Loan Copy
#2

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TRACER STUDIES AND BACKGROUND FLUORESCENCE OF GROUND WATER IN THE OCALA, FLORIDA, AREA

By: Darwin D. Knochenmus

U.S. Geological Survey, WRD
227 N. Bronough Street, Suite 3015
Tallahassee, Florida 32301

Open-File Report

67004

Prepared in cooperation with

U.S. ARMY CORPS OF ENGINEERS

November, 1967

CONTENTS

ILLUSTRATIONS

TABLES

PURPOSE AND SCOPE

The City of Ocala and Silver Springs are situated in an area where the cavernous limestones of the Floridan aquifer are at or near the surface. As the Floridan is the principal aquifer from which most water for private, municipal, and industrial use is withdrawn, any development which may affect the aquifer is of public interest. Such a development is the planned construction of the Cross-Florida Barge Canal. Its planned route will pass south and east of Ocala and Silver Springs (fig. 1). South of Ocala the canal will be cut into the Floridan aquifer where it will cross the natural northward flow of ground water. One of the first questions which arises is what will be the effect of the canal on Silver Springs and Ocala's municipal supply. What the effect will be depends on the direction and rate of the ground-water flow. At the present time, a hydrologic investigation of the Ocala area is concerned with the movement of ground water from areas of recharge to Silver Springs, the major discharge point, 4 miles northeast of Ocala.

The use of tracers for determining direction and rate of movement of ground water is a direct method of measuring these parameters, but before tracer studies can be of value the selection of the specific tracer and its level of natural occurrence in the aquifer should be investigated.

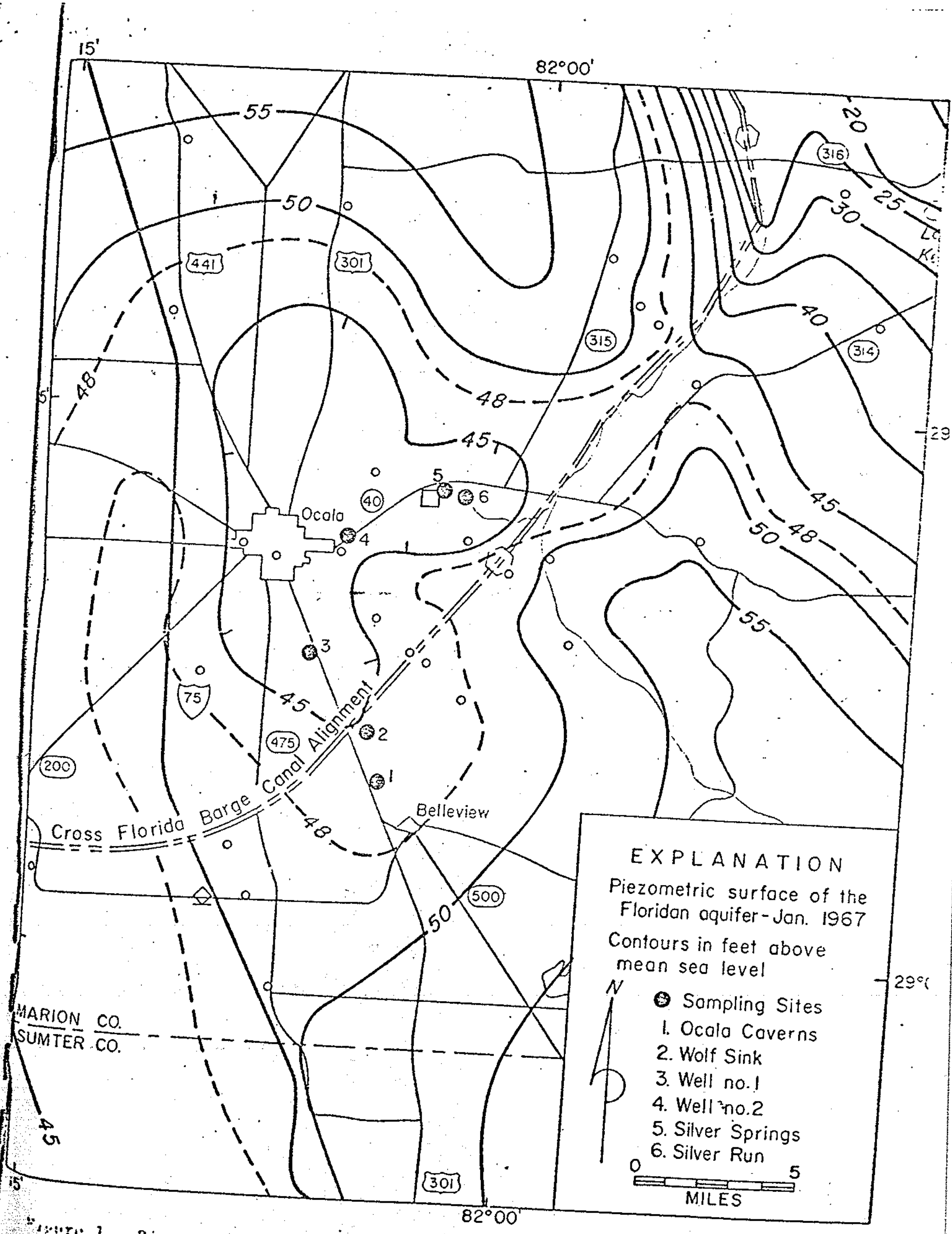

Figure 1. Piezometric map of the Ocala, Fla. area showing location of sampling sites.

The purpose of this investigation was to (1) evaluate the effectiveness of various tracers as they are applicable to the Ocala area and (2) determine the background fluorescence of the water in the aquifer. If a fluorescent dye such as fluorescein or Rhodamine WT were used as a tracer, the background fluorescence level of the water and its variation with time must be known.

GENERAL

Tracers have been used to determine the rate and direction of water movement since the latter part of the nineteenth century. Until about ten years ago the principal interest was in tracing the movement of ground water, but with improved analytical instruments and fluorescent dyes, tracers have been used extensively in surface water studies. Fluorescent dyes and the fluorometer have been used to determine dispersion, time-of-travel, and sediment transport in streams (C. F. Nordin, written communication, 1967).[1/] Radioisotopes such as tritium have recently been used as water tracers.

In 1887, fluorescein was used with much success in France for tracing ground-water movement through cavernous limestone (Dole, 1906, p. 79-82). It was superior to other tracers at that time because it could be detected at low concentrations by visual means and resulted in a qualitative measurement--either the presence or absence of the fluorescein. Since the development of the fluorometer, fluorescein now can be detected at a concentration as low as 0.01 part per billion (ppb). However, in natural environments the background fluorescence has a greater variation than the minimum detection level of the instrument.

[1/] C.F. Nordin, Fluorescent tracers in sediment transport studies, U. S. Geological Survey, WRD Research Note no. 33.

Rhodamine dyes are generally used in dispersion and time-of-travel studies of streams because their presence can be detected with the fluorometer.

Tritium, a radioisotope of hydrogen, is a good tracer. It is about 100,000 times more detectable than fluorescein and, being hydrogen, makes up part of the water molecule. Tritium has been used to trace ground-water movement either by determining the amount and fluctuation of natural tritium in the ground water or by injecting tritium into the ground water (Haskell and others, 1966, p. 3849; Burdon and others, 1963, p. 309).

DYE CHARACTERISTICS

Fluorescent dyes for use as tracers in hydrologic studies should have the following characteristics (Wilson, 1967):

1. A high detectibility range
2. Little effect on plant and animal life
3. A low sorption tendency
4. A low photochemical decay rate
5. Be soluble and disperse readily in water
6. Be chemically stable
7. Be inexpensive
8. Be easily separated from common background fluorescence
9. Be easy to handle

The following table gives the characteristics of the four fluorescent dyes most commonly used in tracer studies:

Table 1.--Characteristics of fluorescent dyes

Dye	Photochemical decay	Adsorption on rock material	Effect of temperature	Effect of ph
Fluorescein	high	low	slight	affected
Rhodamine B	moderately low	high	great	unaffected between 5-10
Pontacyl Pink	low	some	great	unaffected between 5-10
Rhodamine WT	moderately low	low	great	unaffected between 5-10

Fluorescein, because of its photochemical decay which is only a problem in surface waters, is not a satisfactory tracer for use in open channel flow. Bright sunlight rapidly decreases its fluorescence potential. Because rhodamine dyes are largely unaffected by sunlight, they are the fluorescent dyes commonly used in open channel studies.

Rhodamine B has been used as a ground-water tracer even though the dye is greatly adsorbed by sand, clay, and rock particles. Chances are greater for a successful tracing experiment if a new rhodamine dye, Rhodamine WT, were used. Rhodamine WT is adsorbed less by sediments and rocks than is rhodamine B, and appears to be a suitable ground-water tracer.

In most hydraulic experiments a quantitative measurement of the concentration of tracer is desired. The intensity of fluorescence is related to the concentration of the dye; and so, factors which effect fluorescence other than concentration must be controlled. Temperature, in particular, greatly affects the fluorescence of the rhodamine dyes. Fluorescence decreases with increasing temperature and a cold sample will give a much higher reading on the fluorometer than if it were warm. As much as 2 percent reduction in fluorescence may occur for every degree (Centigrade) rise in temperature (Buchanan, 1964, p. 4). When rhodamine dye is used as a tracer either the temperature must be controlled or temperature-correction coefficients must be used.

BACKGROUND FLUORESCENCE

Nearly all natural waters contain minerals and organic compounds which are fluorescent or give a background reading on the fluorometer. The wave lengths emitted by these naturally-occuring substances are the same as those emitted by the various dyes. Therefore, fluorescence, per se, does not indicate that the water contains injected dye. Rather, it is the sudden or abnormal increase in the level of fluorescence that is the indicator. To differentiate between normal and abnormal levels, the naturally-occuring, or background, fluorescence must be measured before a dye study is begun. Measurements should be made over a period of time to determine the natural variations and causes at all sites at which measurements are to be made during the contemplated study.

Background fluorescence in streams and lakes is generally much higher than in ground water because of turbidity, color, and naturally fluorescent material. In a study of sink lakes in the Ocala area, the background fluorescence in equivalent concentrations of fluorescein, varied between 2 and 30 ppb and appeared to be proportional to the color level of the water. Generally in central Florida surface waters the more highly colored the water the more organic material in solution. It is emphasized that the background readings are not due to fluorescein in the water, but are only measured in units of equivalent concentrations of fluorescein.

Chlorophyll, pheophytin, and other naturally occuring organic pigments, when excited with light energy, will emit light (fluoresce) at wavelengths from 220 to 690 millimicrons (mμ). In the fluorometer, primary filters are used to allow only a narrow band of wavelengths from the light source to excite (be absorbed by) the dye, and secondary filters allow only a narrow band, usually of longer wavelengths of emitted light from the dye to reach the photomultiplier. By narrowing the band of absorbed and emitted wavelengths, much of the undesired fluorescence can be screened out. The peak absorption wavelength of fluorescein and rhodamine is 496 mμ and 556 mμ respectively. Apparently natural fluorescent materials have peak absorption wavelengths nearer that of fluorescein than that of rhodamine. Rhodamine, because of its longer wavelength, thus has less interference from natural fluorescence than fluorescein.

The basic fundamentals of fluorometry which make possible the use of fluorescent dyes in tracing the movement of ground water are: (1) some compounds have the ability of discharging the energy obtained from absorbed light, by reemitting light of a longer wavelength; (2) the intensity of light emitted is proportional to the amount of exciting light absorbed; (3) the amount of light of a certain wavelength emitted is proportional to the concentration of the compound; and (4) fluorometer read-out is designed to be proportioned to amount of emitted light.

Procedure

A study was made to determine the magnitude and variation with time of background fluorescence in various ground-water environments in the Ocala area. Samples were collected during a two-month period at six sites representing ground-water environments. The five environments include a limestone cavern (Ocala Caverns), a sink (Wolf Sink), a spring (Silver Springs), a stream (Silver Run), and two wells (well 1, well 2). The location of sites and the piezometric surface are shown on figure 1. The site selection was based on the following criteria: (1) environments which could be used as monitoring sites during a tracer experiment, and (2) location of site along an approximate inferred flow line down the piezometric gradient from Ocala Caverns and Wolf Sink to Silver Springs, an area of discharge. The direction of flow was inferred from the piezometric map (Glen Faulkner oral communication).

The samples were collected and tested under controlled conditions to minimize the effects of photochemical decay, temperature, and instrumental error.

During the sampling period, samples were collected daily, Monday through Friday. Forty samples were collected at each site during the two-month period from January 3 to February 28. On one day, February 7, three samples were collected at Silver Springs and at Silver Run. Immediately after collection, the samples were stored in a covered case until returned to the laboratory. The samples were kept in the dark from the time of collection until they were analyzed with the fluorometer to minimize the chance of photochemical decay.

The samples were stored in the laboratory for 24 hours after collection to allow them to reach room temperature and to allow all suspended material to settle out. As the room temperature varied by only 4 degrees (71°-75°F) over the two-month period, all samples when analyzed were nearly uniform in temperature. This procedure was used to minimize temperature effect on fluorescence. Other procedures to minimize temperature effects were warming up the instrument for a sufficiently long period of time in order for it to reach its maximum operating temperature, and placing each sample in the fluorometer for exactly the same length of time (65 seconds). In 65 seconds, the instrument had time to stabilize and each sample had increased in temperature approximately the same amount.

The samples were tested for background fluorescence relative to both fluorescein and Rhodamine BA. Rhodamine BA was included because it was available as a standard, and because it has the same fluorescent characteristics as Rhodamine WT, a dye which may prove to be a suitable ground-water tracer.

The instrument used was a Turner, Model 111, fluorometer equipped with a high sensitivity conversion kit and a far-ultraviolet lamp as its light source. The kit and the far-ultraviolet lamp increased the sensitivity of the instrument about 20 fold. The primary filter used in conjunction with the fluorescein test passed the maximum amount of light having a wave length of 436 mμ, and the secondary filter passed the maximum amount of light having a wavelength of 510 mμ. The primary filter used in the rhodamine test passed light at a wavelength of 546 mμ and the secondary filter at 590 mμ.

The zero point of fluorescence on the fluorometer was established with distilled water, while the recommended practice is to zero the fluorometer with a dummy cuvette. By zeroing with the dummy cuvette, the background caused by the scattering of light by the sample water is included in the background reading. Standards containing 0.2, 0.5, 1.0, and 5.0 ppb of fluorescein were tested and the corresponding dial readings were plotted against the concentrations of fluorescein in ppb. A curve was drawn through the points relating dial reading to concentration of fluorescein. Four standards were also used to develop a dial reading versus Rhodamine BA concentration curve. These standards had concentrations of 0.8, 1.9, 3.9, and 7.7 ppb of Rhodamine BA. The curves indicated that the fluorometer is more sensitive to fluorescein than to Rhodamine BA, which is probably due to the particular sets of filters used.

The temperature of the sample was recorded immediately before it was poured into the cuvette, a small (3.5 cc) specialized test tube, and inserted in the fluorometer. To minimize instrumental error, the cuvette was always positioned with the same orientation in the instrument. After the sample had been in the fluorometer for 65 seconds, the dial was read and the value recorded. Each day the set of samples was tested for background fluorescence using fluorescein filters after which the filters were changed and the samples were retested for background fluorscence using rhodamine B filters. The zero point of fluorescence had to be reestablished with each change of filters.

Data

The background fluorescence values as determined from the forty samples from each site are listed in table 2. Background fluorescence is low, as would be expected in ground water. The values for fluorescein are more consistant than those for rhodamine. This is probably due to the lower sensitivity of the fluorometer to rhodamine where a small dial change corresponds to a relativity large change in concentration.

The average background fluorescence in equivalent concentrations of fluorescein using fluorescein filters, at each site is: well 1 - 0.1 ppb (8 dial divisions on 30 x scale), well 2- 0.1 ppb (8 dial divisions on 30 x scale), Ocala Caverns - 0.2 ppb (18 dial divisions on 30 x scale), Silver Springs - 0.2 ppb (18 dial divisions on 30 x scale), Wolf Sink - 0.3 ppb (28 dial divisions on 30 x scale), and Silver Run - 0.3 ppb (28 dial divisions on 30 x scale).

The variation of background fluorescence using fluorescein filters, at each site is small so that the difference between the sites is significant. At sites where there is little suspension and dissolution of material, such as in the wells, the background fluorescence is the lowest. At the Caverns and at Silver Springs, where some material is suspended and dissolved in the water, the background fluorescence has intermediate values. At Silver Run and at the sink, where at times surface runoff brings organic material into the water, the background fluorescence is the highest.

Table 2.--Background fluorescence at selected sites in the Ocala area--Continued

Date	Background Fluorescence in equivalent concentrations of fluorescein (ppb)						Background Fluorescence in equivalent concentrations of Rhodamine BA (ppb)					
	Well 1	Well 2	Ocala Caverns	Wolf Sink	Silver Springs	Silver Run	Well 1	Well 2	Ocala Caverns	Wolf Sink	Silver Springs	Silver Run
1-31-67	0.1	0.1	0.2	0.3	0.2	0.3	0	0	0	0	0	0
2- 1-67	.1	.2	.2	.3	.2	.3	0	0	0	0	0	0
2- 2-67	.1	.1	.2	.2	.2	.3	0	0	0	0	0	0
2- 3-67	.1	.1	.1	.3	.3	.3	0	0	0	0	0	0
2- 6-67	.1	.1	.1	.2	.2	.3	0	0	.5	0	.5	.5
2- 7-67	.1	.1	.2	.2	.2	.2	0	0	0	0	0	0
2- 7-67	-	-	-	-	.2	.2	-	-	-	-	0	.5
2- 7-67	-	-	-	-	.1	.2	-	-	-	-	0	0
2- 8-67	0	0	.1	.2	.1	.2	0	0	.5	0	0	0
2- 9-67	0	.1	.1	.3	.2	.3	0	.5	.5	0	0	.5
2-10-67	.1	.2	.1	.2	.2	.3	0	.5	.5	0	0	.5
2-13-67	.1	.2	.7	.3	.2	.5	0	0	0	0	0	0
2-14-67	0	.1	0	.2	.1	.2	0	0	0	0	0	0
2-15-67	0	.1	.1	.3	.2	.3	.8	.5	.8	.8	.5	.5
2-16-67	0	.2	.1	.2	.1	.2	.5	0	.5	0	.5	.5
2-17-67	.1	.1	.2	.3	.3	.4	.5	0	.5	0	.5	.5
2-20-67	.1	.1	.2	.3	.3	.3	0	0	0	0	.5	0
2-21-67	0	.1	.1	.2	.3	.3	.8	.8	.8	0	.8	1.0
2-22-67	.1	.2	.3	.3	.3	.3	0	0	0	.5	0	0
2-23-67	.1	.1	.1	.2	.2	.2	0	.5	0	0	0	0
2-27-67	.1	.1	.1	.2	.2	.3	0	.5	.5	0	0	0
2-28-67	.1	.1	.3	.2	.2	.2	0	0	0	0	0	0

Table 2.--Background fluorescence at selected sites in the Ocala area

	Background Fluorescence in equivalent concentrations of fluorescein (ppb)						Background Fluorescence in equivalent concentrations of Rhodamine BA (ppb)					
Date	Well 1	Well 2	Ocala Caverns	Wolf Sink	Silver Springs	Silver Run	Well 1	Well 2	Ocala Caverns	Wolf Sink	Silver Springs	Silver Run
1- 3-67	0.2	0.2	0.3	0.3	0.3	0.3	0.5	0	0	0.5	0.5	0
1- 4-67	.1	.2	.2	.3	.3	.3	0	0	0	0	0	0
1- 5-67	.1	.2	.2	.3	.3	.3	.8	.5	.8	.8	.8	.8
1- 6-67	.1	.2	.3	.4	.3	.3	.8	.5	0	.5	.5	0
1- 9-67	0	.2	.1	.3	.2	.3	.5	.5	.5	.5	0	0
1-10-67	.1	.1	.2	.2	.2	.3	.5	.5	0	.5	.5	0
1-11-67	0	.1	.1	.3	.3	.3	0	0	0	.5	0	0
1-12-67	.1	.1	.2	.3	.2	.4	0	.8	.8	1.0	.8	.8
1-13-67	.1	.2	.2	.3	.3	.3	0	0	0	.5	.5	.5
1-16-67	.1	.1	.2	.2	.2	.2	0	.5	0	0	0	.5
1-17-67	.1	.2	.2	.3	.3	.3	0	.5	0	0	0	.5
1-18-67	.1	.2	.2	.3	.2	.3	.5	.5	.5	.8	.8	.5
1-19-67	.1	.1	.2	.3	.1	.2	0	0	0	0	0	0
1-20-67	.1	.2	.1	.3	.4	.3	0	0	0	0	0	0
1-23-67	.1	.1	.1	.3	.2	.3	.5	.5	.5	.5	.5	.5
1-24-67	.1	.2	.2	.3	.2	.4	.5	0	.5	0	.8	.5
1-25-67	.1	.1	.5	.2	.3	.2	0	0	.5	0	0	.5
1-26-67	0	.2	.2	.3	.2	.2	0	0	.5	0	0	0
1-27-67	.1	.2	.8	.3	.3	.3	.5	.5	0	.5	0	.5
1-30-67	.1	.1	.2	.3	.2	.2	.5	.5	0	.5	0	.5

Samples from Ocala Caverns had anomalous values when tested with fluorescein filters on January 25, 27, and February 13. The same samples when tested with rhodamine B filters did not have anomalous values. People periodically swim and boat in the cavern which could increase turbidity and result in higher background fluorescence. In each case the background fluorescence dropped to its normal level the following day. It is important to understand that use of different filters will result in different background readings.

Rainfall effects

Silver Run was selected as a sampling site in addition to the main "boil" at Silver Springs because numerous small springs discharge to the run. In the event that these small springs discharge water from the Caverns and the Sink, sampling only at the main boil would result in an unsuccessful tracer study.

The background fluorescence data from Silver Run was analyzed to see if a site which at times contains surface runoff, would have abnormally high fluorescence, because surface water in the area is known to be relatively high in background fluorescence. Surface runoff into Silver Run occurs predominantly during rainfall. To test for a correlation between fluorescence and rainfall, daily values of background fluorescence using fluorescein filters and rainfall were plotted on figure 2. No apparent relation between fluorescence and rainfall was noted with the exception of February 13, when, following 5 days of rain, the highest fluorescence using fluorescein filters (0.5 ppb) was recorded.

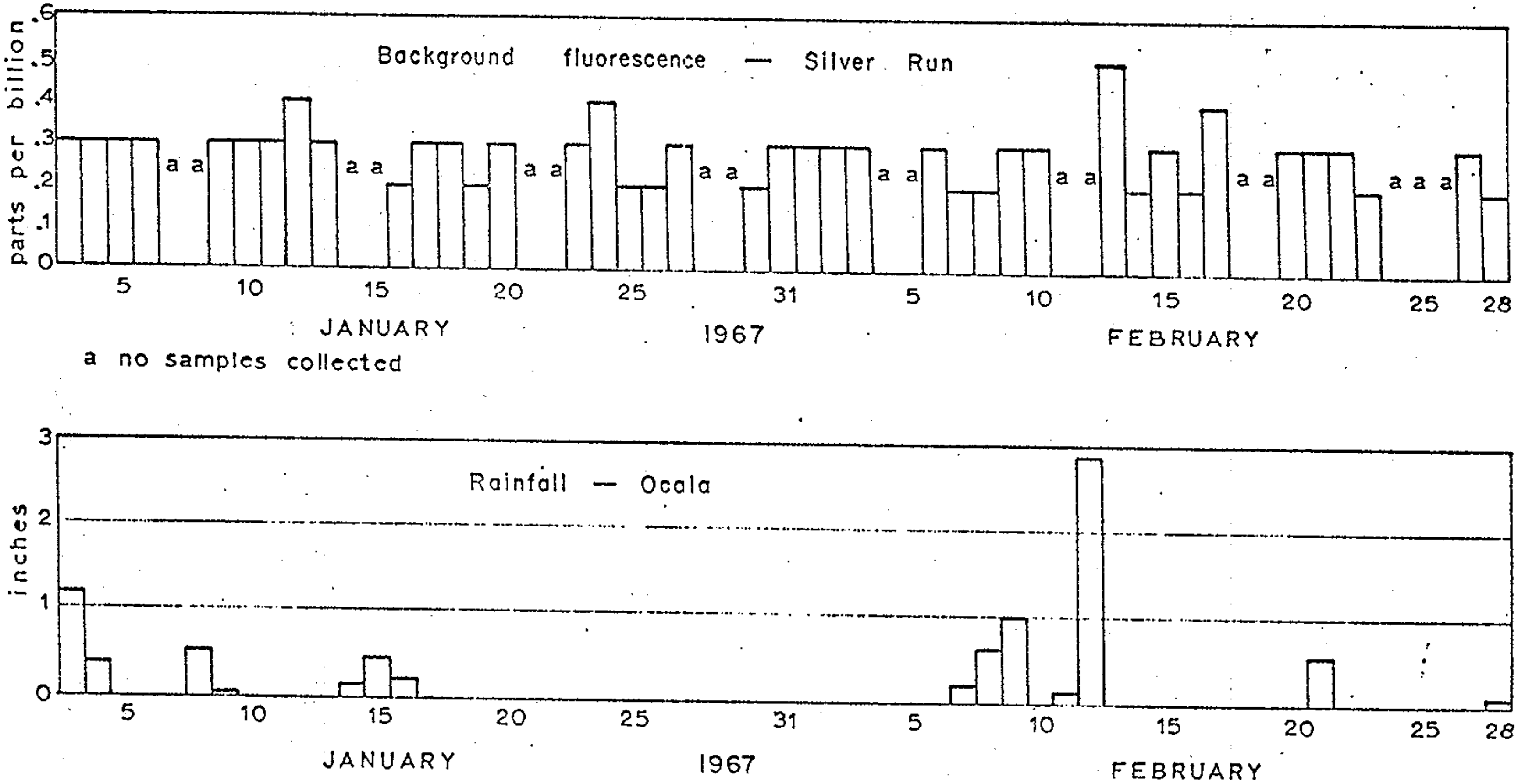

Figure 2. Bar graphs of daily background fluorescence and rainfall

It appears reasonable to infer that the fluorescence value for this date was affected by runoff. Though background fluorescence is a little higher in the run a short distance downstream from the head of the spring, it appears that the run can be used as a sampling site during a tracer study, but following periods of excessive rainfall abnormally high fluorescence may occur.

TRACER STUDIES IN THE OCALA AREA

The upper part of the Floridan aquifer in the Ocala area consists of cavernous limestone. Flow paths through cavernous limestones are never clearly defined and tracer studies in Florida and elsewhere have been made with limited degrees of success.

In the French experiments of 1887, ground-water movement was traced at rates ranging from 0.34 foot per minute to 55 feet per minute through distances up to 8 miles. Generally the heads between the injection and detection points were more than 100 feet. (Dole, 1906, p. 74-82).

Similar experiments were made in Greece in 1963, where tracers were used to determine interconnections between sinkholes and springs. Fluorescein was introduced in a sink at an elevation of 2,000 feet to trace the water movement for 18 miles to some coastal springs. The fluorescein was not detected at the springs but through the use of tritium the ground water was found to move from the sink to the springs in eight days (Burdon, 1963, p. 314).

In New Mexico, water was traced from a sinkhole to a spring with fluorescein. The tracer traveled the three-fourths of a mile in 5 days under a head of 425 feet (Hollander, 1954, p. 15).

Fluorescein was used to trace the movement of water in the Floridan aquifer in the Tampa area from a sink to Sulphur Springs, a distance of about four miles (Menke and others, 1961, p. 73). No calculation of the time of travel was made.

In 1965-66, fluorescein was used to trace the movement of ground water in the Ocala area. The dye was introduced at Ocala Caverns and detected at Wolf Sink, (1.3 miles) to the north (fig. 1). A plot of fluorescein concentration versus time at Wolf Sink is shown on figure 3. Two days after injection in Ocala Caverns the dye had not reached Wolf Sink as shown by the first point on the curve. Nine days after injection the fluorescein concentration in Wolf Sink was 20 ppb. By the 23rd day all the fluorescein has passed through the sink and the fluorescence had returned to the background level. The solid line represents actual data which gives the recession curve of the fluorescein from Wolf Sink. The dashed line represents interpolation of the curve between the measured concentration of the 2nd day and that of the 9th day. If the interpolated curve represents the actual condition, the peak concentration of fluorescein would have reached the sink from the Caverns in 6 days. The estimated velocity calculated from the interpolated curve is 0.8 foot per minute. However, lacking observations, the shortest time in which the dye could have reached the sink was essentially 3 days, or the day following the observation of no dye, which would give a maximum velocity of 1.6 feet per minute. Further, the longest time it could have taken the dye to reach the sink was 9 days which would give a minimum velocity of 0.5 foot per minute.

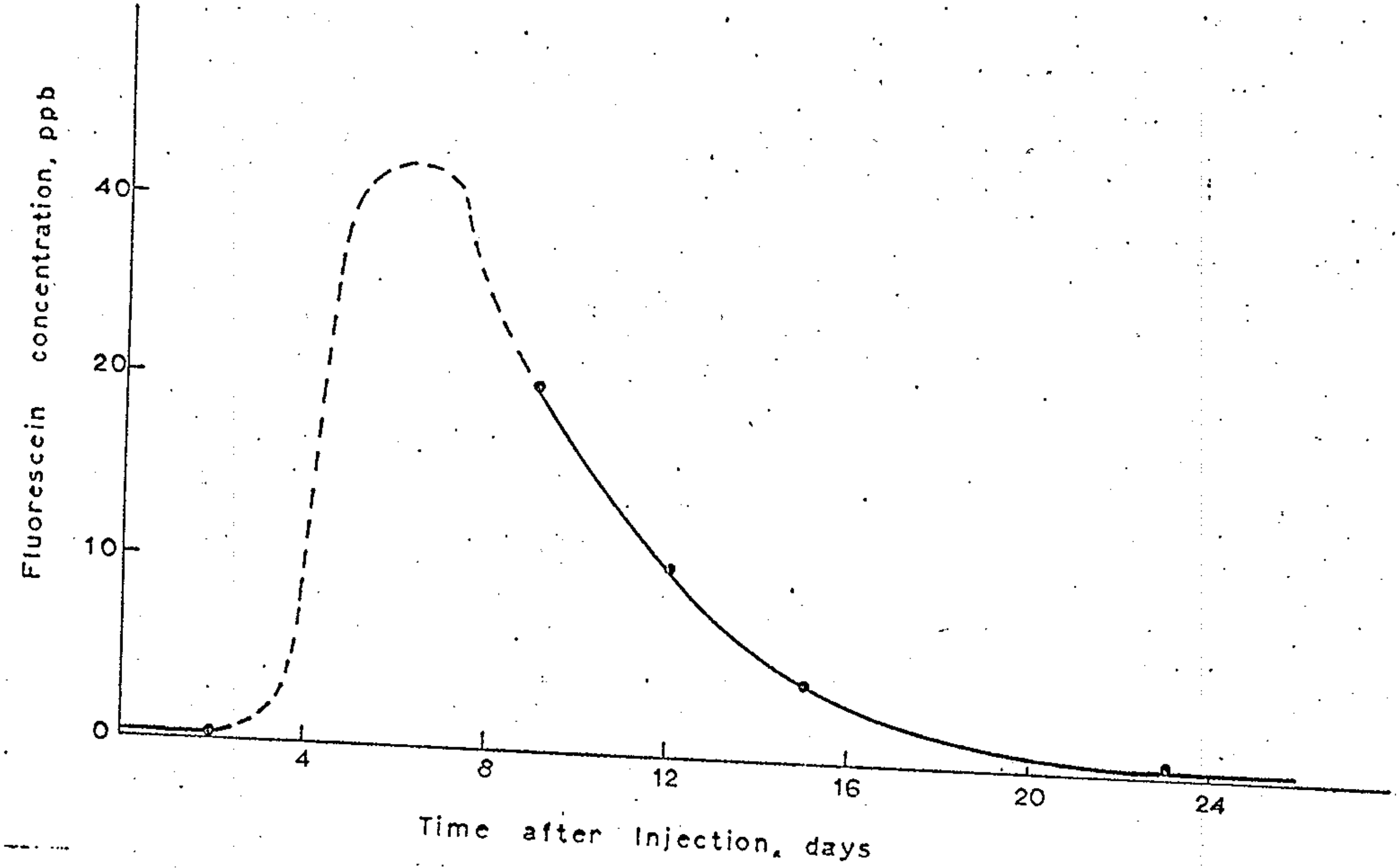

Figure 3. Concentration-time curve of Wolf Sink with injection of 20 pounds of fluorescein in Ocala Caverns, December 8, 1965.

In another test, fluorescein was introduced into Wolf Sink and the recession curve of fluorescein concentration is shown on figure 4. From the recession curve the rate of flow through the sink can be calculated from either an empirical or theoretical relation. It has been found from tracer studies that rate of flow is related to the area under a concentration-time curve and the quantity of dye in the following way:

$$Q = \frac{M}{A}$$

Q = rate of flow
M = quantity of dye injected
A = area under curve

A determination of Q by computing the area under the curve in figure 4 gives a rate of flow through the sink of 19 cubic feet per minute. The rate of flow is also given theoretically by the recession of dye from the sink which follows the exponetial function:

$$C_t = C_o e^{-kt}$$

C_t = concentration of dye at any time t
C_o = initial concentration of dye
e = base of natural logarithms
k = a constant equal to the ratio of the rate of flow to the volume of the sink
t = time in minutes

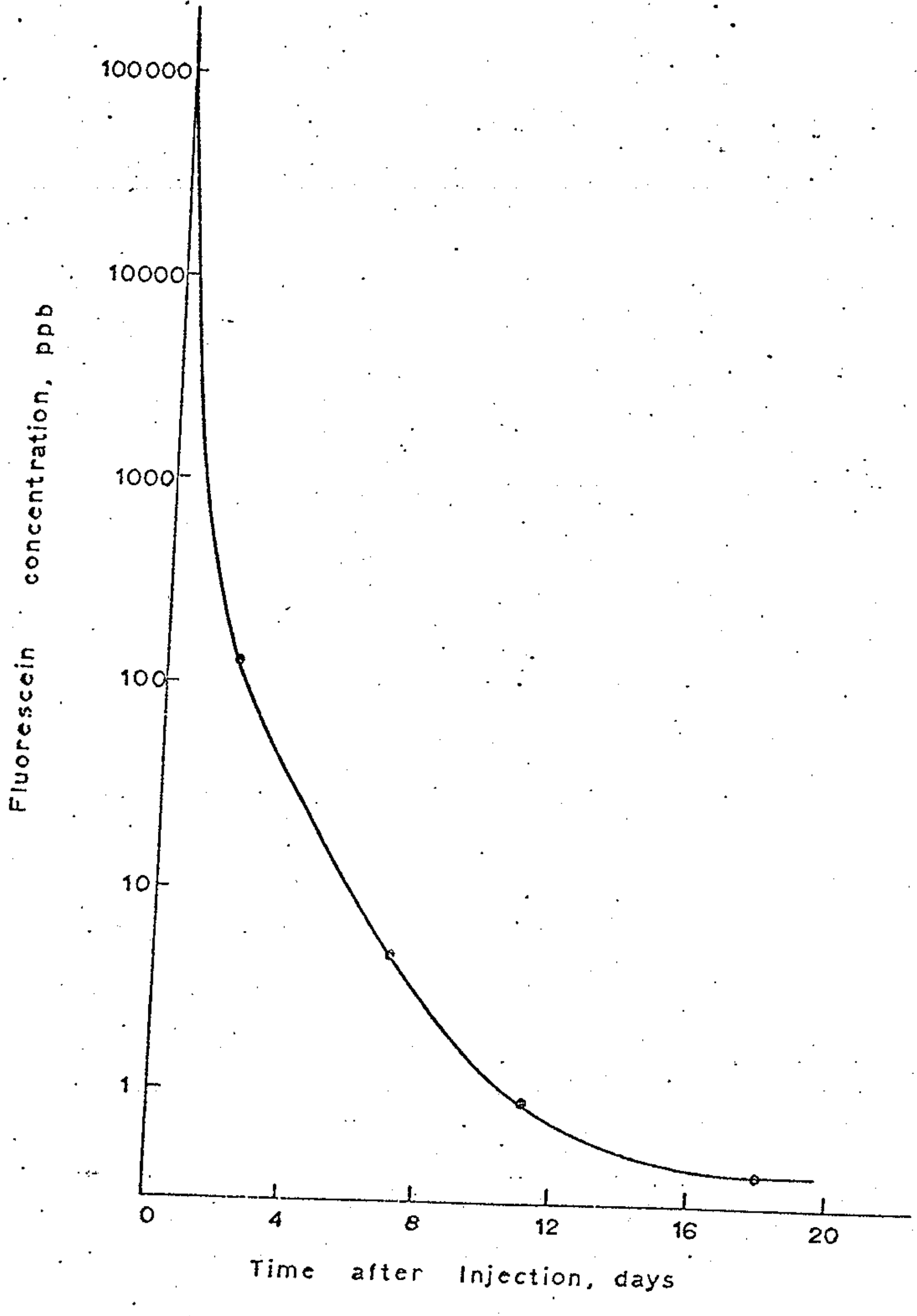

Figure 4. Concentration recession curve of Wolf Sink with injection of 30 pounds of fluorescein in Wolf Sink, January 29, 1966.

Determination of k gives a rate of flow through the sink of 5 cubic feet per minute. Averaging the results from the two calculations gives 12 cubic feet per minute as the estimated rate of flow through Wolf Sink. The discharge of Silver Springs is 5,000 times greater than the above rate of flow, therefore, the dilution factor at Silver Springs of a dye injected at Wolf Sink would be 5,000 fold. Injection of 30 pounds (150,000 ppb) of fluorescein in Wolf Sink would cause a concentration at Silver Springs of 30 ppb from the dilution factor alone. The actual concentration would be much less as a result of dispersion of the dye.

TRITIUM

Natural or injected tritium can be used in tracer studies. Natural tritium originates in the atmosphere and is introduced into the ground-water system through the infiltration of rainfall. With certain events such as hydrogen bomb testing, the tritium content of the rain is increased and as it infiltrates the ground a high tritium front is developed in the ground water. The distance the high tritium front has moved since the time of infiltration is a measure of the ground-water velocity. When tracing with injected tritium, the tritium is put into the aquifer and various sites are sampled for the detection of the tritium. The content of the injected tritium must be well above the concentration of the natural tritium so as to determine when the injected tritium has arrived.

The natural tritium content of ground water was used to estimate velocities in California in a regional study covering 700 square miles (Haskell and others, 1966, p. 3849). From the study, the movement of ground water through clastic sediments was estimated at 22 feet per day.

In Greece the rate and path of ground water movement was determined through the use of injected tritium after a test with fluorescein was unsuccessful.. In areas where dilution is a large factor, tritium can be used successfully whereas other tracers can not due to the ability to detect tritium at such low concentrations, for example, 1,000 times lower than fluorescein.

In the Ocala area, injected tritium would appear to be the best for tracing ground water movement to Silver Springs based on the dilution factor. If movement is to be traced through any distance, the dilution of most other tracers make them difficult to detect. But there are disadvantages to using tritium as a tracer. Before injecting tritium into the ground water, a permit allowing such use must be received from the Atomic Energy Commission. Also, the intention of injecting a tracer into the water supply must be publicized in the local area. Another disadvantage with a study using injected tritium is in the increased effort and cost to conduct it. The samples must be shipped to Washington D. C. for analyses so that before data from the first samples are received at the study site, the experiment would have been underway for some time. This situation allows no adjustments to the sampling procedures such as frequency of sampling and length of sampling period. In a tracer study, when the results are unavailable during the experiment, the cost of conducting the experiment is much higher.

Samples of ground water have been collected in the Ocala area for natural tritium analyses to determine the natural tritium level and as a tool in interpreting the ground-water movement. Also, in Ocala, samples of rain water are periodically analyzed for tritium content, which has ranged from 52 to 1,400 T.U. (tritium units) since 1962.

SUMMARY AND CONCLUSIONS

Fluorescein is a good ground-water tracer in cavernous limestone. In the Ocala area, the background fluorescence in equivalent concentrations of fluorescein is small, being 0.1 ppb in wells, 0.2 ppb in Ocala Caverns and Silver Springs, and 0.3 ppb in Silver Springs, and 0.3 ppb in Silver Run and Wolf Sink. Fluorescein can be detected as low as 0.01 ppb but because the background fluorescence at each site varied by about 0.2 ppb, a concentration higher than the amount of variation must be available to detect the presence of the tracer. Rainfall in excessive amounts increases the background fluorescence in Silver Run. For a successful tracer experiment, fluorescein should have a concentration above 2 ppb at the detection site to overshadow the background fluorescence.

From previous fluorescein tracer studies in the Ocala area, the average velocity of ground-water flow between Ocala Caverns and Wolf Sink was estimated at 0.8 foot per minute at a gradient of about one foot per mile. The rate of flow through Wolf Sink was estimated at 12 cubic feet per minute.

Tritium would appear to be a better tracer for tracing ground-water movement to Silver Springs as it can be detected at very low concentrations compared to other tracers, but because of its radioactive nature a tritium experiment is more costly and requires more effort to conduct.

Tracers are more valuable as a hydrologic tool when used to obtain time-of-travel data between two specific points. When a tracer study is used to determine hydraulic parameters of direction and rate of flow in the aquifer the results are, at best, only estimates. The flow line between the injection site and detection site may or may not represent the average conditions in the aquifer. From an areal sense the direction of flow of ground water can be shown better by means of a piezometric map than a tracer study. In a cavernous limestone the exact path of the water particles cannot be known from tracers. What is known from a successful tracer study is that water has moved from one point to another and a value of the average velocity between the two points determined.

In the Ocala area, fluorescein could be and has been used to trace the movement of ground water. From an injection of 30 pounds it was successfully traced for 1.3 miles. To trace water with fluorescein over a distance of ten miles and to detect it at Silver Springs would require many times the concentration used in the previous experiments.

Tritium would have a greater chance of success than fluorescein for tracing water to Silver Springs, but the exact path of the water would not be known and the rate of flow could only be inferred as representative of the area. An injected tritium experiment would probably not increase the knowledge of the direction of flow as inferred from the piezometric map or of the rate of flow as estimated from the previous fluorescein experiment.

Selected References

1. Buchanan, T. J., 1964, Time of travel of soluble contaminants in streams: Sanitary Engr. Div. Jour., Am. Soc. Civil Engineers Proc., v. 90, no. SA3, p. 1-12.

2. Burdon, D. J., Eriksson, E., Payne, B. R., Papadinitropoulos, T., and Papakis, N., 1963, The use of tritium in tracing karst groundwater in Greece, in Radioisotopes in hydrology: Vienna, International Atomic Energy Agency, p. 309-320.

3. Dole, R. B., 1906, Use of fluorescein in the study of underground waters, in Fuller, M. L., Underground water papers, 1906: U. S. Geol. Survey Water-Supply and Irrigation Paper 160, p. 73-85.

4. Feverstein, D. L., and Selbck, R. E., 1963, Fluorescent tracers for dispersion measurements: Am. Soc. Civil Engineers Proc., v. 89, no. SA4, p. 1-21.

5. Haskell, E. E., Leventhal, J. S., and Bianchi, W. C., 1966, The Use of tritium to measure the movement of groundwater toward irrigation wells in western Fresno County, California: Jour. Geophys. Research, v. 71, no. 16, p. 3849-3859.

6. Hollander, J. T., 1954, Possible flow of water between Rito Resumidera and Poleo Canyon Spring, Rio Arriba County, New Mexico: Reports Sec. technical Div., State Engineer Office, tech. rept. no. 2., p. 18.

7. Lewis, D. D. Kriz, G. J., and Burgy, R. H., 1966, tracer dilution sampling technique to determine hydraulic conductivity of fractured rock: Water Resources Research, v. 2, no. 3, p. 533-542.

8. Menke, C. G., Meredith, E. W., and Wetterhall, W. S., 1961, Water Resources of Hillsborough County, Florida: Florida Geol. Survey Rept. of Invest. no. 25, p. 101.

9. Replogle, J. A., Myers, L. E., and Brust, K. J., 1966, Flow measurements with fluorescent tracers: Hydraulics Div. Jour., Am. Soc. Civil Engineers, v. 92, no. HY5, p. 1-15.

10. Wilson, J. F., 1967, Fluorometric procedures for dye tracing: U. S. Geol. Survey techniques of Water-Resources Inv., Book 3, Chap. A 10 (in press).

11. Wright, R. R., and Collings, M. R., 1964, Application of fluorescent tracing techniques to hydrologic studies: Am. Water Works Assoc. Jour., v. 56, no. 6, p. 748-754.

APPENDIX

Table 3.--Background fluorescence of surface and ground waters at miscellaneous sites in the Ocala area.

Date	Fluorescence in ppb of fluorescein or equivalent concentrations of fluorescein	Location
11-29-65	0.0	Silver Springs
12- 8-65	0	Well, Ocala Municipal Airport
12- 9-65	.2	Silver Springs
12- 9-65	.2	Well, Ocala Municipal Airport
12-10-65	.5	Silver Springs
12-10-65	.1	Well, Ocala Municipal Airport
12-10-65	.1	Wolf Sink
12-11-65	.1	Silver Springs
12-16-65	.1	Silver Run
12-17-65	[a]17	Ocala Caverns
12-17-65	[a]20	Wolf Sink
12-20-65	[a]10	Wolf Sink
12-21-65	0	Silver Run
12-23-65	[a]4.5	Wolf Sink
12-23-65	0	Silver Springs
12-23-65	.2	Silver Run
12-27-65	.1	Silver Springs
12-31-65	[a].8	Wolf Sink
12-31-65	0	Silver Springs
12-31-65	0	Silver Run
12-31-65	0	Well, T16S, R22E, Sec 2 (Paul Shively)
12-31-65	0	Well, T15S, R22E, Sec 35 (A. C. Lisk)
12-31-65	0	Well, T16S, R22E, Sec 2 (John Swoap)
12-31-65	0	Well, T16S, R22E, Sec 14 (Lorene King)
1 -14-66	.2	Wolf Sink
1 -14-66	.1	Well, T15S, R22E, Sec 35 (A. C. Lisk)
1 -14-66	.1	Well, T15S, R22E, Sec 35 (Gillet's Store)
1 -14-66	.1	Well, T15S, R22E, Sec 36 (Piney Woods Trailer Park)
1 -14-66	0	Silver Springs
1 -14-66	.1	Silver Run
1 -14-66	.1	Well, T15S, R22E, Sec 34 (Scroggin)
1 -14-66	.1	Well, T16S, R23E, Sec 6 (Jack Pruitt)
1 -31-66	[a]134	Wolf Sink
2 - 1-66	0	Well, T16S, R22E, Sec 14 (Lorene King)
2 - 1-66	0	Well, T16S, R22E, Sec 10 (Dean's Bar B Q)

[a] contains fluorescein dye.

Table 3.--Background fluorescence of surface and ground waters at miscellaneous sites in the Ocala area--Continued

Date	Fluorescence in ppb of fluorescein or equivalent concentrations of fluorescein	Location
2- 1-66	0.3	Limestone Pit, T17S, R22E, Sec 2
2- 1-66	0	Well, T16S, R22E, Sec 14 (Pine Knoll Motel)
2- 1-66	.1	Well, T16S, R22E, Sec 10 (Lowder's Trailer Park)
2- 1-66	.1	Heil's Springs, T16S, R22E, Sec 13
2- 1-66	7.7	Pond, T16S, R22E, Sec 27
2- 1-66	5.5	Pond, T16S, R22E, Sec 29
2- 1-66	2.8	Pond, T16S, R22E, Sec 18
2- 1-66	25	Stream, T16S, R22E, Sec 34
2- 1-66	2.0	Pond, T17S, R23E, Sec 1
2- 1-66	14	Pond, T16S, R22E, Sec 17
2- 1-66	20	Pond, T16S, R22E, Sec 20
2- 1-66	5.7	Spring, T11S, R22E, Sec 9
2- 1-66	3.8	Pond, T16S, R22E, Sec 18
2- 1-66	12	Sink, T16S, R22E, Sec 17
2- 1-66	9.0	Pond, T17S, R22E, Sec 6
2- 1-66	3.0	Spring, T16S, R22E, Sec 33 (Maverick Farm)
2- 5-66	[a]4.8	Wolf Sink
2- 5-66	0	Well, T16S, R22E, Sec 2 (Paul Shively)
2- 5-66	0	Well, T16S, R22E, Sec 2 (John Swoop)
2- 5-66	0	Well, T16S, R22E, Sec 14 (Lorene King)
2- 5-66	.1	Well, T15S, R22E, Sec 34 (Scroggin)
2- 5-66	0	Well, T16S, R22E, Sec 10 (Dean's Bar B Q)
2- 5-66	0	Well, T16S, R22E, Sec 10 (Lowder's Trailer Park)
2- 5-66	0	Well, T16S, R22E, Sec 9 (Cyrus)
2- 5-66	0	Well, T16S, R22E, Sec 4 (C. Longs)
2- 5-66	0	Well, T16S, R22E, Sec 16 (Willis)
2- 5-66	0	Well, T16S, R22E, Sec 9 (Anne Griffen)
2- 5-66	.2	Limestone Pit, T16S, R22E, Sec 9
2- 9-66	[a].9	Wolf Sink
2-16-66	.4	Wolf Sink
2-16-66	0	Well, T16S, R22E, Sec 9 (Cyrus)
2-16-66	0	Well, T16S, R22E, Sec 4 (C. Longs)
2-16-66	0	Well, T16S, R22E, Sec 4 (Murphy's Spur Station)
2-16-66	.2	Well, T16S, R22E, Sec 3 (Jimmy's Grocery)
2-16-66	0	Well, T16S, R22E, Sec 16 (Willis)

a/ contains fluorescein dye.

Table 3.--Background fluorescence of surface and ground waters at miscellaneous sites in the Ocala area--Continued

Date	Fluorescence in ppb of fluorescein or equivalent concentrations of fluorescein	Location
2-16-66	0.0	Well, T16S, R22E, Sec 10 (Dean's Bar B Q)
2-28-66	.2	Silver Springs
3-14-66	.2	Well, T15S, R22E, Sec 35 (Gillet's Store)
3-14-66	.2	Wolf Sink
3-14-66	0	Well, T16S, R22E, Sec 10 (Dean's Bar B Q)
3-14-66	.2	Well, T16S, R22E, Sec 14 (Pine Knoll Motel)
3-14-66	0	Silver Springs
3-14-66	.2	Silver Run
3-14-66	.6	Well, T16S, R22E, Sec 4 (Murphy's Spur Station)
3-18-66	0	Well, 290400N0820910.1 (CE 33)
3-21-66	.3	Well, 285900N0820720.1 (CE 36)
3-23-66	.2	Well, 290810N0820250.1 (CE 40)
3-28-66	.3	Silver Springs
4- 1-66	1.1	Well, 291130N0820150.1 (CE 47)
4-11-66	.2	Silver Springs
4-11-66	0	Silver Run
4-13-66	0	Well, 290820N0820320.1 (CE 39)
4-13-66	0	Well, 291310N0820450.1 (CE 45)
4-18-66	0	Well, 291600N0815500.1 (CE 55)
4-21-66	0	Well, 291110N0820600.1 (CE 44)
4-25-66	0	Silver Springs
5- 4-66	0	Well, 291810N0815700.1 (CE 53)
5- 9-66	.2	Well, 291740N0815620.1 (CE 54)
5-10-66	0	Silver Springs
5-10-66	0	Well, 291920N0814800.1 (CE 52)
5-10-66	0	Silver Run
5-10-66	0	Limestone Pit, T14S, R22E, Sec 31
5-17-66	0	Well, 291030N0820030.1 (CE 49)
5-18-66	.1	Well, 291130N0820150.1 (CE 47)
5-18-66	0	Well, 290830N0815840.1 (CE 61)
5-19-66	0	Well, 290910N0820450.1 (CE 38)
5-20-66	0	Well, 290700N0820150.1 (CE 41)
5-23-66	0	Well, 290830N0815840.1 (CE 61)
5-23-66	0	Well, 290740N0821000.1 (CE 32)
5-25-66	0	Well, 290250N0820910.1 (CE 34)
5-26-66	0	Well, 290623N0821807.1 (CE 20)
5-27-66	0	Well, 290739N0822457.1 (CE 12)
5-31-66	0	Well, 290421N0821908.1 (CE 21)