In situ measurements of hillslope runoff components with different types of forest vegetation

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Abstract The aim of the project was to identify the components of hillslope runoff in micro catchment scale and to assess the impact of the forest vegetation types on the hydrologic response. At two experimental sites in an alpine forested catchment, measurement devices have been installed. The first is covered by coniferous trees (spruce), the second by mixed type forest (beech, spruce, fir trees) with domination of deciduous species. The subsurface runoff components have been collected and continuously autologged in trenches at three depths (20, 110 and 160 cm). Soil physical analysis and measurements of soil moisture and matric head described the soil water characteristics of the above hillslope sections. First analysis of the data showed differences of hydrologic response due to vegetation type caused by different interception and retention capacities.

INTRODUCTION

In Austria forestry plays an important role not only for economical purposes but also for the capacity of forested hillslopes for flood retention and torrent and avalanche protection. Due to increasing intensity of forestry as an economical factor the original mixed type forest in the alpine regions changed more and more to monocultural spruce forest during the last century. This may have caused changes in the hydrologic response in the catchments, but these effects are hardly to identify and not much investigated.

Therefore the aim of the project was the assessment of hillslope runoff components in different depths at specific sites considering monocultural and mixed type forests. Groups of hydrologists and forest ecologists have been involved and thus interdisciplinary approach was supported.

STUDY AREA

The study area is located in an alpine subcatchment of the River Enns in Styria, Austria. About 60–70% of the subcatchment is covered by forest. The two experimental sites, where the micro scale hillslope runoff has been measured, are at elevations of 1050–1100 m a.s.l. The first site has mixed type vegetation cover with beech, spruce and fir trees. Its slope is 35 degrees. The second site has monocultural spruce cover with a slope of 40 degrees. Slope aspect is directed from northeast to east respectively. The soil depth varies from 60 cm to 2 m. The permeable bedrock consists of fractured phyllite slate and was located in the experiment pits at a depth of 160 cm.
MEASUREMENT DEVICE AND INSTRUMENTATION

Hillslope runoff can be divided into Hortonian surface runoff—which could hardly be observed in the monitored forested slopes—and into subsurface flow. The latter consists of near-surface flow (0–20 cm), intermediate flow or interflow (20–110 cm) and of base flow near the bedrock zone. The layer boundaries are irregular and their contribution to the runoff depends on soil properties and stratifications, on actual soil moisture contents, on precipitation intensities and duration.

For the assessment of runoff components a pit has been excavated at both sites down to the bedrock layer (160 cm). Metal sheets with a width of 160 cm have been pushed about 40 cm into the front face of the pit (Fig. 1). Runoff gutters lead the flux to containers, where the accumulation of discharge is measured by pressure probes. The containers are emptied by siphon tubes. Similar hillflow measurement applications have been referred to in Atkinson (1978) and Peters et al. (1995).

Soil moisture characteristics of the hillslope sector above are measured by three tensiometers and 16 TDR probes. A multiplexer enables simultaneous measurements of all probes. These measurements provide data for estimating soil retention

![Fig. 1 Cross-section scheme of the pit for the assessment of hillslope runoff components.](image)

<table>
<thead>
<tr>
<th>Table 1 Instrumentation and measured parameters of the runoff measurement device.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Instrumentation</strong></td>
</tr>
<tr>
<td>2 tipping bucket gauges</td>
</tr>
<tr>
<td>3 pressure probes (in runoff containers)</td>
</tr>
<tr>
<td>3 tensiometers + 1 soil temperature probe</td>
</tr>
<tr>
<td>1 TDR-Trase System 1 with multiplexer and 16 TDR-probes (buriable wave guides)</td>
</tr>
<tr>
<td>1 data logger (GEALOG S)</td>
</tr>
<tr>
<td>1 solar panel + car battery</td>
</tr>
</tbody>
</table>
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characteristics and are reasonable to fit analytical retention curves to the *in situ* measurements (Campbell, 1985; Van Genuchten *et al.*, 1994). The latter are required for numerical modelling of the runoff process (e.g. in Simunek *et al.*, 1994). Precipitation is collected with tipping bucket gauges for non-covered and forested domains (throughfall). The observations of the latter are compared and adjusted to data from the gutter collectors, which are distributed in the forest and provide more representative interception areas. Table 1 shows the installed instrumentation components. All data are stored in a data logging device at 15-minute intervals. Figure 2 shows a scheme of the instrumentation.

For the measurement of climatic parameters a portable meteorological station was installed. The instrumentation and measured parameters are summarized in Table 2. These parameters enable the computation of potential evapotranspiration (Doorenbos & Pruitt, 1975).

Table 2 Instrumentation and measured parameters at the meteorological station.

<table>
<thead>
<tr>
<th>Instrumentation</th>
<th>Measured component (dt = 15 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 wind velocimeter (Type 263)</td>
<td>wind velocity and direction</td>
</tr>
<tr>
<td>1 temperature sensor (Type YSI)</td>
<td>air temperature in °C</td>
</tr>
<tr>
<td>1 star pyranometer (Model no. 8101)</td>
<td>radiation</td>
</tr>
<tr>
<td>1 tipping bucket gauge (Type AP22)</td>
<td>precipitation in mm</td>
</tr>
<tr>
<td>1 hygrometer (Type MP)</td>
<td>air humidity</td>
</tr>
<tr>
<td>1 solar panel + car battery</td>
<td>autonomous energy supply</td>
</tr>
</tbody>
</table>

**RESULTS OF CONTINUOUS MEASUREMENTS**

In the summer period of 1995 and 1996 continuous measurements have been carried out on both experimental sites. Due to instrumentation facilities only one site could be equipped with automatic probes and data logging device. At the complementary
site only accumulated runoff components at three depths have been monitored periodically (one or two times a week). Thus comparisons and conclusions can only be made for a periodic approach, not for single events. In the summer period 1995, the automatic data-logging system has been used for the site with mixed type forest. In summer 1996 it was installed for the coniferous site. The accumulated rainfall and the runoff components are shown in Fig. 3 (1995) and Fig. 4 (1996).

The observation period 1995 started on 4 August and ended on 31 October. The total amount of precipitation for that period of 88 days is similar for both experimental sites. Single events may differ due to the distance (2 km) and regional distribution. The throughfall at the mixed type forest was 264 mm, at the coniferous forest 247 mm. The difference is caused by lower interception capacities for deciduous trees and stemflow existence, and also by different event-based rainfall intensities (Fig. 3).

At the mixed type forest, runoff was dominated by the near-surface component (0–20 cm). Its contribution to the total runoff amount is about 70%. The interflow component (20–110 cm) was about 20% and the baseflow (110–160 cm) was 10% of

![Diagram](image-url)
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the total collected runoff. It has to be mentioned, that for both sites no impermeable bottom layer (impermeable bedrock) exists and thus the total amount of runoff could not be collected with the installed measurement device.

At the coniferous forested site the total amount of collected runoff was about 260 litres and thus higher than at mixed type forest (210 litres). The runoff contributions of the different layers were similar (Fig. 3). This may be caused by the higher conductivities in the upper layers (Table 3) but also, due to the lower root depths, the retention and transpiration capacities will be lower for coniferous vegetation and thus cause increasing hillslope runoff.

In 1996 the observation duration lasted from 8 June to 19 August. In that period of 73 days the mixed type forest site showed total surface runoff of 195 litres, 76% contributed by the near-surface flow. At the coniferous forest site the total runoff was 382 litres and thus much higher than at the mixed type site. Note the different ordinate scale for runoff in Fig. 4(b)!

The rainfall amount of the coniferous forest is based on measurements of tipping bucket gauge. These values have not yet been adjusted to the rainfall gutter measurements.

![Fig. 4](image-url) Accumulated rainfall and runoff components for mixed type forest (a) and coniferous forest (b) for the vegetation period of the year 1996.
The observations for the wet summer period of 1996 showed significant higher hillslope runoff at the coniferous site. Its runoff contribution was uniformly distributed over the total depth of collection.

Table 3 Saturated hydraulic conductivities (ks) of the two experimental sites.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Mixed type forest:</th>
<th>Coniferous forest:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>soil type</td>
<td>ksmean</td>
</tr>
<tr>
<td>30</td>
<td>IS</td>
<td>23.9</td>
</tr>
<tr>
<td>80</td>
<td>siS</td>
<td>50.6</td>
</tr>
<tr>
<td>110</td>
<td>siS</td>
<td>24.7</td>
</tr>
</tbody>
</table>

Hydraulic conductivity from laboratory soil sample analysis (m day⁻¹)

Hydraulic conductivity from in situ measurements with Guelph permeameter (m day⁻¹)

<table>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>soil type</td>
<td>ksmean</td>
</tr>
<tr>
<td>30</td>
<td>IS</td>
<td>3.0</td>
</tr>
<tr>
<td>70</td>
<td>siS</td>
<td>2.4</td>
</tr>
</tbody>
</table>

IS = loamy sand
siS = silty sand
S = sand

RESULTS OF IRRIGATION EXPERIMENT

Due to the fact that the implementation of the data-logging device could only be carried out for one experimental site, there exists a deficit in the ability of direct comparison of event-based measurement values like runoff or soil moisture distribution. Thus irrigation experiments were undertaken from 19 to 23 August 1996. Under the existing circumstances the following appropriate conditions could be fulfilled at both sites:

- comparable (constant) starting conditions (dry conditions without flux);
- identical rainfall intensities and temporal distributions;
- availability of automatic measurement device as shown in Fig. 2 leads to reliable temporal resolutions of measurement parameters.

Fortunately the rainfall experiment took place under excellent weather conditions. Thus no natural rainfall effected the experiment.

The rainfall simulator covered an area of 12 m². The width was 2 m, the horizontal length 6 m. The required water amount has been pumped from a nearby brook and was intermediately stored in big balloons with a volume of 8 m³. The rainfall intensities could be varied during operation by computer software. The duration of irrigation was 3 h. The rainfall depth for the first 2 h was about 60 mm h⁻¹ and 100 mm h⁻¹ for the third hour. This means an application of about 2700 litres for the whole area. These intensities are comparable to experiments by other authors (e.g. Markart & Kohl, 1995).

The results show very low rates of collected hillflow (Fig. 5). In the mixed type forest only 1.2% of applied rainfall discharge could be collected as subsurface runoff. At the coniferous site 8% of rainfall have been collected. The soil moisture measurements showed significant increase of moisture content. An extrapolation of the point measurement values to the representative volume of irrigated domain showed an increase of moisture storage of 1371 litres for the mixed type forest, which is 52% of the rainfall amount. In the coniferous forest 1050 litres, 39% of total rainfall, are stored in the corresponding soil domain. Figure 5 shows the time series of accumulated rainfall depth, subsurface runoff and soil moisture increase.
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Fig. 5 Accumulated rainfall and runoff components for mixed type forest (a) and coniferous forest (b) for the rainfall experiment.

About 50% of the rainfall application could not be measured by TDR probes or runoff collectors. This amount can be interpreted as the lateral and vertical vanishing moisture flux. This shows that irrigation experiments for local domains imply three-dimensional infiltration and moisture redistribution processes, which could only partly be monitored with the installed instrumentation.

ONGOING INVESTIGATIONS

Within the research project several further investigations have been carried out, which are specified in the following section. They are described in detail in Hager & Holzmann (1995) and Hager & Holzmann (1996).

- soil physical analysis;
- measurement of plant physiological parameters like interception capacities of trees and bushes, root depths and densities, stem runoff etc.;
- modelling of subsurface slope runoff in the hydraulic laboratory;
- numerical, two-dimensional modelling of the runoff process in microscale for laboratory application and in situ experimental site, considering vegetation impact.
These data provide a good database for further research on hillslope runoff processes.

CONCLUSIONS

One aim of the project was the assessment of the basic hillslope runoff processes in micro catchment scale and the identification of the impact of vegetation type (forest species) on the hydrologic response. Regarding the runoff process, no surface runoff could be observed at both test sites. This is caused by the high conductivities of the existing soils and of the organic layer. Similar conclusions are found by Mosley (1979). Near surface runoff component is dominant in the mixed type forest. In the coniferous site, the quantities of near surface, intermediate and baseflow are uniformly distributed. The mixed type forest showed less runoff both in continuous observation periods and in the irrigation experiment. This may be caused by higher retention capacities of the soil due to soil physical characteristics but also due to the higher transpiration rates of deeper root zones.

Because of different soil conductivities (see Table 3) the direct impact of vegetation to the runoff process could not directly be proved. Only differences of the interception capacities between coniferous (spruce) and deciduous trees (beech) could be evaluated directly. Additional applications of numerical, physically based models, which have to be calibrated with in situ conditions, will give further information. These investigations are in progress and further results on that topic are expected in the near future.

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REFERENCES


