

## *Use of Tracer Injections to Measure Discharge and Quantify Pollutant Loading*

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### Background

Bureau of Land Management (BLM) hydrologists are often faced with the problem of obtaining stream discharge measurements in streams where the traditional measurement technique is not appropriate. The traditional technique (current meter measurement, see Buchanan and Somers, 1973) is appropriate when the channel bottom and banks are relatively smooth and the assumption of a logarithmic vertical velocity profile is reasonable. In small streams with large roughness elements like cobbles and boulders, a logarithmic velocity profile cannot be assumed (Marchand et al., 1984). Also, in streams with highly porous beds, some of the water will be flowing through the bed material where it cannot be measured by a current meter (Kimball, 1997).

The traditional current meter technique allows some latitude in selecting optimal measurement cross section. In water quality studies where the objective is to quantify several inputs in a stream reach, the location of measurement cross sections is severely restricted. If the hydraulics of the measurement sections do not conform to the assumptions of the traditional method, then the resulting inaccuracies may mask the change in discharge due to lateral inflow. In

synoptic water quality studies, there is usually insufficient time to make a traditional current meter measurement at each sampling location.

These short comings of the traditional current meter method can be overcome by injecting a conservative tracer to measure stream discharge. In water quality studies, the tracer injection is used in conjunction with synoptic water chemistry sampling to quantify lateral inputs.

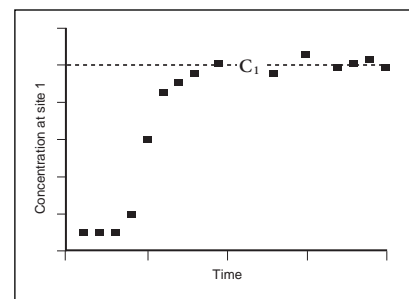
### Discussion

The general approach to using tracer injections is to measure the downstream dilution of the injected tracer and use this information to compute stream discharge. Since the tracer is conservative, the downstream decrease in concentration is due solely to dilution. There are two methods of measuring stream discharge using tracer injections: slug injection and constant rate injection (Kilpatrick and Cobb, 1985). The slug injection method instantaneously injects a known amount of tracer into the flow. The method requires that the dilution of the tracer be accounted for by the complete measurement of its mass downstream. The constant rate injection method requires only the measurement of the plateau

concentration that results downstream after equilibrium has been reached. Only the constant rate method will be considered here.

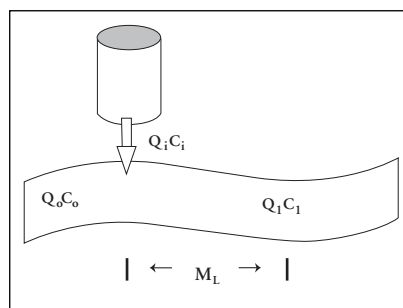
During a constant rate injection, a tracer solution (injectate) with a known concentration ( $C_i$ ) is injected into the stream at a known flow rate ( $Q_i$ ) (Fig. 1).

After a sufficient amount of time, the tracer will arrive at each of the downstream sampling points, and



**Figure 2.** Tracer concentration over time at the first measurement site where  $C_1$  is the plateau concentration.

an equilibrium or plateau concentration will be established (Fig. 2). The arrival of the tracer at each sampling point can be used to determine the time of travel throughout the study reach. To compute a discharge at the first measurement site downstream of the injector, the concentration of the tracer upstream of the injector ( $C_o$ ) and the plateau concentration of the tracer at the measurement site ( $C_1$ ) must be known (Fig. 1). It is important that the discharge measurement point be located downstream of the tracer mixing length ( $M_L$ ) so that complete lateral mixing is a valid assumption (Fig. 1). For a discussion of mixing length computations, see Buchanan and Somers, 1973.



**Figure 1.** Variables used to define stream discharge at the first downstream site.



Measurement of discharge at the first downstream site assumes that no lateral inflow (tributaries, seeps, ground water) enters the stream between the injector and the first site. Actually, lateral inflow is allowed if the tracer concentration in the lateral inflow is zero or if the tracer concentration in the lateral inflow is equal to the tracer concentration upstream of the injector ( $C_o$ ). Usually the first measurement site is located such that no tributary inflow occurs between the injector and the measurement site.

The flow balance at the first measurement site is given by:

$$Q_1 = Q_o + Q_i \quad (1)$$

Where  $Q_1$  is the discharge at the first measurement site, and  $Q_o$  is the discharge upstream from the injector. Mass balance is given by:

$$Q_1 C_1 = Q_o C_o + Q_i C_i \quad (2)$$

Equation (1) can be solved for  $Q_o$  ( $Q_o = Q_1 - Q_i$ ) and substituted into equation 2 yielding:

$$Q_1 = \frac{Q_i(C_i - C_o)}{C_1 - C_o} \quad (3)$$

Note that if the upstream concentration of the tracer ( $C_o$ ) is zero, equation (3) simplifies to:

$$Q_1 = \frac{Q_i(C_i)}{C_1} \quad (4)$$

For synoptic water quality studies, the following modification of equation (3) is solved sequentially in the downstream direction.

$$Q_n = \frac{Q_{n-1}(C_{n-1} - C_L)}{C_n - C_L} \quad (5)$$

Where  $C_L$  is the tracer concentration in any lateral inflows (tributaries, seeps, ground water) that occur between points  $n$  and  $(n-1)$  (Fig. 3).

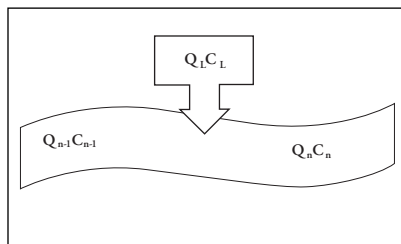


Figure 3. Variables used to define stream discharge at downstream sites.

## Conclusion

Constant rate injection of a conservative tracer can be used to measure stream discharge in locations where traditional current meter measurements are not appropriate. The downstream increase in discharge due to lateral inputs is computed by measuring the dilution of the tracer. The technique is particularly useful in quantifying sources of pollutants that may be entering the stream from tributaries, seeps, or from ground water. Multiple discharge measurements can be obtained by measuring the tracer concentration at several points downstream and repeating the dilution calculation sequentially from point-to-point. For multiple discharge measurements the tracer injection technique represents a considerable time savings compared to making multiple current meter measurements.

## Literature Cited

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