Flow measurement under difficult measuring conditions:
field experience with the salt dilution method

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ABSTRACT First of all, flow measurement by salt dilution
method is described as well as the record and analysis of
data by means of a microcomputer. The next chapter inclu­
des a vice-versa comparison of the salt dilution method,
the flow meter measurement and the dilution method by
fluorescence dye tracer on field experiments. Finally the
use as well as the advantages and disadvantages of the
three methods are discussed.

INTRODUCTION
In the last years many discharge measurements by the salt dilution
(integration) method have been carried out. The comparison of
those discharge measurements with other methods were missing. In
cooperation with the Swiss National Hydrological and Geological
Survey (SNHGS) a field campagne took place to get first informa­
tion about the quality of the different methods. Eight river
gauging stations of the monitoring network of the SNHGS were cho­
sen for discharge measurements with the following three methods:
a) integration (gulp) method (salt dilution method, tracer: NaCl)
b) constant-rate injection method (tracer:sulforhodamine)
c) hydrological current meter (SNHGS-type)
The results presented of the three different methods in this paper
are directly comparable, because the measurements were carried out
at the same time.

PRINCIPLES
The main points of the three methods are described in a short
form. The integration (gulp) and the constant-rate injection me­
thod are the two basic dilution gauging methods. The current meter
method is used worldwide and therefore well known.

INTEGRATION (GULP) METHOD: In the integration method of dilu­
tion gauging, a simple gulp of tracer solution is added to the ri­
er. At the sampling station the passage of the entire tracer
cloud is monitored to determine the relationship between the con­
centration and time.
The discharge is calculated of the equation:

\[ M_1 = c_1 V_1 = Q \int_{t_1}^{t_2} (c_2 - c_0) \, dt \]

Where \( M_1 \) is the quantity of tracer, \( c_1 \) the concentration and \( V_1 \) the
volume of the initial tracer solution, \( t_1 \) is a time before the lea­
ding edge of the tracer cloud arrives at the sampling point, and
\( t_2 \) is a time after all the tracer has passed this point. The background tracer concentration is \( c_0 \) and \( c_2 \) is the recorded tracer concentration [5].

In our case salt (NaCl) was used as a tracer. The detection of the salt in the small rivers is very easy, because a conductivity meter can measure the throughflow of the tracer. A microcomputer monitors the results from the conductivity meter. When the entire tracer cloud has passed the sampling point the runoff can be calculated from the concentration-time diagram. The microcomputer makes the result of the discharge measurement available in the field. Therefore the check of the results whether plausible or not can be made [7].

If the salt dilution method (integration) is used for discharge measuring then some conditions should be fulfilled:

a) the exact quantity of tracer must be known
b) the tracer added to the river must be completely diluted
c) the runoff should be constant
d) all the tracer must pass the sampling cross section
e) flow must be turbulent between the injection and the sampling point
f) no dead water between the injection and sampling point
g) in order to get a good mixture of the tracer over the whole cross section it must be diluted homogenously
h) the tracer must be stable
i) the background level (conductivity) of the river should be stable

The tracer used was salt (NaCl) which is available in every food shop. The salt concentration in the river water was measured with a WTW LF 91 conductivity meter at a one second interval. The monitoring, interpretation and plot of the discharge measurements were available in the field. The whole measuring equipment (Fig. 1) is build in a synthetic suitcase (microcomputer, printer, conductivity meter, A/D-converter and battery).

**CONSTANT-RATE INJECTION METHOD:** In the constant-rate-injection method an exactly known tracer solution, of a determined concentration is injected continuously, at a fixed volumetric rate, for a certain time, so that an equilibrium concentration is established for a limited time at a sampling station downstream. The sampling time has to be chosen in a way that the tracer concentration at the sampling point is constant. The total discharge can be

![Diagram](https://via.placeholder.com/150)

**FIG. 1** Measuring equipment for salt dilution and current meter.
calculated from the dilution of the injected tracer concentration and the tracer concentration at the sampling point [5]. Some conditions must be fulfilled:

a) the amount of tracer injection must be constant during the measurement

b) the flow must remain steady for the measuring time

c) the method requires that the same amount of tracer per time passes the sampling cross section as was injected

d) the tracer must be stable (no sorption)

e) turbulent flow between the injection and the sampling point

f) the tracer must be completely mixed with the river water and at the sampling cross section distributed homogenously

g) the background level of the river water must be stable [3]

For the constant tracer injection a "Mariott'sche Flasche" was used [6]. The bottle contains 12 litres. The applied tracer was sulforhodamine. (Fig. 2)

FIG. 2 Mariott'sche Flasche (constant-rate injection equipment).

CURRENT METER METHOD: The principle of discharge measurements with common current meter are known. The flow velocity is measured by a cross section of the river at different points. We used the 5-point method of the SNHGS [6]. This method takes about 20 profiles over the transsection of the river and at every profile 5 vertical measuring points. The total runoff is calculated with a double integral calculus on the wet area and the time.

Some conditions have to be considered at current meter measurements:

a) The runoff must be constant during the measuring time

b) stable discharge area (the best results are known from solid measuring cross sections)

c) laminar flow conditions

d) measuring cross section free of vegetation

e) calibration of the current meter at regular intervals

The shovels of the used current meter from the SNHGS have a diameter of 8 cm.
TEST STATIONS

The selection of the discharge test stations was based on the following criterions:

a) runoff not more than 4 m³ s⁻¹
b) monitoring station of the SNHGS
c) long term water gage relation curve
d) turbulent flow between the injection point and the sampling cross section for the dilution methods

Therefore we chose eight stations in Central Switzerland for a field campaign. (Table 1)

<table>
<thead>
<tr>
<th>gauging station</th>
<th>m.a.r m³ s⁻¹</th>
<th>temp °C</th>
<th>cond μS cm⁻¹</th>
<th>velocity m s⁻¹ m</th>
<th>dist m</th>
<th>amount of trac kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grossthalbach</td>
<td>1.84</td>
<td>9.2</td>
<td>260</td>
<td>2.40</td>
<td>300</td>
<td>3</td>
</tr>
<tr>
<td>Alpbach</td>
<td>1.80</td>
<td>6.5</td>
<td>86</td>
<td>2.60</td>
<td>200</td>
<td>3</td>
</tr>
<tr>
<td>Walenbrunnen</td>
<td>0.25</td>
<td>10.6</td>
<td>237</td>
<td>0.27</td>
<td>300</td>
<td>-</td>
</tr>
<tr>
<td>Schächten</td>
<td>5.39</td>
<td>10.4</td>
<td>221</td>
<td>1.50</td>
<td>450</td>
<td>10</td>
</tr>
<tr>
<td>Erlenbach</td>
<td>1.63</td>
<td>6.3</td>
<td>216</td>
<td>1.73</td>
<td>250</td>
<td>10</td>
</tr>
<tr>
<td>Engelberger Aa</td>
<td>4.64</td>
<td>8.9</td>
<td>146</td>
<td>1.10</td>
<td>400</td>
<td>10</td>
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<tr>
<td>Chli Schliere</td>
<td>0.75</td>
<td>15.1</td>
<td>304</td>
<td>0.05</td>
<td>450</td>
<td>2</td>
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<tr>
<td>Würzenbach</td>
<td>#</td>
<td>14.6</td>
<td>461</td>
<td>0.50*</td>
<td>200</td>
<td>1</td>
</tr>
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</table>

- no value
# monitoring less than one year
* estimated velocity

m.a.r. : mean annual runoff, periode 1986-1988,
velocity: mean velocity at the monitoring cross section
dist. : distance between injection and sampling point
const. : constant-rate injection (Mariott'sche Flasche), sulforhodamine
integr. : integration (gulp) method, salt (NaCl)

RESULTS

Table 2 shows the results of the tests. The reference for the comparison of the three different measuring methods was the water gage relation curve (1989). This reference was chosen because the water gage relation curve is derived from many discharge measurements with the current meter and therefore the influence of incorrect values could be eliminated. The relationship of the water gage and the runoff is a mean value and therefore is suitable as a reference value.

The results can be interpreted as follows:

The integration (gulp) method with salt dilution measurement gave differences between -7.0 and +21%. The highest negative deviation was -7% (Erlenbach). This effect is very unusual, mostly the measurements are too high because of tracer loss between the injection point and the measuring point.

The greatest difference to the water gage relation resulted at the Chli Schliere. It was 0.019 m³ s⁻¹ or +21%. At the time of our field campaign the measuring conditions in the large and braced riverbed with threshold and pools were very difficult. It might be
Flow measurement under difficult measuring conditions

<table>
<thead>
<tr>
<th>gauging station</th>
<th>Runoff</th>
<th>Differences from w.g.r.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>w.g.r.</td>
<td>corr. m</td>
</tr>
<tr>
<td></td>
<td>m$^3$/s$^-1$</td>
<td>m$^3$/s$^-1$</td>
</tr>
<tr>
<td>Grossthalbach</td>
<td>1.310</td>
<td>1.319</td>
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<tr>
<td>Alpbach</td>
<td>1.880</td>
<td>1.890</td>
</tr>
<tr>
<td>Walenbrunnen</td>
<td>0.260</td>
<td>0.280</td>
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<tr>
<td>Schächen</td>
<td>4.700</td>
<td>4.555</td>
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<tr>
<td>Erlenbach</td>
<td>1.850</td>
<td>1.862</td>
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<tr>
<td>Engelberger Aa</td>
<td>3.620</td>
<td>3.696</td>
</tr>
<tr>
<td>Chli Schliere</td>
<td>0.090</td>
<td>0.074</td>
</tr>
<tr>
<td>Würzenbach</td>
<td>0.120</td>
<td>-</td>
</tr>
</tbody>
</table>

- : no value
w.g.r. : water gage relation (1989)
curr. m : current meter method
cost. : constant-rate injection method, sulforhodamine
integr : integration (gulp) method, salt (NaCl)

possible, that a certain amount of the salt was lost in the pools of the riverbed due to higher specific density of the brine. The other variations are less than ±3%, that lays in the accuracy of the conductivity meter. By another test we made 7 discharge measurements one after the other (from 13.45 until 16.15 hours), to show the variation of the results. The test rivulet was the Luterbach near Berne. The first measuring was 15.3 l s$^-1$ and the last was 15.8 l s$^-1$. That means that the difference of the results is not more than 0.5 l s$^-1$ or less than 3%.

To consolidate those few results we must get more data from field measurements.

The constant-rate injection method with sulforhodamine as tracer shows similar results. The variations are between -21.7% (Würzenbach) and +3.8% (Alpbach). This result lays in the accuracy of the method (Alpbach). The mixing conditions between the injection point and the sampling point were excellent. The Würzenbach had a background conductivity of 461 µS cm$^-1$, that means that the water is possibly contaminated with wast water. The background level of sulforhodamine was 0.2 mg m$^-3$ in the blank samples, what influenced the fluorescence analysis. Therefore the value of this streamlet differs so much from the water gage relation. The other results vary from -5.4 to +2.4%. A negative result means that we measured too much of the tracer, positive differences are from a loss of tracer. Usually the results have a positive difference because of little tracer loss by sorption or exfiltration.

The current meter measuring varied between -17.8% and +7.7% to the actual water gage relation. The negative difference of -17.8% was measured at the Chli Schliere. Due to the large riverbed (6.6m) and the low runoff (about 13% of the mean annual runoff, Tab. 3), where the mean streamflow velocity with 0.05m s$^-1$ was also very low for a correct measuring. The natural bottom of the river bed at the measuring cross section makes it more difficult to measure with the current meter (Tab. 2). The low water discharge measurements are in general very difficult to realize with the
current meter if the cross section is not concrete and therefore not stable.
The next highest positive difference was at the Walenbrunnen with +7.7%. The reason of this variation is not known.
The other differences are between -3.1% (Schächen) and +2.1% (Engelberger Aa). That lays in the accurancy of the method.

A comparison of the differences of the three involved methods shows that the Chli Schliere gave the greatest variation. The relative difference between the current meter and the salt dilution method was 38%. This difference is partly a result of the low runoff and the large riverbed and the reasons mentioned above.
The smallest relative variation was measured at the Schächen with only 0.6% difference between the three methods. This results are equal with the tree involved methods.
Mostly the relative differences are not more than 8% (cf. Tab. 2). Therefore the three methods are similar, at good mixing conditions for the dilution methods (salt, sulforhodamine) and concrete cross sections for the current meter, to each other.

OUTLOOK

The aim of this investigation was to have basic information about discharge measurement with the three different methods under the same conditions. Those first results allow an estimation about the reliability of the three methods; as there is only little data available, we can not get a final conclusion. The next step must be collecting more data for statistical analysis.

The advantages of the integration (gulp) method is that it can be applied to natural rivulets with turbulent flow. The use of a bridge or some other installation is not necessary. The limit of
the salt dilution method is the amount of tracer to be added (about 5 kg per m$^3$ runoff) to increase the conductivity about 100 $\mu$S cm$^{-1}$ at the peak of the tracer flow-trough curve. If the background level of the conductivity is less than 100 $\mu$S cm$^{-1}$ a smaller amount of salt per cubic meter runoff can be added. If the background conductivity is more than 500 $\mu$S cm$^{-1}$ then more than 5 kg salt per cubic meter should be used. An advantage of the method is that the measuring equipment is in a suitcase (about 10 kg) and therefore it is very easy to move. The salt can be dissolved in a vessel (bucket, barrel) and from this it can be injected. The microcomputer records the data and plots the result after the monitoring is finished. The plausibility check can be made in the field and if the result seems to be incorrect an other measurement can be made immediately. A disadvantage of this method is that only a runoff less than 4 m$^3$ s$^{-1}$ can be made easily, because the amount of salt to be dissolved is difficult to handle (about 20 kg for 4 m$^3$ s$^{-1}$ runoff). In the literature a discharge measurement of 14 m$^3$ s$^{-1}$ is mentioned [1], but such a runoff needs a great amount of salt and some heavy injection equipment.

For the constant-rate injection method (sulforhodamine) a special injection equipment is necessary (Mariott'sche Flasche or similar constant-rate injection equipment). The analysis of the samples must be done in a laboratory by a costly spectral fluorometer. The results of the measurements are therefore not available in the field and the plausibility check can not be made there. The advantage of the method is that only a small amount of the tracer (about 5 g per cubic meter) is used. Therefore the limiting factor for this method is not the runoff but the distance of the complete mixing of the tracer, because the tracer must be distributed homogenously at the measuring cross section. By rule of thumb we can say that the amount of tracer to be injected is about:

- 5 g SR per cubic meter, constant-rate injection
- 5 kg salt per cubic meter, integration (gulp),

Therefore the transport of the tracer for the constant-rate injection is no problem, but for the salt dilution method it could be one.

An advantage of the current meter method is that the amount of runoff to be measured is not a limiting factor. In mountainous rivulets with only a few cubic meter runoff and a concrete cross section for the measurement, the current meter gives good results. A disadvantage of this method is the calibration of the current meter every 10 to 20 operations with a lot of technical installation needed. Another problem is that at low water at natural cross sections the discharge measurement is very difficult. The question of measuring high water runoff, with a lot of suspended matter is not yet solved, because the current meter is very sensible about suspended matter in its moving parts.

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REFERENCES


