Runoff generation in an alpine research catchment – methods, results, data base

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Abflussbildung in einem alpinen Forschungseinzugsgebiet – Methoden, Ergebnisse und Datenlage

Introduction

Runoff generation is a result of the interplay of a range of processes, the relative importance of which varies, among other things, with climate, catchment properties and catchment scale. Within the same catchment, the process features are different from event to event, depending on pre-event conditions and rainfall intensity. A better understanding of these spatio-temporal patterns of runoff generation is critical for obtaining realistic model simulations of events, such as extreme floods and runoff behaviour associated with changes in environmental and land use conditions. One means of addressing the complexity and variety of processes is to try and isolate dominant processes and to observe them at appropriate scales (Kirnbauer and Haas, 1998, Peschke et al., 1999).

Field site, instrumentation and methods

The Löhnersbach research catchment is situated near the skiing resort Saalbach in the province of Salzburg, Austria (47°20 N, 12°40 E). The research basin is a 16 km^2 alpine catchment. Elevations in the catchment range between

Zusammenfassung

Im alpinen Testeinzugsgebiet Löhnersbach (Österreich, Bundesland Salzburg) wurden von 1991 bis 2005 die Abflussbildungsprozesse in verschiedenen Maßstabsbereichen (7 ha bis 150 km^2) untersucht. Dieser Beitrag gibt einen Überblick über die Art der Untersuchungen, die Beobachtungsdaten und die erzielten Ergebnisse. Herkömmliche Niederschlags- und Abflussbeobachtungen wurden mit Beregnungsversuchen, geophysikalischen Erkundungen und Tracerversuchen kombiniert. Die Gebietseigenschaften (Topographie, Vegetation, Hydrogeologie und Bodeneigenschaften) wurden kartiert und liefern gemeinsam mit den hydro-meteorologischen Beobachtungsdaten die Basis zum besseren Verständnis der Abflussprozesse. Ein Gebietsmodell mit Berücksichtigung der raschen und langsamen Abflusskomponenten wurde entwickelt und an verschiedenen Standorten überprüft. Alle Beobachtungsdaten sind in einer Datenbank abgespeichert und stehen für weiterführende Forschungsvorhaben zur Verfügung.

Schlagwörter: Sättigungsflächen, Abflussentstehung, hydrologische Modellierung.

Summary

In the alpine research catchment Löhnersbach (Austria, province of Salzburg), runoff generation processes were investigated from 1991 to 2005 at different scales (7 ha to 150 km^2) in a hierarchical, nested observation network. This paper gives an overview of the investigations performed, results achieved and data collected. Conventional rainfall runoff observations were combined with irrigation experiments, geophysical exploration and artificial tracer methods. Catchment characteristics (topography, vegetation, soils, hydrogeology and lithosphere) were mapped in addition to the hydrometeorological observations, directed towards a better understanding of surface and subsurface runoff processes. A two-parts catchment model was derived and subject to a multi-site validation. All data are incorporated in a database and available for further research.

Key words: Saturation areas, surface and subsurface flow, hydrological modelling.

1100 and 2200 m a.s.l. The vegetation is characterized by spruce forests, alpine pasture and alpine roses above the timber line. The topography is typical of the greywacke bedrock formed by glaciers and rock slides. Fissures, fractures and caverns caused by slope deformations created possibilities for internal drainage along preferential pathways. Springs emanating from these pathways tend to form permanently soaked areas on concave terrain, referred to as "saturation areas". The soils on these areas are gley with very low permeability. These saturation areas cover about 8% of the whole catchment. Figure 1 (left) shows the complete drainage network, the location of the saturation areas and the receiving waters of the Löhnersbach (Figure 1, right). Including observations from the standard network of the hydrographical service, the investigations covered catchment areas of 0,07 km², 1 km², 16 km² and 150 km². For more information see KIRNBAUER et al. (2009)

Simple hydrometeorological rainfall-runoff observations on saturation areas have shown the significance of subsurface flow for the runoff generation process. Subsurface flow had been clearly observed in the micro-scale subcatchment Limbergalm (Figure 2). Thus, where specific investigations were performed in cooperation with the Federal Research and Training Centre for Forests, Natural Hazards and Landscape (Innsbruck), GFZ Potsdam and the Universities in Freiburg, Vienna and Bochum (2001 and 2002). The results of irrigation experiments, geoseismic and geoelectric investigations, along with tracer hydrological and hydrochemical studies were combined with the long term rainfall runoff observations performed in the catchments. The results and details for the tracer methods are given in TILCH et al. (2006a & 2006b).

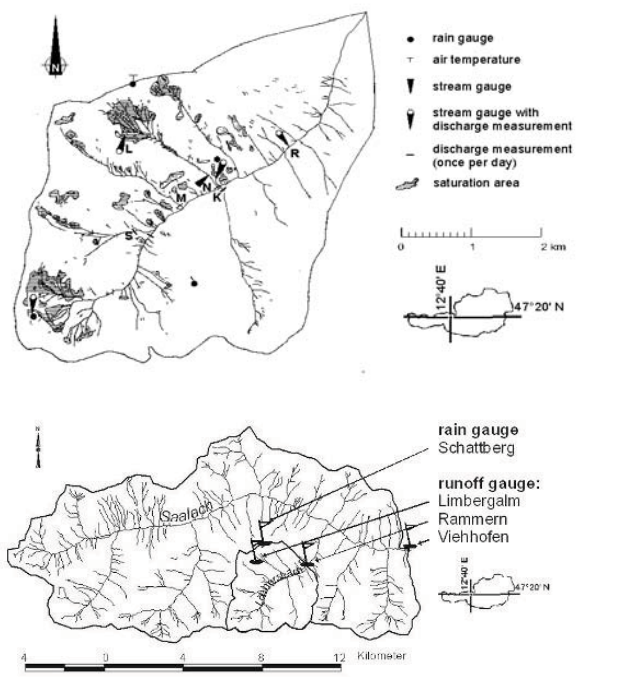

Figure 1: Observational network in the Löhnersbach catchment (left) and of the nested study area of the upper Saalach basin (right): upper Saalach (150 km^2, gauge Viehhofen), Löhnersbach (15,5 km^2, gauge Rammern "R"), and Limberg (0,07 km^2, gauge Limberg "L"; situated above the timberline)

Abbildung 1: Lageplan des Beobachtungsnetzes im Löhnersbachgebiet (links) und des übergeordneten Einzugsgebiets der Saalach (links)

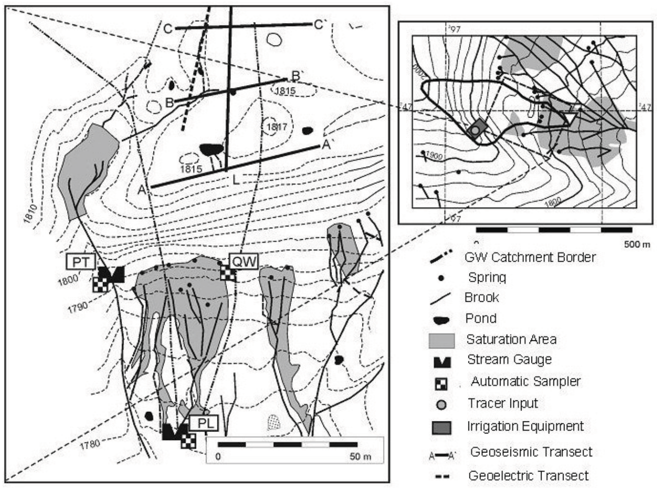

Figure 2: Headwater catchment Limbergalm ("L" in Figure 1) with stream network, saturation areas, ponds and springs

Abbildung 2: Quellbereich Limbergalm ("L" in Abb. 1) mit Gewässernetz, Sättigungsflächen, Speicher und Quellen

Results

Model concept and model structure for quick runoff response

The detailed investigations in the Limbergalm catchment provided the basis for modeling quick runoff generation in the headwaters of the Löhnersbach catchment (see Figure 3). The fraction q_{GW1} soaks the saturation area, initiating quick saturation overland flow q_{SOF} in case of precipitation. During more intense events, an episodic quick sub surface reaction q_{duff} is initiated beneath the duff layer, upstream from the saturation area. This increases the amount of runoff from there. Fraction q_{GW2} partly appears in springs or disappears as deep seepage q_{out} respectively. In general, the surrounding of all the saturation areas in the catchment is very similar to that sketched in Figure 3a, especially on the left hand slopes of the Löhnersbach valley.

The model for the micro-catchment was tested making use of runoff measurements from the gauge at Limbergalm ("L" in Figure 1, "PL" in Figure 2 and Figure 3a) and precipitation data from rain gauge at Schattberg (see Figure 1, right) measured during the summer months of 1997 (mid June until end of September) for calibration and the summer months of 1998–2002 for validation. This limitation to summer times is due to the fact that real processes in winter cannot be measured correctly because they are covered up by snowmelt, by freezing of discharge on the saturation areas and by enhanced catch deficit of the rain gauge during snowfall (ZILLGENS et al., 2005).

The catchment model

The basic concept of the model for simulating runoff from the total Löhnersbach is to describe rapid processes – saturation overland flow (q_{SOF}) and quick subsurface flow (q_{duff}) – that are physically sound and in high time resolution. The slower subsurface flow components are modelled using conceptual hydrotope approach combined with a cascade of linear reservoirs. The model for the quick processes (q_{SOF} and q_{duff}) follows a simplification of the St. Venant equations with the diffusion analogy (MERZ, 1996) and is applied for the many saturation areas in the Löhnersbach catchment. Runoff from the major part of the catchment is dominated by subsurface processes. These are modelled with an approach similar to that used in the HBV-Model

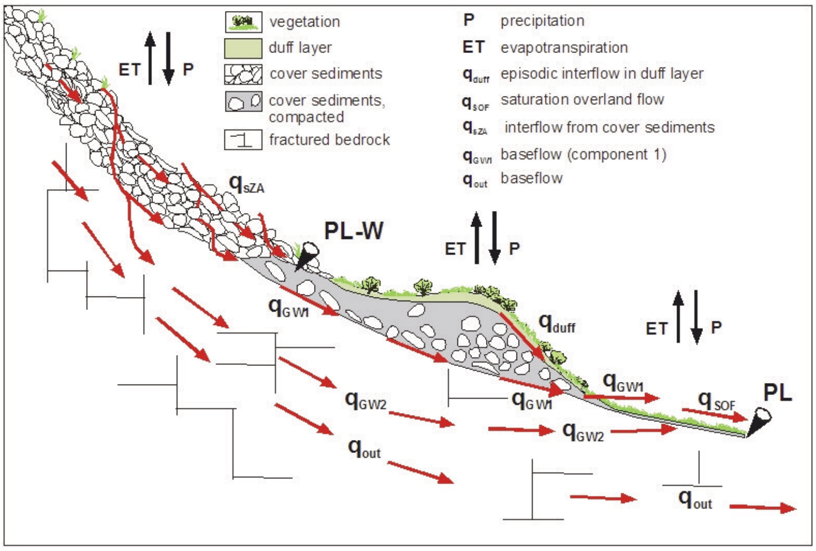

Figure 3a: Model concept for quick and slow runoff response, derived from hydrogeological investigations, interpretation of rainfall-runoff data and tracer, hydrochemical and geophysical investigations in the Limbergalm catchment

Abbildung 3a: Modellkonzept mit Berücksichtigung der raschen und langsamen Abflusskomponenten

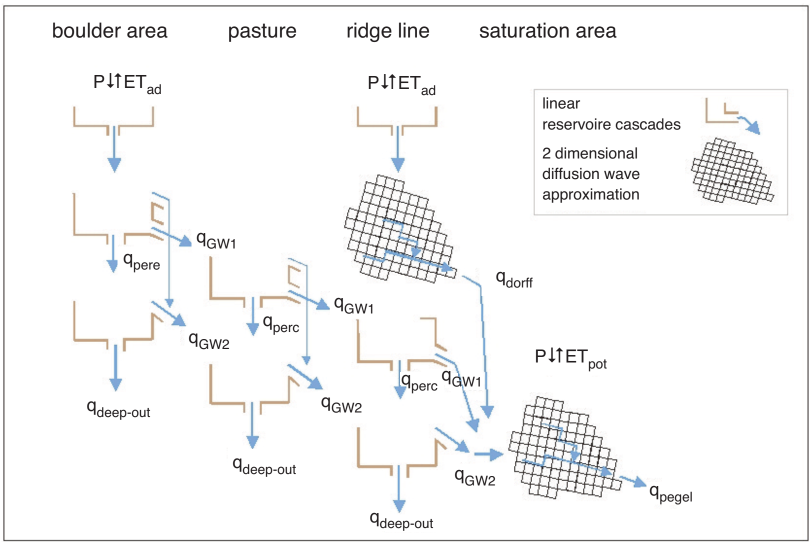

Figure 3b: Model structure for quick and slow runoff response according to the concept displayed in Figure 3a

Abbildung 3b: Modellstruktur basierend auf dem Konzept gemäß Abbildung 3a

Table 1: Calibration parameters of the model, timestep 15 min
Tabelle 1: Kalibrierungsparameter des Modells (bei 15 min Zeitschritte)

Parameters of the diffusionanalogy	Description	Wert	Einheit
K_{str}	Roughness parameter for saturation overland flow	1.5	$[m^{1/3}/s]$
K_{str_z}	Roughness parameter for duff layer flow	0.5	$[m^{1/3}/s]$
Parameters of the reservoirs			
q_{GW1}	permanent groundwater flow		
k1	Time constant for cover sediments and compacted cover sediments	0.010	$[Dt^{-1}]$
k_perc1	Time constant for seepage through cover sediments	0.001	$[Dt^{-1}]$
volmax1	Maximum storage volume	38.0	[mm]
q_{GW2}	episodic groundwater flow		
k2	Time constant for fractured bedrock	0.100	$[Dt^{-1}]$
k_perc2	Time constant for seepage through fractured bedrock	0.004	$[Dt^{-1}]$
volmax2	Maximum storage volume in fractured bedrock	210.0	[mm]

(BERGSTRÖM, 1992). For calibration parameters see Table 1. The model is fully distributed with these two different approaches for quick and slow runoff components. For more details see ZILLGENS et al. (2005).

The model was applied to the whole Löhnersbach catchment. A multi-site validation during the flood period of 2002 gave satisfactory simulation results compared to daily runoff measurements from the tributaries of the Löhnersbach (salt tracer dilution method). As can be seen from Figure 4, the model describes the contrasting runoff responses on the two hillsides of the valley (KIRNBAUER et al., 2005): The dots, crosses and triangles denote observed runoff, the solid lines in corresponding colours are simulated hydrographs of the respective streams. The streams Klammbach (observation point “K” in Figure 1 left; black line and signature + in Figure 4 left) and Neuhausengraben (observation point “N” in Figure 1 left; green line and signature triangle in Figure 4 left) have the most contrasting runoff regimes of all torrents in the catchment. The simulation results are of similar quality although, none of the observations fromt those torrents were used for model calibration. This is an argument that the model has good results for the right reasons.

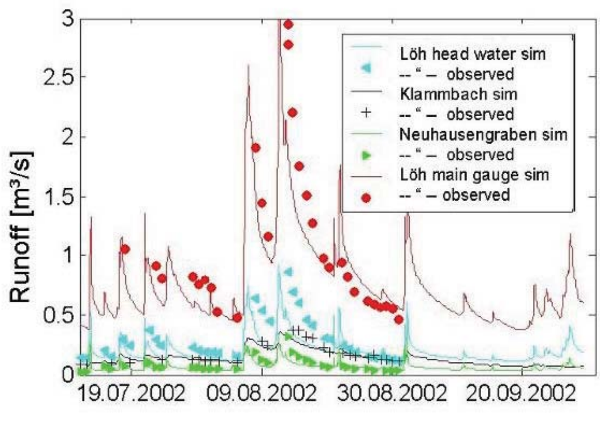

Figure 4: Multi-site validation of the Löhnersbach tributaries (data not used for calibration)
Abbildung 4: Validierungsergebnisse an verschiedenen Zubringern

An intercomparison of runoff characteristics across scales (0,07 – 15,5 – 150 km²) showed that the processes observed at the smallest scale is an indicator for those processes at greater scales (ZILLGENS et al., 2007).

The Löhnersbach data base

To complete the project, a database was established that incorporated all the data collected from the Löhnersbach catchment (i.e. hydrological, morphological, vegetation, soil, geology) into a GIS environment, as well as an external database for the hydrological data (see Figure 5).

All these data are collected on a DVD and can be provided for researchers interested in runoff generation in alpine catchments, in cooperation with the Vienna University of Technology.

Conclusions

Based on long time observations of rainfall runoff processes, some knowledge about the significance of subsurface runoff was achieved, which initiated detailed field work with adequate methods to investigate this phenomenon. Based on these new data and experiences, a two-part catchment model was set up. Rapid runoff processes from typical parts of the catchment, e.g. saturation areas, are physically modelled with fine resolution time steps on a small grid. For the remainder of the catchment a conceptual hy-

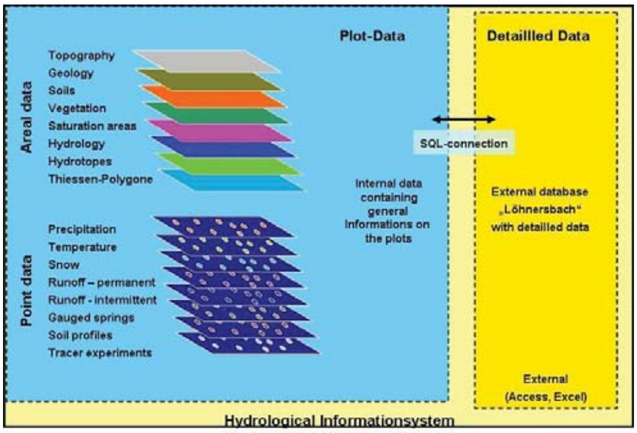

Figure 5: Database for the Löhnersbach catchment
Abbildung 5: Datenbanksystem des Löhnersbach Einzugsgebiets

drological approach was used. A multi-site validation of the model gave satisfactory results, suggesting that the model is valid.

As the project involved a considerable length of time for field work, a significant resource of numerical and other data has been accumulated. This data is stored in the Löhnersbach database, which is available on a DVD for further research in cooperation with the Institute for Hydraulic and Water Resources Engineering, Vienna University of Technology.

References

Bergström, S. (1992): The HBV-model – its structure and applications. SMHI Hydrology Report No. 4, Swedish Meteorological and Hydrological Institute Narrkoping, Sweden.

Kirnbauer, R. and Haas, P. (1998). Observations on runoff generation mechanisms in small Alpine catchments. *In* “Hydrology, water resources and ecology in headwaters.” (K. Kovar, U. Tappeiner, N. E. Peters and R. G. Craig eds.; Proc. of the HeadWater’98 Conference, Meran, Italy, Apr. 1998). IAHS Publ. no. 248, pp. 239–247.

Kirnbauer, R., Blöschl, G., Haas, P., Müller, G., Merz, B. (2005): Identifying space-time patterns of runoff generation – A case study from the Löhnersbach catchment, Austrian Alps. In: ‘Global change and mountain regions – a state of knowledge overview’. Ed.: Ulli Huber, Harald Bugmann & Mel Reasoner; Springer Verl., pp. 309–320.

Kirnbauer, R., Haas, P., Chifflard, P., Zillgens, B., Tilch, N. (2009): Hochwasserentstehung in der nördlichen Grauwackenzone. Abschlussbericht. Hrsg.: Abteilung für Ingenieurhydrologie und Wassermengenwirtschaft Technische Universität Wien. 218 S., 196 Fotos, 141 Abb., 39 Tab. Wien, 2009.

Merz, R. (1996): Modellierung des Niederschlag-Abfluss-Vorgangs in kleinen Einzugsgebieten unter Berücksichtigung der natürlichen Variabilität. Dissertation, Mitteilungen des Instituts für Hydrologie und Wasserwirtschaft, Universität Karlsruhe, Heft 56, 215 S.

Peschke, G., Etzenberg, C., Müller, G., Töpfer, J. and Zimmermann, S. (1999). „Das wissensbasierte System FLAB – ein Instrument zur rechnergestützten Bestimmung von Landschaftseinheiten mit gleicher Abflußbildung.“ IHI-Schriften, H.10, Internat. Hochschulinstitut Zittau.

Tilch, N., Uhlenbrook, S., Didszun, J., Wenninger, J., Kirnbauer, R., Zillgens, B. & Leibundgut, C. (2006a): Hydrologische Prozessforschung zur Hochwasserentstehung im Löhnersbach-Einzugsgebiet (Kitzbüheler Alpen, Österreich). – Hydrologie und Wasserbewirtschaftung 50(2): 67–78.

Tilch, N., Zillgens, B., Uhlenbrook, S., Kirnbauer, R. & Merz, B. (2006b): GIS-gestützte Ausweisung von hydrologischen Umsatzräumen und Prozessen im Löhnersbach-Einzugsgebiet (Nördliche Grauwackenzone, Salzburger Land). – Österreichische Wasser- und Abfallwirtschaft 58 (9–10): 141–151.

Zillgens, B., Merz, B. and Kirnbauer, R. (2005): Tracing runoff generation processes through different spatial scales; Data analyses and modelling approach. In: HEADWATER 2005, Bergen, Norway, Conference CD: Section 9 CATCHMENT AND STREAMFLOW HYDROLOGY 135.pdf; Abstract: http://headwater. nve.no/-abstractSessionOverview.php#9

Zillgens, B., Merz, B., Kirnbauer, R. and Tilch, N. (2007): Analysis of the runoff response of an alpine catchment at different scales. Hydrol. Earth Syst. Sci. (HESS), 11, 1441–1454, 2007.

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