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HYDROBOD: obtaining a GIS-based hydrological soil database and a runoff coefficient calculator for Lower Austria

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Abstract

In the State of Lower Austria, rainfall-runoff models it is an acknowledged method used when estimating flood peak discharges for small catchments where there are no direct gauging observations. An important input parameter for these models is the volumetric runoff coefficient, which was estimated by rather simple methods until now (for instance the CN-method of the U.S.G.S), which did not provide very reliable results.
The project HYDROBOD intends to provide a solid and homogeneous database of some basic soil hydraulic parameters over the whole state area (over 19.000 km²) and contains a hydrological model for estimation of these runoff coefficients which takes into account some relevant input variables.
In a first step (HYDROBOD I), hydraulic soil parameters are calculated by regionalization methods and assembled for the whole area of Lower Austria, using a GIS-database (ESRI ArcGIS 10.2; at a 50 x 50 m grid). They include soil layer depth, storage capacity, saturated vertical conductivity, plus a classification of the soil reaction types referring to storm events. These data are now available for three soil layers, from top soil down to 1 m below surface. In a second step (HYDROBOD II), a vertical one-dimensional event model was set up which allows to calculate storm event runoff coefficients on a cell-by-cell basis for any given area in Lower Austria.
This model uses the hydraulic soil parameters obtained from HYDROBOD I, plus an estimation of unsaturated vertical pore flux and a soil water storage model with several modules. This model needs the following input parameters: a shape-file with the catchment area, and pairs of rainfall data (duration + rainfall depth).
Results of a calculation process are: runoff coefficients (as an average over the catchment area) for each pair of rainfall data, and for different initial wetness scenarios (from "dry" to "saturated"). Validation of the model is promising.

Keywords: *runoff coefficient, soil classification, soil mapping, soil hydraulic properties, regional scale, Lower Austria*

Rezumat. HYDROBOD: obținerea unui SIG – bazat pe o bază de date cu soluri hidrologice și un calculator al coeficientului de scurgere pentru Austria de Jos

În statul federal Austria de Jos, modelul ploaie-scurgere este o metodă recunoscută si utilizata în estimarea debitelor maxime ale viiturii, în bazine hidrografice mici, acolo unde nu exista măsurători hidrometrice directe. Un important parametru de intrare pentru aceste modele este coeficientul de scurgere volumetric, care până în prezent a fost estimat prin metode destul de simple, (de exemplu, metoda CN a U.S.G.S), însă aceasta nu a oferit rezultate foarte fiabile.
Proiectul HYDROBOD își propune să ofere o bază de date solidă și omogenă a unor parametrii hidraulici de sol de bază pe întreaga suprafață a statului (peste 19.000 km²) și conține un model hidrologic pentru estimarea coeficienților de scurgere, care să țină cont de anumite variabile relevante de intrare. În prima etapă (HYDROBOD I), parametrii hidraulici ai solului se calculează prin metode de regionalizare și se asamblează pentru întreaga Austriei de Jos, folosind un baze de date SIG (ESRI ArcGIS 10.2; 50 x 50 m celulă). Acestea includ adâncimea stratului de sol, capacitate de stocare, conductivitate verticală saturată, plus o clasificare a tipurilor de reacție a solului specifice evenimentelor pluviale. Datele sunt acum disponibile pentru trei straturi de sol, de la suprafața solului în jos, pană la 1 m. În a doua etapă (HYDROBOD II), a fost reglat un model eveniment vertical unidimensional, care sa permită calculul coeficienților de scurgerile pentru o ploaie in fiecare celulă din zonă Austriei de Jos. Acest model utilizează parametrii hidraulici ai solului obținuți din HYDROBOD I, plus o estimare a fluxului vertical a porilor nesaturați și un model de retenție a apei in sol cu mai multe module. Modelul are nevoie de următorii parametri de intrare: un fișier cu forma bazinul hidrografic și un set de precipitații (durata si strat). Rezultatele calculelor sunt: coeficienți de scurgere (ca medie pe bazinul hidrografic) pentru fiecare pereche un set de precipitații pentru diferitele scenarii de umiditate inițiala (de la "uscat" la "saturat"). Validarea modelului este promițătoare.

Cuvinte-cheie: *coeficient de scurgere, clasificarea solului, cartarea solului, proprietăți hidraulice ale solului, scara regionala, Austria de Jos*

Introduction

The estimation of the hydrological response of a catchment on precipitation with high intensity represents a major issue in fluvial hazard mitigation which often consists of designing hydraulic retention structures. Different approaches are available to assess the runoff behaviour of complex landscape regions e.g. Mishra and Singh (2003), Schmocker-Fackel (2007) or Peschke (1999).

All of them are based on an existing database about the geo-, pedo-, and bio-inventory including additional information about land use issues. For the estimation of hydropedological parameters like the distribution of the pore volume or the saturated

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hydraulic conductivity from known soil properties, diverse approaches exist, e.g., Wösten et al. (2001) or Puhlmann and von Wilpert (2011).

A multiplicity of different rainfall-runoff models is using hydropedological parameters (e.g. Schulla, 1997) as well as generated conceptual hydrological maps (e.g. Kohl, 2011). While deterministic models need a very specific knowledge about site characteristics, empirical models often do not respect physical characteristics of the site.

For small ungauged catchments, it is common in Lower Austria to use rainfall-runoff models in order to calculate flood design discharges. Lower Austria is Austria's largest state, with a total area of more than 19.000 km², and with elevations between 150 and 2000 m above sea level.

The climate ranges from semi-arid to semi-humid. Figure 1- left shows the project area, and Figure 1- right, a map of mean annual precipitation Austria.

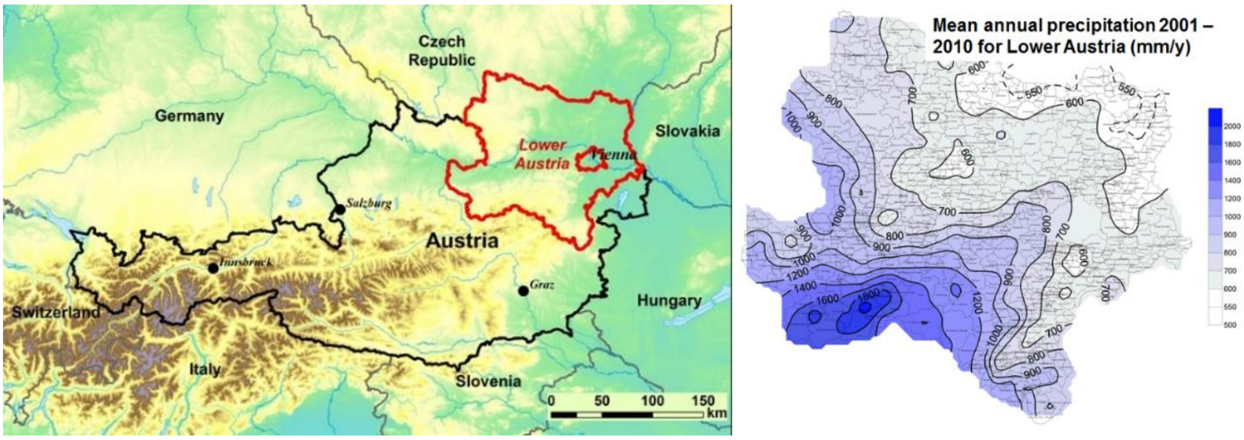

Fig. 1: Location of the project area (left) Mean annual precipitation in Lower Austria (right)

Materials and methods

One main input parameter for these rainfall-runoff models is the volumetric runoff coefficient, which represents the relation between the part of the rainfall that contributes to the flood wave, divided by the total rainfall (equation 1).

$$y = N_{eff}/N_{total} \qquad (1)$$

where:

y = runoff coefficient
N_{eff} = effective rainfall
N_{total} = total rainfall

Before the HYDROBOD project, the volumetric runoff coefficient was estimated by rather simple methods using a relation to land cover and a gross estimation of the density of the soils. However, until shortly ago, no continuous database of soil parameters was available to cover the whole area of Lower Austria.

The actual availability of lots of data concerning orography, geology, soil maps and land cover allowed to start an ambitious project to put these together and obtain a new database and a tool which might help to calculate the runoff coefficient in a different way, with more reliable results. This project is carried out in two steps:

HYDROBOD I

The goal of the first part of this work (HYDROBOD I) was to obtain a continuous GIS-based data set for the whole area of Lower Austria (plus a buffer outside the border line), in a 50 x 50 m grid, with soil parameters which are relevant for hydrological processes, such as soil layer depth, storage capacity, saturated vertical conductivity, plus a classification of the soil reaction types referring to storm events.

These data are now available for three soil layers, from top soil down to 1 m below surface (or less, if soil thickness is smaller): 0 - 20 cm; 20 - 50 cm; 50 - 100 cm).

These soil hydraulic parameters were calculated cell-by-cell, using the available information about elevation, soil types (including soil maps), geological maps, land use, etc., and applying pedo-transfer functions which were calibrated by using point data from Lower Austrian soil inventory.

For agricultural land, soil information input (soil maps, point data) is available at a high spatial density; however, in forest areas, the available information comes from a rather widely scattered network of sample points. Figure 2 shows the calculated storage capacity as an example for the results.

HYDROBOD II

In the second part of the work, an ESRI GIS-based tool was developed which allows estimating a volumetric runoff coefficient for storm events, on a cell-by-cell basis, for any pair of precipitation input data (duration + rainfall depth).

It is a 1D model, based on vertical columns for each grid cell. No restrictions are made for horizontal efflux from the system cells in any layer.

These were the requirements for the tool:

- storage model which contains the main flux and storage processes in every vertical column (each grid cell from a 50 x 50 m grid);
- running in ESRI ArcGIS 10.x;
- giving results for any defined shape file ("catchment") within the project area (Lower Austria + buffer);
- for any pair of values for rainfall events (given by event duration + rainfall depth);
- scenarios "with" and "without" capping (due to silting);
- 4 different initial wetness scenarios (at the beginning of the event): dry, medium, wet, saturated.

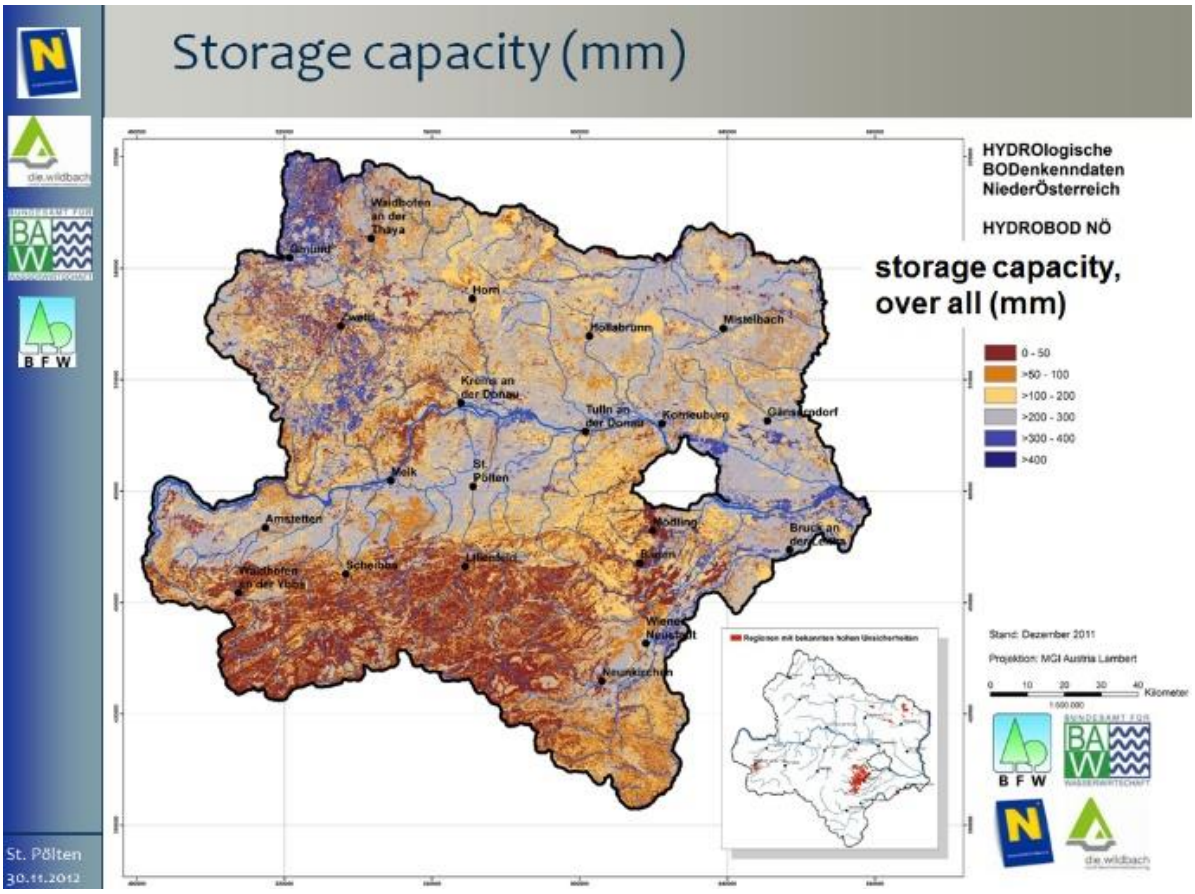

Fig. 2: Calculated storage capacity (for top 100 cm of soil)

The program provides the results in a text file and (as option) also in maps. A storage model was set up to simulate the behavior of the soil surface and three soil layers down to 1 m below surface.

It was calibrated with data from several catchments and research plots.

For this tool, results of "HYDROBOD I" are used as input parameters. Additionally, an estimation of unsaturated vertical pore flux [using the "G-value" concept according to the definition of Smith and Parlange (1978), see equation (2)] is applied.

$$G = \frac{1}{K_s}\int_{-\infty}^{0} K(\psi) * d(\psi) \qquad (2)$$

where:

G = effective net capillary drive;
K_s = saturated hydraulic conductivity;
ψ =matrix potential;
$K(\psi)$ = hydraulic conductivity at matrix potential;
d = diffusivity.

The calculation itself uses a one-dimensional soil water storage model, consisting of several modules (Fig. 3), to calculate vertical flux and lateral efflux. Referring to initial wetness scenarios, HYDROBOD II allows to calculate different initial wetness scenarios, using a topographic wetness index to classify areas where the wetness class is increased or decreased by one step in respect to the orographic position (for slopes higher than 2%). Another module takes into

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account the effects of capping (siltation), and simulates decreases in saturated vertical hydraulic conductivity of the upper soil layer between 0 and 90%, depending on the soil type and the land use.

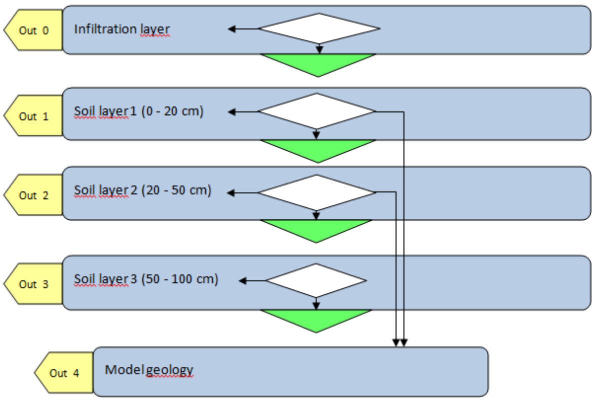

Fig. 3: Scheme of modular concept HYDROBOD II

Results and discussions

Figure 4 shows a result for a catchment in the Flysch region of Lower Austria, the catchment of Boeheimkirchen/Perschling (app. 50 km²), for design precipitation of 100 years return period. The HYDROBOD database is limited in its accuracy due to the fact that for forested regions there was a scarcity of good data, and therefore regionalization methods had to account for the estimations.

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Moreover, the size of the grid cells (50 x 50 m) is a limiting factor for spatial resolution. The storage model takes into account only 1-dimensional flux for a rainfall event. It is an event model, neglecting evaporation or other fluxes from down to up.

Further studies will have to be performed, to define which linear combinations of wetness scenarios are relevant in different parts of Lower Austria to obtain the best predictor for the runoff coefficient, in order to combine it with the given design precipitations of different time durations, for the calculation of appropriate flood waves.

Advantages of HYDROBOD:

- quick calculation of runoff coefficients, without need of field exploration;
- homogeneous data set for whole Lower Austria; flexible tool, also apt to calculate historic events;
- capable of calculating different initial wetness scenarios;
- map of soil hydraulic parameters also useful for other projects and studies.

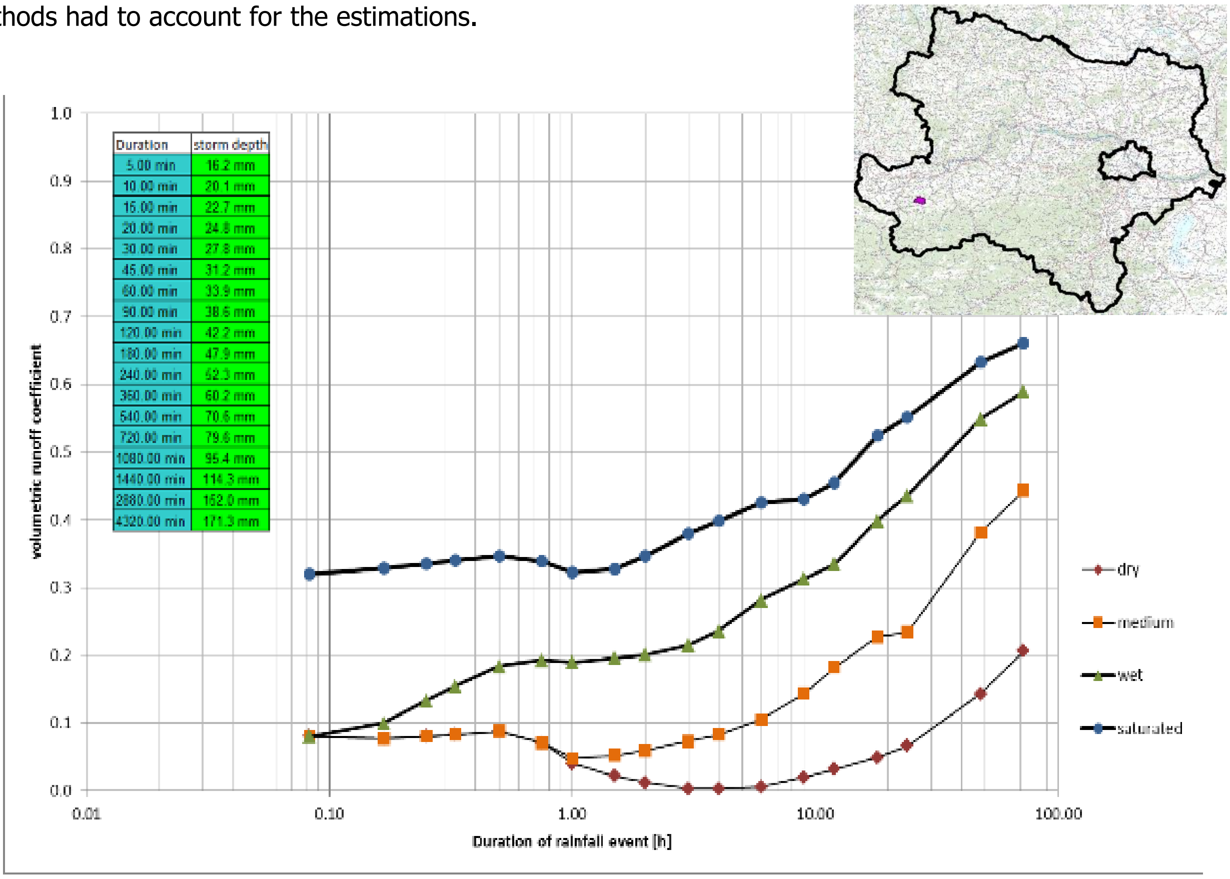

Fig. 4: The runoff coefficients for the 100-year's rainfall event at different wetness scenarios in "Boeheimkirchen/Perschling" catchment (up)

Conclusion

The HYDROBOD project provides the first homogeneous GIS database of hydrological soil parameters that covers whole Lower Austria.

Furthermore, a GIS-based model allows a quick calculation of volumetric runoff coefficients which can be used in rainfall-runoff models, for any given area within Lower Austria, and at different initial wetness scenarios.

Acknowledgements

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