CDM Federal Programs Corporation

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November 20, 1989

Ms. Donna McCartney
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U.S. Environmental Protection Agency
841 Chestnut Building 6th floor
Philadelphia, PA 19107

PROJECT: EPA CONTRACT NO.: 68-W9-0004

DOCUMENT NO.: TES7-C0340-EP-BJZL

SUBJECT: Work Assignment C03040
Delta Quarries

Dear Ms. McCartney:

The purpose of this letter is to inform you that CDM FPC determined that the aquifer test data obtained at the Delta Quarries site during the month of August may be suspect and should be repeated at selected locations.

As noted in the Delta Quarries Field Trip Report, CDM FPC witnessed approximately 20% of the slug/pump tests conducted. The primary problem with the observed testing was that the change in head (i.e., water level drop caused by pumping or bailing or water level rise caused by introducing a mechanical slug or a 'slug' of water) was not sufficient to allow calculation of representative hydraulic conductivity values. For example, a 2-inch diameter mechanical slug which was 2-feet in length was used to create a water level rise in a 6-inch open borehole well in a limestone aquifer. A larger slug would have been more appropriate in this application.

Data logging was initiated immediately after the slug was introduced or withdrawn. The RISOP indicates that data logging should be started such that at least two static water level readings are taken first.

During the test observed at well 18-88 the transducer used to record water levels was malfunctioning. This was evident by the indication that the water level had risen to 9.96 feet above the top of the casing. This water level was recorded 40 minutes after the well had been bailed ten times with a 1-1/4-inch diameter bailer two feet long. Selected data points are a follows:

Minutes after test start	Feet below top of protective casing
46	-25.20
40	- 9.96
34	2.74
28	5.30
20	7.34
5	7.71
2	7.73

CDM FPC personnel commented to Canonie staff that the transducer was apparently malfunctioning. Canonie staff experienced problems during the set-up for the following test at 10A. After some time the Canonie staff person indicated that there was something wrong with the transducer and another transducer was used. The malfunctioning transducer was numbered #1, while the replacement transducer was numbered #3.

Canonie staff also was not familiar with the use of the Organic Vapor Analyzer (OVA) instrument. OVA readings of 0 ppm were recorded on opened well heads on 3 wells before CDM FPC staff informed Canonie that the instrument switch was not turned on.

Therefore due to these incidents, as well as the questionable methodology employed, CDM FPC questioned the validity of the aquifer test data. It should be noted that aquifer testing in the complex geology found at the Delta Landfill may not be conclusive even if properly completed. A relatively inexpensive technique which may prove useful in determining contamination travel times and dispersivity of the site formations is tracer testing with a Rhodamine WT dye. This dye, as well as several other tracer types, has been successfully used in groundwater investigations in karst terranes. The enclosed attachment provides further information on dye tracers.

If you have any comments regarding this submittal please contact me at (215) 293-0450.

Sincerely

CDM Federal Programs Corporation

Bruce R. Pluta
Environmental Scientist

BRP/dmh

Enclosure

cc: Elaine Spiewak, EPA Regional Project Officer, CERCLA Region III (letter only)
Jean Wright, EPA TES VII Project Officer (letter only)
Stephen Kovash, EPA TES VII Contracting Officer (letter only)
Donald Senovich, CDM Federal Programs Corporation Program Manager

from Ground Water Tracers, by S.N. Davis, D.J. Campbell, H.W. Bentley, & T.J. Flynn NWWA, Worthington, Ohio, 1985

Dyes

Various organic dyes have been used for surface-water and ground-water tracing since the late 1800's. Dyes are relatively inexpensive, simple to use, and effective. The extensive use of fluorescent dyes for water tracing began around 1960. Fluorescent dyes are preferable to non-fluorescent varieties due to much better detectability. Some non-fluorescent dyes include Congo Red and Malachite Green, which have been used in conjunction with cotton strip detectors (Drew, 1968) or with visual detection, often in soil studies. This discussion will concentrate on fluorescent dyes, which are more suitable for ground-water studies.

The most commonly used tracer dyes to be discussed include fluorescein, pyranine, lissamine FF, rhodamine B, rhodamine WT, and sulfo rhodamine B. Photine CU and amino G acid, two optical brighteners, will also be mentioned.

Table 4.4 gives the dyes by color, lists alternative names, and provides spectra wavelengths and filter combinations for their analysis. Several dyes may be used in a single tracer test if the absorption and emission spectra do not overlap. For example, Smart and Laidlaw (1977) recommended a combination of lissamine FF, amino G acid, and rhodamine WT. In general, the spectra do overlap, particularly for dyes of the same color. Figure 4.7 illustrates the excitation and emission spectra of rhodamine WT.

Although fluorescent dyes exhibit many of the properties of an ideal tracer, a number of factors interfere with concentration measurement. Fluorescence is used to measure dye concentration, but it may vary with suspended sediment load, temperature, pH, $CaCO_3$ content, salinity, etc. Other variables which affect tracer test results are "quenching" (some emitted

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TABLE 4.4

Generic and Alternative Names
And Chemical Structure of the Tracer Dyes

Name	Alternative Names	Maximum Excitation, nm	Maximum Emission, nm	Primary Filter	Mercury Line, nm	Secondary Filter
Blue Fluorescent Dyes						
Amino G acid	7-amino 1,3 napthalene disulphonic acid	355 (310)	445	7-37*	365	98**
Photine CU		345	435(455)			
Green Fluorescent Dyes						
Fluorescein	Fluorescein LT Uranine Sodium fluorescein	490	520	98**	436	55**
Lissamine FF	Lissamine yellow FF Brilliant sulpho flavine FF Brilliant acid yellow 8G	420	515			
Pyranine	Pyranine Conc. D & C green 8	455(405)	515			
Orange Fluorescent Dyes						
Rhodamine B		555	580	2x1-60*+61**	546	4-97+3-66*
Rhodamine WT		555	580			
Sulfo rhodamine B	Pontacyl brilliant pink B Lissamine red 4B Kiton rhodamine B Acid rhodamine B	565	590			

Figures in parentheses refer to secondary maxima. For all spectra, pH is 7.0.
* Corning filter.
** Kodak Wratten filter.

Source: Smart and Laidlaw (1977)

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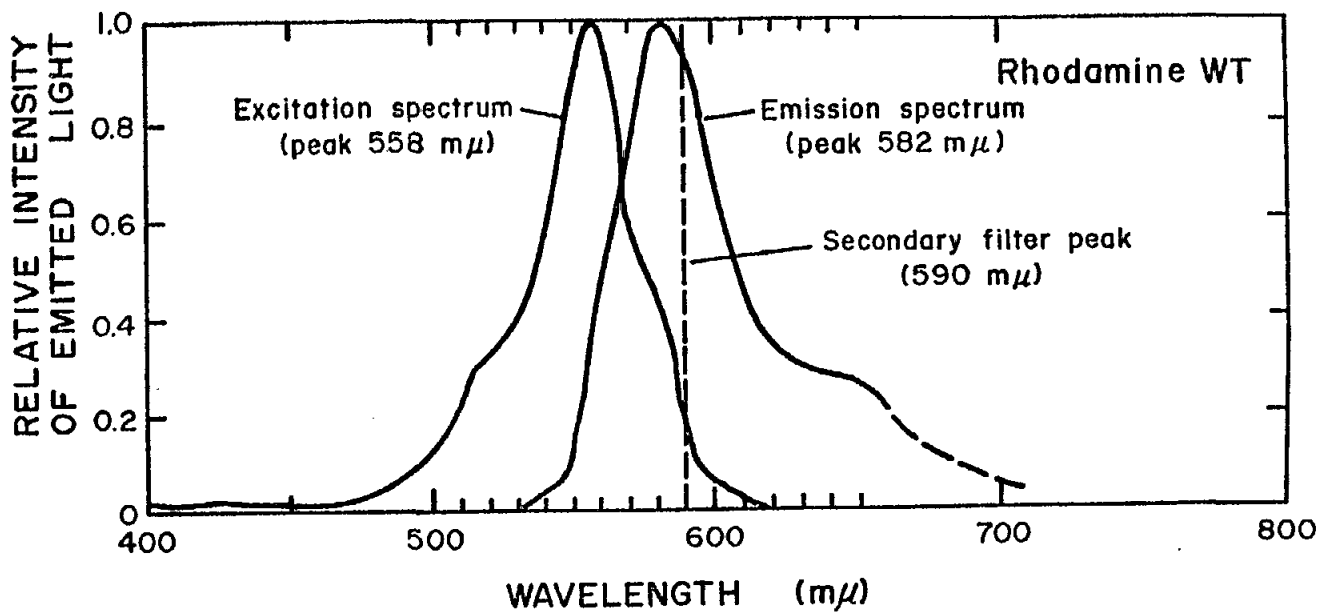

Figure 4.7. Excitation and emission characteristics of rhodamine WT, a fluorescent dye commonly used as a tracer (source, Wilson, 1968).

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fluorescent light is reabsorbed by other molecules), adsorption, and photochemical and biological decay. These effects will be discussed in more detail in reference to specific dyes. Another disadvantage of fluorescent dyes is their poor performance in tropical climates, due to chemical reactions with dissolved carbon dioxide.

The advantages of using these dyes include their very high detectability, rapid field analysis, and relatively low cost and low toxicity. The theory of fluorescence is described by McLaughlin (1982) and Skoog and West (1980). As described by McLaughlin, the process of fluorescence involves the following steps: (1) energy is absorbed by the molecule from sunlight or an ultraviolet lamp and a transition to a higher, excited electron state takes place; (2) the molecule relaxes from the highest to the lowest vibrational energy of that state, losing energy in the process; and (3) if the excess energy is not further dissipated by collisions with other molecules (quenching), the electron returns to the lower ground electron state. This emission of energy due to the transition from the higher to the lower state is fluorescence.

- Field Methods

The basic equipment necessary for dye tracing is a manual or automatic sampler and a field or laboratory detection device. Sampling is performed by adsorption of dye onto packets of activated charcoal suspended in the water (in karst topography), or by taking grab samples at a discharge point (for karst, porous media or fractured rock studies). A filter fluorometer or a spectrofluorometer is generally used for analysis, although visual detection is sometimes used for qualitative results.

The tracer is introduced at a sink hole or well. The detection limit for fluorescent dyes is very low, so the quantity of tracer used is

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relatively small. The amount of tracer needed has been approximated for karst systems by Drew and Smith (1969). They recommended using 60 grams of dye per kilometer of underground travel, per 0.15 cubic meters per second of discharge, at the largest likely rising. Atkinson et al. (1973) also described a method to calculate dye injection quantities for karst tests.

One sampling technique used in karst tracing is the Dunn method, developed in 1957. Small packets of fine mesh nylon or window screen are filled with activated charcoal and suspended in the watercourse at the sampling point. The dye adsorbs very strongly onto the charcoal, and is later eluted by placing the bag in a solution of 5% NH_3OH and ethyl alcohol. After soaking for one hour, the dye can be analyzed. The charcoal packets must be changed periodically, depending on flow rates and dilution of the tracer. Some examples of the use of this method are given in Gann and Harvey (1975) and Drew and Smith (1969). Cotton strip detectors have been used in a similar manner. Marston and Schofield (1962) described a tracer test using rhodamine B and cotton detectors.

Flow-through fluorimeters are sometimes used, which eliminate the need for sample collection. However, the most common method is collection of samples in sample bottles. Automatic samplers have been discussed in Chapter 3. Glass bottles should be used rather than polyethylene to avoid adsorption (Hubbard et al., 1982). Reznek et al. (1979) described procedures for sampling and analyzing fluorescein, and many of the procedures apply to other dyes. The samples and standards should be buffered to within a 5 to 11 pH range before analysis. If the samples are turbid, it is preferable to centrifuge the samples rather than filter them, as dye adsorbs

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onto the filter. The dye to be injected and the samples should both be stored out of sunlight and preferably in light-proof containers. Feuerstein and Selleck (1963) found that some fluorescent dyes exhibit a 50% photochemical chemical decay in two days, even when stored in light-proof flasks. Obviously, it is advisable to analyze samples as soon as possible after sampling.

- Detection and Analysis

It is possible to visually detect some dyes in water at a concentration of about 40 ppm (Corey, 1968). This concentration is much higher than 10 ppb, which is the maximum permissible concentration allowed at drinking water intakes (Wilson, 1968). The visual detection method is qualitative and rarely used.

Other detectors are the filter fluorometer and the spectrofluorometer. The filter fluorometer (or fluorimeter) consists basically of an ultraviolet light source, glass curvets (sample holders), and sets of primary and secondary filters which correspond to the absorption and emission wavelengths of the dyes used. The filter fluorometer must be calibrated with standard solutions at the same temperature as the samples to be analyzed. As mentioned before, the fluorescence of a sample is affected not only by concentration of the dye, but also by background fluorescence, temperature, pH, turbidity, photochemical decay, and adsorption. Temperature control apparatus and correction charts are available, and methods to avoid the other interferences have been briefly discussed. Two U.S. Geological Survey publications are very useful for planning a fluorescent dye test and avoiding these interferences. "Fluorometric Procedures for Dye Tracing," by Wil son (1968) is a classic report, and in 1982, Hubbard et al. published a very useful updated report, "Measurement of Time of Travel and Dispersion in

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Streams by Dye Tracing." These two are excellent references, as is the article by Smart and Laidlaw (1977).

Fluorometers are available with individual sample analysis capability, or with flow-through sampling (see Figure 4.8). They can be equipped with strip-chart recorders, and can be powered in the field with a portable generator (with a transformer) or a car battery (Hubbard et al., 1982). Some of the most well-known fluorometers are made by American Instrument Company and by G. K. Turner Associates.

Spectrofluorometers are more expensive and more complex to operate than filter fluorometers. They are generally not taken into the field. An example of this type of instrument is the Aminco-Bowman ultraviolet spectrophotofluorometer made by American Instrument Company. Table 4.5 shows sensitivity and minimum detection for certain dyes.

- Additional Information

The effects of temperature, pH, and suspended solids concentration on fluorescence have been mentioned. Fluorescence intensity is inversely proportional to temperature. Smart and Laidlaw (1977) described the numerical relationship and provide temperature correction curves. The effect of pH on rhodamine WT fluorescence is shown in Figure 4.9. An increase in the suspended sediment concentration generally causes a decrease in fluorescence. Adsorption on kaolinite caused a decrease in the measured fluorescence of several dyes, as measured by Smart and Laidlaw (see Figure 4.10).

The detected fluorescence may decrease, as in this example, or actually increase due to adsorption. If dye is adsorbed onto suspended solids, and the fluorescence measurements are taken without separating the water samples from the sediment, the dye concentration is a measurement of sediment

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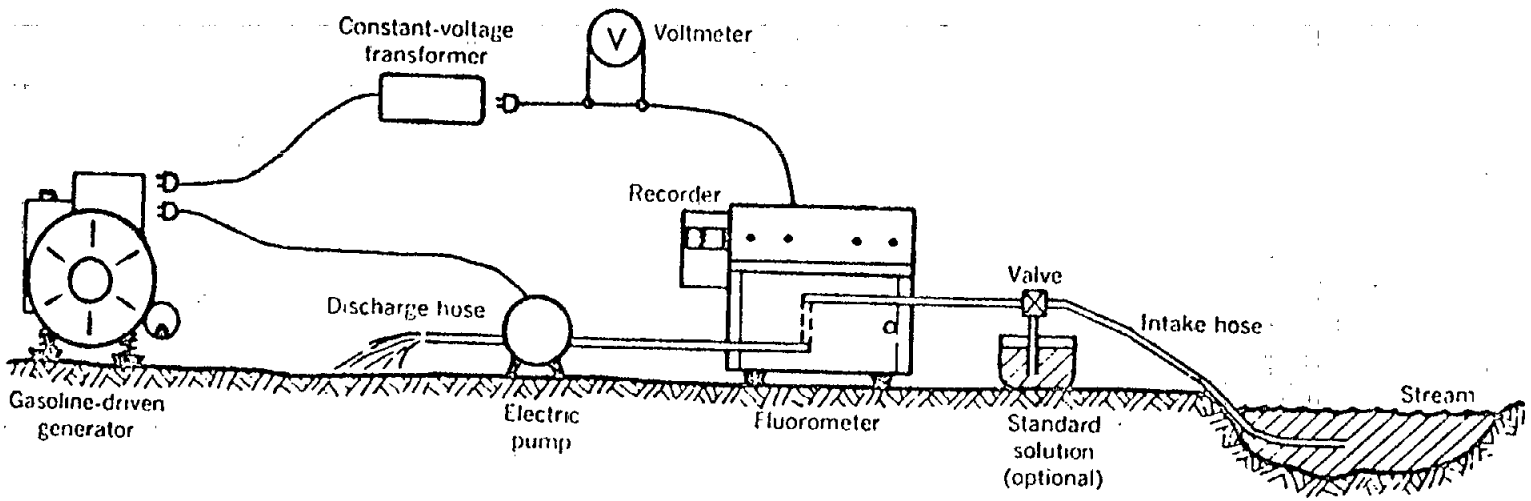

Figure 4.8. Cave streams or large springs can be monitored for dye tracers by using continuously recording fluorometers as shown schematically in this diagram by Wilson (1968). Less expensive but also less precise methods of monitoring for dye can use packets of activated charcoal which are placed in the stream. The dye, if present, is strongly sorbed on the charcoal which is then taken into the laboratory for analysis. The charcoal packets are replaced periodically in the stream until the test is finished.

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TABLE 4.5

Sensitivity and Minimum Detectable Concentrations for the Tracer Dyes

Dye	Sensitivity* µg/l Per Scale Unit	Background Reading** Scale Units 0-100	Minimum Detectability*** µg/l
Amino G Acid	0.27	19.0	0.51
Photine CU	0.19	19.0	0.36
Fluorescein	0.11	26.5	0.29
Lissamine FF	0.11	26.5	0.29
Pyranine	0.033	26.5	0.087
Rhodamine B	0.010	1.5	0.010
Rhodamine WT	0.013	1.5	0.013
Sulfo rhodamine B	0.061	1.5	0.061

For a Turner 111 filter fluorometer with high-sensitivity door and recommended filters and lamp at 21°C.

* At a pH of 7.5.

** For distilled water.

*** For a 10% increase over background reading or 1 scale unit, whichever is larger.

Adapted from Smart and Laidlaw (1977).

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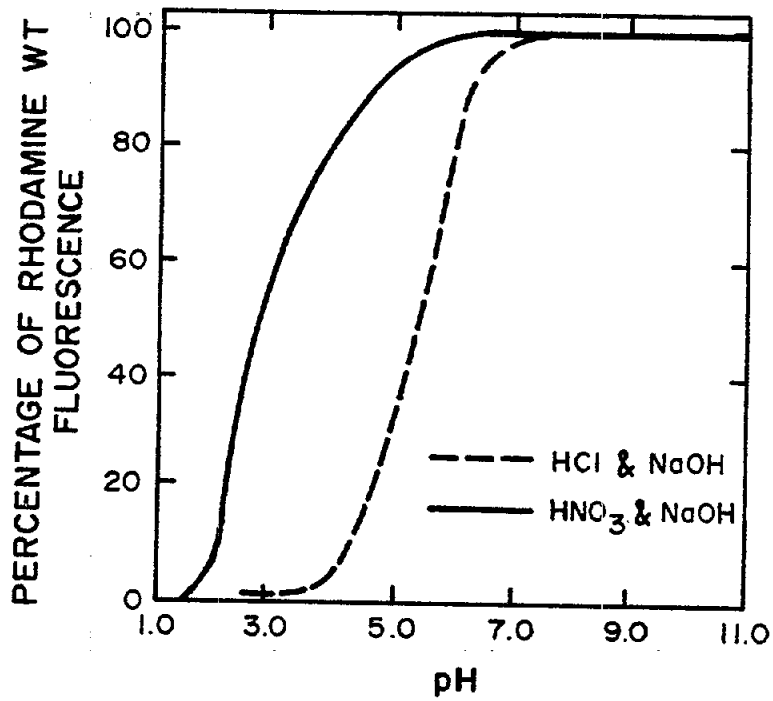

Figure 4.9. The fluorescence of most dyes is dependent on pH and the types of dominant ions present. Results of some experiments on the fluorescence of rhodamine WT are shown in this figure adapted from Smart and Laidlaw (1977).

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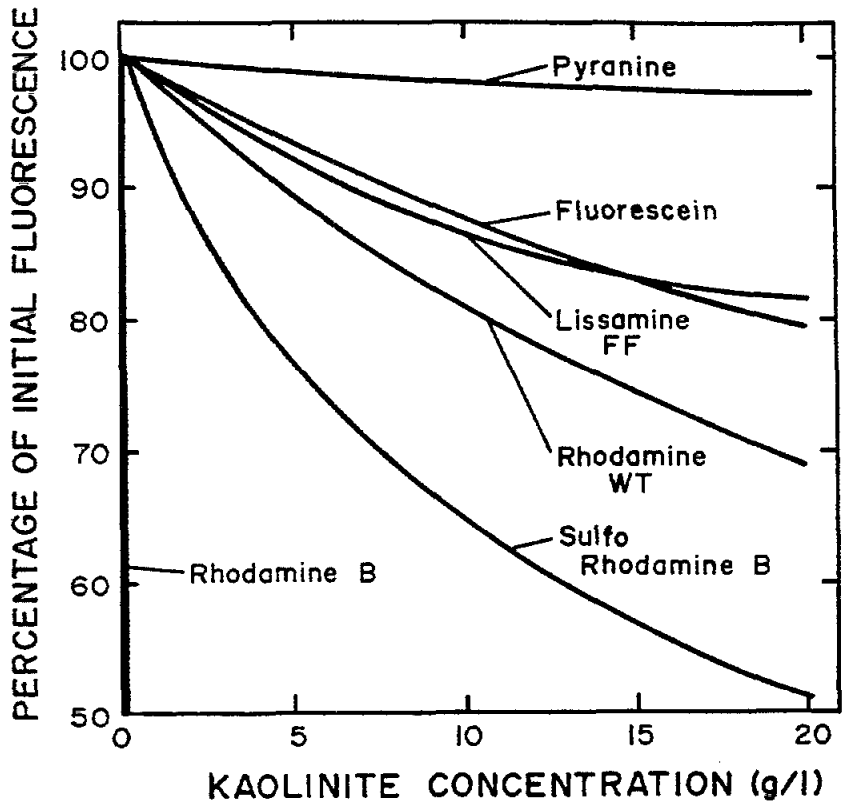

Figure 4.10. Most dyes will be adsorbed on fine particulate material, particularly on organic fragments and clays. Results of experiments with the adsorption of dyes on kaolinite (a type of clay) as reported by Smart and Laidlaw (1977) are shown in this illustration.

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content and not of water flow. As mentioned before, the ideal separation is with a centrifuge, as the dye can adsorb onto filter paper. Adsorption can can occur on organic matter, clays (bentonite, kaolinite, etc.), sandstone, limestone, plants, plankton, and even glass sample bottles. These adsorption effects are a strong incentive to choose a non-sorptive dye for the type of medium tested.

Dyes travel slower than water due to adsorption, and are generally not as conservative as the ionic or radioactive tracers. See Figure 4.6 in the ion section for a comparison of chloride, dextrose, fluorescein, and I^{131}. Drew (1968) compared lycopodium, temperature, and fluorescein as karst tracers and found fluorescein breakthrough to be slowest (Figure 4.11). He questioned the ability of fluorescein to give accurate data on flow rates. Field data comparing the more recently developed dyes are not yet available. Atkinson et al. (1973) stated that an advantage of fluorescent dye measurement over lycopodium analysis is the ability to make deductions about discharges, changes in storage, and the geometry of the system. They suggest that dyes are more useful than spores for obtaining the maximum amount of quantitative information about a small karst system.

A final point concerning the interpretation of tracer tests is emphasized by Brown and Ford (1971). They obtained some very interesting results by running three identical dye tracer tests in the same karst system. These yielded three different flow-through times. One of the values differed by 50% from the original test value. Although only one test is generally run due to economic considerations, it may be advisable to run several tests to check reproducibility if accuracy is important.

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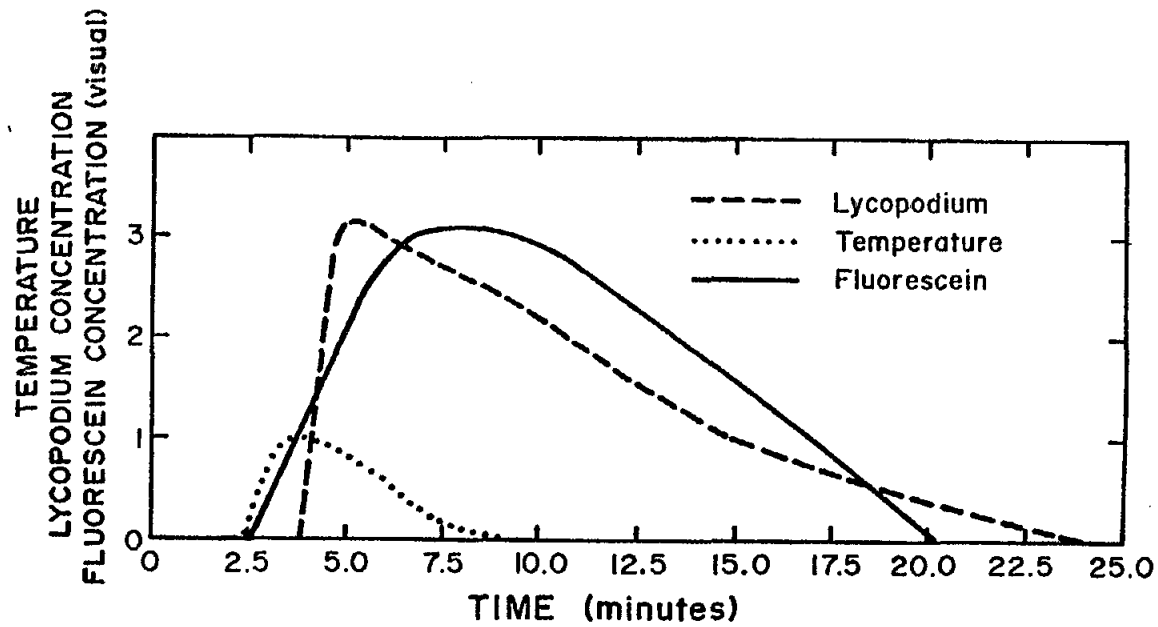

Figure 4.11. A comparison of the results of three simultaneous tracer tests in a karst system (data from Drew, 1968).

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A comparison of the cost of various fluorescent dyes is given in Table 4.6. Prices are given in British pounds per kilogram for bulk dye. Volume labeled per unit cost is also listed, and rhodamine B appears to be the most cost effective. However, problems with its use will be discussed in a subsequent section.

Some of the available toxicity data will be mentioned in regard to specific dyes in the following section. Smart and Laidlaw (1977) discussed the toxicity of dye tracers, but regulations may change rapidly and should be researched before conducting a test. Current World Health Organization, Environmental Protection Agency, and state health standards should be consulted.

- Discussion of Specific Dye Tracers

Green Dyes

Fluorescein

Fluorescein, also known as uranin, sodium fluorescein, and pthalien, has been one of the most widely used dyes. Like all green dyes, its use is commonly complicated by high natural background fluorescence, which lowers sensitivity of analyses and makes interpretation of results more difficult. It has a very high photochemical decay rate compared to other dyes (Feuerstein and Selleck, 1963), but this is generally of little concern in ground-water tracing.

Feuerstein and Selleck (1963) recommended that fluorescein be restricted to short-term studies of only the highest quality water. Because this dye is affected strongly by pH (it becomes colorless in acidic conditions), they suggested that the sample pH be adjusted to greater than 6 before analysis. Fluorescein also exhibits an appreciable decrease in fluorescence with

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TABLE 4.6

Relative Costs of Dyes

Dye	State	Relative Cost Per Kilogram*	Volume Labeled Per Kilogram** ($10^6 m^3/kg$)	Volume Labeled Per Unit Cost ($10^5 m^3/cost$)
Amino G Acid	powder	4	2	5.7
Photine CU	20% solution	1	3	6.0
Fluorescein	powder	4	4	10.0
Lissamine FF	powder	14	4	2.8
Pyranine	powder	13	12	9.2
Rhodamine B	powder	5	100	200.0
Rhodamine WT	20% solution	7	77	22.0
Sulfo rhodamine B	powder	9	16	17.8

After Smart and Laidlaw (1977).

* Costs are approximate and based on 1975 prices; the higher the number, the higher the price of the dye.

** Based on minimum detectabilities in Table 4.5.

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increasing salinity, and is similarly affected by oxidizing agents and suspended solids (Reznek et al., 1979).

Some examples of fluorescein use include a fractured rock study by Lewis (1966). Borehole dilution tests resulted in hydraulic conductivity values similar to pump test values. Another example is a mining subsidence investigation in South Wales, where more than one ton of fluorescein was used in a sandstone tracer test (Mather et al., 1969). A distance of 1,100 feet was traversed. Tester et al. (1982) used fluorescein to determine fracture volumes and diagnose flow behavior in a fractured granitic geothermal reservoir. He found no measurable adsorption or decomposition of the dye during the 24-hour exposures to rocks at 392°F. Omoti and Wild (1979) stated that fluorescein is one of the best tracers for soil studies, but Rahe et al. (1978) did not recover any injected dye in their hillslope studies, even at a distance of 2.5 meters downslope from the injection point. The same experiment used bacterial tracers successfully. Figure 4.11 compares fluorescein, lycopodium, and temperature as karst tracers.

An advantage of using fluorescein (or any of the green dyes) is its emission in the green band of the visible spectrum. Fluorescein can be visually detected at a concentration of about 40 ppm, but other means of detection are preferred since this is a relatively high concentration. The approximate sensitivity and minimum detection limit for fluorescein are given in Table 4.5.

Fluorescein is less costly in bulk than many of the dyes (see Table 4.6), but due to its high photochemical decay rate and high amount of adsorption, it increases in relative cost as the length of the test increases (more dye must be added to compensate for loss).

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Pyranine

Another green fluorescent dye, pyranine, has a stronger fluorescent signal than does fluorescein, but is much more expensive. It has been used in several soil studies, and Reynolds (1966) found it to be the most stable dye used in an acidic, sandy soil. Omoti and Wild (1979) recommended pyranine and fluorescein as the best tracers for soil tests, although pyranine is relatively unstable if the organic matter content of the soil is high. Drew and Smith (1969) stated that pyranine is not as easily detectable as fluorescein, but is more resistant to decolorization and adsorption. Pyranine has a very high photochemical decay rate, and is strongly affected by pH in the range found in most natural waters (McLaughlin, 1982).

Lissamine FF

This green dye has been used primarily for aerosol tracing (Yates and Akisson, 1963), and has not been used extensively in ground-water tests. Little information is available on the performance of lissamine FF; however, Smart and Laidlaw (1977) recommended it as the best quantitative tracer of the three green dyes discussed. The dye is extremely stable and resistant to adsorption losses, but is much more expensive than most dyes.

Orange Dyes

Rhodamine B

Rhodamine B was the first of the three orange (or red) dyes to be used in water tracing. Its high adsorption losses make it a less suitable tracer for ground-water work than rhodamine WT or sulfo rhodamine B, although it has been used more frequently. Aulenbach et al. (1978) concluded that rhodamine B should not be used as a ground-water tracer due to sorption losses, and Feuerstein and Selleck (1963) reported significant adsorption. They also found that the fluorescence of rhodamine B is affected by large

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salinity changes. Knuttson (1968) reported that the dye is relatively unaffected by pH in the range found in most natural waters (5-10). The dye however, is sensitive to temperature (Omoti, 1977) and exhibits optical quenching by suspended solids. Like fluorescein, rhodamine B has a large interference from high background fluorescence in tropical areas. It is less affected than the other rhodamine dyes by bacteria and light, but it adsorbs readily on bentonite, sand and gravel, till, and karst channels, pure quartz sand, and even plastic and glass laboratory columns (Table 4.7). Hubbard et al. (1982) compared rhodamine B and rhodamine WT and found high adsorption of rhodamine B on aquatic plants, suspended clays, and glass and plastic sample bottles. They found rhodamine WT easier to handle and more economical than rhodamine B. Although the unit cost of rhodamine B is lower, its loss rate is much higher than that of rhodamine WT.

Rhodamine B was decertified for use in cosmetics by the U.S. Food and Drug Administration in the 1960's. In 1968, it was illegal for use as a water tracer in the U.S. (Drew, 1968). Both rhodamine B and fluorescein were placed on toxicological classification C111 by the Food and Agriculture Organization/World Health Organization. Of the dyes discussed in this article, rhodamine B is generally recognized as the most toxic to man, as it is readily adsorbed onto body tissue. Currently, the U.S. Geological Survey recommends that tracer tests should result in a final concentration less than 10 μg/l. Numerous studies related to toxicity tests for various aquatic organisms are reported by Smart and Laidlaw (1977), and they recommend that the dye not be used as a water tracer.

Rhodamine WT

This dye has been considered one of the most useful tracers for quantitative studies, based on minimum detectability, photochemical and biological

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decay rates, and adsorption (Smart and Laidlaw, 1977; Wilson, 1968; and Knuttson, 1968). Hubbard et al. (1982) stated that it is the most conservative of dyes available for stream or karst tracing.

Some recent uses of rhodamine WT include projects by Burden (1981), Aulenbach et al. (1978), Brown and Ford (1971), Gann (1975), and Aulenbach and Clesceri (1980). Burden successfully used the dye in a water contamination study in New Zealand in an alluvial aquifer. Aulenbach and Clesceri also found rhodamine WT very successful in a sandy medium.

Gann (1975) used rhodamine WT for karst tracing in a limestone and dolomite system in Missouri. He used grab samples and activated charcoal packets, and traced a 14 km (8.7 mile) path. Three fluorescent dyes (rhodamine B, rhodamine WT, and fluorescein) were used by Brown and Ford (1971) in a karst test in the Maligne Basin in Canada. The highest recovery of dye (98%) was obtained for rhodamine WT. The fluorescein was not recovered at all. The horizontal flow path was 1.3 miles, and a Turner III fluorometer was used for analysis.

Aulenbach et al. (1978) compared rhodamine B, rhodamine WT, and tritium as tracers in a delta sand. The project involved tracing effluent from a sewage treatment plant. Sampling was performed with drive points, pumped wells, and lysimeters. The rhodamine B was highly adsorbed, while the rhodamine WT and tritium yielded similar break-through curves (Figure 4.12). Rhodamine WT seems to be adsorbed less than rhodamine B or sulfo rhodamine B (Table 4.7). Wilson (1971) found that in column and field studies, rhodamine WT did show sorptive tendencies.

Rhodamine WT is thought to be slightly less toxic than rhodamine B and sulfo rhodamine B (Smart and Laidlaw, 1977). This source notes that rhodamine WT and fluorescein are of comparable toxicity, but Aley and Fletcher

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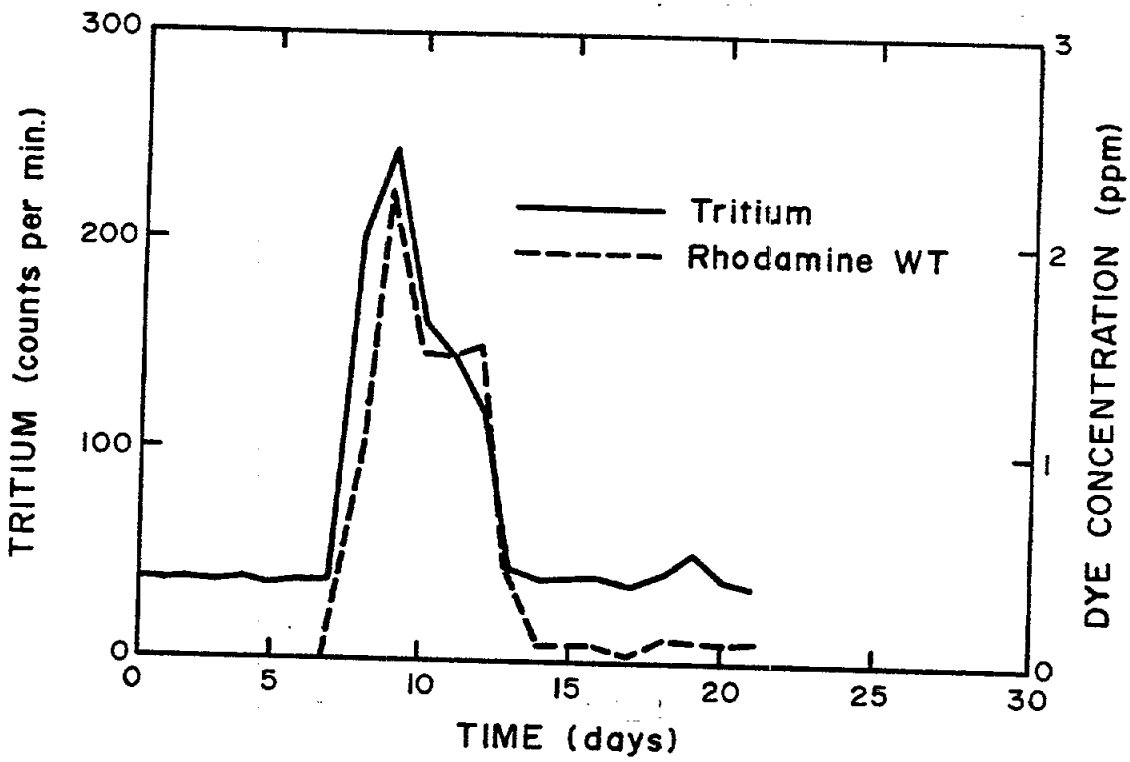

Figure 4.12. Although many researchers have found that rhodamine WT is sorbed on aquifer material, data presented by Aulenbach et al. (1978) suggest that this dye can be used in coarse, permeable sand. Comparative data from the study by Aulenbach et al. (1978) using tritium and rhodamine WT indicate little difference between the two tracers as shown in this figure adapted from their study.

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TABLE 4.7

Measured Sorption of Dyes on Bentonite Clay

Dye	Losses Due to Adsorption on Clay
Rhodamine WT	28%
Rhodamine B	96%
Sulfo Rhodamine B	65%

Source: Repogle et al. (1966)

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(1976) stated that rhodamine WT is not as "biologically safe" as fluorescein.

Sulfo rhodamine B

Sulfo rhodamine B, also known as pontacyl brilliant pink, has not been used extensively as a ground-water tracer. Its fluorescence is affected slightly by high salinity, and it exhibits low adsorption on suspended sediment (Feuerstein and Selleck, 1963). Table 4.7 compares the adsorption of the rhodamine dyes onto bentonite. This dye is more expensive than the other rhodamine dyes, and its toxicity appears to be slightly higher than that of rhodamine WT.

Blue Dyes

The optical brighteners are blue fluorescent dyes which have been used in increasing amounts in the past decade in textiles, paper, and other materials to enhance their white appearance. Water which has been contaminated by domestic waste can be used as a "natural" tracer, if it contains detectable amounts of the brighteners. Glover (1972) described the use of optical brighteners in karst environments. Examples of the brighteners are amino G acid and photine CU. These two are the least sensitive of the dyes reviewed (Table 4.5), but the blue dyes have much lower background levels in uncontaminated water than do the green or orange dyes.

Photine CU is significantly affected by temperature variations, and both dyes are affected by pH below a pH of 6.0. The dyes have high photochemical decay rates, similar to those of pyranine and fluorescein. Amino G acid is fairly resistant to adsorption.

Toxicity studies on optical brighteners were reviewed by Akamatsu and Matsuo (1973). They concluded that the brighteners do not present any toxic hazard to man, even at excessive dosage levels.

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