Freiburg HydroNotes

Series Paper 1

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Technical report on experimental hillslope hydrology

Experiences from field data collection during a PhD project:

Construction and installation of different instruments and evaluation of measurement techniques

2012
Institute of Hydrology

University of Freiburg

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1. Introduction

Hillslopes are fundamental landscape units that strongly govern the processes whereby rainfall or snowmelt is vertically and laterally transported to the stream network. Sound process knowledge of hillslope hydrological dynamics is thus highly important. Collecting hydrological data at different temporal and spatial scales lays the foundation for gaining process understanding, hypothesis testing, and model validation and rejection.

Everybody who has worked experimentally knows the work behind collecting data and the many decisions prior to a field campaign: Which measurement technique is most suitable? Which spatial and temporal resolution of data is required? How many measuring points are feasible given the cost and labor intensity of each technique? How reliable is the data obtained with a certain instrument? Especially for students new to collecting field data, practical knowledge on how to build and install instruments and on advantages and disadvantages of different measuring techniques seems useful. We therefore want to pass on experiences from a PhD project on experimental investigations of hillslope subsurface flow processes, in which we monitored hydrological dynamics of three adjacent large-scale hillslopes differing in vegetation cover: shallow subsurface flow dynamics with 90 wells, three trenches, and a novel subsurface flow velocity instrument, overland flow, discharge in the creek at the foot of the hillslopes, meteorological data, and spatially variable rainfall input.

The aim of this report is two-fold: A first part provides information on how the instruments used in our study were built and installed in the field. Since we often work under financial constraints self-made instruments and creative solutions are necessary. A second part evaluates the used measurement techniques in terms of data quality (reliability of the device, accuracy, potential error sources), and value of data versus costs and labor intensity (i.e. building of instruments, installation in the field, maintenance, data collection). Normally, we are only interested in the results obtained from data; however, insider knowledge about the data collection process per se is valuable as well. This report is by no means an attempt to cover all methods common to experimental hillslope hydrology. We simply want to pass on information that is normally not found in such detail in the methods section of a research article. Sharing information about experimental work may help others to stop “re-inventing the wheel”, thereby making future experimental hillslope studies better comparable.

2. Overview of different measurement techniques at study site

To characterize hydrological processes of three adjacent large-scale hillslopes with different vegetation cover (grassland, coniferous forest, and mixed forest) located within a 0.21 km² zero-order catchment at the foot of the black forest (47.957°N, 7.838°E) we continuously monitored the following parameters (see Figure 1):

Input to the system:

- Meteorological data (rainfall, temperature, humidity, wind speed, wind direction, solar radiation) with a Davis weather station Vantage Pro 2 (10 min measurement interval). Since this commonly used weather station is a ready-to-use instrument we do not further describe it in section 3.
- Spatially variable rainfall input with 66 rainfall totalizators. The totalizators were designed for efficient data readout in the field.

Internal hydrologic dynamics:

- Shallow water table dynamics with 90 wells equipped with Odyssey water level capacitance probes (2 min measurement interval).
- Trench flow at the foot of each hillslope with a 10 m wide trench; we differentiate between trench flow from the right and left side of the trench (5 m trench width each) by separately routing water into tipping buckets.
- Overland flow via one surface flow collector with attached tipping bucket per hillslope.

Outflow:

- Discharge in the creek at the foot of the hillslopes with a v-notch weir and a pressure transducer (10 min measurement interval).

In addition, we attempted to continuously measure subsurface flow velocity with a novel tracer technique. Laboratory tests of the novel instrument provided promising results; however, the instrument failed in the field and modifications are required for proper functioning. In the following the construction and installation of each instrument will be described.

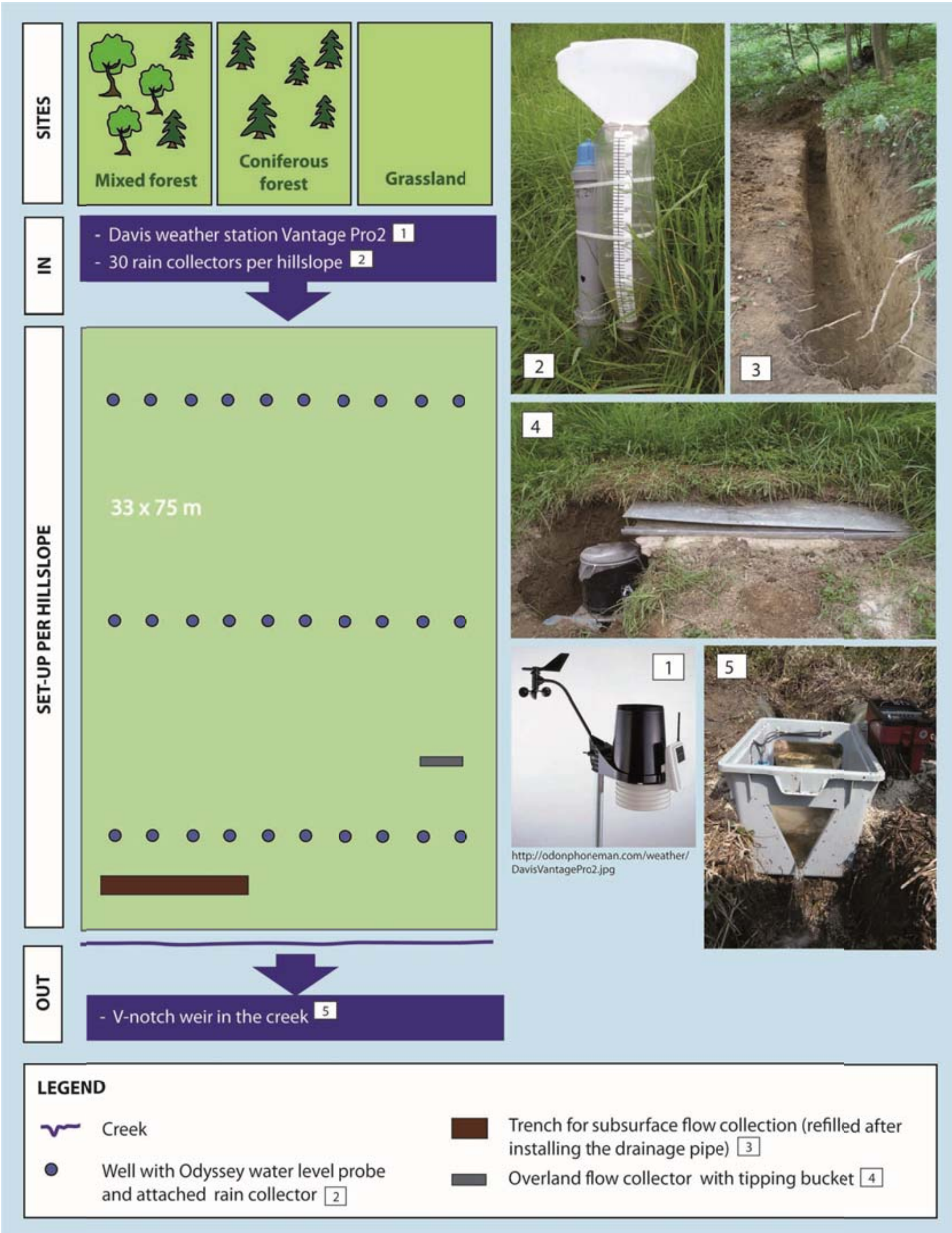

Figure 1: Overview of experimental set-up and measurement techniques.

3. Construction of instruments and installation in the field

3.1 Water table measurements

Material: PVC pipes, geotextile, cable ties, duct tape, bentonite clay pellets, gasoline-powered breaker, water level probes (Odyssey Capacitance Water Level Recorder, Data Flow Systems)

Prior to drilling wells, PVC casings were built. PVC pipes of different lengths (1-2 m, 4 cm diameter) were perforated with a drilling machine over the entire length. Next, the perforated PVC pipes were wrapped into geotextile, which was fixated with duct tape, to prevent fine material transport into the pipe. Geotextile was also wrapped around the lower end of the open PVC pipe and closed with a cable tie. The wells were drilled with a hand-held, gasoline-powered breaker (Cobra Standard, see Figure 2.2). After inserting the PVC casing into the well, bentonite clay pellets were pressed around the PVC casing at the soil surface to seal the well against preferential flow along the pipe. In each well an Odyssey Capacitance Water Level Recorder (Data Flow Systems) was placed that had been calibrated before. We first calibrated the Odyssey probes in plexiglass tubes of different length (Figure 2.1). However, for low-conductivity water, which is the case at our study site, this procedure yields inaccurate results. Better validation results were achieved when calibrating the probes in a water-filled bucket with the Teflon cable coiled into the bucket, although this seems more prone to errors due to the cable touching the bucket.

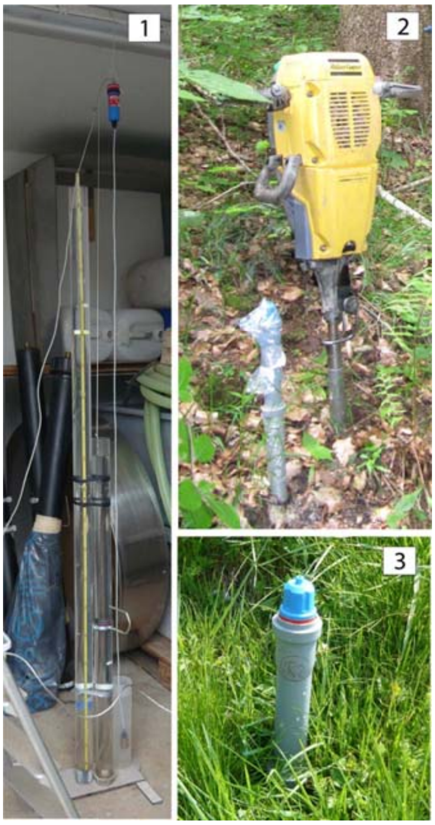

Figure 2: 1) Calibration of Odyssey capacitance probes. 2) Hand-held, gasoline-powered breaker (Cobra Standard). 3) Well with Odyssey water level capacitance probe.

3.2 Trench flow measurements

Material: drainage mat, drainage pipe, solid PVC pipes, possibly sewer pipes, pond foil, long nails, silicon, cable ties, tipping buckets (RainWise Inc.), data loggers (Onset HOBO Pendant Event Data Loggers UA-003-64), box/ housing for tipping buckets

Hillslope trenching for subsurface flow measurements is a common approach in hillslope hydrology (e.g. Anderson et al., 2008; Burns et al., 1998; Freer et al., 1997; Hrncir et al., 2010; Kienzler and Naef, 2008b; Scherrer et al., 2007; Uchida et al., 2005; Woods and Rowe, 1996). At our study site we opened one 10 m wide trench at the foot of each hillslope. In most trench studies subsurface flow is measured in the trench above the bedrock, sometimes at different depths via inserted steel plates. In contrast to that, we refilled our trenches after installing a drainage system that leads subsurface flow out of the trench. We believe refilling the trench is more suitable for long-term measurements since initial conditions are more or less restored.

At the grassland and the coniferous forest hillslope an excavator opened the trenches (10m x 0.6 m, 2 m deep) and a trench outlet (see Figure 3.1 and 3.2). The trench depth was set to 2 m (with a slight gradient to the trench outlet); at our study site there is no clear soil-bedrock interface but dense layers of periglacial drift cover. The trench at the mixed forest hillslope was manually dug; on the right side of the trench bedrock was located in shallow depths (<1m). Due to the strongly irregular bedrock topography the installation of the drainage system was more complicated (see Figure 3.5).

Generally, after the trench had been opened up, a pond foil (~10.5m x ~0.6 m) was placed on the bottom of the trench (Figure 3.2). The edge of the pond foil facing the trench wall was attached to the trench wall with long nails, overlapping the trench wall by approximately one cm from the bottom. Two pieces of drainage pipe (each piece 5 m long, 4 cm diameter) were placed on top of the pond foil one after another. The pipe draining the first 5 m of the trench was funnelled into a solid PVC pipe at 5 m distance; the pipe draining the second half of the trench was routed into a solid PVC pipe at the beginning of the outlet. Subsurface flow leaves the trench through solid PVC pipes running though the trench outlet; at the forested hillslope the solid PVC pipes were placed inside break-proof sewer pipes, since a forest road crosses the trench outlet. Next, a drainage mat was mounted on the trench face so that water leaving the trench face is channelled down the mat, onto the pond foil, and into the drainage pipe. The downslope edge of the pond foil was wrapped around the drainage pipe and attached to the mat (Figure 3.3). At the side of the trench outlet, the pond foil was tightly wrapped around the pipes leaving the trench and fixated with silicon and cable ties, so that trench water cannot leak. Then, the excavated trench material was refilled into the trench. Due to high surface flow rates at the mixed forest hillslope, a pond foil was inserted into the Ah horizon approximately 20 cm upslope of the refilled trench (Figure 3.7). This prevents overland flow from running into the fissure where the drainage mat meets the soil surface.

To quantify trench flow, the solid PCV pipes leaving the trench are lead into a plastic box containing two tipping buckets (RainWise Inc.) and attached data loggers (Onset HOBO Pendant Event Data Loggers) (Figure 3.8). There is an outlet hose at the bottom of the plastic box (see Figure 3.6). The tipping buckets are mounted on a 0.5 cm thick plate on the bottom of the box; after running through the tipping buckets water is channeled out of the box through the hose. The maximum amount of logged data points with HOBO loggers is roughly 40,000. After monitoring a few events it turned out the original-size tipping buckets were too small for the actual trench flow volume (> 40,000 data points per event). Thus, we enlarged the manufacturer’s tipping buckets by mounting larger cups into the original buckets (design by Fabian Ries). The enlarged tipping buckets were calibrated to hold 50 ml per tip.

Figure 3: 1) Excavated trench at the forested hillslope; the outlet is on the left side. 2) Trench at the grassland hillslope during the installation of the pond foil, drainage pipe, and solid PVC pipe. 3) Trench after the installation of the drainage mat. 4) Transfer of trench flow into sewer pipes running through the trench outlet. 5) Trench at the mixed forest hillslope after the installation of the drainage system (irregular topography due to bedrock and roots). 6) Location of trench flow measuring box (box with tipping buckets at the end of the sewer pipes). 7) Surface pond foil routing surface flow over the fissure where the drainage mat meets the soil surface. 8) Trench flow measuring box: water from the left and right part of the trench is channeled into tipping buckets with attached HOBO event loggers, and out of the box.

3.3 Subsurface flow velocity measurements

Material: small-diameter steel tube screened at the lower end, 3 steel poles and a plate for tripod design (see Figure 4.2), plug valve, plastic bottle, NaCl solution, 5TE soil moisture and electrical conductivity probe (Decagon devices), PVC pipe, possibly a steel steel model in the shape of the 5TE probe, CR1000 measurement and control data logger (Campbell Scientific), possibly gas-powered breaker for field installation

Due to the large heterogeneity in time and space, we are faced with the need to continuously measure SSF velocity at several locations within a hillslope over a distance being representative for certain hillslope segments. At present, SSF velocity is either measured by tracer tests over larger distances or via small-scale (mm to cm) measurements using heat dissipation or other tracers (e.g. Labaky et al., 2009; Lewandowski et al., 2011). This calls for a cheap and easily applicable method to continuously detect subsurface flow velocity in the field over a distance representative for certain hillslope segments.

We thus developed a novel technique, which is based on an automatic salt tracer injection into a small-diameter borehole once the soil matrix has reached saturation. The idea is to install a probe measuring soil moisture and electrical conductivity (5TE, Decagon Devices) a few decimetres downslope of the injection point into the soil, which is connected to a CR1000 Logger (Campbell Scientific). The probe serves to both monitor soil wetness conditions and to capture the tracer signal. Once the probe reports saturated conditions, the automatic salt tracer injection will be initiated. A plug valve attached to an above-mounted bottle with NaCl solution, which is controlled by the CR 1000 logger, is opened and the tracer is injected into the borehole via a thin steel tube screened at the bottom. Under saturated conditions the automatic injection is conducted in a fixed interval and the breakthrough curves are analyzed for mean effective velocity.

The technique was developed in a sand filled box with constant in- and outflow conditions representing a homogeneous miniature hillslope (see Figure 4.1). As a first step, several experimental set-ups differing in distance from injection point to 5TE probe, orientation of 5TE probe, and amount and concentration of tracer injection were tested for manual injection. For different hydraulic gradients the effective velocity determined by tracer breakthrough matched well the filter velocity determined by measuring outflow rates. After an optimal experimental set-up had been identified, the automatic injection unit (tripod holding plug valve and above-mounted tracer bottle) was built and tested in the sand filled box (see Figure 4.2). After the instrument had properly functioned in the lab it was installed in the field.

For the field installation we first determined the depth of the saturated zone through well observations. In summer, there is no continuous perched water table at the study site; a water table develops under certain events and in depths > 1 m below the soil surface. We thus drilled two boreholes 30 cm apart along the slope gradient with a depth of 110 cm. In the top borehole we installed a long steel tube screened at the bottom. We tried to hammer the screened end of the steel tube further into the soil (ca. 10 cm deeper than the bottom of the borehole). However, due to the high density material, this was not possible. We thus refilled the borehole with fine sand and placed the tube in it. The automatic tracer injection unit was put over the steel tube (see Figure 4.3). In the downslope borehole we mounted a 5TE probe, which we had glued into a PVC pipe for easier installation. Initially we planned on installing the probe into the original soil material, similar to the injection tube. A steel model in the shape of the probe had been designed for pre-piercing. However, the 5TE probe broke during installation and a new one was placed into fine sand refilled into the borehole.

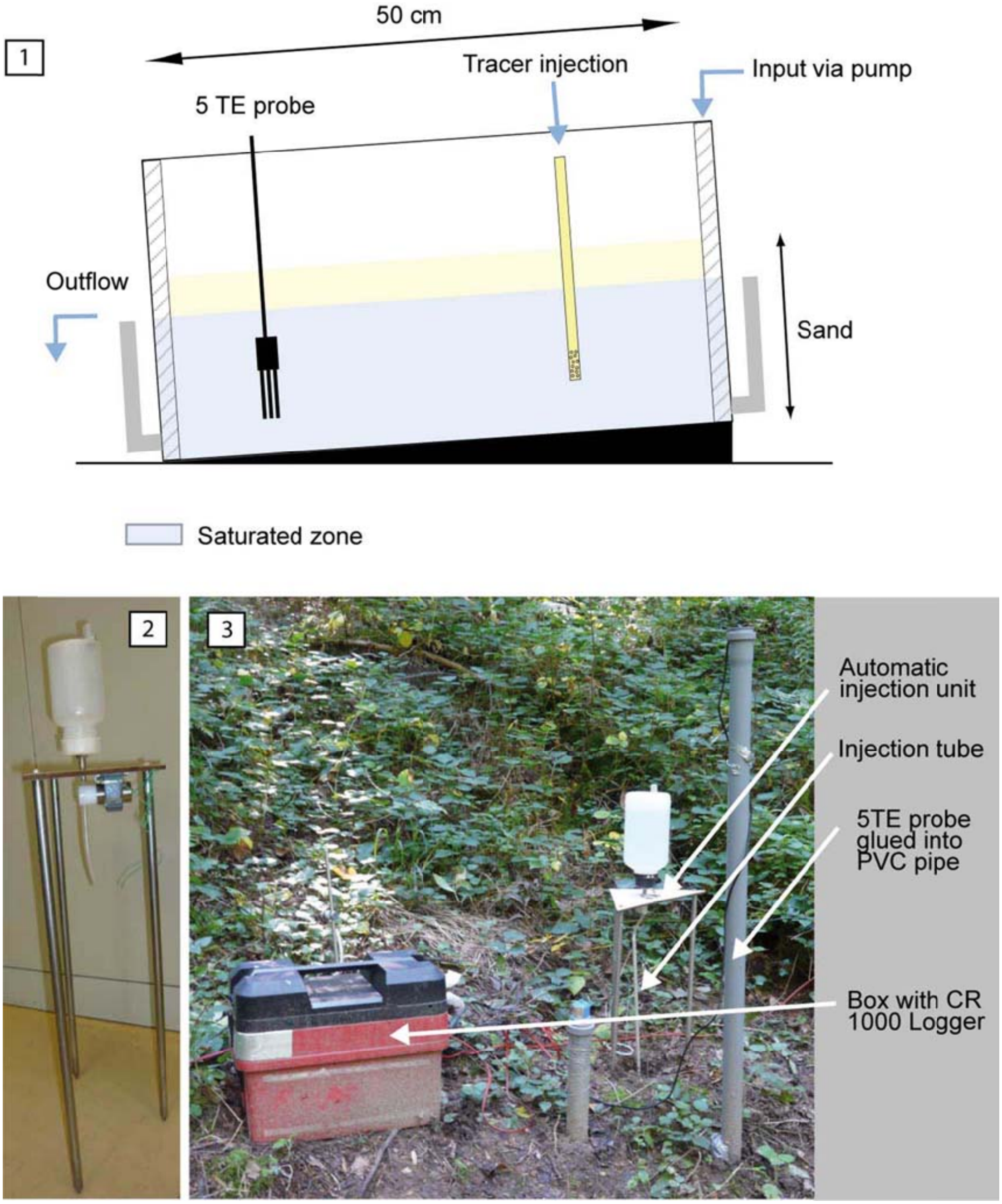

Figure 4: 1) Lab test in a sand filled box with constant in- and outflow conditions. 2) Design of automatic tracer injection unit (plug valve connected to a bottle with NaCl solution). 3) Set-up in the field.

3.4 Overland flow measurements

Material: tin plate (1m x 0.4 m, 1 mm thick; one sharp edge, the other edge slightly recurved so that surface water does not flow underneath the plate), rain gutter (one end closed e.g. with silicon, the other end with a small groove for easier dripping), cement, tipping bucket (RainWise Inc.), wire mesh, steel plate for mounting the tipping bucket, steel poles for levelling the steel plate, data logger (Onset HOBO Pendant Event Data Loggers UA-003-64), rain shield (e.g. wire mesh lined with plastic tarp)

In the field, the sharp edge of the tin plate was driven into the soil ca. 5 cm below the surface until about half of the plate was covered. Underneath the recurved end of the tin plate the rain gutter was fixated with cement so that there is a slight gradient to the outlet (see Figure 5.1 and 5.2). A hole was dug next to the rain gutter outlet. At first, surface flow was routed into a canister. We later replaced the canister with a tipping bucket (RainWise Inc.) and attached HOBO event data logger for continuous overland flow measurements (Figure 5.3). The tipping bucket was mounted on a steel plate, which is levelled out by placing it onto three poles. The poles also allow free vertical drainage of water leaving the bucket. To prevent insects from falling into the funnel and clogging it, we protected the funnel with a fine wire mesh. The entire instrumentation was covered with a rain shield made out of wire mesh lined with plastic tarp.

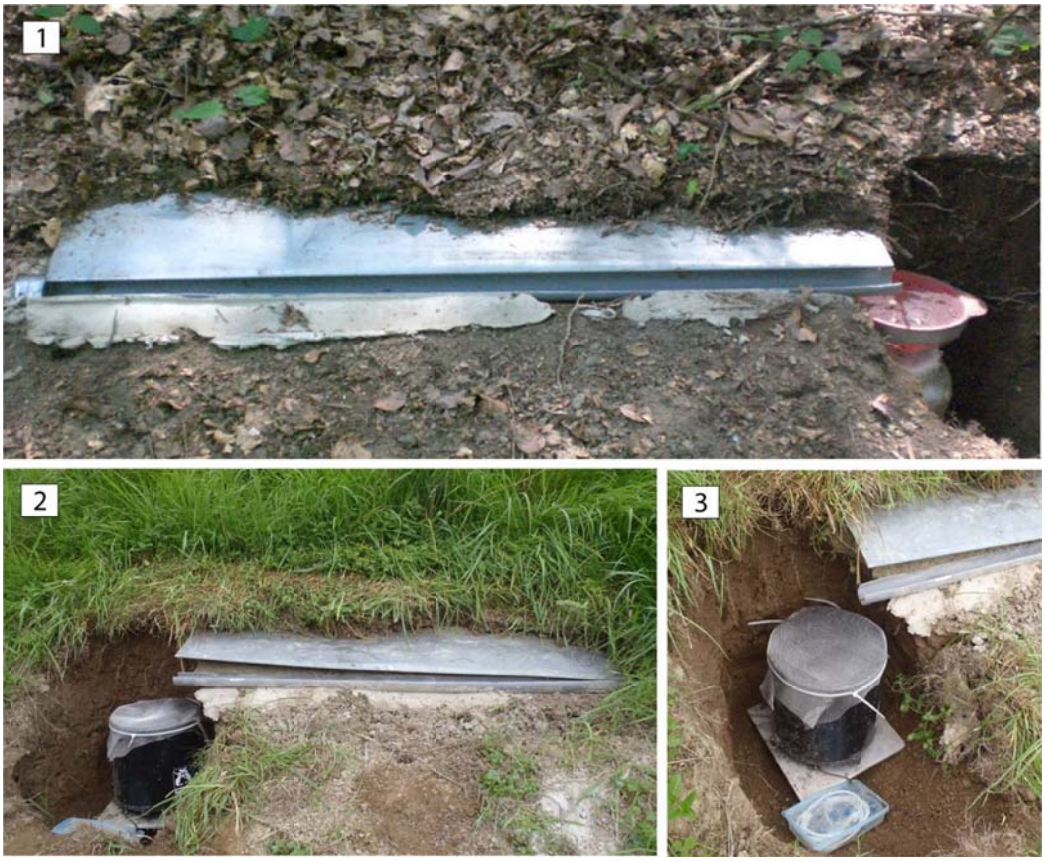

Figure 5: 1) Surface flow collector at the mixed forest hillslope. In the beginning, surface flow was collected in a canister. 2) Surface flow collector at the at the grassland hillslope after the installation of the tipping bucket. 3) Close-up of the tipping bucket, which is fixated on a steel plate leveled out by three poles.

3.5 Rainfall totalizators

Material: PVC funnels, empty plastic bottles (e.g. Coca Cola bottles), silicon or hot glue, adhesive foil, cable ties

At first, we constructed 66 rainfall totalizators (30 per forested hillslope, 6 at the grassland hillslope) by gluing funnels into the mouthpiece of plastic bottles. In the field we mounted the totalizators on the PVC well casings with thick rubber bands. After each event, we detached the bottle from the well casing to pour the water into a measuring cylinder. We also tried to suck the water out of the bottle via a large plastic syringe to speed up the data collection in the field. We later re-designed the rainfall totalizators: We bought 66 empty Coca Cola bottles since they seem to be of standardized shape. A hole was drilled into the bottom of each bottle, and the funnel glued into that hole with silicon. Next, a measuring scale was developed by filling defined volumes of water into the upside down bottles (capped bottles). The scale was digitized and printed on adhesive foil. A scale was glued on each bottle. The new rainfall collectors were fixated to the well casings with cable ties (see Figure 6). After an event the throughfall volume can be directly read out. The bottle is emptied by untwisting the cap. Slightly bending the bottle in downslope direction before untwisting the cap helps to prevent flow along the PVC pipe.

Figure 6: Rainfall collector with integrated measuring scale attached to the PVC well casing. This bottle was just emptied.

3.6 Discharge measurements

Material: plastic box, wire mesh as dirt trap, screened PVC pipe, pond foil, sandbags, pressure transducer (Mini-Diver DI 501, and Baro-Diver DI 500, Schlumberger Water Services)

A v-notch weir was built by preparing a robust plastic box (with lid) according to Figure 7 (v-notch at the front side, open box at the back side). A wire mesh was installed into the box as dirt trap and a screened PVC pipe as housing for the pressure transducer. In the field, a pond foil was placed slightly below the channel bed and fixated with sand bags. For installing the box into the channel bed, water in the pond foil was routed around the installation spot. After leveling the box in the channel bed, the pond foil was led into the box so that water is routed into the weir. In the first phase, a pressure probe PDCR930 and a mikromec logger 4.1 were used as shown in Figure 7 (the second cable leading into the probe housing was an electrical conductivity probe). Due to frequent logger failure we later replaced the instruments with pressure probes by Schlumberger Water Services (mini-diver DI 501 and baro-diver DI 500).

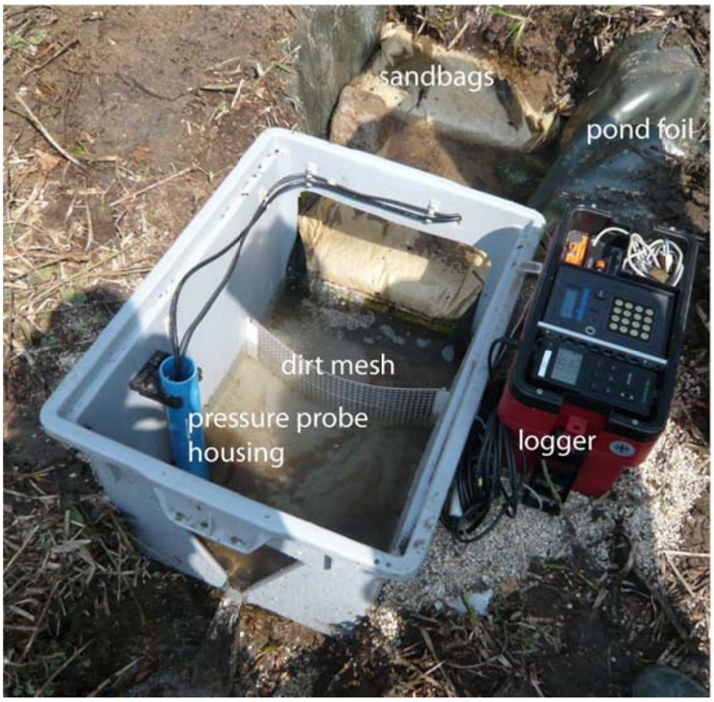

Figure 7: V-notch weir.

4. Evaluation of measurement techniques

In the following, each technique will be evaluated in terms of data quality (reliability of instrument functioning, data accuracy), labor intensity, and approximate costs. In addition, an overall evaluation is given considering the value of the data, representativity, advantages and disadvantages of the instrument.

4.1 Water table measurements

Technique	Data quality	Labor intensity	Costs	Overall evaluation
Wells with Odyssey water level capacitance probes	**Reliability of instrument:** Good in terms of Odyssey probe functioning: generally low number of probes with missing or flawed data; due to the brass counter weight and O-ring, there are no measurements possible in the lower 7.5 cm. **Accuracy of data:** Calibration: the probes are sensitive to temperature and electrical conductivity, even though this is not explicitly stated by the manufacturer. This was also reported by Larson and Runyan (2009). We recommend calibration under native groundwater conditions. Generally, the probes are less accurate under low EC conditions, which is the case at our study site (about 200µS/cm). Manufacturer's accuracy is ±5 mm. However, the validation of Odyssey data with manually measured water table levels (using an electronic contact gauge after pulling out the Odyssey probe) showed low accuracy for dry wells or wells with low water table. Values differed up to 10 cm and there was no continuous bias. Odyssey probes in some dry wells indicated values up to 15 cm, whereas other probes in dry wells recorded water levels < 7.5 cm (which we consider 0 since there are no measurements possible in the lower 7.5 cm). Larson and Runyan (2009) also reported high data inaccuracy. We ran several tests concerning this problem. Above the surface the probes provide accurate data; once inserted into wells with no or low water table the probes seem to be influenced by soil moisture and provide inaccurate results. Drilling a hole into each PVC casing for better air circulation and avoidance of condensation on the Teflon cable, and frequent cleaning (both recommended by the manufacturer) did not help to improve accuracy.	**Calibration:** In our case high due to the inaccuracy of the probes and several re-calibration attempts (in tubes, in a bucket, using different EC water, trying polynomial instead of linear calibration etc.); for high EC water this may be different. **Manufacturing of screened PVC casings:** high due to large amount of required casings in our case **Installation of wells:** High, at least two workers needed; maximum amount of boreholes per work day ca. 7 at our study site (due to dense parent material making it hard to drill and to pull out borehole cores). **Installation of Odyssey probes:** low **Maintenance:** low to medium (frequent probe cleansing is necessary since film accumulation influences probe accuracy) **Data collection**: low (every 2-3 months when probes run in compressed logging mode)	Roughly 200NZ$ per probe depending on probe length (1-2 m); cheap in comparison to pressure probes.	The low accuracy of the Odyssey water level capacitance probe data poses a serious problem. We thus cannot recommend Odyssey probes for field sites with a) low-conductivity groundwater, and b) only temporarily occurring perched water table development. Since pressure probes are far more expensive (but more accurate), the only possibility for gaining measurements of high spatial resolution was to use Odyssey probes. Nevertheless, even if absolute values are of low reliability, the relative change in water table depth provides valuable information. An advantage of the Odyssey probes is the compressed logging mode (measurements only if water level change > 5 mm), which results in very compact data files.

4.2 Trench flow measurements

Technique	Data quality	Labor intensity	Costs	Overall evaluation
Hillslope trenching and subsurface flow quantification with tipping buckets and HOBO data loggers	**Reliability of instrument:** Trench drainage system: Reliability cannot be assessed since the trench was refilled. The instrumentation was conducted with greatest care, but it cannot be assured that all trench flow is routed into the PVC pipes and thus measured (e.g. small portions lost by flow underneath pond foil). Proper functioning can be better assessed in an open trench; yet, the boundary conditions are thereby severely disturbed and there is the risk of trench collapse. RainWise Inc. tipping buckets: reliable functioning HOBO loggers: 1) Few cases with data loss due to no obvious reason; for data download or logger launch under bright sunshine we recommend covering the logger/base station, otherwise data transmission may be disturbed. 2) Rather frequent data loss due to exceeding the maximum amount of logged data points (ca. 40,000); this can be avoided by replacing original size tipping buckets with larger buckets. **Accuracy of data:** Tipping buckets: high for original size buckets and low tipping frequency (manufacturer's accuracy specification: 0.5% at 12.7 mm per hour); for higher tipping frequencies additional calibration will yield higher accuracy; medium accuracy for self-constructed enlarged tipping buckets (2% in lab test); frequent recalibration will help to maintain high accuracy.	**Field installation of drainage system:** Highly labor intensive and physically demanding: organization of construction material, trench excavation manually or with an excavator, installation of drainage material into the trench, refilling. **Enlargement of tipping buckets and calibration:** medium **Maintenance**: low **Data collection**: Frequency of data download depends on logger capacity (maximum amount of logged data points ca. 40,000 for HOBO loggers) and on tipping frequency (controllable via size of buckets); generally we read out data after every major event.	Material (drainage mat, drainage pipe, pond foil etc.) ca. 800€ for 3 trenches Costs for excavations (depends on type of excavation, soil volume etc.) RainWise Inc. tipping bucket (rain gauge) ca. 75€ per tipping bucket HOBO Pendant Event Data Logger UA-003-64 ca. 100€ per logger	Very valuable data since it represents/aggregates entire hillslope behaviour (larger-scale observations); especially in combination with point observations through wells this provides high process information. However, the high labor intensity and costs of excavating and equipping the trench are a serious drawback; for sites with shallow soil labor intensity and costs may be less.

4.3 Subsurface flow velocity measurements

Technique	Data quality	Labor intensity	Costs	Overall evaluation
Instrument for continuous subsurface flow velocity measurements via automatic tracer injection	**Reliability of instrument:** The instrument worked well under laboratory conditions in a box filled with fine sand. However, the instrument failed in the field, where 3 instruments had been installed as described in section 3.3. The reasons for malfunctioning are: • Strongly heterogeneous soil substrate (dense periglacial drift cover) resulting in heterogeneous flowpaths. The design with only one 5TE probe measuring the tracer breakthrough in downslope direction of the injection is not suitable. Several probes mounted in a row need to be installed for capturing the tracer signal. • At the study site, saturated conditions only occur in depth > 1m below the soil surface. Accurate installations via small-diameter boreholes in such great depths are difficult (e.g. same depth of injection and location of 5TE probe). • Only during very short time periods saturated conditions occurred in the zones where the 5TE probes had been installed. Frequent tests could thus not be conducted. For advancing this technique, sites with shallower soil and more frequent saturation would be helpful. For future test we recommend following modifications during the installation: Instead of mounting the 5TE probe via a borehole, we would open up a trench downslope of the injection tube. Piercing the 5TE probes into the soil from within the trench allows more precise installation and still assures non-disturbed conditions in the lateral zone between injection and 5TE probe. In addition, we recommend mounting several 5TE probes in a row to capture the tracer signal. After testing which/ how many 5TE probes are necessary to capture the tracer signal, the surplus ones can be pulled out and the trench refilled. **Accuracy of data:** not yet assessable	**Preparation of material and field installation:** high **Maintenance and data collection:** not yet known due to malfunctioning in the field	Automatic injection unit (tripod with attached plug valve and above-mounted bottle) <100€ 5TE probe: ca. 275€ per probe CR1000 Logger: ca. 1000€	Subsurface flow velocity is an important parameter to measure. The velocity measurements obtained in a box filled with fine sand ('homogeneous miniature hillslope') were promising. However, the novel approach did not function in the field (saturation hardly occurred; difficult installation due to dense substrate; tracer could not be recovered). Further tests under more suitable conditions are suggested (shallower soil, higher frequency of saturated conditions). We also recommend modifications during the installation (installation via a trench).

4.4 Overland flow measurements

Technique	Data quality	Labor intensity	Costs	Overall evaluation
Overland flow collector with tipping bucket	**Reliability of instrument:** Overland flow collector: Reliable functioning if set-up is frequently controlled. Rain gutter and tipping bucket often become clogged by soil/insects/leaves, especially through sediment transport and burying animals. In contrast to other overland flow measurements (e.g. tubes containing small holes placed onto the soil surface) this instrumental set-up may also collect soil water from the upper few cm of the soil. RainWise Inc. tipping buckets: reliable functioning HOBO loggers: reliable (few cases with data loss, see comment under hillslope trenching) **Accuracy of data:** Tipping buckets: high (manufacturer's specification: 0.5% at 12.7 mm per hour) Tipping buckets need to be frequently checked that they are level.	**Organization of suitable material:** medium **Installation:** medium **Maintenance:** medium **Data collection**: The frequency of data download is not determined by logger storage (ca. 40,000 data points and little overland flow in comparison to trench flow) but by necessity of maintenance (frequent control that rain gutter is not clogged). Instrument functioning was checked after every major event.	Material for 3 overland flow collectors < 100€ RainWise Inc. tipping bucket (rain gauge) < 100€ HOBO Pendant Event Data Logger UA-003-64 ca. 75€ per logger	Data provides valuable insight into runoff generation processes for medium effort and rather low costs. Questionable in terms of representativity for entire hillslope; longer tin plates (thus larger upslope contributing area) or more collectors per hillslope may be appropriate. Simplicity of the device assures high quality data if instrumental set-up is frequently checked for non-clogged rain gutter etc.

4.5 Weather station and rainfall totalizators

Technique	Data quality	Labor intensity	Costs	Overall evaluation
Davis weather station Vantage Pro 2	**Reliability of instrument:** high (no data failure in over 2 years); since funnel is not heated not representative for snow. **Accuracy of data:** high (manufacturer's accuracy; verification of tipping bucket calibration)	**Installation:** low **Maintenance:** very low (cleaning during fall of leaves) **Data collection:** logger storage capacity depends on measuring interval (for 10 min interval data has to be downloaded roughly every 2 weeks)	595$	High temporal resolution, minimum effort, no data failure; good reference regarding timing and magnitude of events and weather conditions.
Rain collector	**Reliability of instrument:** high due to simplicity of technique; few data failures (e.g. funnel knocked over by animals) **Accuracy of data:** Medium: the measuring scale (20 ml units) was developed for one Coca Cola bottle; even though the bottles seem of standardized shape, there will be small discrepancies.	**Manufacturing:** high due to large amount of required bottles in our case **Installation:** low **Maintenance:** low (sometimes funnels become loose; understory vegetation needs to be cut away) **Data collection:** after every event (medium to high labor intensity due to large number of totalizators but efficient data readout)	Material ca. 200€ for 66 totalizators	High spatial resolution, low costs. Once totalizators are manufactured (high labor intensity), data collection is efficient.

4.6 Discharge measurements

Technique	Data quality	Labor intensity	Costs	Overall evaluation
V-notch weir with pressure transducer	**Reliability of instrument:** high **Accuracy of data:** manufacturer's accuracy of Mini-Diver DI 501 and Baro-Diver DI 500: ±0.5 cm Potential error sources: Sediment settling in the weir during/after an event V-notch box needs to be frequently checked that it is still levelled out.	**Manufacturing of box:** medium **Installation in the field:** medium **Maintenance:** medium (during high rainfall intensity events lots of sediment accumulation and cleaning after each major event necessary) **Data collection:** for a 10 min interval a mini-diver/ baro-diver has a storage capacity of > 160 days	V-notch box:< 50€ Mini-Diver and Baro-Diver ca. 1000€	Highly valuable data for low effort after the weir has been installed. Except for necessary sediment cleaning after high rainfall intensity events low maintenance and data collection effort.

5. Conclusion

Hydrological dynamics of three adjacent large-scale hillslopes (spatially variable rainfall input, shallow water table dynamics, hillslope trench flow, overland flow, and stream runoff) were monitored with a variety of partly self-made instruments. We hope the detailed description on how to construct and install the instruments used in our study and the evaluation of different techniques provide guidance to researchers new in the field of experimental hillslope hydrology. Similar reports for other areas of experimental hydrology (e.g. snow hydrology, urban hydrology) would be desirable.

Acknowledgements

Special thanks go to Emil Blattmann, who constructed most of the technical equipment and helped during field installation. Without his commitment this work would not have been possible. We also thank all people who helped with fieldwork: Jakob Sohrt, Benjamin Grahler, Andreas Hartmann, Fabian Ries, Jakob Garvelmann, Christian von Sperber, Matthias Ritter, Klemens Rosin, Anita Gundel, and Ramona Skozilas.

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