Measuring Mountain Stream Discharge Using the Salt Dilution Method

A practical guide

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This guide is based on a manual edited by the Swiss Hydrological and Geological Survey in Berne/Switzerland (LHG 1994) and the authors' experiences in measuring the discharges of streams in the Swiss and Bhutanese mountains and the PARDYP watersheds in the Indian and Nepal Himalayas.

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Cover photo : Mixing the salt in a bucket – *Juerg Merz*
Inset : Measuring discharge in the Woochhu catchment near Paro, Bhutan – *Juerg Merz*

Contents

The Salt Dilution Method

- is perfect for measuring the discharge of small mountain streams with turbulent flows
- is a simple, easy to use method even in bad weather conditions
- allows for fast measurement during flood and high flow conditions
- allows for simple data analysis and the direct availability of discharge data

What do scientists say?

Mohammad Jehangir and Sohail Zokaib, PARDYP Pakistan

The salt dilution method is an interesting and fun method to measure discharge. Field staff can easily obtain the discharge values by sitting on stream banks and measuring conductivity. But remember always to check the list of materials needed beforehand, otherwise all the excitement will vanish and you will return without any achievements.

Padma K. Verma, PARDYP India

The salt dilution method for measuring the discharge of mountain streams is an easy and handy method. It is appropriate to use in the turbulent flows that are common in mountains. Other methods such as the area-velocity method need stable channels. This salt method, like others, demands reliability and accuracy.

Pradeep M. Dangol, PARDYP Nepal

Discharge measurement by salt is a god-gifted technology for hydrologists who like to enjoy their work in the field. There is no pulling up and down of a fish weight and no standing in the water while it is raining. You keep dry sitting under a big umbrella and take the readings.

Judith Dobmann, University of Berne

The salt dilution method for determining discharge is easy to learn and use. The equipment needed is light and suitable to use in the field. Whenever possible it is best to use two probes to measure in order to have a control of the values. To get good results it is very important to have a good estimation of the flow velocity of the stream and of the length of stream needed to thoroughly mix the salt. If the estimate is too high you have to wait a long time for the diluted salt to pass through the measurement section. If it is too low, the salt will not be diluted properly. Always make sure that the stream bed is not too permeable (e.g. sandy or gravelly) as this may cause high losses of diluted salt.

Thomas Payer, University of Vienna

The salt dilution method is a quick and favourable method to use. Stream discharge from several litres per second up to dozens of cubic metres per second can be measured using small, easy to use, lightweight devices. The method is ideal for use in remote high altitude regions. The measured discharge can be directly interpreted using hydrological software.

Introduction

Improved management of water resources is becoming more important as more and more areas of the world suffer from water shortages. An important starting point for designing management improvements is to record the baseline state of the resources, including the amount of discharge from watercourses. Seven methods are commonly used by scientists and hydrologists to measure the discharge of surface water from rivers and streams (Table 1).

This paper describes the salt dilution method for measuring discharge from high turbulence, low flow streams. It describes how the method uses salt as a tracer to measure discharge. It outlines the theory and then details the practical steps to be followed to use this method in the field. Field checklists and a data input form are provided at the back for field use.

Table 1: Methods for discharge measurement in open streams

Turbulence	Flow	Method
High turbulence	High flow	Float method
		Dilution method with fluorescent tracer/salt
	Low flow	Dilution method with salt
		Volumetric method
Low turbulence	High flow	Float method
		Current meter (large)
		Acoustic Doppler Current Profiler (ADC P)
	Low flow	Current meter (small)
		Electromagnetic flow sensor
		Volumetric method

Why use the salt dilution method?

The salt dilution method is an easy-to-use technique for measuring discharge in the small turbulent streams that are typically found in mountain areas. The equipment is light and suitable for use in the field, thus the method is ideal for use in remote high altitude regions. The method has been used successfully in small turbulent mountain streams in many places worldwide. It is being used by the Swiss Hydrological Survey in Switzerland; the People and Resource Dynamics Project in Mountain Watersheds of the Hindu Kush-Himalayas (PARDYP) in China, India, Nepal, and Pakistan; in Nepal to assess small hydropower potential; and in the Wang Watershed Management Project (WWMP) in Bhutan. The method may be used in different mountain streams in Tibet by the Water Conservancy Bureau of the Tibet Autonomous Region as part of its erosion monitoring network.

Despite its advantages, the method and its potential are not widely known; and the original manual and handbook with detailed descriptions of the method are only available in German (LHG 1994, Wolf 1998). The aim of this guide is to raise awareness of and provide information about the technique, especially for scientists, technicians and practitioners carrying out hydrological studies, erosion assessments, and water resources management on Himalayan mountain streams.

What is the salt dilution method?

The salt dilution method is a simple and practical technique for measuring the discharge of mountainous streams where turbulence is high and flow does not exceed $5m^3/s$. The optimal flow for this measurement method is $1\text{-}2m^3/s$. The technique is based on the principle that a given amount of salt is diluted more by a large amount of water than by a small amount. This means that the higher the discharge the more diluted will be salt that is placed in the water upstream.

The salt dilution method involves injecting (inserting) a known amount of salt into a stream. This process is technically known as slug injection. The salt acts as a tracer to measure the discharge. The concentration of dissolved salt is measured downstream at a point where it has fully mixed with the stream water.

Attention – The following conditions are needed for the salt dilution method to be used accurately:

- stream discharge is constant during the measurement period;
- all the injected salt passes the measurement point without any of it being absorbed or lost in any way;
- there are no ponds or calm zones or other conditions that prevent the salt from being evenly dispersed in the stream; and
- there are no livestock bathing in the stream whose urine and other body fluids (sweat) could cause fluctuations in the conductivity of the water which is used to measure the discharge.

Figure 1 shows the dilution conditions along a stretch of water after salt has been injected. At the beginning, the salt cloud is compact and the salt is unevenly distributed. With increasing distance from the injection point, the salt becomes evenly distributed throughout the cross-section of the watercourse and eventually reaches an optimal and even degree of dilution. It is at this point that the concentration should be measured.

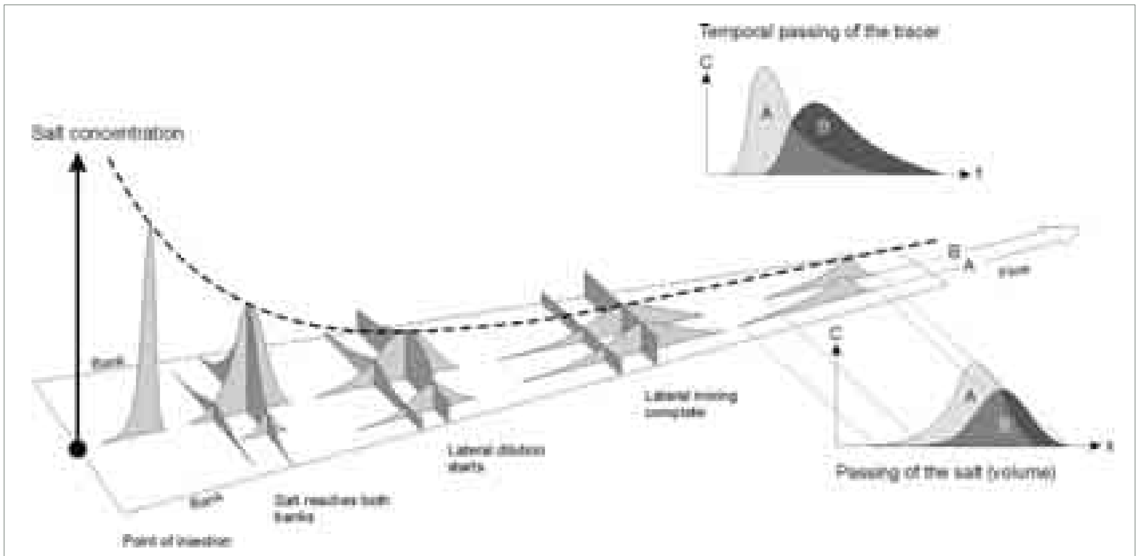

Figure 1: Mixing conditions in a stream (adapted from Wolf 1998)

The concentration of salt is not determined directly but by measuring the conductivity of the stream water. Hence the relationship between the concentration of salt and the electric conductivity needs to be known. This is determined by taking calibration measurements to identify the relationship between the concentration of salt and the conductivity. This relationship is represented in Figure 2 with conductivity on the x-axis and the salt concentration on the y-axis. The calibration measurements, shown as dots, form a straight line that can be described in the form of a linear regression:

$$y = ax + b \qquad (1)$$

where y = salt concentration [mg/l]
x = conductivity [μS/cm]
a = slope [no dimension]
b = intercept

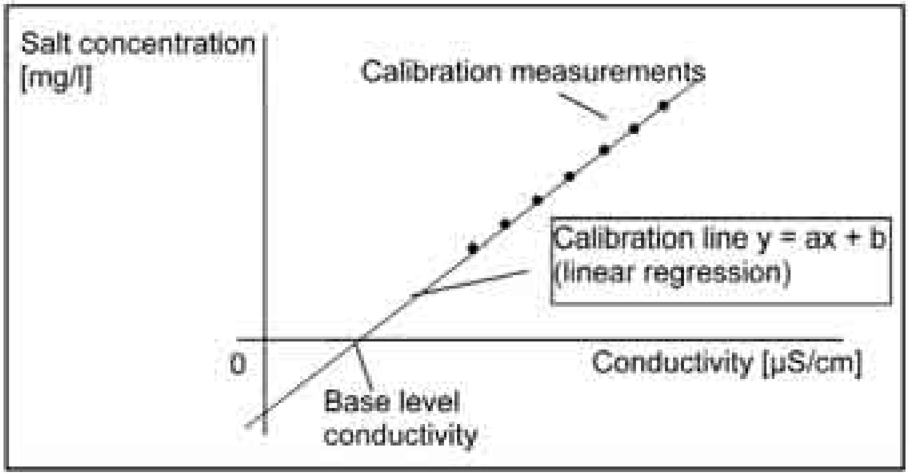

Figure 2: Relationship between salt concentration and conductivity
(adapted from Wolf 1998)

Up to about 1000 µS/cm the relationship is linear with a slope of about 0.45-0.6. This slope is called the calibration factor (Cal) and its exact value needs to be known to calculate the rate of discharge. It varies with the type of salt, the natural conductivity of the stream water, and the type of instrument used (Wolf 1998).

The result of the conductivity field measurements in the stream is a concentration-time diagram at the measurement point as shown in Figure 1. Discharge is determined by integrating the area below the curve using the following equation

$$Q = \frac{S}{Cal * \int (C_{(t)} - C_0) * dT} \qquad (2)$$

where Q = discharge [l/s]
S = amount of salt injected [mg]
Cal = calibration factor [(µS/cm)/(mg/l)]
$C_{(t)}$ = conductivity after time step t [µS/cm]
C_0 = base level conductivity [µS/cm]
dT = time interval [s]

This theoretical equation can be adapted to give a more practical approach for calculating the discharge as described below in the analysis and calculation section (see also sheet 3).

Impact of salt

Some scientists who consider using this technique are concerned about the impact of salt on the ecological conditions in small streams. In theory, salt can affect the surrounding fauna and flora (LHG 1994). However the impact is usually very small, especially during flood conditions, as the salt cloud moves very rapidly along the stream.

The potential impact can be kept to a minimum by using the minimum amount of salt necessary for the measurement. The amount of salt that needs to be injected varies with the length of the mixing distance and the amount of discharge and also depends on the amount of vegetation in the streambed and along the bank. As a general rule, between 2 and 5 kg of salt is needed to measure the discharge of streams with a flow of about 1 m^3/s.

How to use the salt dilution method

Note: the equipment needed, procedures to be used, calculation methods, and data sheets to be used for recording data, are summarised in Sheets 1 - 4 provided at the end of this document. These sheets can be printed out (and laminated) and taken to the field for easy reference.

Preparations at the field station

1. **Prepare the salt** – Sodium chloride (NaCl) is generally used because it is easily available. Put approximately 50, 100, and 500g amounts of salt into separate plastic bags and weigh them to an accuracy of $\pm$1%. Mark the weight on the bags with a waterproof pen.

2. **Prepare for calibration** – Prepare a salt solution of 3g/l by adding 3g of salt to 1000 ml of distilled water. This solution must contain the same kind of salt as will be injected into the stream.

3. **Prepare equipment and materials** – Collect together and prepare all the equipment and materials shown in the box. The conductivity meter must be robust and field proof. The instruments made by WTW of Germany have proven very reliable when used by the authors and other hydrologists, other equipment should be tested. The data input sheet should be laminated to prevent it getting wet. Prepare as many data input sheets as you intend to do discharge measurements in the field.

Equipment

To determine calibration factor

- 500 ml measurement flask
- 1 ml pipette
- 1 l jug/beaker
- salt solution of 3g salt in 1000 ml distilled water
- ~ 1 litre distilled water
- a robust, field-proof conductivity meter

To measure discharge

- a robust, field-proof conductivity meter (preferably two when determining the measurement length) with spare batteries
- key for water level recorder
- 20 litre bucket
- stop watch
- adequate number of bags of salt (approx. 50/100/500g, exact weight written on bag)
- calibration and discharge measurement instructions (3 sheets, laminated)
- data input sheets (laminated), one per discharge measurement
- waterproof pens
- umbrella

Preparations in the field

4. **Determine the calibration factor** – Determine the calibration factor by measuring the conductivity of ten different dilutions of salt in the stream water as described in Sheet 1 below, and calculating the factor using equation (1) above. A macro – Smacro.xls – is available on ICIMOD's website at <http://www.icimod.org/downloads/macros/smacro.xls>, or on request from <jmerz@gmx.net> or <g.doppmann@bluewin.ch>. This macro can be used to calculate the factor automatically. The calibration factor is usually between 0.45 and 0.6 and should be determined before each discharge measurement. Note the conductivity values on the back of the data input sheet as shown in the table in Sheet 4.

   Note: at times of flooding there is usually no time to determine the calibration factor as the flood wave that needs to be measured moves very quickly through the stream cross-section. In this case the last determined factor, or a value of 0.5, should be used instead. After the calibration factor has been calculated a few times the value may become stable, in which case only occasional checks need to be made. Note that this is only true if the same equipment and the same salt are used.

5. **Select the measurement length** – The next step is to identify the part of the stream along which the discharge is to be measured. The length of stream from the point of injection to the point at which the salt becomes fully mixed across the stream profile is known as the mixing length. A length of stream needs to be identified equal to the mixing length (as shown in Figure 1) that has no eddies with back flow effects or pools or ponds; no water extractions or inflows; and is not influenced by hanging vegetation. It should also be as short as possible (equal to the mixing length). A simple rule of thumb is to take a length 20-50 times the average width of the stream, or 100 times the width of the narrowest part of the stream.

   Note: The mixing length of a section of stream varies with stream flow. It will be longer at times of high flow than at times of low flow. To assess the correct length accurately, the scientist needs to have a good knowledge of the stream conditions including the flow velocities and streamline of the flow. The situation should be reassessed after each discharge measurement by evaluating the measurement and the end result. Distance information painted on rocks in the streambed can assist in choosing the appropriate mixing length and are particularly useful during flood events when measurements usually have to be made very quickly.

   Note: It is possible to check that the length selected for the measurement is at least equal to the mixing length by taking measurements with two conductivity meters at the same time that are installed at different locations in the streambed (Figure 3). The meters can be installed at different positions in the stream cross-section if the stream is more than 2m wide (Version 1) or at different positions in the same line of flow (Version 2). The discharge value calculated at the two measurement points should be the same, even if the shape of the curve is different. If the results are different then the length chosen is shorter than the mixing length.

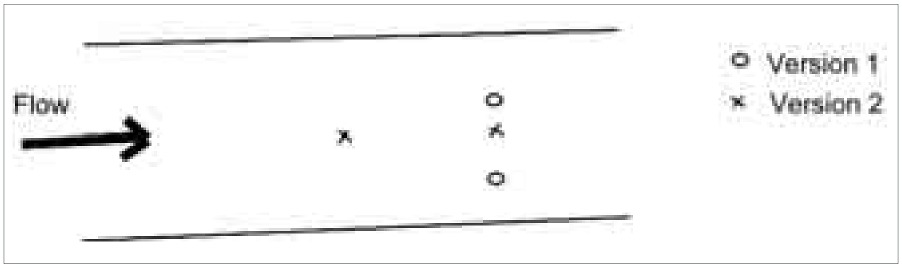

Figure 3: Position of conductivity meters for checking mixing length

Measuring the discharge

6. **Equipment setup** – Once the initial preparations have been made, transport all the equipment and materials to the site and place them at the appropriate locations. Locate the conductivity measuring point as close as possible to the site where the water level is recorded, i.e. the staff gauge or the automatic water level recorder, to ensure that the same amount of water is measured as actually passes the water level measurement cross-section.

7. **Sensor placement** – Place the conductivity meter's sensor in the line of flow where the fastest velocity is expected. This is generally in the middle of the stream but may be elsewhere depending on the shape of the stream cross-section. The sensor must be fixed, immovable and in the water constantly whilst measurements are being taken. Air and air bubbles must not be allowed to get into the sensor.

   Note: For wider streams, place two sensors, one at each bank, and compare the end results to ensure that the salt has fully mixed with the stream water at the position chosen (see above). Another option on wider streams or small rivers is to place the conductivity sensor on a bridge pillar or to hold it into the stream from a bridge with the help of a long immobile rod.

8. **Record preliminary information** – Before the salt is injected, complete the upper part of the data input sheet (Sheet 4) by recording the information about the station and the reading. At times of high flow, it is sufficient to record only the injected salt, the water level of the stream and the base level conductivity before injecting the salt. Record the remainder afterwards.

9. **Salt injection** – Roughly estimate the amount of discharge. Work out the appropriate amount of salt to use on the basis of the estimated discharge according to the rule of thumb 2-5 kg per m^3/s. (It is possible to check whether the amount used was appropriate after the measurements are complete, see below.) Dissolve the salt fully in a bucket (see Photograph 1) and immediately inject it into the stream by:

   - gently pouring the contents upstream into the stream line without splashing as shown in Photograph 2; and then
   - rinsing out the bucket with water from above the point of injection and pouring it downstream.

   Note: It is best to have two people to do the measurements although it is possible for a single person. With two people, one injects the salt, then holds the umbrella if it is raining, reads the time, and indicates when measurements need to be taken, whilst the second person notes down the conductivity values on the data input sheet.

   Attention: 1) For flows of less than 10 l/s inject the salt solution carefully so as not to create a stream surge. 2) Take care to ensure the safety of the person taking the measurements at all times and in particular during high flow conditions.

10. **Meter readings** – It is easy to identify when the salt cloud reaches the sensor because the conductivity values start to rise. Immediately the cloud reaches the sensor, note down the reading on the conductivity meter on the data input sheet and the time that has passed since the salt was injected. Record the meter readings every five seconds thereafter until the water conductivity returns to its base value (see Photograph 3). Next, note any remarks on the mixing length, salt use, quality of measurements, and other relevant features at the bottom of the data input sheet.

    Attention: 1) Do not forget to record the water level on the recording instrument or staff gauge before and after measurement, and to record the base level conductivity of the water. 2) During times of high flow, several measurements can be made consecutively at different water levels, e.g., during the rising and/or falling limb of the hydrograph.

Thomas Payer

Photo 1: Preparing the salt dilution, Tarina II lake outlet (Bhutan)

Juerg Merz

Photo 2: First bucket full of salt solution being injected into a stream, Bhutan

Judith Dobmann

Photo 3: Taking conductivity readings every five seconds

Analysis and evaluation

11. **Calculate the discharge** – Once the measurements are complete, the integral of the area under the curve of the time-conductivity diagram needs to be calculated (see above). The amount of injected salt S, the calibration factor Cal, the sum of all the conductivity values ($C_{(t)}$), the number of conductivity values N, the base level conductivity C_0, and the measurement interval T, are all needed to work out the conductivity measurement. The discharge Q in litres per second can be determined from the following equation.

$$Q = \frac{S}{Cal * \left(\sum C_{(t)} - (N * C_0)\right) * T} \qquad (3)$$

Q can be worked out on a calculator or with an Excel spreadsheet macro. The macro greatly simplifies the calculation. This macro – Smacro.xls – is available on ICIMOD's website at <http://www.icimod.org/downloads/macros/smacro.xls> or on request from <jmerz@gmx.net> or <g.doppmann@bluewin.ch>. The macro includes the data input sheet, the data input format based on the data input sheet, and the discharge calculation sheet. Instructions for use are given in Sheet 3.

12. **Evaluate the measurements** – Evaluate every measurement carefully so that:
    - future measurements can be improved, for example by adjusting the amount of salt used and/or the length taken for measurement (mixing length); and
    - measurements can be qualified in terms of use for establishing the rating curve. It helps to have a system of ‘good for use’, ‘use only if absolutely necessary’, and ‘useless’. The appropriate qualification should be noted after each measurement in the remarks box at the end of the discharge calculation sheet.

    Note: It is helpful to record remarks on the quality of the data. For a measurement to qualify as good for use:
    - the difference between the base level and the peak level of conductivity should be between 50 and 100 μS/cm. A smaller or bigger range indicates that too little or too much salt has been used;
    - the measurement should take place over no longer than a 15 to 20 minute period. Taking longer would indicate either that there are pools or other disturbing features or that the length chosen as the mixing length is too long.

References

LHG (1994) Manual fuer die Abflussmessung nach dem Salzverduennungsverfahren, Technical Report. Berne: Swiss Hydrological and Geological Survey

Wolf, P. (1998) Handbuch zur Bestimmung des Abflusses nach dem Verduennungsverfahren unter Anwendung der Integrationsmethode. Publikation Gewaesserkunde Nr. 198. Berne: University of Berne, Department of Geography

Sheet 1: Calibration Checklist and Procedure

Equipment and materials

- 500 ml measurement flask
- 1 ml pipette
- 1 l jug/beaker
- Salt solution of 3g salt per 1000 ml distilled water
- ~ 1 l distilled water
- a robust, field-proof conductivity meter

Calibration procedure

1. Prepare a salt solution with 3g salt per 1000 ml distilled water using the same salt that will be injected into the watercourse.
2. Measure out exactly 500 ml of stream water.
3. Put the stream water into a 1 litre clean beaker or jug.
4. Turn on the conductivity meter and put the sensor into the beaker/jug.
5. Measure the conductivity and note it on the back of the data input sheet as shown in Sheet 4. This is the measurement of the water with no salt in it.
6. Add 1 ml of the prepared salt solution and stir thoroughly.
7. As soon as the value is constant and unchanging, measure the conductivity and note it again on the back of the data input sheet.
8. Repeat the procedure (steps 6 and 7) until the volume in the jug or beaker is 510 ml.

Analysis

The calibration factor can be determined using either an Excel macro or a spreadsheet.

Excel macro

Available at <http://www.icimod.org/downloads/macros/smacro.xls> or on request from <jmerz@gmx.net> or <g.doppmann@bluewin.ch>

1. Open 'Smacro.xls'
2. Click on 'Data input' under the heading 'Determination of Calibration factor'
3. Fill in conductivity values in the yellow cells
4. Click on 'Output'
5. Print out the sheet

Excel spreadsheet

1. Write the concentration values in one column.
2. Write the conductivity values in the next column
3. Produce a scatter plot with concentration as the y and conductivity as the x values
4. Insert a linear regression line and display the equation
5. Edit the graph and the sheet so that all information fits on one sheet
6. Print out the results

Sheet 2: Discharge Measurement Procedure with Salt

Preparations in the field station

- Place approximately 50, 100, and 500g amounts of salt into separate plastic bags and weigh them to an accuracy of ± 1%. Mark the weight on the bags with a waterproof pen.
- Collect together the following equipment and check it is in working order
  - a robust, field-proof conductivity meter (preferably two) with spare batteries
  - stop watch
  - data input sheet (laminated)
  - an umbrella
  - key for water level recorder
  - a 20 litre bucket
  - adequate number of bags of salt
  - waterproof pens

Measurement

1. Fill in the base information at the top of the data input sheet.
2. If conditions allow, and whenever possible, determine the calibration factor (see Sheet 1: Calibration Checklist and Procedure) and note it on the data input sheet.

Attention: Do not determine the calibration factor during a high flow event.

3. Fix the conductivity meter's sensor in the main line of flow of the stream.
4. Roughly estimate the amount of discharge.
   Dissolve an appropriate amount of salt in the bucket (2-5 kg per m^3/s) and note the amount of dissolved salt on the data input sheet in mg.
5. Turn on the conductivity meter.

Attention: Make sure that it is set correctly, for example by using the instrument WTW 330
- Reference temperature: 25°C
- Measurement unit: μS/cm

6. Read the water level from the water level recorder or the staff gauge and note the value on the data input sheet.
7. Note the base level conductivity on the data input sheet.
8. Inject the salt into the stream by gently pouring the contents of the bucket upstream into the stream line without splashing and then rinsing out the bucket with water taken from above the point of injection and pouring this water downstream.
9. As soon as the salt cloud is seen to reach the measurement point, note down the time that has passed since injecting the salt and note down the measured value from the conductivity meter on the data input sheet. Note down repeat measurements every five seconds.
10. Continue taking measurements every five seconds until the value returns to the base level conductivity. If there is not enough space on a single form, continue noting measurements on the back of the form.
11. Note the water level on the data input sheet.
12. Note the remaining information on the data input sheet.

Sheet 3: Analysis of Discharge Measurements Using Salt

1. With the Excel macro

1. open the file smacro.xls
2. click on 'Data input' under the heading 'Calculation of discharge'
3. enter all necessary background information in the yellow cells
4. enter conductivity measurements in the yellow cells
5. save the file at an appropriate location
6. print out the sheet

2. With a calculator

Add all the conductivity values together $\left(=\sum c_{(t)}\right)$ and count the number of measurements (N)

Then calculate: $$Q = \frac{S}{Cal * \left(\sum C_{(t)} - (N * C_0)\right) * T}$$

where

Q	=	discharge [l/s]
S	=	amount of salt injected [mg]
Cal	=	calibration factor [(mg/l)/(µS/cm)]
$\sum c_{(t)}$	=	sum of all measured conductivity values [µS/cm]
N	=	number of values
C_0	=	base level conductivity [µS/cm]
T	=	measurement interval [s]

Sheet 4: Salt Dilution Measurement Data Input Sheet

Station no.		Station name	
Date		Reader	
Weather		Estimated discharge (l/s)	

Gauge Height

At beginning (m)		At end (m)	

Time

At beginning		At end	
Sampling interval (s)		Time until first signal (s)	

Distance

Injection point		Sampling point	
Mixing length (m)			

Other

Water temperature (°C)		Injected salt (mg)	
Calibration coefficient Cal		Base level conductivity (µS/cm)	

Serial No.	Conductivity (µS/cm)	Serial No.	Conductivity (µS/cm)	Serial No.	Conductivity (µS/cm)	Serial No.	Conductivity (µS/cm)
1		36		71		106	
2		37		72		107	
3		38		73		108	
4		39		74		109	
5		40		75		110	
6		41		76		111	
7		42		77		112	
8		43		78		113	
9		44		79		114	
10		45		80		115	
11		46		81		116	
12		47		82		117	
13		48		83		118	
14		49		84		119	
15		50		85		120	
16		51		86		121	
17		52		87		122	
18		53		88		123	
19		54		89		124	
20		55		90		125	
21		56		91		126	
22		57		92		127	
23		58		93		128	
24		59		94		129	
25		60		95		130	
26		61		96		131	
27		62		97		132	
28		63		98		133	
29		64		99		134	
30		65		100		135	
31		66		101		136	
32		67		102		137	
33		68		103		138	
34		69		104		139	
35		70		105		140	

Remarks:

Format for recording the calibration coefficient data

Volume of water in jar (ml)	Measured conductivity (ì S/cm)	Salt concentration (mg/l)
500		0
501		6
502		12
503		18
504		24
505		30
506		36
507		42
508		48
509		54
510		60

(The calibration table can be printed on the back of the Salt Dilution Measurement Sheet.)