CALCULATION OF CONSERVATIVE-TRACER AND FLUME-DISCHARGE MEASUREMENTS ON A SMALL MOUNTAIN STREAM

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ABSTRACT

An experiment was conducted to (1) determine which sections of a reach of a stream were losing water, (2) test if a sequence of three simultaneous lithium-tracer injections spaced along the 231-meter reach could detect the loss, and (3) compare discharge measurements from three 3-inch Parshall flumes with discharge calculations from the tracer-dilution method. Results indicate that about 2 liters per second, approximately 20 percent of the discharge, was being lost in the lower half of the study reach. The multiple tracer-injection method was able to detect the loss and to determine where in the reach the loss was occurring. Flume-discharge measurements also indicate the loss but did not agree with the tracer-dilution discharge measurements at all sites.

INTRODUCTION

Each year during August, when discharge is about 10 L/s (liters per second), the lower reach of St. Kevin Gulch, Lake County, Colo., loses water by a combination of evaporation, percolation, or transpiration, resulting in the complete disappearance of the stream a few hundred meters below an area of ongoing research (McKnight and others, 1988). A field experiment was conducted at this stream on August 29, 1989, with three purposes: (1) to determine from discharge calculations which parts of the stream reach were losing water; (2) to test whether three tracer injections spaced along the stream could be used to calculate discharge simultaneously at three locations in a stream that loses water, and (3) to compare discharge measurements calculated from tracer dilution with those obtained using portable modified Parshall flumes. This paper presents the results of the experiment.

DISCHARGE MEASUREMENTS

Tracer-Dilution Method

Ionic tracer injections have been used previously to measure discharge, traveltime, dispersion, storage volumes, and one-dimensional model parameters (Bencala, 1984; Jackman and others, 1984). In small, shallow streams with rough bottoms, when discharge is low, the tracer-dilution method is a practical alternative to calculating discharge from current-meter measurements (Zellweger and others, 1989). However, because the concentration of the tracer needs to be at least 0.5 milligrams per liter, the method is limited by practical restraints to streams with discharges of about 1,000 L/s or less.

In the tracer-dilution method, discharge is calculated by dividing the mass-addition rate of the tracer (the injection-pump rate times the tracer concentration of the injectant) by the increase in tracer concentration between the upstream sample location and a downstream sample location (Kilpatrick and Cobb, 1985). The method requires that the tracer be conservative--that is, not be lost because of reaction with the water or streambed. Complete mixing of the tracer is necessary, but the method is not otherwise affected by the morphology of the stream. A single tracer injection can be used to measure discharge at many downstream locations in a stream that is gaining water because water inflows dilute the tracer. In streams that are losing water, discharge can be calculated only at the point of tracer injection because water subsequently lost from the stream does not affect the concentration of tracer in the remaining water. Separate injections were thus necessary to obtain discharge at points along St. Kevin Gulch.

Parshall Flume Method

Parshall flumes are the primary means of measuring discharge in streams too small to use velocity meters. The 3-in. (inch) modified Parshall flume is 12 in. high, 18 in. long, 8 in. wide at the upstream end constricting to 3 in. at the downstream end. Discharge values for the 3-in. modified Parshall flume were read from a rating table and compiled by the Colorado district office of the U.S.Geological Survey using field measurements of water depth in the flumes. Under controlled conditions, the 3-in. Parshall flume has an uncertainty of less than 1 percent (Davis, 1963), but the uncertainty of flumes similar to those used in this work could vary by 7 percent according to Kilpatrick and Schneider (1983), who attribute the variation to imprecision in flume shape and suggest that flumes be calibrated separately. Two advantages of the Parshall flume method over the tracer-dilution method are cost, especially in labor, and the ability to measure discharge without the need to collect samples and wait for their analysis. Disadvantages are that flumes require some vertical gradient, and do not work well in coarse bottom streams or channels where the flow cannot be readily confined to the flume.

EXPERIMENT

Discharge was measured at three sites, 1878, 1981, and 2109. Each site name is the distance, in meters, downstream from a reference point established in previous work at St. Kevin Gulch (fig. 1). The reach between sites 1878 and 2109 had been suspected of losing water. Each site consisted of an upstream sample site, a tracer-injection point, a 3-in. modified Parshall flume below the injection point, and a downstream sampling site sufficiently distant from the

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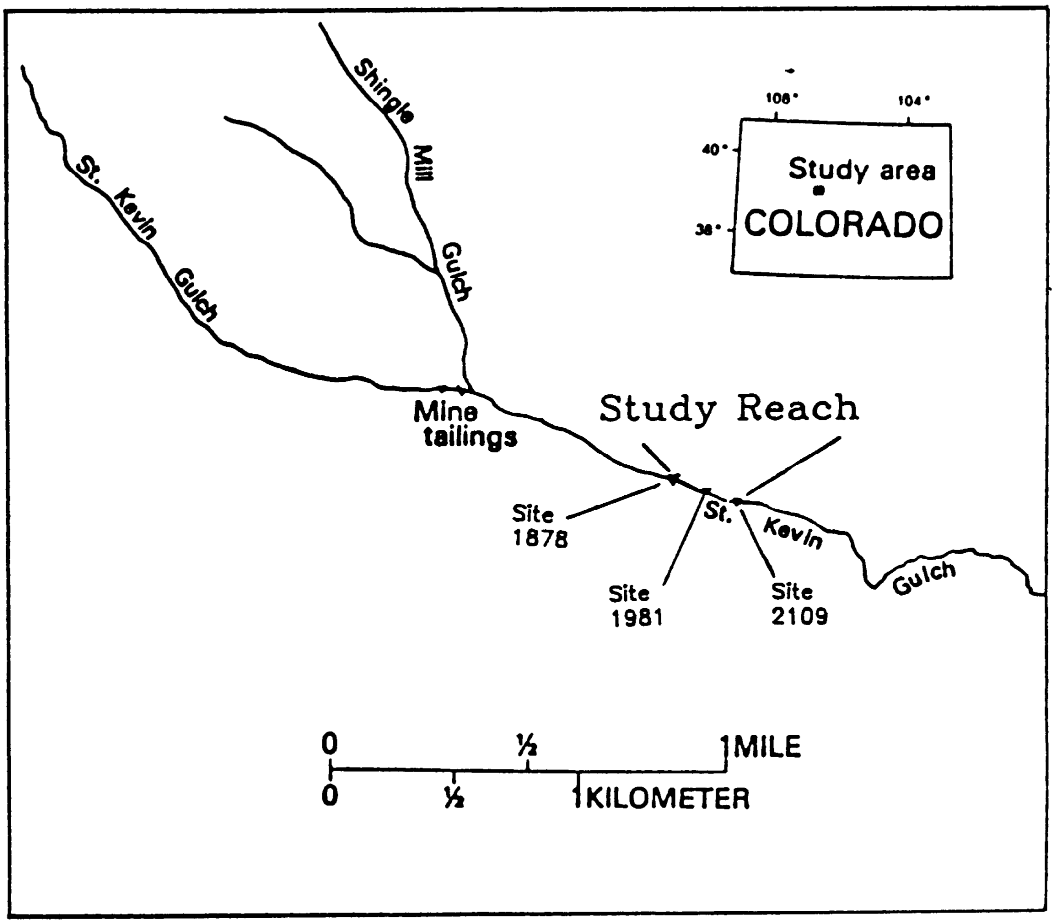

Figure 1. Site map showing location of the study reach relative to St. Kevein Gulch (From McKnight and others, 1988.) The site names are their distance downstream of a reference point (not shown).

injection point to allow for complete mixing of the tracer. A well-mixed lithium chloride solution was divided into three containers and injected at each site by an adjustable-rate, battery-powered, constant-flow pump. In streams with near-neutral pH, where lithium would be adsorbed onto the streambed, a suitable tracer would have been an anion such as chloride, bromide, or sulfate. However, the acidic nature of St. Kevin Gulch (pH~3.7) made it possible to use lithium (Bencala and others, 1990). Computational accuracy improves as the ratio of the downstream tracer concentration to upstream concentration increases (Zellweger and others, 1989). Thus, the rate at which tracer was added at the three sites was increased substantially at succeeding downstream sites. The injection at site 2109 began at 9:18 a.m. followed by an injection at site 1981 at 9:49 a.m., and at site 1878 at 11:00 a.m. Samples were collected in pairs above and below each injection. Measurements of the depth of water in the Parshall flumes were made approximately hourly. The concentration of lithium in the stream samples and in dilutions of the injection solutions were measured by atomic- adsorption spectroscopy. Discharge was calculated as described above; each measurement was calculated from a discrete sample below the injection point and from an interpolated value from above the injection point.

RESULTS

Discharge for the three sites as calculated from the dilution of the lithium tracer is shown in figure 2. Virtually, no loss of flow occurred between sites 1878 and 1981, and about 2 L/s was lost between sites 1981 and 2109. Discharge measurements by Parshall flume for the same sites are shown in figure 3. On the basis of the flume data a loss of about 1 L/s occurred between sites 1878 and 1981 and a loss of about 2 L/s occurred between sites 1981 and 2109. Both methods detected a decrease in discharge from morning to late afternoon. Analysis of lithium concentrations in streamwater that had traveled from site 1878 to site 1981 and from site 1981 to site 2109 indicated that no change in lithium concentration occurred over the distance between the sites. This indicates that the lithium tracer was conservative and that no water was gained by the stream.

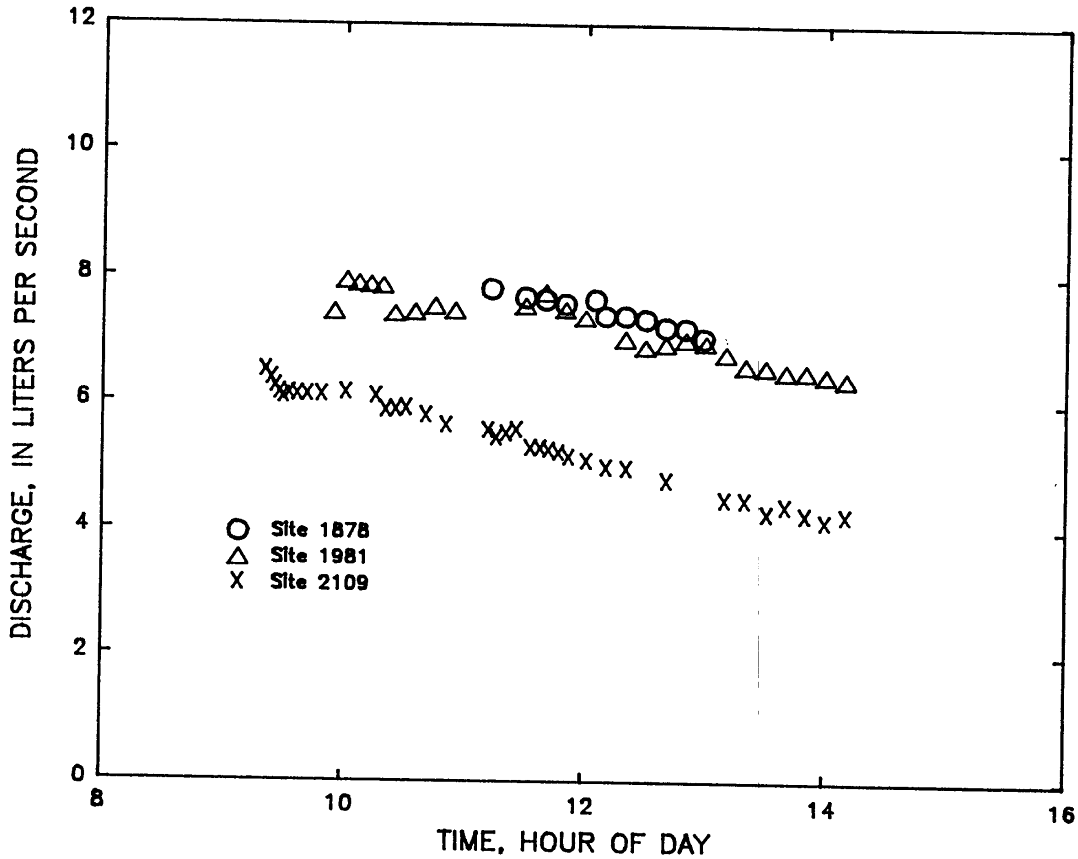

Figure 2. Discharge calculated on the basis of dilution of lithium tracer.

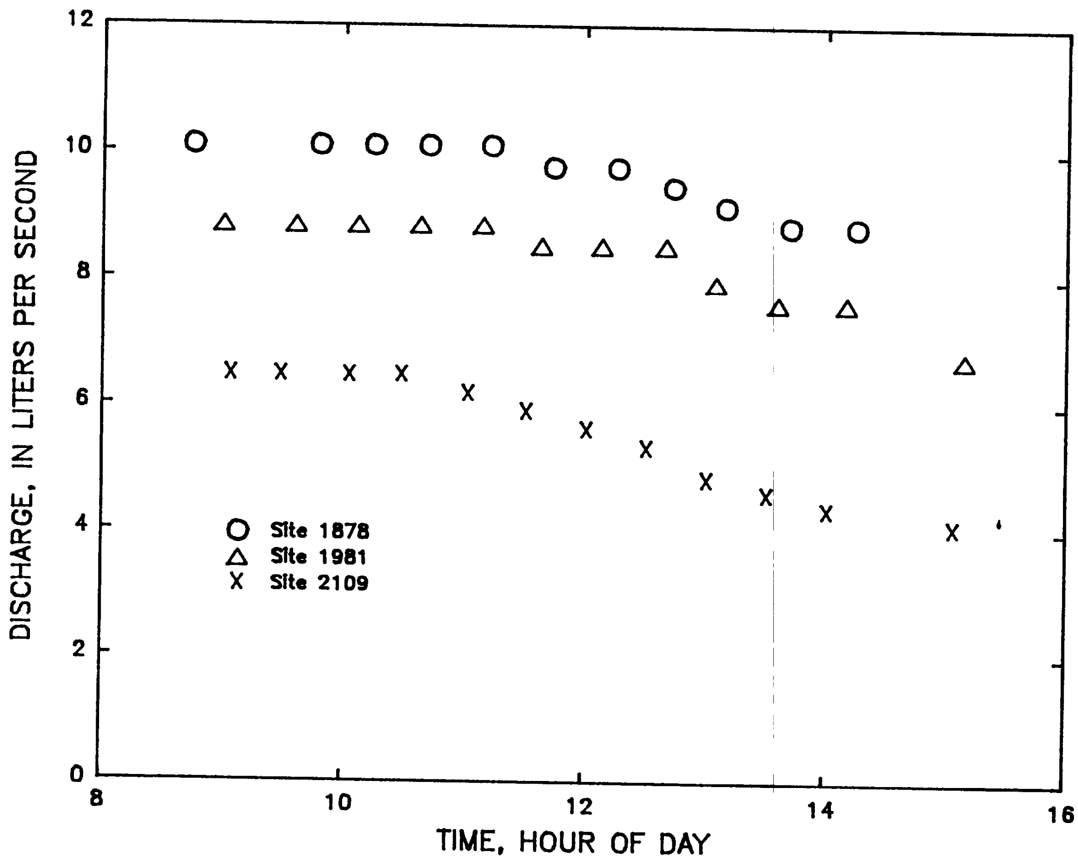

Figure 3. Discharge calculated on the basis of water depth in a 3-inch Parshall flume.

DISCUSSION

Both methods detected water loss over the length of the reach. Agreement between the two methods at site 2109 is good. Evaluation of the results at the two other sites shows that, although both methods detected a pattern of decreasing discharge during the day, there was a nearly constant difference of about 1 L/s between the methods at site 1981 and 2 L/s at site 1878. It is unknown whether this difference exceeds the variation that would be expected for the methods or if there was an error in one of the methods. Discharge measurement by the Parshall flume method is calculated from a single measurement that can easily be made with an accuracy of ±2 millimeters, equivalent to about 0.2 L/s. Accuracy, however, depends on proper positioning of the flume in the channel so that the rating curve is valid. The discharge measurements made by the tracer-dilution method were more variable than those made by the flumes, probably because the result of the 1 to 2 percent random error in the measurement of lithium concentration that was incorporated in the calculation of discharge. Errors in the installation of a Parshall flume generally produce readings less than the true discharge, but, at site 1878, discharge measured by the Parshall flume was greater than that measured by the tracer-dilution method. This suggests a possible error in the tracer-dilution discharge values calculated for site 1878.

SUMMARY

Discharge in small streams can be measured by using either small Parshall flumes or tracer-dilution methods. In this study, both methods were able to confirm that water was being lost in the reach between the sites 1981 and 2109, and to show that the late-afternoon discharge was less than the morning discharge. Differences in the results of the two methods at site 1878 indicate the need to determine which method is capable of substantial error.

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