DILUTION GAUGING

- the NaCl-gulp method

Introduction

Dilution gauging is used as an alternative to the velocity-area method for measuring streamflow. It is to be preferred in small, highly turbulent streams with rough irregular channels. As with the velocity-area method it is most accurate when there is no change in discharge during the measurement. It involves introducing a tracer into the flow at an upstream location and measuring the rate of arrival of the tracer at a downstream location. There are two techniques for dilution gauging, constant rate injection and gulp injection (Dingman, 1994). In the constant rate method the tracer solution is injected at a constant rate for a period of time sufficient for the downstream concentration to reach a steady equilibrium value. Gulp injection involves dumping a volume of tracer solution with a known concentration into the stream at the upstream site. Concentration at the downstream site is then measured as a function of time until it recedes to its background value. The chemical used should have a high solubility, be stable in water, have low background concentrations in the stream, be harmless to the environment and the observer, and be capable of accurate quantitative analysis in dilution concentrations.

In this note an example of the gulp method is demonstrated using sodium chloride (NaCl) as a tracer. This is probably the best tracer to be used in most situations; its concentration can be readily detected by developing a calibration curve between conductivity and concentration in the stream water. The electrical conductivity of the water can be measured directly in the field using an electrical conductivity meter.

Equipment

Electrical conductivity instrument
Timer
NaCl (exactly weighted)
Thermometer
Bucket (with volume measuring scale)
Stirring rod
Pocket calculator

Method

A certain volume of streamwater is filled into the bucket and a measured amount of NaCl is added. The required volume of water and amount of NaCl depend on the size of the stream and background conductivity of the streamwater. The amount of NaCl to be introduced should be sufficient to at least double the conductivity; roughly 1 kg per cubic meter of streamflow. Stir well to make sure that the NaCl is completely dissolved in the water. This tracer solution is then introduced into the stream by emptying the bucket in one stroke onto an area with high velocity and turbulence. The distance between the upstream and downstream location must be long enough to allow complete mixing of the tracer solution with the flow, but short enough so that the change in discharge is insignificant. Approximately 100 meters is in most cases sufficient. The conductivity is measured some distance off the bank of the stream (e.g. from a bridge) at frequent time intervals. It is advisable to use a short and regular time interval (e.g. 5 seconds) in the beginning to capture the tracer wave correctly. Towards the end a longer time interval can be used (15 – 30 seconds). Measurements are continued until the conductivity has reached the background value again. The total time for the pulse of NaCl to pass the downstream location should be about 8 to10 minutes. Water temperature should be read during the time of measurement. Correction factors for deviation from 25^oC are given in Table 1. Some instruments automatically correct for temperature.

Table 1 *Temperature dependent correction factors, k_T, for conductivity for NaCl to 25^oC.*

°C	k_T	°C	k_T	°C	k_T
0	2.03	10	1.44	20	1.11
1	1.95	11	1.40	21	1.09
2	1.88	12	1.36	22	1.06
3	1.80	13	1.32	23	1.04
4	1.74	14	1.29	24	1.02
5	1.68	15	1.25	25	1.00
6	1.63	16	1.22	26	0.98
7	1.58	17	1.19	27	0.96
8	1.53	18	1.17		
9	1.48	19	1.14		

Calculation

Stream discharge is calculated as:

$$Q = \frac{(C_T - C_b) \cdot V_T}{\int_0^\infty (C_d - C_b) \cdot dt} \tag{1}$$

where:

Q discharge in l/s
V_T volume of injected tracer solution in l
C_T concentration of the tracer solution in mg/l
C_b background concentration in the stream in mg/l
C_d measured concentration in the stream during the passage of the injected tracer

If the water temperature remains constant, an increase in NaCl-concentrations is proportional to an increase in conductivity. At 25 °C an increase in NaCl-concentration of 1 mg/l causes an increase in conductivity of 2.19 µs/cm. At other temperatures the temperature correction factor for conductivity has to be considered. A change in NaCl-concentration can the be calculated based on a change in conductivity in the following way:

$84\,mS = 84 \cdot 1000\,\mu S$

$$(C_{d2} - C_{d1}) = \frac{(cond_{d2} - cond_{d1}) \cdot k_T}{2.19 \frac{\mu S/cm}{mg/l}} \tag{2}$$

where:

C_{d1} and C_{d2}	concentration at times 1 and 2 in mg/l
$cond_{d1}$ and $cond_{d2}$	conductivity at times 1 and 2 in µs/cm
k_T	temperature dependent correction factor

In case of a constant water temperature this gives:

$$Q = \frac{\dfrac{(cond_T - cond_b) \cdot k_T}{2.19 \frac{\mu S/cm}{mg/l}} \cdot V_T}{\int_0^{\infty} \left(\dfrac{(cond_d - cond_b) \cdot k_T \cdot V_T}{2.19 \frac{\mu S/cm}{mg/l}} \right) \cdot dt} = \frac{(cond_T - cond_b) \cdot V_T}{\int_0^{\infty} (cond_d - cond_b) \cdot dt} \tag{3}$$

where:

Q	discharge in l/s
V_T	volume of injected tracer solution in l
$cond_T$	conductivity of the tracer solution in µs/cm
$cond_b$	background conductivity in the stream in µs/cm
$cond_d$	measured conductivity in the stream during the passage of the injected tracer in µs/cm

so that discharge can be calculated directly from conductivity measurements. The integral corresponds to the area under the conductivity curve as shown in Figure 1. A simple solution is to consider the integral as a step function. For a sufficient extended curve with high time resolution this approximation gives satisfactory results. The integral is then replace by: d

$$\int_o^t \Delta * dt = \sum \Delta * t' \tag{4}$$

where:

Δ	change in conductivity between conductivity measured and time t_i and the background conductivity, i.e. $\Delta = (cond_{di} - cond_b)$
t'	the time interval between to succeeding measurements, i.e. $t' = t_i - t_{i-1}$

And equation (3) becomes:

$$Q = \frac{(cond_T - cond_b) \cdot V_T}{\sum_0^{\infty} (\Delta * t')} \tag{3.2}$$

$= \frac{[\frac{\mu m}{cm}] \cdot l}{\frac{\mu m}{cm} \cdot s} = \frac{l}{s}$

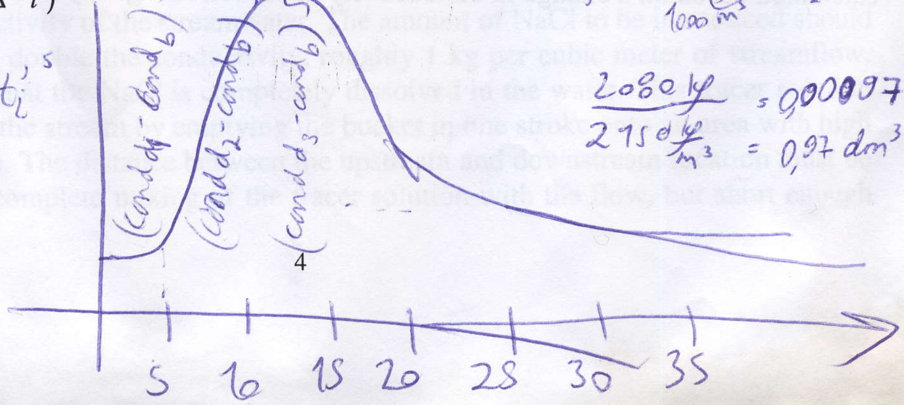
$= \sum_0^{\infty} (cond_i - cond_b) t_i'$ aha!

$2{,}15\ g/cm^3$

$\frac{2080\ kg}{2{,}15\ 1000\ kg / 1000\ m^3} = 0{,}97\ m^3$

$1\ dm^3 = 10^{-3}\ m^3$

$\frac{2080\ kg}{2150\ kg/m^3} = 0{,}00097\ m^3 = 0{,}97\ dm^3 = 0{,}97\ l$



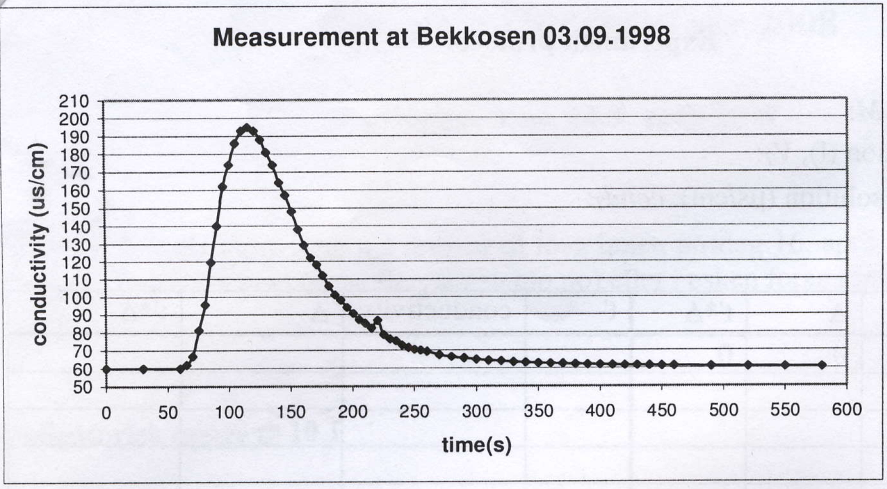


Figure 1 *Conductivity measurements using the NaCl-gulp injection method*

References

Dingman, S.L. (1994) Physical hydrology. Prentice Hall, New Jersey.

Experiment protocol

Amount of NaCl (kg), M:
Volume of tracer solution (l), V_T:
Conductivity of tracer solution (µs/cm), $cond_T$:
Temperature (^{o}C), T:

t'	conductivity	Δ	t'*Δ	t'	conductivity	Δ	t'*Δ
Start.		0	0				
						Sum:	