# COMPARISON OF TRACER-DILUTION AND CURRENT-METER DISCHARGE MEASUREMENTS IN A SMALL GRAVEL-BED STREAM, LITTLE LOST MAN CREEK, CALIFORNIA

By Gary W. Zellweger, Ronald J. Avanzino, and Kenneth E. Bencala

---

U. S GEOLOGICAL SURVEY

Water-Resources Investigations Report 89-4150

Menlo Park, California
1989

TABLE OF CONTENTS

ABSTRACT ..... 1

INTRODUCTION ..... 3

Background..... 3

Purpose and Scope..... 5

FIELD SITE ..... 5

EXPERIMENT ..... 6

TRACER-DILUTION DISCHARGE METHOD ..... 7

CURRENT-METER DISCHARGE METHOD ..... 10

COMPARISON OF METHODS..... 10

DISCUSSION ..... 16

CONCLUSION ..... 18

REFERENCES ..... 19

LIST OF ILLUSTRATIONS

Figure 1. A map of the study reach..... 4

Figure 2. Ion tracer limits..... 8

Figure 3. Chloride concentration curve at Site "224m"... 11

Figure 4. Discharge from current-meter measurements..... 12

Figure 5. Longitudinal variation in discharge..... 14

Figure 6. Discharge from three tracers..... 15

Figure 7. Summary of discharge at Site "330m"..... 17

# Comparison of Tracer-Dilution and Current-Meter Discharge Measurements in a Small Gravel-Bed Stream, Little Lost Man Creek, California

By Gary W. Zellweger, Ronald J. Avanzino, and Kenneth E. Bencala

## ABSTRACT

Discharge was determined in a small gravel-bed stream, Little Lost Man Creek, California, using both a current meter and two tracer dilution measurements: one with a mixing length of 25 meters and the other with a mixing length of 300 meters. Comparison of discharge values obtained indicated that as much as 25 percent of the channel discharge may have been flowing as underflow through gravel zones in the channel. Current-meter discharge measurements were used to obtain point discharge; tracer-dilution discharge measurements were used to obtain discharge measurements which incorporated mixing of surface water and underflow over 25 and 300 meters of stream reach.

Within the study reach, the confined channel contained gravel and cobble to a depth of at least one meter. During summer low flow of 5 to 20 L/s, the surface stream appeared to be 1 to 2 meters wide, about 20 percent of the channel width.

Determining discharge in small pool-and-riffle streams using conventional current-meter techniques is hampered by shallow depths, rough bottoms, and flow through the gravel bed under and parallel to the stream. Furthermore, discharge can vary both diurnally and longitudinally over relatively short reaches. Discharge measurement by continuous tracer dilution can accommodate these factors to some extent.

Chloride was injected for eight days during which the stream water was sampled along a 300-meter reach below the injection point. On the seventh day, a second injection of sodium, chloride, and rhodamine WT dye was made for 24 hours, 305 meters below the first injection, and was sampled 25 meters downstream. Current-meter discharge measurements were made along the study reach three times during the experimental period.

The average discharge of 17.4 L/s calculated from the tracer that traveled 300 meters was greater than the average of 15.9 L/s calculated for the tracer that traveled 25 meters. Both of these tracer-dilution measurements were greater than the average current-meter discharge measurement of 13.0 L/s. The comparison supports the hypothesis that a significant part of total stream discharge is moving as underflow through gravel zones within the stream channel.

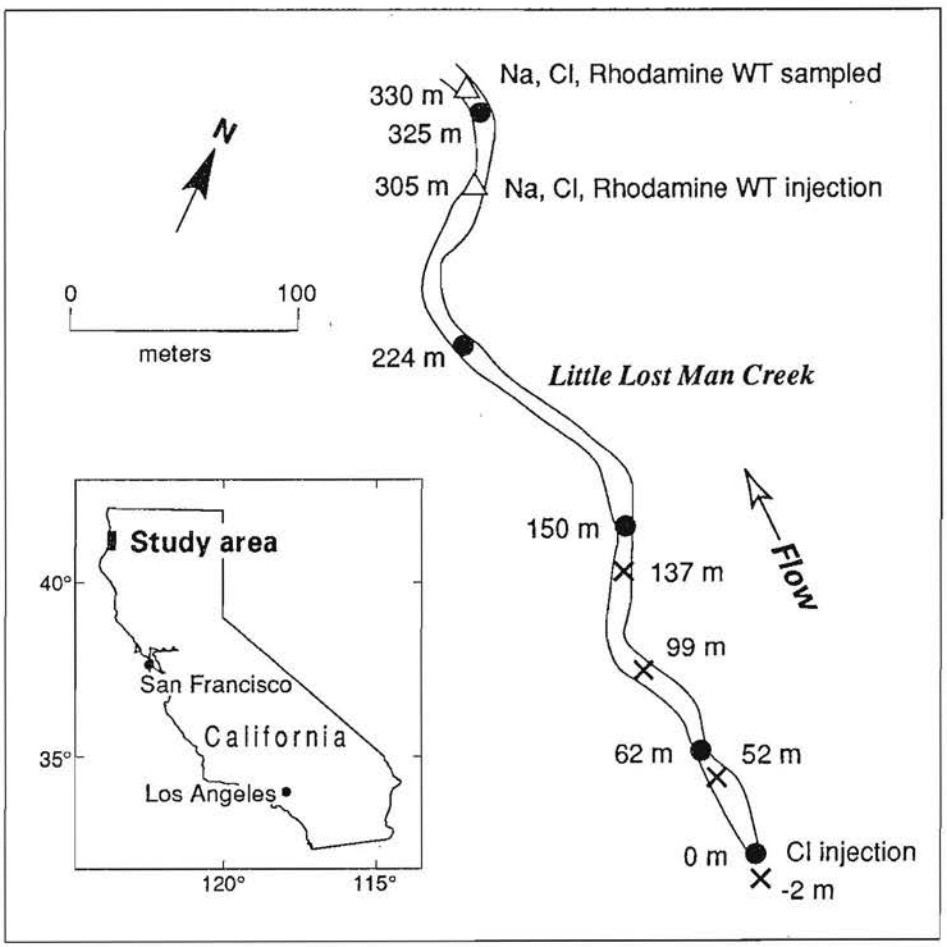


Figure 1. A sketch of the study reach on Little Lost Man Creek. The primary injection was at Site "0m", at the bottom of the map, the secondary injection was at Site "305m" and was sampled at Site "330m". Routine sample sites were at "-2m", "52m", "99m", "137m" and "224m" and current meter sites at "62m", "150m", "224m", and "325m".

## Purpose and Scope

This report was written with two purposes. First, data are presented showing differences between measurements of discharge in a small stream made by the current-meter method and the tracer-dilution method. The second purpose is to suggest the possibility that the differences between the measurements may be due to as much as four liters per second, or 25 percent of discharge, flowing through channel gravel.

# FIELD SITE

Little Lost Man Creek is a third-order, pool-and-riffle, coastal stream within Redwood National Park, in northwestern California, about 40 miles north of the city of Eureka. The 10-km, north-northwest flowing stream drains an area of 9.4 $km^2$ (3.6 $mi^2$) and is at elevations between 24 and 695 meters above sea level (Iwatsubo and others, 1975). Discharge ranges from typical late summer lows of 6 L/s to a winter high of 5,700 L/s. Average annual rainfall is 1,780 mm at the Orick Prairie Creek rain gage, approximately 3 km northwest of the study reach. The study reach was 330 meters long, located in the lower section of the stream where the gradient was 0.018. The streambed sediments were poorly sorted and ranged from sand to boulder size. There was little clay and silt in the streambed permitting considerable water flow through the gravel (Bencala and others, 1984). Of five shallow wells dug into the gravel bed in and beside the stream, two of which extended a meter below the stream bottom, none reached the lower limit of the gravel deposit, indicating that the gravel sediments, in these locations, were at least one meter thick. No precipitation occurred during the study period. Background concentrations of sodium and chloride just above the study reach were each approximately 6 mg/L.

Figure 1 is a map of the study reach. The sample sites along the reach were identified by their distance, in meters, below the lithium chloride injection site. Routinely sampled sites were located two meters above the injection (Site "-2m") and at 20, 52, 99, 137, and 224 meters below the injection. Current-meter discharge measurements were made 62, 150, 224, and 325 meters below the injection site.

## EXPERIMENT

The primary tracer was a solution of lithium chloride pumped into the stream continuously beginning at 2:30 p.m. PDT on August 15, 1984 and ending at 10:00 a.m. on August 23. The chloride concentration of the injectant was 170.1 g/L. The injection rate was maintained using a battery-powered, 12-volt, metering pump. Daily measurements of the injection rate, made by timing the filling of a 50-mL volumetric flask, averaged 37.29 ±.32 (1 sd) mL/min.

On the seventh day of the eight-day injection, a secondary injection of sodium, chloride, and rhodamine WT was made for 24 hours, starting at 11:02 a.m. on August 21, 305 meters below the primary injection. This secondary injection was intended for comparison with discharge calculations made from the primary injection. The stream was sampled hourly above the injection site at 300m, and below at 330m, using automatic samplers. Rhodamine WT loses have previously been observed within Little Lost Man Creek (Bencala and others, 1983), however in this study the dye was used over a short mixing reach.

On August 14, 21, and 28, personnel of the U.S. Geological Survey field office in Eureka, California, measured discharge with a current meter following routine procedures (Buchanan and Somers, 1969). Two measurements were made on each date at each site usually three to four hours apart.

Samples collected for chloride and sodium analysis were filtered through a 0.45 $\mu$m membrane and stored in darkness until analyzed a few months later. Samples for rhodamine WT analysis were collected in glass bottles and kept in darkness until analyzed on August 25, 1984.

Samples were analyzed for chloride using a Dionex ion chromatograph[1]. Sodium was analyzed by atomic absorption spectroscopy using a Perkin-Elmer model 303 spectrophotometer, following the method described by Skougstad and others (1975). Rhodamine WT fluorescence was measured with a Turner Designs Model 10 fluorometer. Because lithium is known to adsorb to sediments in this stream in as few as 62 meters (Bencala and others, 1984), it was not measured in this experiment.

---

1. Use of a product name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey

## TRACER-DILUTION DISCHARGE METHOD

Discharge can be measured from dilution of a tracer by equating the increase in the stream tracer mass to the mass being added and solving for discharge (Kilpatrick and Cobb, 1985). All tracer-dilution discharge measurements in this paper were made using continuous injection. For this method, the tracer is injected as a concentrated solution at a constant rate for an extended time. Downstream of the injection site, the tracer concentration in the stream increases as the tracer arrives and eventually stabilizes at a nominally constant concentration referred to as the plateau concentration. The plateau concentration of the tracer reflects dilution of the tracer by all of the water with which the tracer has mixed between the injection point and the sample point. This method requires that the tracer is thoroughly mixed with the stream, and that it is conservative. A conservative tracer neither gains nor loses mass by any chemical or physical action within the study reach. When this is the case, the tracer dilution reflects the discharge of the stream.

Discharge below the injection point is calculated as $Q_b = \frac{Q_i \ (C_i - C_a)}{(C_b - C_a)}$ .

where:

$Q_b$ = Stream discharge below the injection point

$Q_i$ = Injectant discharge

$C_i$ = Tracer concentration in injectant

$C_a$ = Tracer concentration in stream above injection point

$C_b$ = Tracer concentration in stream below injection point

Discharge determination is not limited to one site near the injection. The tracer-dilution method allows discharge to be calculated at any downstream site where the tracer reaches plateau. Temporal patterns may be determined by sampling as long as the injection continues.

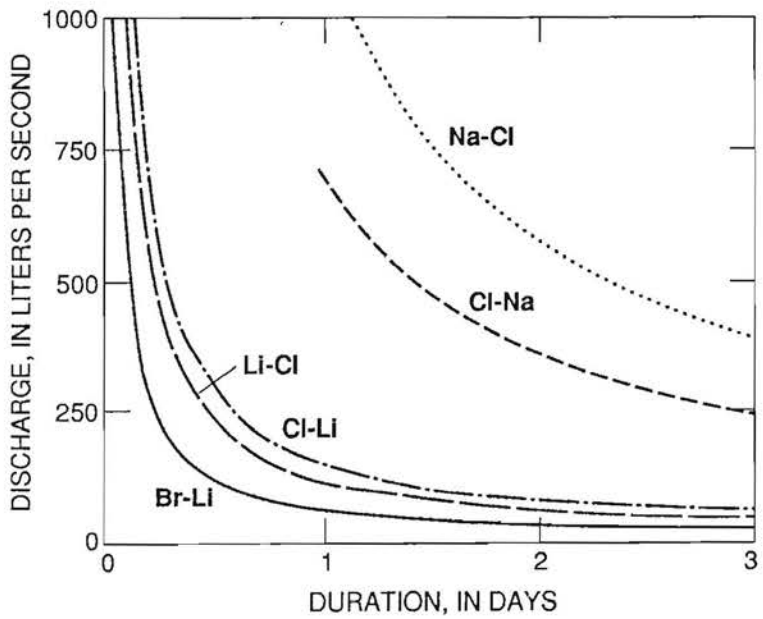


Figure 2. Limits on the use of ionic tracers assuming an injection rate of 1 L/min, maximum tank capacity of 1400 L, a $500 budget restriction and a tracer increase equivalent to 5 mg/L of chloride. Different analytical sensitivities have been taken into account. The notation Cl-Li indicates the tracer is chloride from the salt LiCl. The pump rate is exceeded for Cl as NaCl at discharges above 750 L/s.

Chloride is useful as a tracer in small streams because it behaves conservatively and is easy to sample and to measure. In typical streams, chloride is not appreciably involved in ionic exchange with the streambed (Kennedy and others, 1984). As noted by Feth (1981) "The chemical behavior of chloride in natural water is very tame and subdued *** an element that is characterized by its existence in ionic form, and one that is stable with respect to chemical reactions that greatly influence the behavior of many other common elements." When ion chromatography is used to measure chloride, relative standard deviation is at most 1 to 2 percent at levels of a few milligrams per liter and analytical interference due to other solutes is rare. Sample filtration is necessary only to prevent clogging of chromatographic columns and can be done by the chromatograph at the time of analysis. There is normally no need to store the samples chilled.

Sodium can exchange with other cations at charged sites on sediments. However, it is a monovalent cation and is a weak competitor for exchange sites. Sodium sometimes behaves conservatively over short distances (Bencala, 1985).

The usefulness of anion tracers is limited by background concentrations and stream size. Calculations used with tracers require subtracting any background concentration from the total concentration. Precision decreases as the signal concentration nears background. Quality results can be obtained when the total tracer concentration is at least double background concentration.

Because stream concentrations must be increased by milligrams per liter, the rate and total amount of added tracer becomes limiting as stream size or injection duration increases. If pumping rates are limited to 1 L/min and storage tanks limited to about 1,400 L, then anion tracers become impractical in streams with flows greater than 600 L/s (50 $ft^3/s$) especially for injections of 24 hours or longer. These limits can be seen graphically in figure 2 which includes consideration of salt solubility and measurement sensitivity.

Rhodamine WT fluorescent dye often is a suitable tracer for streams without high concentrations of suspended sediment or large amounts of organic material. Rhodamine WT can be used in larger streams where anionic tracers are not practical and where adsorption by stream sediments and organic

materials is minimized. The dye can be used at concentrations of a few micrograms per liter; Smart and Laidlaw (1977) reported a minimum detection level of 0.013 $\mu g/L$ in distilled water on a Turner Model 111 fluorometer. Portable battery-powered fluorometers can be used to measure fluorescence in the field.

## CURRENT-METER DISCHARGE METHOD

Discharge measurements were made on Little Lost Man Creek using routine U.S. Geological Survey methods (Buchanan and Somers, 1969). A Price pygmy meter, which is more suitable for shallow streams than the standard Price type AA current meter, was used to measure stream velocities. The stream was modified at four locations by removing large cobbles from the stream channel, creating a short reach of uniform width and relatively even flowing water. A measuring tape was secured across the channel of 1 to 2 meters width, and the depth and average water velocity were measured at 17 to 25 vertical sections across the width of the channel. Summing the flows through each subsection determined stream discharge.

## COMPARISON OF METHODS

Figure 3 is a plot of the concentration of chloride measured in samples from Site "224m". The rapidly rising left side of the concentration curve represents samples collected while the chloride concentration was increasing toward the plateau level. That chloride required about two days to reach plateau indicated that there was a considerable volume of water in the stream channel that was not in immediate contact with the visible surface stream. Once plateau was reached, the concentration curve showed a slow steady increase, as would be expected during a period of no precipitation.

The averages of each pair of current-meter discharge measurements are plotted against downstream distance in figure 4. These data show a decrease in discharge with time and a variation along the length of the stream. An estimate of the precision of the current-meter method was made by pooling all of the 11 sets of two measurements from the three times the stream was measured. This estimate assumes that the stream discharge did not change

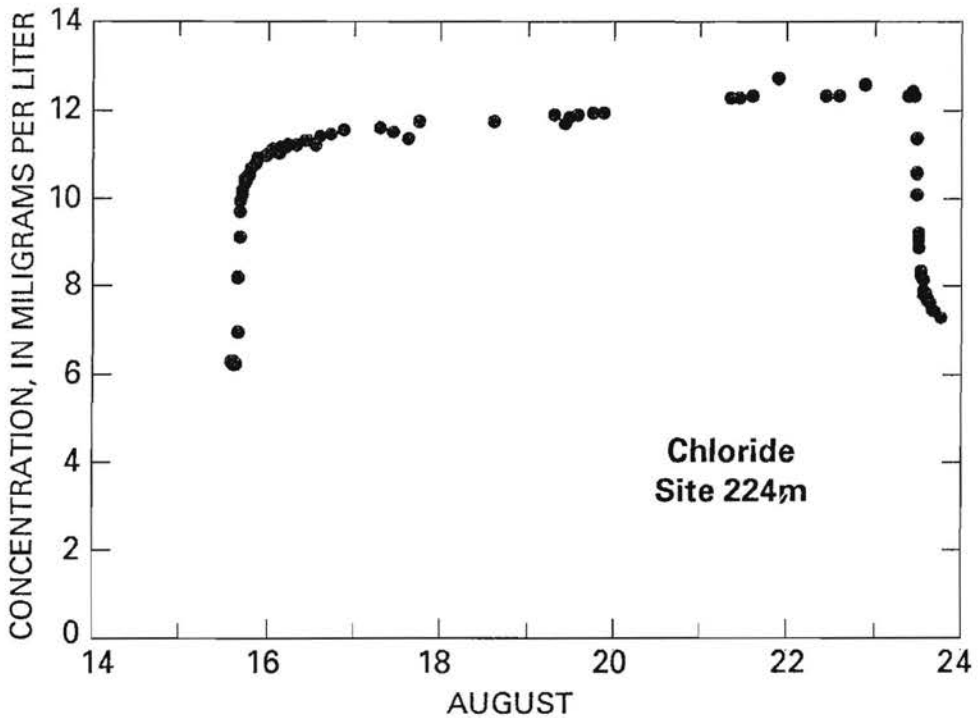


Figure 3. A plot of the chloride concentration at Site "224m". The concentration rises soon after the start of the injection at 2:30 pm, August 15 and continues to rise reaching a "plateau" about two days later.

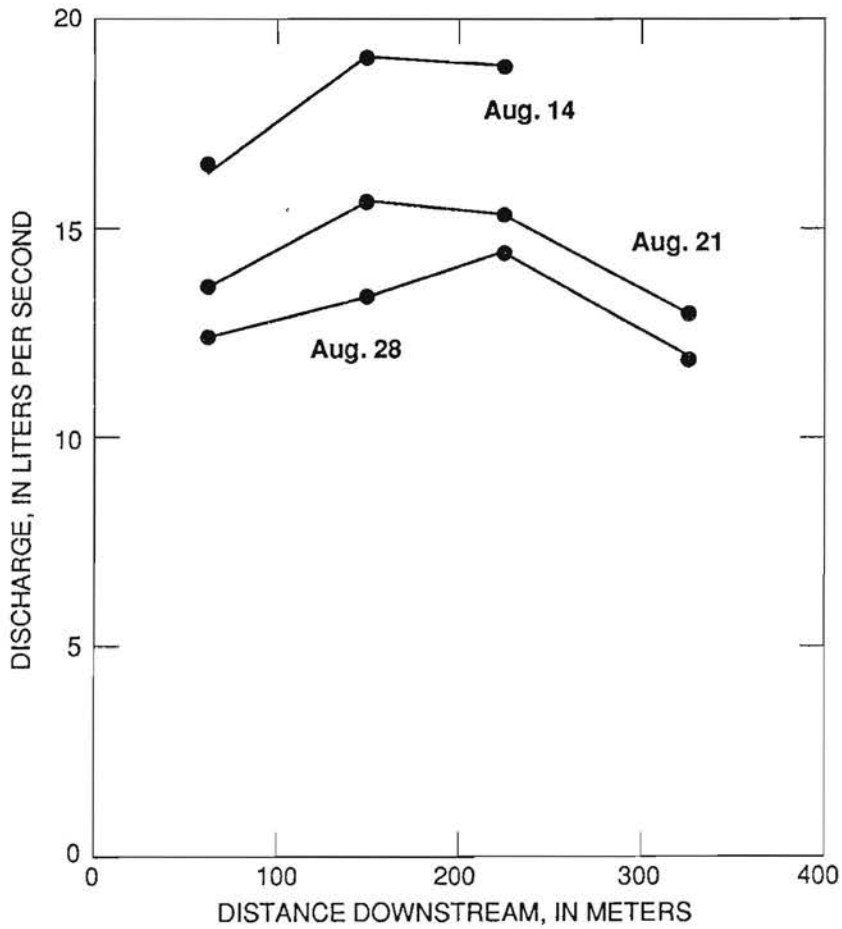


Figure 4. Longitudinal discharge for the averages of pairs of current-meter discharge measurements made on August 14, 21, and 28, at the four (three on Aug. 14) metering sites.

substantially during the 3 to 4 hours between the two measurements. The measurements ranged from 10 to 19 L/s and the estimated standard deviation of the method was calculated to be 1.4 L/s for one measurement and 1.0 L/s for the average of two. There is no independent measurement of discharge in this experiment that can be used to determine if there is a systematic under or over registering of discharge by the current-meter method.

The decrease in discharge between August 14 and the two other dates is much greater than the precision of the current-meter method and is reasonable for a small stream recovering from the last rain on July 7. The longitudinal variation could easily be due to differences between the prepared gaging sites.

The average values of current-meter discharge for August 21 are shown again in figure 5, along with discharge, for the same date, calculated for six sites from dilution of the primary chloride tracer. The discharges calculated from tracer dilution were clearly greater than those from current-meter measurements at each of the four sites.

Samples from the secondary injection of August 21/22, collected at "Site 330m", were analyzed for sodium, chloride, and rhodamine WT. Discharge was calculated from each hourly sample and the corresponding background sample from site "300m". The average calculated discharges were 15.98 ±0.25 L/s for chloride, 15.88 ±0.50 L/s for sodium, and 15.78 ±0.57 L/s for rhodamine WT. The precision values are one standard deviation and assume that no change in discharge occurred during the 24-hour injection. These discharge values are shown in figure 6 along with the discharge values from the two current-meter measurements which averaged 13.0 L/s. Again, as in figure 5, the current-meter discharge values are less than the tracer-dilution discharge values.

The agreement between the three sets of tracer-discharge calculations indicates that the analytical techniques used were precise. This does not necessarily mean that the discharge calculations are accurate. All three tracers would have had the same hydraulic behavior, so to the extent that mixing was not complete, each tracer would have been equally affected.

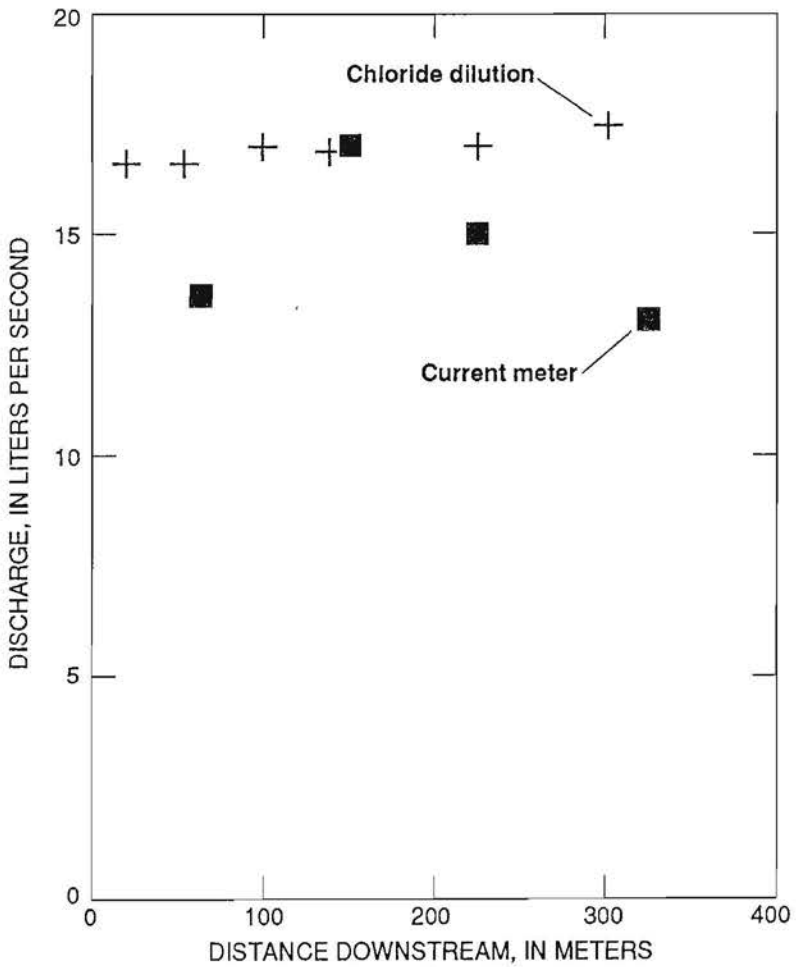


Figure 5. Longitudinal discharge downstream of the primary chloride injection on August 21. The plus symbols represent discharge measured by chloride dilution from the primary injection; the squares represent discharge measured by current meter.

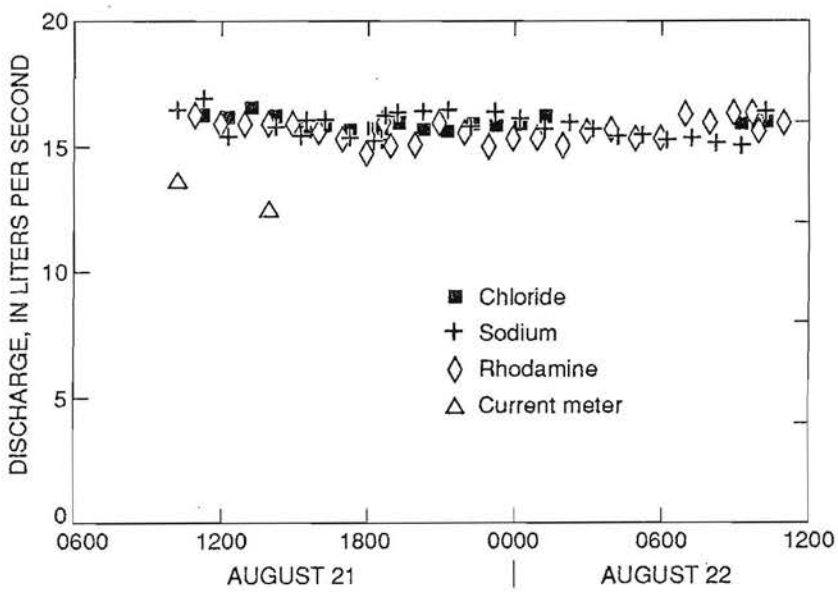


Figure 6. Discharge for 24 hours, near "Site 330m", as calculated from the three tracers of the secondary injection on August 21/22. Squares, plus signs, and diamonds represent discharge by dilution of Cl, Na, and rhodamine WT, respectively. The triangles represent the two current-meter discharge measurements.

Agreement of the sodium discharge calculations with those of chloride and rhodamine WT is evidence that sodium can sometimes act as a conservative ion. For the 25-meter reach of the secondary injection, in which the observed travel time appeared to be less than 5 minutes, the discharges calculated from sodium were not different from those calculated from chloride or from rhodamine WT. Either the rate of adsorption was so low as to be trivial, or the reaction was fast and reached equilibrium within 13 minutes before the first sample was collected. Whichever the case, for this experiment, sodium behaved essentially as a conservative tracer.

The hourly background samples from Site "300m" were also used as the downstream site to calculate discharge from the primary lithium chloride injection using the chloride analyses from Site "-2m", as the site above the injection. For this calculation the chloride tracer traveled 300 meters. The average of these values, 17.40 ±0.15 L/s, along with the averages from figure 6, are shown in figure 7.

## DISCUSSION

The discharges calculated from the averages of the three methods are 13.0 L/s for the current-meter measurements, 15.9 L/s for tracer dilution over 25 meters, and 17.4 L/s for tracer dilution over 300 meters. The differences are great enough, when compared with their respective standard deviations of 1.0, 0.46, and 0.15 L/s, to indicate actual differences in discharge.

The explanation may be that there is enough water flowing through the coarse gravel deposits in the stream channel to account for the differences in discharge measurements. In this concept, the gravel zone, which is several times wider than the surface stream during the low flow season and at least one meter thick in some locations, might carry as much as 25 percent of the total channel flow (4 L/s). Water does not travel permanently in the gravel zone but moves from the gravel zone into the surface stream in some reaches and from the stream into the gravel zone in other reaches. Thus, over longer distances greater mixing occurs. The current meter, which measures only the surface flow, would miss all of the underflow water. The tracers traveling 25 meters would have some opportunity to mix with underflow water, and the tracer traveling 300 meters would have the greatest opportunity to mix with underflow water.

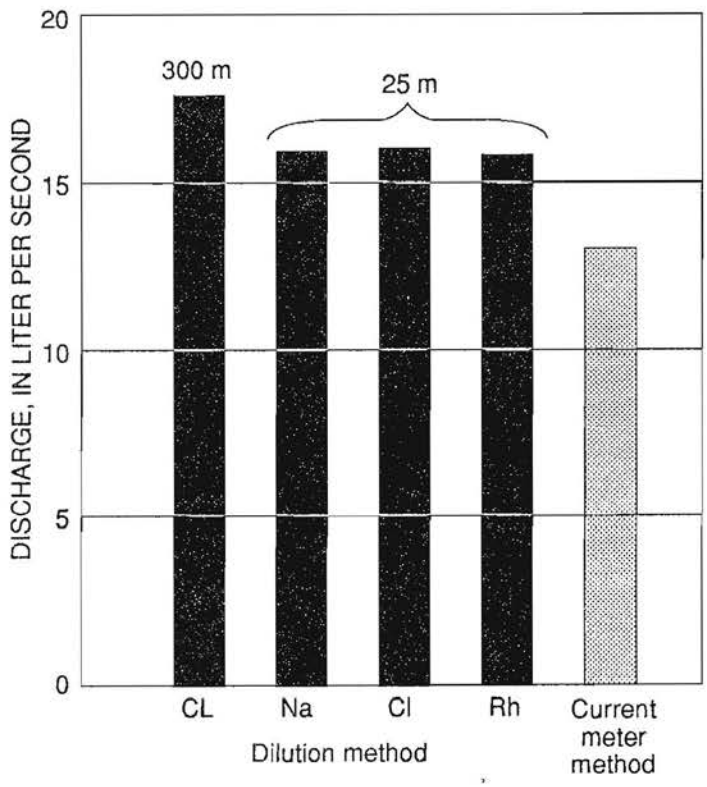


Figure 7. Summary of measurement of discharge near Site "330m" by three methods. First, by chloride dilution over 300 meters of reach; second, by dilution of sodium, chloride, and rhodamine WT over 25 meters of reach; and third, by current-meter method.

## CONCLUSION

It has long been known that water occupies inter-gravel spaces in steam channels and presumably moves down the channel as underflow. In some systems, that underflow can be large enough to measure. Furthermore, when such flow does occur it can affect discharge measurements to different degrees, depending on the method used to measure discharge. Not only can tracer-dilution and current-meter methods result in different values, but the tracer-dilution method seems to produce different results when used over different stream lengths.

## REFERENCES


Bencala, K. E., Rathbun, R. E., Jackman, A. P., Kennedy, V. C., Zellweger, G. W., and Avanzino, R. J, 1983, Rhodamine WT dye losses in a mountain stream environment: Water Resources Bulletin, v. 19, no. 6, p. 943-950.

Bencala, K. E., Kennedy, V. C., Zellweger, G. W., Jackman, A. P., and Avanzino, R. J., 1984, Interactions of solutes and streambed sediment. Part 1. An experimental analysis of cation and anion transport in a mountain stream: Water Resources Research, v. 20, no. 12, p. 1797-1803.

Bencala, K. E., 1985, Performance of sodium as a transport tracer--Experimental and simulation analysis. Selected Papers in the Hydrologic Sciences: U.S. Geological Survey Water Supply Paper 2270, p. 83-89.

Buchanan, T. J., and Somers, W. P., 1969, Discharge measurements at gaging stations: U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Chapter A8, 65 p.

Feth, J. H., 1981, Chloride in natural continental water--A review: U. S. Geological Survey Water-Supply Paper 2176, 30 p.

Iwatsubo, R. T., Nolan, K. M., Harden, D. R., Glysson, G. D., and Janda, R. J., 1975, Redwood National Park Studies: Data Release Number 1. Redwood Creek Humboldt County, California, September 1, 1973-April 10, 1974: U.S. Geological Survey Open-File Report.

Jarrett, R. D., 1984, Hydraulics of high-gradient streams: Journal of the Hydraulics Division, American Society of Civil Engineers, 110, (11), p. 1519-1539.

Kennedy, V. C., Jackman, A. P., Zand, S. M., and Zellweger, G. W., 1984/1985, Transport and concentration controls for chloride, strontium, potassium and lead in Uvas Creek, a small cobble-bed stream in Santa Clara County, California, U.S.A. 1. Conceptual model: Journal of Hydrology, v. 75 p. 67-110.

Kilpatrick, F. A., and Cobb, E. D., 1985, Measurement of discharge using tracers: U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Chapter A16, 52 p.

Kondolf, G. M., Webb, J. W., Felando, Thomas, 1987, Basic hydrologic studies for assessing impacts of flow diversions on riparian vegetation: Examples from streams of the eastern Sierra Nevada, California, USA: Environmental Management, 11, no. 6, p. 757-769.

Marchand, J. P., Jarrett, R. D., and Jones, L. L., 1984, Velocity profile, water-surface slope, and bed-material size for selected streams in Colorado: U.S. Geological Survey Open-File Report 84-733, 82p.

Skougstad, M. W., Fishman, M. J., Friedman, L. C., and Erdmann, D. E., 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 5, Chapter A1, 626 p.

Smart, P. L., and Laidlaw, I. M. S., 1977, An evaluation of some fluorescent dyes for water tracing: Water Resources Research, v. 13, no. 1, p. 15-33.