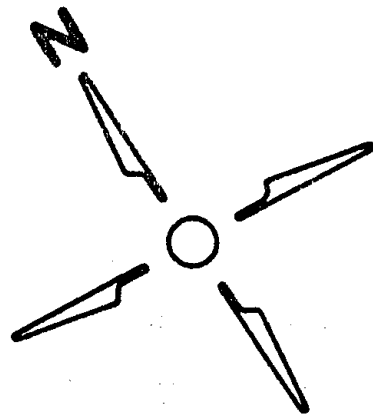
Two examples are cited of experience with stored deicing salt contaminating local water supply wells. The first involved an area with predominately fissured limestone which was of sufficient quality for partial quarrying. Shortly after the local highway department began storing salt in a former quarry hole, local residents observed over

2,000 mg/l chloride in their water.

In order to appreciate the impact of this, one must recall the consequences of high chloride in water. Besides rendering the water unfit for drinking, the high chloride content burns plants and lawns and in this instance the seepage field from the septic tank showed the first signs of burning of the grass due to the salt which passed through the sewage system. All the potable water must be carried into the house, thus, adding to the expense as well as considerable inconvenience. Problems encountered using the contaminated water for non-potable uses include a sticky feeling after taking a shower, finding a layer of salt at the bottom of the bath tub, lack of suds with soap, ruining the finish on the marble counter in the bathroom and the formica top in the kitchen, corroding the plumbing, especially the water heater and the hot water pipes, and even rusting the chrome from washing the car and motorcycle. Thus, a suit was brought against the local highway department to reclaim the cost of the damages. On July 2, 1974 rhodamine WT dye was distributed in the area of the salt storage area as shown in Figure 13. The fluorometer was hooked directly to the well pump at the house and the pump was operated through the fluorometer for approximately 1/2 hour twice a day from the period from July 3 to October 4. The first appearance of the dye was detected on July 16. Records were correlated with the local rainfall showing that after a rainfall greater than about 2 cm the dye appeared in the well from three to six days later. Thus, there was proof of precipitation entering into the fissured limestone carrying with it the stored salt and reaching the household water supply.

As the result of this study, damages were paid by the local highway department and a salt storage shed with a concrete pad was constructed

FIGURE 13



●—Locations where dye was placed

SKETCH OF
GENERAL AREA
OF CONCERN
not to scale

to prevent any further contamination of the area.

In the second example, the local highway department garage was located in a gravelly area of a river valley as shown in Figure 14. In this instance, the chloride content was as high as 1700 mg/l but generally was slightly under 1000 mg/l. Similar problems were being encountered by several homeowners in the area but the extent of the problem was not so great as in the previous study, and the copper plumbing was springing leaks at only the joints. However, drinking water had to be carried by hand and plants and grass could not be watered using this supply. On June 16, 1977 ten pounds of a 20% solution of rhodamine WT dye was placed in two holes dug in the salt storage area. The summer was one of moderate rainfall but on September 16-22 over 5 cm fell on the area. On September 22, the first appearance of the dye was recorded in the fluorometer, confirming the passage of the dye from the salt storage area to the local well. In this instance, two adjacent houses were complaining of the same problem. After the appearance of the dye in the house closer to the potential contamination the fluorometer was moved to the farther house and the dye was identified there also. This, again, provided conclusive evidence that the contamination in the wells was caused by the storage of salt by the local highway department and here again, after paying for damages, the highway department is constructing a covered salt storage area on a concrete slab.

A third attempt to use dye for tracing contamination was found to be unsuccessful. In this instance the chloride content was much lower but still high enough to be of concern to the local homeowner. It was considered possible that the placement of salt for thawing a culvert uphill and across the street from the affected home was the source of the chloride content in the well. Rhodamine WT was placed in the culvert area during the winter of 1978 but the dye was not traced to the well supply

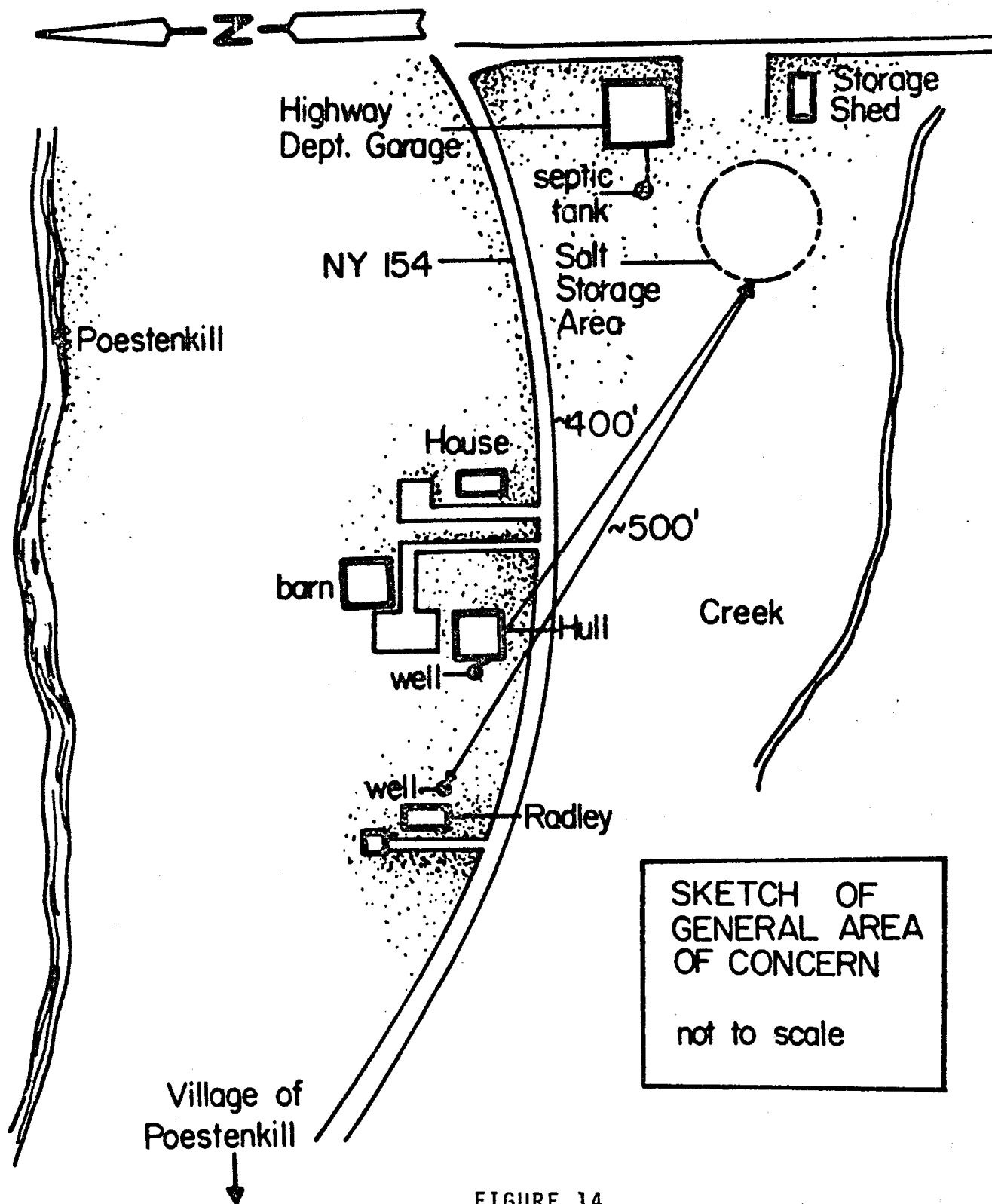


FIGURE 14

through June and the fluorometer was removed. In this case, it is possible that the source of the chloride was still highway department deicing salt but that it was not this specific culvert. In addition, in the interim the highway department had constructed along the side of the road some gutters which this year may have diverted the high chloride content water away from the previously affected well.

Thus, it may be seen that rhodamine WT alone does not assure the successful evaluation of a contamination. In this case, the dye would have had to have been placed in numerous locations around the area to identify which specific location reached the affected well. Since this was not within the financial means of the affected household, this study was discontinued.

CONCLUSIONS

Various tracers are available to follow ground water flow. Those considered in these studies were the chemical tracers sodium and potassium chloride, the color tracers rhodamine B and rhodamine WT, and the radioactive tracer tritium as tritiated water. Of these the rhodamine WT proved to be the most satisfactory. It could be applied easily in a soluble form and is readily available. It is moderately expensive, but the cost of the dye is one of the lesser costs in conducting a thorough study. It can be detected instantly and continuously in very low concentrations by means of a moderately priced instrument. It showed little degradation in the saturated zone. It is not sure if its depletion in passing through the unsaturated zone was due to adsorption or due to degradation by sunlight while standing for a day on the surface of the infiltration bed. Of all the tracers studied the rhodamine WT came closest to the parameters for describing a good tracer.

The tritium also rates as a good tracer. Its main disadvantages are: (1) its measurement requires returning samples to the lab for preparation and detection using fairly expensive radiation detection equipment, and (2) due to the present concern over radioactivity, regulatory officials tend to be overly conservative and may not approve a quantity of tritium sufficient to conduct the study. Its major advantages are that it acts just like water in its reactions in the soil.

The rhodamine B proved unsatisfactory in the studies conducted. It was apparently adsorbed rapidly in the unsaturated zone of the sand.

The chemical tracers employed in this study did not provide any positive results. This was attributed to the high chloride residual in the area studied, and to greater dilution than anticipated. Although chemical tracers are relatively inexpensive, the large quantities needed to increase their concentrations to detectable levels above background negates much of their cost advantage. Detection equipment varies from inexpensive for chloride, to expensive for sodium and potassium. Also in most cases samples must be secured and returned to a laboratory for analysis.

Tracers alone do not solve all the problems of following ground water flow. Samples must be secured in the direction of the flow. However, when the observation well is in the right location, tracers can provide positive proof that the flow travels from the location of the tracer addition to the observation location.

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