Introduction to Salt Dilution Gauging for Streamflow Measurement: Part 1

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Editor's note: This is the first in a series of planned articles that will explore the topic of salt dilution gauging for streamflow. The other articles will discuss constant rate injection, slug injection (solution), and dry salt injection.

Introduction

Discharge is an important variable that governs many aspects of stream function, such as habitat diversity and rates of nutrient export. It is also a direct measure of the amount of water available to meet instream and extractive water uses. The most common approach to measuring discharge is the velocity-area method, which involves measuring water depth and velocity at points across a stream section with a current meter. Hydrometric agencies including Water Survey of Canada and U.S. Geological Survey favour this method, which is endorsed by the provincial Resource Inventory Standards Committee.

Measuring discharge using a current meter can be difficult, if not impossible, in small streams, especially steep streams with a step-pool or boulder-cascade morphology (Figure 1). These channel morphologies are common in small and intermediate-sized catchments (drainage areas up to about 100 km^2), especially in mountainous areas. In these streams, the irregular, bouldery cross-section and strong turbulence decrease the accuracy with which depth and velocity can be measured.

In addition, flow depths and velocities in small streams during low-flow conditions may be too small for reliable measurement. An alternative method of stream gauging involves injecting a chemical tracer and determining its dilution following complete mixing into the flow. Dilution gauging can be effective where current metering would not be accurate, and vice versa, so the techniques are complementary. An additional advantage is that dilution can be measured without wading across the stream, which can be hazardous in steep streams at higher flows. Under good conditions, salt dilution gauging can be precise to within 5% (Day 1977; Johnstone 1988), equivalent to the accuracy of current metering at a suitable cross-section.

There are two variations on dilution gauging, depending on whether the tracer is injected into the stream at a constant rate or as a near-instantaneous "slug." In both cases, the tracer is injected at some point along the stream, and the tracer concentration in streamwater is measured at a downstream point, where the tracer has become uniformly mixed with the streamwater. For a given volume or rate of injection, greater stream discharges will result in greater tracer dilution and lower concentrations measured at the downstream site. Equations based on the mass balance principle are applied to compute the stream discharge.

This note introduces the general principles and applicability of streamflow measurement by salt dilution. Articles in future issues of *Streamline* will give more detailed information on dilution gauging procedures.

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Figure 1. A steep stream unsuitable for gauging with a current meter. Because of the significant approach velocity, a standard weir equation may not be accurate, and the weir should be rated using discharge measurements.

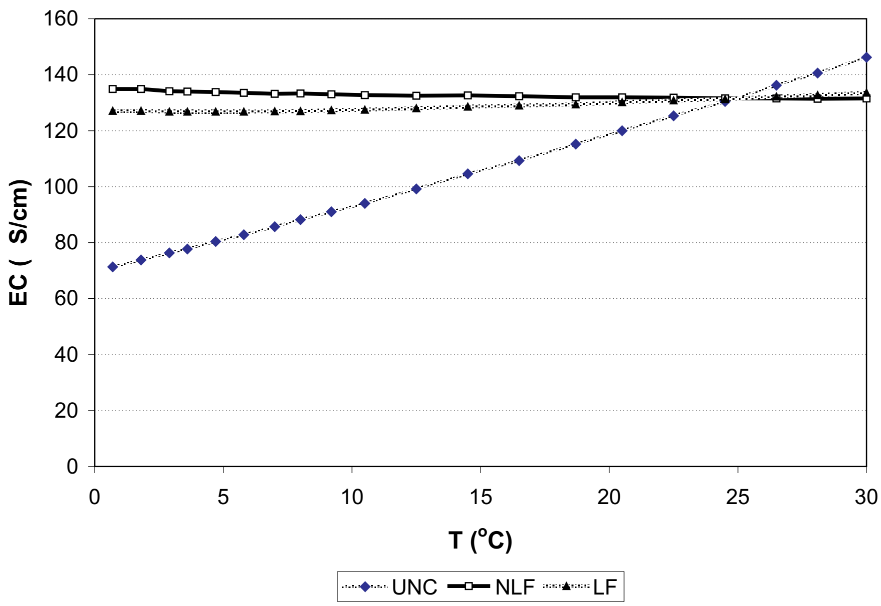

Figure 2. Dependence of electrical conductivity on temperature for a moderate strength solution. UNC = uncorrected; NLF = corrected to 25°C using a non-linear function; LF = corrected to 25°C using a linear correction (2%/°C). Measurements were made with a WTW LF-340 probe and meter.

Advantages of Salt as a Tracer

A range of tracers has been used for dilution gauging. Fluorometric dyes such as Rhodamine WT can be measured at very low concentrations, and thus can be used for higher flows and greater dilutions than tracers such as salts. However, dyes require specialized, expensive equipment for measuring their concentrations, and are more expensive and not as readily available as salts.

Common table salt (sodium chloride, NaCl) is popular for dilution gauging for three reasons. First, table salt is inexpensive and readily available, even in rural areas. Second, it can be accurately measured in the field using an electrical conductivity meter. Third, it is non-toxic for the concentrations and exposure times typically associated with discharge measurements. For example, in the author's experience, peak concentrations of NaCl at the lower end of the mixing reach are usually well under 100 mg/L, far lower than any of the toxicity thresholds shown in Table 1. This value is also substantially lower than the U.S. water quality standard for chloride concentration for protection of aquatic life (230 mg Cl/L, equivalent to a concentration of 373 mg NaCl/L) and the recommended ambient water quality guidelines specified by the B.C. Ministry of Water, Land and Air Protection (Table 2). In addition, the high concentrations usually persist for a few minutes at most, compared with the 48-hour exposures typically used in toxicity trials. While high concentrations may occur at the point of injection, these will decrease rapidly as the tracer disperses into the downstream flow.

Electrical Conductivity as a Measure of Salt Concentration

Electrical conductivity is a measure of the ease with which an electrical current can travel through water. For low solute concentrations, the conductivity will vary linearly with the salt concentration; inversely, there should be a linear relation between the concentration of salt and the electrical conductivity of the solution. This relation can be expressed as follows for application to dilution gauging:

$$C = k(EC - EC_{bg})$$

where C is the concentration of the salt in stream water, EC is the electrical conductivity of the streamwater-injection solution mixture, EC_{bg} is the background or natural electrical conductivity of the streamwater, and k is a proportionality constant, to be determined by calibration. In general, the relation depends on the natural streamwater chemistry (i.e., background conductivity) (e.g., Hongve 1987). For the greatest accuracy, therefore, calibrations should be conducted for each measurement.

The electrical conductivity of a solution varies with temperature. Therefore, it is important to use an EC probe that is capable of adjusting measured EC to a standard temperature, typically 25°C. These adjustments can be based on a linear correction, typically about 2%/ºC, or a non-linear function. Both types of adjustments appear satisfactory if temperatures vary by up to a few degrees Celsius (Figure 2), but the author has found that the non-linear function performs slightly better, especially for more dilute solutions.

Constant-Rate versus Slug Injection

Constant-rate injection allows for greater accuracy, especially for low flows, but requires a pump or other device for injecting the tracer. The author and his co-workers have successfully measured flows as low as 1 L/s and up to 100 L/s using a 10-L Mariotte bottle for injection, but lower and higher flows could be measured at suitable sites with appropriate equipment. Johnstone (1988) measured flows up to 100 m^3/s in a New Zealand stream using a siphon-based system to inject tracer at about 1 L/s. However, use of constant-rate injection will not

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Table 1. Aquatic toxicity of table salt (NaCl)

Species	Parameter	Threshold concentration (mg/L)
Rana breviceps (frog)	NOEC	400
Daphnia pulex	48-h LC50 or EC50	1 470
Daphnia magna (water flea)	48-h EC50	3 310
Myriophyllum spicatum (water milfoil)	Phytotoxicity (EC50 for growth)	5 962
Pimephales promealas (fathead minnow)	69-h LC50	7 650
Lepomis macrochirus (bluegill)	LC50 or EC50	7 846
Anguilla rostrata (American eel)	48-h LC50 or EC 50	13 085

Source: U.S. EPA, Ambient Water Quality Criteria for Chloride, 1988, cited by the Salt Institute: http://www.saltinstitute.org
Notes:
NOEC = no observed effect concentration.
EC50 = concentration at which 50% of individuals show a toxic effect.
LC50 = concentration at which 50% of individuals perish.

Table 2. Recommended ambient water quality guidelines for chloride

Water use	Guideline (mg Cl/L)
Drinking water	250
Freshwater aquatic life (maximum concentration)	600
Freshwater aquatic life (30-day average concentration)	150
Livestock watering	600
Wildlife	600

Source: http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/chloride.html

normally be feasible for such high flows, especially for remote sites, due to the large volumes of tracer solution and the bulky equipment required to maintain a high rate of injection. Slug injection, on the other hand, can be readily used for higher flows at remote sites, but requires that the tracer concentrations at the downstream monitoring point be recorded through time, either manually or by using an electronic data logger. Table 3 summarizes the relative advantages of the two approaches.

The traditional approach to salt dilution gauging by slug injection is to use a salt solution as the tracer. However, for flows greater than about 15 m^3/s, the volumes of tracer solution required may become unworkable (Kite 1993). To overcome this problem, a number of workers have used dry salt as a tracer (Elder *et al.* 1990; Hudson and Fraser 2002). While injection of dry salt can allow higher flows to be gauged, one potential disadvantage is the need for a longer mixing length to ensure complete dissolution of salt within the streamwater.

Salt dilution techniques can often be used to measure streamflow where conventional current metering may be inaccurate.

Table 3. Relative advantages of constant-rate versus slug injection

Injection method	Advantages	Disadvantages
Constant-rate	• can easily verify complete mixing • only requires measurement of background and steady-state EC values • at steady-state, losses to transient storage zones such as pools and the streambed do not affect discharge measurement	• requires equipment for constant-rate injection • maximum flow that can be gauged is limited by the rate of tracer injection; therefore is best suited to lower range of flows
Slug	• special equipment for injection not required • can be used for higher discharges than constant-rate injection	• requires recording of EC variations • cannot verify directly whether complete lateral mixing has occurred unless two probes are available

Choice of Measurement Reach

The success of both constant-rate and slug injection methods requires a reach that provides complete lateral mixing in as short a distance as possible. The reach should also have minimal pool volume. An ideal situation occurs where the tracer is injected just upstream of a flow constriction (e.g., where the flow narrows around a boulder) and the reach below contains no pools or backwater areas.

A rough guideline for the required length of the mixing reach is 25 times the stream width (Day 1977). However, the actual mixing length can vary significantly from this value depending on channel morphology, and should be verified for each site and flow condition. For constant-rate injection, lateral mixing can be checked once "steady state" conditions have been achieved (i.e., EC has reached a "plateau" and has stopped increasing) by measuring EC at different points across the stream cross-section. For slug injection, complete mixing can be verified by using two probes, located either on each side of the stream, or at two different distances downstream of the injection point. If only one probe is available, consecutive measurements during a steady discharge can be made using different reach lengths, or by measuring EC on each side of the stream. If mixing is complete, consistent discharge values should be determined.

Streams with significant in-stream vegetation are not suitable candidates for salt-dilution gauging. The vegetation will suppress mixing, and may adsorb or absorb salt (L. Tolland, pers. comm., 2003; J. Fraser, pers. comm., 2003).

Summary

Salt dilution techniques can often be used to measure streamflow where conventional current metering may be inaccurate. Salt is a useful tracer because it is (1) inexpensive and readily available, (2) easily measured in the field as electrical conductivity, and (3) non-toxic at the concentrations that occur during dilution gauging. Future articles in *Streamline* will provide more detail on field procedures and computations.

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UPDATE

Workshops, Events, and News

May 1–5, 2004

BC Water & Waste Association 2004 AGM. Whistler, BC

http://www.bcwwa.org/agm2004/index.php

May 2–6, 2004

Fourth World Fisheries Congress. Vancouver, BC

http://www.worldfisheries2004.org/

May 12–14, 2004

BC Land Summit 2004 Conference. University of British Columbia, Vancouver, BC

http://www.bclandsummit.com/program.html

June 6–10, 2004

North American Benthological Society, 52nd Annual Meeting. University of British Columbia, Vancouver, BC

http://faculty.forestry.ubc.ca/richardson/NABS2004.htm

June 11–15, 2004

BCLSS Annual Conference. 108 Mile Resort, 108 Mile House, BC

http://www.nalms.org/bclss/

June 13–16, 2004

2004 International Mountain Logging Conference - Forest Operations under Mountainous Conditions. Vancouver, BC

http://www.feric.ca/en/wd/home/events/mountainlogging/MountainLogging.htm

June 16–18, 2004

57th Annual Water Resources Conference: Water and Climate Change, Knowledge for Better Adaptation. CWRA. Montreal, PQ

http://www.ouranos.ca/acrh/

June 22–25, 2004

International Instrumented Watershed Symposium 2004. University of Alberta, Edmonton, AB

http://www.rr.ualberta.ca/oilsands/IIWS.htm

June 27–30, 2004

International Conference on Sediment and Geochemical Budgets in Geomorphology to Honour Professor Olav Slaymaker. University of British Columbia, Vancouver, BC

http://www.geog.ubc.ca/department/activities/

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