

RHODAMINE WT DYE LOSSES IN A MOUNTAIN STREAM ENVIRONMENT¹Kenneth E. Bencala, Ronald E. Rathbun, Alan P. Jackman,
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ABSTRACT: A significant fraction of rhodamine WT dye was lost during a short term multitracer injection experiment in a mountain stream environment. The conservative anion chloride and the sorbing cation lithium were concurrently injected. In-stream rhodamine WT concentrations were as low as 45 percent of that expected, based on chloride data. Concentration data were available from shallow 'wells' dug near the stream course and from a seep of suspected return flow. Both rhodamine WT dye and lithium were nonconservative with respect to the conservative chloride, with rhodamine WT dye closely following the behavior of the sorbing lithium.

Nonsorption and sorption mechanisms for rhodamine WT loss in a mountain stream were evaluated in laboratory experiments. Experiments evaluating nonsorption losses indicated minimal losses by such mechanisms. Laboratory experiments using sand and gravel size streambed sediments show an appreciable capacity for rhodamine WT sorption.

The detection of tracers in the shallow wells and seep indicates interaction between the stream and the flow in the surrounding subsurface, intergravel water, system. The injected tracers had ample opportunity for intimate contact with materials shown in the laboratory experiments to be potentially sorptive. It is suggested that in the study stream system, interaction with streambed gravel was a significant mechanism for the attenuation of rhodamine WT dye (relative to chloride).

(KEY TERMS: tracers; dye releases; streams; low flow; water quality; mountain watershed.)

INTRODUCTION

Fluorescent dyes have been used for a variety of water tracing measurements in both surface and ground water systems. An extensive review of these uses and evaluation of many dye properties was presented by Smart and Laidlaw (1977). Rhodamine WT is one of the dyes recommended for use by them and others (e.g., Wilson, 1968).

It is the purpose of this note to present data showing the losses of rhodamine WT during a field experiment in a mountain stream. The tracer chloride was injected concurrently with the dye. Rhodamine WT is nonconservative to the degree that it does not respond identically to chloride. Possible mechanisms for the departure of rhodamine WT from the response of chloride are: photochemical decay in the stream,

sorption onto streambed materials (mineral and organic), reaction in solution, volatilization, and uptake by living organisms. Biologic mechanisms were not studied in the experiments.

It would be difficult, if not impossible, to distinguish these mechanisms based only on data from the stream channel. However, data from water samples taken in areas of intimate contact with streambed materials can highlight the sorption mechanisms, along with suppressing the influence of the photochemical decay or volatilization. Data will be presented that show the extent of the attenuation, relative to chloride, of the rhodamine WT concentration in shallow 'wells' and a suspected seep of return flow.

As an indication of the significance of sorption mechanisms in this stream system, the rhodamine WT behavior is also compared to that of lithium. Lithium is known to be adsorbed by clay minerals (Goldschmidt, 1954). Thus we expect it to be sorbed by streambed sediment (although not as strongly as the other alkali metals exclusive of sodium or alkaline earth metals (Rose, *et al.*, 1979).

Data will be presented from laboratory experiments, showing the potential influence of the mechanisms of volatilization, reaction with salts, and sorption.

FIELD SETTING AND EXPERIMENT

Field Setting

The tracer was injected into Little Lost Man Creek, a mountain pool and riffle stream in Redwood National Park (Humboldt County, California). The experiment was carried out in late summer, during a period of low flow (approx. $0.007 \text{ m}^3 \text{ s}^{-1}$). The study reach was 327 m long and the water was typically 2-4 m wide and 0.1-0.6 m deep. Particle size distributions of streambed materials have been measured for several streams in Redwood National Park (Iwatsubo, *et al.*, 1976). Gravel comprised a significant fraction of the streambed in all cases. Our visual assessment of the gravel and cobble bed of

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Little Lost Man Creek is qualitatively consistent with these measurements. Suspended sediment concentration was not measured at the time of the field study, but from the data of Iwatsubo, *et al.* (1976), a value of 1 to 10 mg L⁻¹ would be reasonable at low flow.

The rhodamine WT injection lasted approximately 15 hours, from 1000 on August 21, 1979, to 0100 on August 22, 1979. The chloride and lithium injections started at the same time and then continued long after the end of the rhodamine WT injections. A common feed tank for all tracers was used over the initial 15 hours, after which a feed tank without rhodamine WT dye was used.

During the experiment, water samples were taken from the stream, from seepage flows into the stream, and from several shallow "wells" along the streambank (see Figure 1). The tracer data from the seepage flow and wells are indicators of exchange between stream water and intragravel water in the bed. The three tracers were present in the seep and in the wells.

There was a seep 80 m downstream of the injection point at a distance of about 3 m from the stream channel. Seepage outflow at this location is thought to be part return flow that had moved through the gravel bed. Intensive sampling of the outflow showed a sharp increase in chloride concentration after the injection began. The entry point for much of the water in this seep is believed to have been approximately 45 m upstream of the seep near the outlet of a pool 1.3 m higher in elevation than the sampling site. Solute laden water is believed to have entered the gravel in this steep riffle section.

Shallow pits (henceforth designated as wells) along the streambank were 0.1 m to 1.0 m deep and located between 0.5 m and 5 m from the stream. Results of intensive sampling of these wells during the arrival of the leading edge of the injected pulse in the adjacent stream show that well stream communication was very rapid in many places.

Experimental Summary

The experiment was done as part of a more extensive experiment concerned with the interaction of nutrients and strongly sorbing cations with stream sediments. A solution of rhodamine WT, lithium (Li), sodium (Na), potassium (K), strontium (Sr), chloride (Cl), and nitrate (NO₃) was injected into Little Lost Man Creek at a known constant rate, and water samples were collected at various sites downstream and also in shallow wells to determine how the transport of Cl compared with that of the other solutes added. The injection was made using an FMI pump (the use of the brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey) which was capable of providing a flow which did not vary by more than one percent.

Rhodamine Determinations

The concentration of rhodamine WT in the injection solution was $1.58 \times 10^5 \mu\text{g L}^{-1}$. Average injection rate of the solution was 0.67 mL sec^{-1} .

Samples of water were collected frequently from the stream at several sampling points and from wells throughout the period of injection of the dye. Samples were collected in 32 mL glass bottles with polyseal caps. These bottles were rinsed at least twice in the water before collecting the samples.

Samples were stored in a cabinet and allowed to equilibrate to room temperature. Standard dye solutions prepared according to procedures described by Wilson (1968) were stored in the same cabinet so that samples and standards were at the same temperature. Dye concentrations were determined using a Turner Model 111 fluorometer and standard procedures described by Wilson (1968). The fluorometer was calibrated at least once each day. The background fluorescence was determined by analyzing water samples from the stream containing no dye. The average concentration of 47 such samples was equivalent to $0.05 \mu\text{g L}^{-1}$ of rhodamine WT dye; and all dye concentrations were corrected for this background.

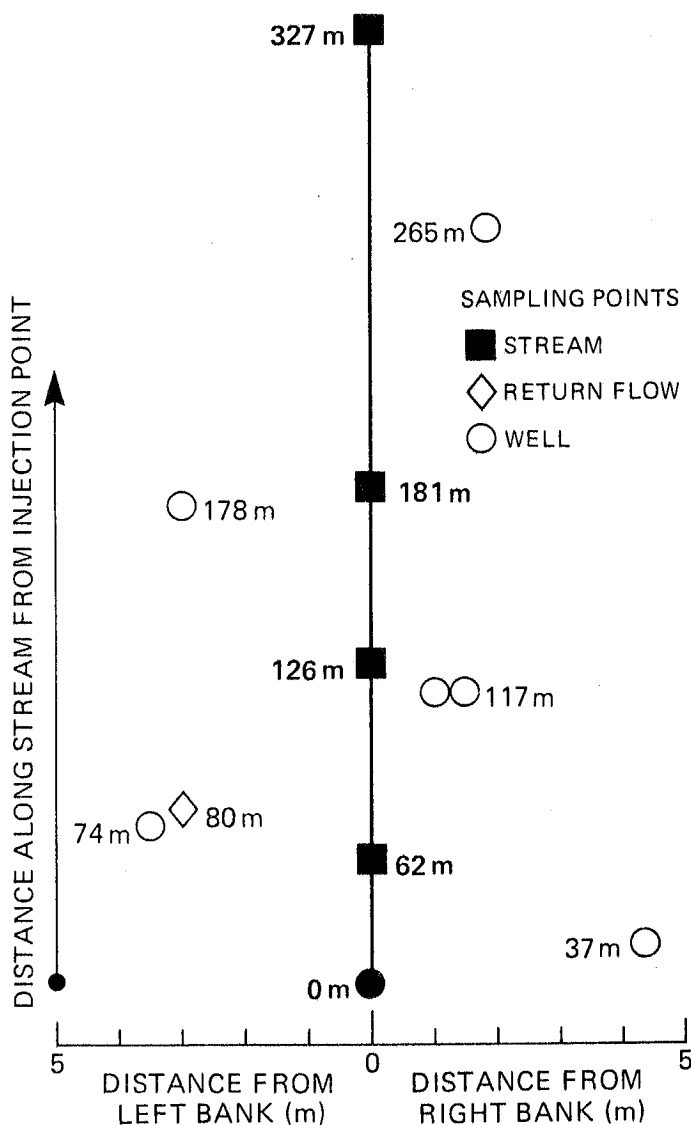


Figure 1. Schematic Map of Little Lost Man Creek Study Reach (sampling locations are indicated).

Chloride Determinations

The samples were filtered at the time of collection, using a 0.45 μm Millipore HATF membrane. Chloride was determined using an automated mercuric thiocyanate method adapted from O'Brien (1962). Precision (1SD) was $\pm 0.03 \text{ mg L}^{-1}$ at 6 mg L^{-1} and $\pm 0.12 \text{ mg L}^{-1}$ at 24 mg L^{-1} . Rhodamine WT produced an apparent increase of 0.05 mg L^{-1} Cl in a standard containing 6 mg L^{-1} Cl and 60 $\mu\text{g L}^{-1}$ rhodamine WT. Interference was assumed to be negligible with 15 $\mu\text{g L}^{-1}$ rhodamine WT.

Lithium Determinations

The samples used for lithium analysis were the same as those used for chloride analysis.

In the laboratory, lithium was analyzed by atomic absorption spectroscopy, using a Perkin-Elmer Model 303 spectrometer. The conductivity of the samples was about 100 $\mu\text{S cm}^{-1}$; there were no interferences noticed and there was no sample preparation other than the forementioned filtration. Reference samples were routinely measured during the analyses to determine precision between samples. Over a period of two months the precision of three such reference samples was 0.003 $\mu\text{g L}^{-1}$ at 0.132 $\mu\text{g L}^{-1}$ ($n = 11$), 0.005 $\mu\text{g L}^{-1}$ at 0.382 $\mu\text{g L}^{-1}$ ($n = 7$), and 0.012 $\mu\text{g L}^{-1}$ at 1.377 $\mu\text{g L}^{-1}$ ($n = 22$).

Field Data Analysis

Relevant concentration data are shown in Table 1 for chloride, rhodamine WT, and lithium. Background levels and 'injection' levels measured just below a well mixed reach are shown along with the concentrations at 'cut-off' time at several locations in the study reach. Also shown are relative concentrations, adjusted for background and injection level concentrations. The differences in these relative concentrations between the chloride and the rhodamine WT and lithium are a measure of the attenuation of the latter constituents. At the 327 m location, the rhodamine WT concentration was,

in effect, only 45 percent of that expected based on the chloride. The response of the rhodamine is shown in Figure 2. The attenuation and the slow rise of the concentrations at 327 m are clearly shown. The concentration of chloride at the downstream locations did not reach plateau levels during the 15-hour rhodamine WT injection period. This is a hydrologic effect related to the transient storage of solutes in 'dead zones' and not a chemical loss of chloride (Bencala and Walters, 1983).

Comparing the concentrations in the wells to those in the stream allows the observation of a difference between the tracer constituents that will reflect the influence of sorption. The well concentrations as a percentage of the in-stream concentration (after adjusting for background levels) are shown in Figure 3. The times of comparison are approximate, within an hour, and the in-stream values are from sampling locations that range from 3 m to 62 m in distance from the wells. The comparison is to the nearest sampling station downstream of the indicated well. The in-stream sampling locations were at 62 m, 126 m, 181 m, and 327 m downstream from the injection point. The samples were taken 10 to 12 hours after the injection started. Any given point on the plots is open to interpretation because of the ranges in sampling times and relative distances; however, taken together they show the clear pattern of lithium and rhodamine WT sorption compared to chloride.

Further evidence for rhodamine WT sorption is shown in Figure 4. The seep of suspected return flow present at 80 m downstream from the injection point contains water that has probably spent several hours in gravel beds underlying or adjacent to the stream. The figure shows the concentrations in the seep as a percentage of the in-stream concentrations at the 126 m sampling location (after adjusting for background levels). The rhodamine WT values are typically about 50 percent of the conservative chloride values. There is little doubt that the lithium has been sorbed as it was transported through the gravels to the seep.

TABLE 1. Absolute and Relative Tracer Concentrations in Little Lost Man Creek.

	Concentration			Concentration - Background Injection - Background x 100		
	Chloride (mg L^{-1})	Rhodamine WT* ($\mu\text{g L}^{-1}$)	Lithium (mg L^{-1})	Chloride	Rhodamine WT	Lithium
Background	6.2	0.0	<0.005			
Injection**	21.6	14.7***	1.86			
Sampling Location (m)						
			After 15 Hours of Continuous Injection			
62	21.3	13.7	1.75	98	93	94
126	19.3	8.6	0.99	85	58	53
184	17.8	6.4	0.64	75	43	35
327	14.7	3.7	0.36	55	25	20

*Background fluorescence is observed and subsequently subtracted from the fluorometer readings for all samples.

**'Injection' values measured 5 m downstream of injection point.

***Calculated value from flow rates and feed tank solution.

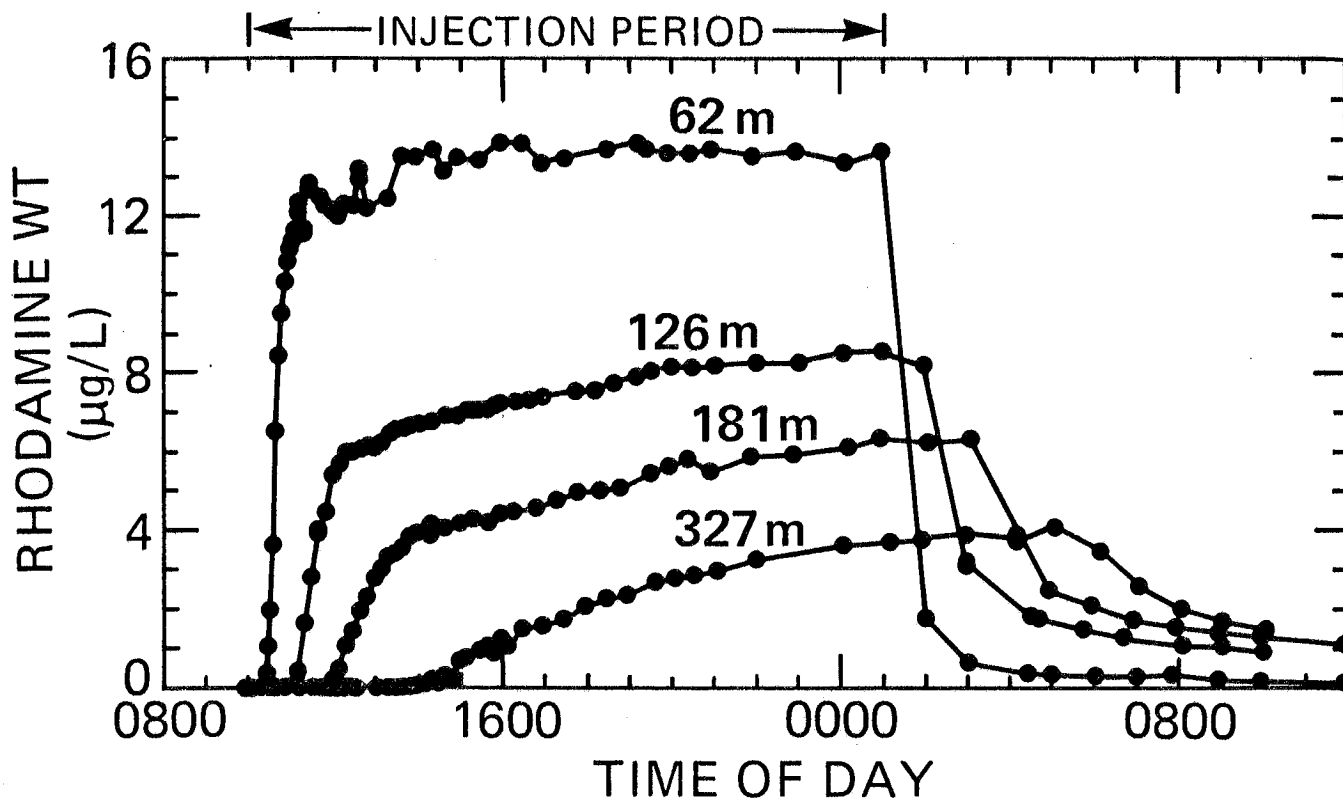


Figure 2. Rhodamine WT Concentrations in Little Lost Man Creek at Four Monitoring Sites.

The comparisons in the well and seep data must be made relative to the in-stream values to eliminate the influence of attenuation mechanisms that may have occurred in the stream prior to flow into the gravels. In a mountain pool and riffle stream the attenuation of even a chemically conservative tracer can be significant. This has been discussed by Bencala and Walters (1983) in terms of zones for transient storage of solute. Attenuation may also be caused by lateral inflows. Thus, the relative rhodamine WT dye concentrations must be compared to relative chloride concentrations to eliminate the influence of these attenuation mechanisms which act on all tracers.

Loss of rhodamine WT dye to suspended sediment is a potential mechanism in many streams. However, the suspended sediment concentrations in the experiments reported by Smart and Laidlaw (1977) are on the order of 10^3 to 10^5 mg L^{-1} . These levels are several orders of magnitude greater than typical values for Little Lost Man Creek at low flow.

The appreciable attenuation observed in the lithium concentrations is similar to the behavior of strontium in another small mountain pool and riffle stream, Uvas Creek (Santa Clara County, California), which has been analyzed by Bencala (1983).

The possibility of nitrosation of rhodamine WT by nitrite can be disregarded as responsible for a significant part of the observed loss. Abidi (1982) reported the results of the reaction of nitrite with rhodamine WT to form diethylnitrosamine. In the case of stream water, the reaction could remove up to

94 percent of the rhodamine in 24 hours at 20°C when the nitrite concentration was 110 $\mu g L^{-1}$ and rhodamine WT, 10 $\mu g L^{-1}$, and 21 percent loss when the nitrite concentration was 10 $\mu g L^{-1}$ and rhodamine WT, 10 $\mu g L^{-1}$. The reaction is sensitive to nitrite concentration and the molar ratio of nitrite to rhodamine WT. Little Lost Man Creek had a nitrite level of less than 2 $\mu g L^{-1}$ and a maximum rhodamine WT level of 14.7 $\mu g L^{-1}$. Based on extrapolation of the Abidi data, loss by this method would not exceed 5 percent.

Compared to chloride, lithium is clearly attenuated in the stream, in the wells, and in the return flow seeps. Rhodamine WT more closely follows this lithium response than it does the chloride response.

LABORATORY EXPERIMENTS

Volatilization of rhodamine WT dye from streams would not generally be considered as a mechanism for dye loss because of the relatively large molecular weight of the dye and its low vapor pressure. However, Mackay and Wolkoff (1973) have suggested that several pesticides and polychlorinated biphenyls will volatilize from water much faster than expected on the basis of molecular weight and vapor pressure. These large volatilization rates result because of the very large activity coefficients of these compounds in water. This conclusion is supported by the experimental results of Acree, Beroza,

and Bowman (1963), who found that DDT volatilized from water much faster than expected.

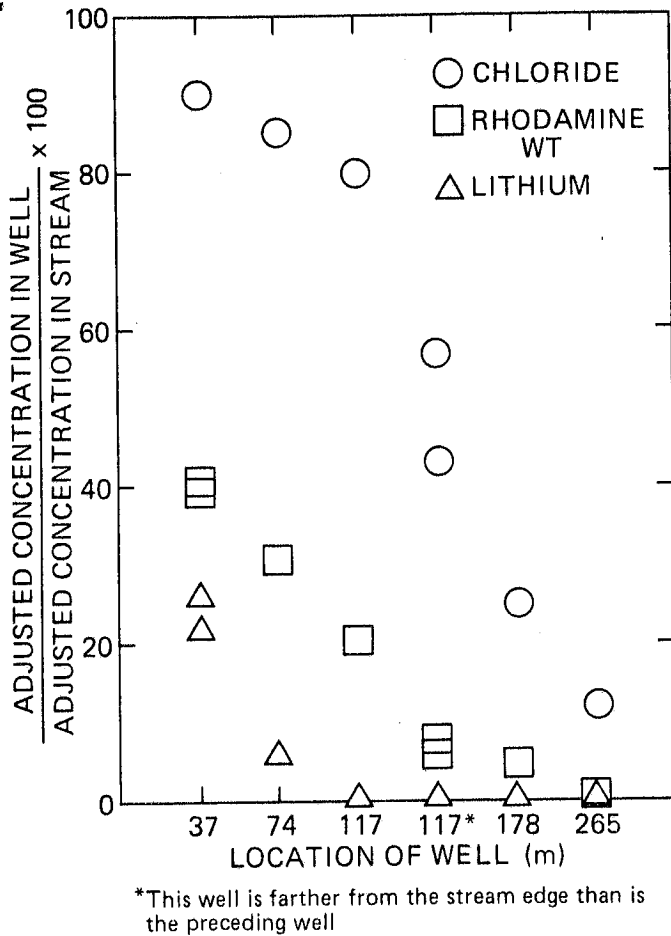


Figure 3. Comparison of Relative Concentrations for Chloride, Lithium, and Rhodamine WT in Wells (adjusted for background levels).

There have been a limited number of studies of the volatilization of dyes. Feuerstein and Selleck (1963) found that moderate agitation of solutions of rhodamine B and Pontacyl Brilliant Pink B in light proof flasks resulted in up to 50 percent loss during a two-day period, whereas mild agitation resulted in no losses. Watt (1965), as reported by Smart and Laidlaw (1977), also studied this effect, concluding that rhodamine B was more susceptible to this type of loss than rhodamine WT or Pontacyl Brilliant Pink B. These results suggest that volatilization of rhodamine WT dye might be a possible mechanism for loss in streams with turbulent mixing conditions.

Another possible mechanism for loss of rhodamine WT dye is interaction of the dye with anions and cations of salts that might be present in the stream water or that might be used in conjunction with the dye. Smart and Laidlaw (1977) showed large losses of rhodamine WT dye in mixtures with sodium

chloride and potassium chloride, with the amount of loss increasing with time. The loss was also greater for potassium chloride than for sodium chloride. This work was later disputed by Stanbro and Pyrch (1979), who concluded that rhodamine WT dye could be considered conservative for periods of at least one week for the same range of sodium chloride concentrations as considered by Smart and Laidlaw (1977).

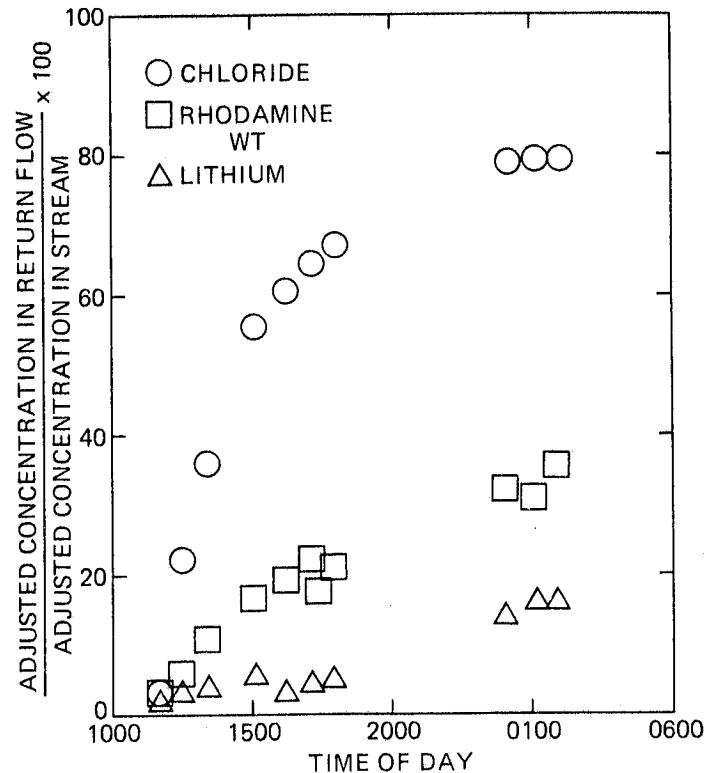


Figure 4. Comparison of Relative Concentrations for Chloride, Lithium, and Rhodamine WT in Return Flow at 80 m (adjusted for background levels).

Smart and Laidlaw (1977) presented data showing the sorption losses of rhodamine WT to both mineral and organic materials. Their studies focused on the potential influence of suspended sediments.

Volatilization, reaction with salts, and sorption were all viewed as potential attenuation mechanisms in the Little Lost Man Creek system. Thus, laboratory experiments were conducted to determine if:

- (1) rhodamine WT dye volatilized significantly from water at mixing conditions comparable to those in Little Lost Man Creek;
- (2) rhodamine WT dye reacted with any of the anions and cations of the salts used with the dye in the study; and
- (3) rhodamine WT dye sorption can, in fact, be measured on sand and gravel size sediment.

Part (2) was done both for concentrations approximately the same as those observed after mixing in the creek and for concentrations approximately the same as in the injection solution.

Volatilization and Salt Reaction Experiments

A constant temperature bath 0.91 m long by 0.45 m wide was filled with distilled water to a depth of 0.26 m. Mixing was provided by a stirring motor, and water temperature was maintained at 25.0 °C by a temperature controller and heater. A quantity of rhodamine WT dye sufficient to give a concentration of about $16 \mu\text{g L}^{-1}$ was added to the bath. The dye concentration in the bath water was measured on a Turner Designs Model 10 fluorometer at approximately one-hour intervals for two days. A dye standard of about the same concentration was also measured each time the bath concentration was measured.

After two days, a solution of salts was added to the bath to give ionic concentrations approximately the same as in the creek at the upstream end of the study reach. Concentrations of these ions in the bath and at the upstream end of reach are given in Table 2 for comparison. Measurements of the dye concentrations of the bath were then continued at approximately one-hour intervals for an additional two days.

TABLE 2. Ionic Concentrations in the Laboratory Solution and at the Upstream End of the Study Reach.

Ion	Concentration (mg L^{-1})	
	Laboratory Experiment	In-Stream (approximate)
Lithium	2.01	2.0
Sodium	5.96	8.0
Potassium	2.73	3.0
Strontium	2.27	2.0
Chloride	23.30	22.0
Nitrate	0.97	0.9

On the fifth day, the reaeration coefficient was measured, using procedures described previously by Rathbun, *et al.* (1978). This coefficient was used as a measure of mixing conditions in the water.

To determine if the rhodamine WT dye reacted with the salts in the injection mixture, a salt solution having a concentration approximately the same as the injection solution was prepared. A quantity of rhodamine WT dye sufficient to give the desired concentration was added to this salt solution, and the resultant stock solution was immediately subsampled. This subsample was then diluted to a concentration such that it could be measured on the fluorometer. A dye standard was measured at the same time. This subsampling of the stock solution, dilution, and analysis was repeated daily for three days and then at time intervals of 4, 7, 14, and 22 days after the initial preparation of the solution. All diluted samples were also reanalyzed each time a new sample was prepared.

Composition of this stock solution and the actual injection solution is given in Table 3. Using commonly available laboratory salts it was possible to closely, but not exactly, match the concentrations of the major ions. The dye concentration in the injection solution was $1.58 \times 10^5 \mu\text{g L}^{-1}$ as determined by measurement on the fluorometer. The dye concentration in the laboratory solution was $1.45 \times 10^5 \mu\text{g L}^{-1}$ as calculated from the quantity of dye added to the solution. The volume of water was corrected for the volume change on mixing resulting from the addition of the salts.

TABLE 3. Ionic Concentrations in the Stock Laboratory Solution and the Injection Solution.

Ion	Concentration (g L^{-1})	
	Laboratory Stock Solution	Injection Solution
Lithium	20.4	20.4
Sodium	18.8	19.0
Potassium	21.1	21.1
Strontium	12.8	21.5
Chloride	158.0	165.0
Nitrate	8.4	8.4

Volatilization Analysis

No consistent trends with time over a two-day period were observed in the water bath/standard dye concentration ratios. The measured reaeration coefficient for the mixing conditions in the bath was 22.9 days^{-1} ; a coefficient of this magnitude is representative of high mixing conditions. It was concluded that volatilization of rhodamine WT from water under these conditions was not a significant mechanism for loss.

Salt Reaction Analysis

No consistent trends with time over a two-day period were observed in the water bath/standard dye concentration ratios after the addition of the salt mixture to the bath water. It was concluded that rhodamine WT dye did not react to any appreciable extent with any of the salts used in the study at concentration levels approximately the same as those in the stream water at the upstream end of the study reach.

No consistent trends with time over a 22-day period were observed in the injection solution/standard dye concentration ratios. This was true both for the dilutions of the injection solution which were freshly prepared seven times during the 22-day period as well as for the dilutions previously prepared which were reanalyzed each time a new dilution was prepared. It was concluded that rhodamine WT dye did not react to any appreciable extent with any of the salts used in the study at concentration levels approximately the same as those in the injection mixture.

Sorption Experiment

Laboratory studies of rhodamine WT sorption were conducted using a sample of streambed sediment collected from the study reach at Little Lost Man Creek. The sample was segregated according to size by wet sieving. Studies were run using the fractions from 1.0 to 6.3 mm. Comparisons between sorption characteristics in the field and in the laboratory cannot be precise. The streambed sediment is coated with a slick layer of presumed organic material. As a result of sieving it is believed that very little organic material remained attached to the sediments.

The rhodamine WT solutions were prepared using water having approximately the same concentration of major ions found naturally in Little Lost Man Creek to assure that the adsorbed ions on the clay minerals were close to those adsorbed during the field experiment. Concentrations of major ions are given in Table 4.

TABLE 4. Ionic Concentrations in the Laboratory Solution for the Sorption Studies.

Ion	Concentration (mg L ⁻¹)
Sodium	6.9
Potassium	0.67
Magnesium	2.0
Calcium	5.4
Chloride	9.5
Sulfate	8.6
Bicarbonate	18.4

Experiments were conducted in 500 mL beakers. Steambed sediment was distributed over the bottom of the beaker previously filled with rhodamine WT solution. Initial dye concentrations were approximately 40 $\mu\text{g L}^{-1}$. Experiments were run using water/rock mass ratios of 10 to 1 and 5 to 1. Beakers were unstirred and covered by Parafilm except during sampling. The entire beaker was enclosed in aluminum foil to prevent photochemical decay. The beaker was maintained at $22^{\circ} \pm 2^{\circ}\text{C}$ in room air.

Sorption Analysis

The experiment having a water-to-sediment mass ratio of 10 to 1 was terminated after 10 days, at which time the rhodamine WT concentration in the solution had dropped from 40.5 $\mu\text{g L}^{-1}$ to 27.5 $\mu\text{g L}^{-1}$, a 32 percent uptake of dye by the sediment. Subsequent analysis indicated that sorption was still occurring when this experiment was terminated. The experiment with a water to sediment ratio of 5 to 1 was therefore conducted over a 22-day period. Figure 5 shows concentration versus time for this experiment. Rhodamine WT concentration dropped from 39.3 $\mu\text{g L}^{-1}$ initially to 16.3 $\mu\text{g L}^{-1}$ after 22 days, a 58.5 percent uptake by the sediment. Assuming the system was at equilibrium at the conclusion of the experiment, the distribution coefficient for sorption of rhoda-

mine WT on the sediment was $5.6 (\text{g dye on sediment} \cdot \text{g}^{-1} \text{ sediment}) \cdot (\text{g dye in solution} \cdot \text{g}^{-1} \text{ solution})^{-1}$.

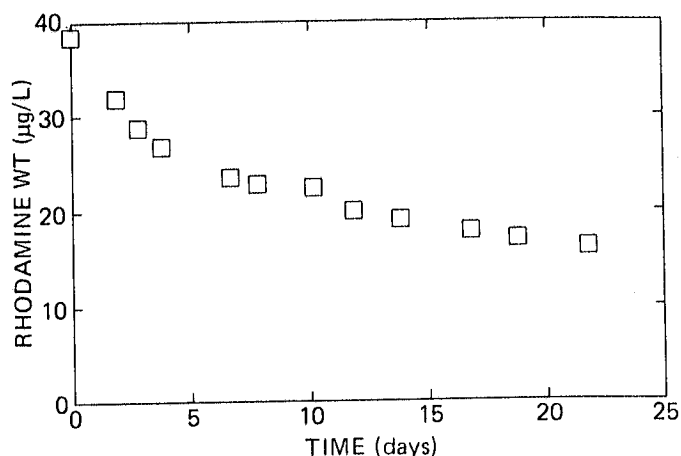


Figure 5. Uptake of Rhodamine WT from a Solution in Contact with Sediment (ratio of 5 to 1; solution to sediment).

DISCUSSION

The data from the field experiment show the losses of rhodamine WT in a mountain stream environment. Attenuation was observed in the main channel and clear losses are shown in the gravels along the stream. The data are particularly useful for showing the extent of dye loss because of: (1) the low suspended sediment concentration, less than 10 mg L⁻¹; (2) the length of the injection, 15 hours; (3) concurrent injection of recognized conservative and sorptive tracers, chloride and lithium, respectively; and (4) evidence for significant interaction between flow in the stream and flow in the surrounding subsurface, intergravel water, system.

The effectiveness of rhodamine WT as a ground water tracer has been discussed by Smart and Smith (1976) and Aulenbach, *et al.* (1978). In the subsurface, intergravel water, system that interacts with Little Lost Man Creek, rhodamine WT would be useful only as a qualitative tracer. The details of rhodamine WT interaction with solids are not well understood and apparently are dependent on site specific conditions.

The laboratory sorption studies clearly show very substantial uptake of rhodamine WT by relatively small amounts of sediment. Water flowing from the stream through the sediments to wells most likely came in contact with many times its weight in sediment. The same is probably true of water moving down the channel from the injection site to the sampling site 327 m downstream. The relatively slow time course of the laboratory uptake studies is probably due to the large particle sizes, believed typical of the stream sediments, and the complete absence of stirring in the beaker, which is not similar to the turbulent flow in this high gradient mountain stream. This suggests that the high uptake of dye observed in the stream during the 15-hour injection would likely have persisted for many days had the injection been continued.

The laboratory sorption studies find a distribution coefficient of $5.6 \text{ (g dye on sediment} \cdot \text{g}^{-1} \text{ sediment)} \cdot \text{(g dye in solution} \cdot \text{g}^{-1} \text{ solution)}^{-1}$. Since full equilibration may not have been achieved at the completion of the experiments, the true value may be somewhat higher. This compares with distribution coefficients for the strongly sorbed strontium ion of approximately $50 \text{ (g cation on sediment} \cdot \text{g}^{-1} \text{ sediment)} \cdot \text{(g cation in solution} \cdot \text{g}^{-1} \text{ solution)}^{-1}$ which we have obtained in separate experiments using sand and gravel sized sediments from Uvas Creek (Bencala, *et al.*, 1983). The fact that rhodamine WT has a distribution coefficient within a factor of 10 of such a strongly sorbed ion suggests that interaction with the streambed should be evaluated as a possible loss mechanism in dye tracer studies. This is particularly true of streams with highly permeable beds and banks where stream water contacts a significant amount of bed sediments.

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