Catchment Hydrological and Biogeochemical Processes in a Changing Environment

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Hydrological studies performed mostly in small catchments addressed a variety of issues. They were focused on several aspects of runoff generation including application of the knowledge in the assessment of the origin of nitrates in the streams, lysimeter studies, snow hydrology and the assessment of impacts of anticipated climate and land use changes.

Runoff generation

Herrmann et al. (2001) developed the Integrated Catchment Approach (ICA) for application in catchment hydrology research The ICA is based on combined application of tracers, GIS, mathematical models, etc. Runoff generation was studied in different environments with different land use: alpine-highland-lowland, dominant porous-fractured rock aquifer, agricultural (with/without irrigation)-forestry, humid mid-latitude-monsoon climate catchments located in Europe and South Asia. The analysis of runoff generation in eight central European catchments (Herrmann, 2002) showed that groundwater was by far the major components of flood hydrographs in all types of environments (lowland, highland, alpine). Several experiments with artificial tracers (Vitasin Blue AE-90, bromide, D_2O, mixtures of pesticides) in agricultural soils in Nepal and Germany showed that preferential flow paths may play an important role for transport of agrochemicals and hence groundwater contamination (Schumann, 2004; Schumann et al., 2004). The role of preferential flow in the leaching of nitrate from arable soils using the dual permeability model was studied also in the Czech Republic (Doležal et al. 2004, 2005).
A number of issues connected with runoff generation was studied by Uhlenbrook et al. (e.g. 2002, 2003). Extensive field measurements in the network of boreholes clearly demonstrated important contribution of groundwater during flood events in the Black Forest Mountains, Germany (Wenniger et al., 2004). Long-term separation of hydrograph components in the Brugga catchment, Germany (Uhlenbrook et al., 2002) showed that during the period of almost three years the mean event water contribution to total catchment runoff was only about 11%. A modified methodology of 3- and 5-component hydrograph separations using ^{18}O and silica was proposed (Uhlenbrook and Hoeg, 2003). The analysis of uncertainties in hydrograph separations showed that only qualitative results on hydrograph components can be obtained by hydrograph separation.
Tesař et al. (2001) proposed the concept of retention-evapotranspiration unit to explain the relationship between soil moisture regime and runoff generation in mountainous catchments of the Czech Republic. According to the concept, the catchment runoff is the result of two transformations. The first one - transformation of rainfall to the outflow from the soil into the more permeable drainage layer, represents the rainfall water movement through the soil in a vertical direction. The second one -

transformation of outflow from the drainage layer to the runoff, represents transport of water in the drainage layer on the sloping impermeable horizon to the stream. The proportion of both transformations during runoff formation changes in accordance with the phase of the soil water regime. During the percolation phase, water flows through the soil into the drainage layer and outflows into the stream in discharge waves immediately reacting to precipitation. During the accumulation phase, the rainwater accumulates in the soil and does not outflow into the drainage layer. During percolation phase, the rising hydrograph limb grows very quickly and its duration is short (a few minutes or hours). Later, the soil water content and consequently the outflow and runoff decreases, the accumulation phase begins and the falling hydrograph limb is generated.

Precipitation peaks are attenuated in the soil and in the drainage layer. The biggest attenuation takes place in the drainage layer. The runoff peak in catchment Liz, southern Czech Republic, reached up to 10% of the precipitation peak. The source area, in which the runoff peak was generated, represented about 25% of the whole catchment area. The width of the source belt bordering the flow channels did not exceed about 90 m. During the whole vegetation season, 50% of seasonal precipitation sum was used for plant transpiration, 25% run off, and 25% was stored in the drainage layer.

Various aspects of soil moisture/runoff generation relationship were studied also in the lowlands. Somorowska (2002) investigated the extreme stages of the wetness conditions in a lowland catchment Lasica in central Poland. Temporal decrease of soil water storage was presented as a function of groundwater level change and storage coefficient. The function was used to estimate water demands needed to preserve the valuable protected wetland ecosystem during dry conditions (Somorowska, 2002a). Analysis of the long-term variability of precipitation, groundwater tables and discharges along with the assessment of the soil water storage indicated that the catchment was more sensitive to water deficit than water surplus (Somorowska, 2003). Combined analysis of water storage in the soil profile and the recession analysis based on runoff measurements at catchment outlet revealed substantial dynamics of the surface-subsurface interactions (Somorowska, 2004). Merging of the soil water storage at a plot scale with discharge and dynamic groundwater storage at a basin scale helped bridge observational and modeling scales of the soil water study. Measured soil moisture data was also used to evaluate the satellite products (NOAA NCEP/NCAR and ERA-40 ECMWF reanalysis data). It was found out that the reanalysis data products generally reproduced the dynamics of soil moisture correctly (Somorowska, 2005).

Doležal and Kvítek (2004) applied knowledge of runoff generation (schematised into recharge, transitional and discharge zones) in explanation of the origin of nitrates in surface streams in highland regions of the Czech Republic. Separation of runoff components in the small experimental catchment of the Kopaninský creek indicated that the highest concentrations of nitrates were connected with interflow. The finding was tested in other catchments in the region. While the interflow still seemed to be the "main polluter" in a slight majority of catchments, the results indicated that baseflow or direct runoff were more important sources of nitrate pollution in other catchments. It was suggested that the nitrate concentration patterns could meaningfully characterise the peculiarities of individual regions and catchments. The tile drainage hydrographs and water quality patterns were similar to those of small surface streams but nitrate concentrations were significantly higher. The work resulted in the proposal of implementation of an alternative management system of soil and water protection on the landscape scale (Kvítek, 2005).

Lenartowicz (2003) applied a physically based mathematical model in the study of movement of water and solutes in the lowland swampy catchment during vegetation season. Hydrological cycle in such a catchment is dominated by vertical component (net precipitation-evaporation-infiltration). The most important role in groundwater recharge of the catchment was played by long intensive precipitation events. The low intensity precipitation influenced soil moisture only in the top layer of the soil. Except precipitation intensity, the rate of groundwater recharge and migration of solutes is controlled by thickness of unsaturated zone.

Lysimeter studies

Unique long-term lysimeter data (1941-2001) on the influence of vegetation on water balance was presented by Van der Hoeven at al. (2005, 2005a). Four lysimeters (25x25x2.5 m) were constructed in the dunes near Amsterdam. One lysimeter was left bare, others were planted with natural dune scrub, oak-seedlings and seedlings of Pinus Nigra Austriaca, respectively. The dune scrub was trimmed annually till 1972. Annual evapotranspiration from lysimeter-1 with bare soil surface was practically constant (Fig. 1). Lysimeter-2 overgrown with dune scrub showed constant annual evapotranspiration while it was regularly trimmed. When the trimming finished, the annual evapotranspiration was gradually increasing. Evapotranspiration in lysimeters-3 and -4 with oak and pine, respectively, increased rapidly during the first 10 years. Later, it remained constant. The bare soil lysimeter showed an 'usable' fraction of 75% of the average annual precipitation. The scrub, oak and pine vegetation leaving respectively 30%, 35% and 12% of the precipitation usable.

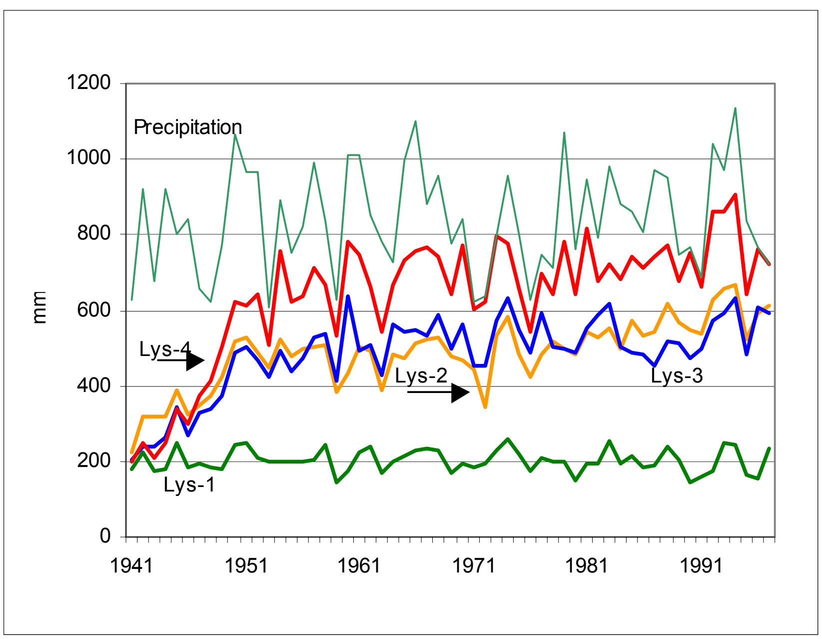

Fig. 1. Annual values of precipitation (upper curve) and evapotranspiration from lysimeters with bare soil (lys-1), dune scrub (Lys-2), oak forest (Lys-3), and pine forest (Lys-4) from 1941 to 1997 at Castricum, the Netherlands. Precipitation data in 1987-1997 were corrected for wind-induced errors.

The least known component of the water balance is the evapotranspiration. Lysimeter data from the lowland area at Rheindahlen, Germany (Schumacher and Wellens,1993) were used to test several methods of evapotranspiration calculation (Van der Velde et al., 2004) – Penman (2 modifications), Priestley&Taylor, Thom&Oliver, Penman-Monteith and Makkink. Comparison of computed and measured values was done separately for rainy and rainless days of warm period (15 April to 15 September) of years 1983 to 1991. The days were selected so that potential evapotranspiration was measured, i.e., the evapotranspiration was not limited by moisture supply. The following conclusions were drawn from the comparison:

- the mainly radiation-based methods (Makkink, Priestley&Taylor, Penmann) showed substantially less scatter in the “calculated - measured” scatterplots than the remaining methods (Thom&Oliver and Penman-Monteith), which are less radiation-based
- the simple Makkink method (inputs – air temperature, global radiation) provided similar results as the more complex Penman method (inputs – air temperature, relative humidity, net radiation and wind speed). In practice, the Makkink method is a good alternative to estimate evapotranspiration through a smaller investment and less intensive maintenance
- there is a significant systematic underestimation of calculated evapotranspiration for rainy days. For the mainly radiation-based methods the discrepancy between the rainy and rainless datasets amounts approximately 6%. For the less radiation-based methods the discrepancy extends to 10 %. The most plausible explanation is that none of the methods, as used in this study, account for the enhancing ET-effect by intercepted water. Only the Thom&Oliver and the Penman-Monteith methods can account for this effect by lowering the canopy resistance incidentally.

Snow hydrology

Stehlík and Bubeníčková (2002) and Jirák (2005) summarised the results of the long-term measurements of snow depth and water equivalents at paired sites (forest-open area). The snow depths and water equivalents in the forest were most of time smaller than in the open area. Only at the end of winter at some places there was more snow in the forest than at adjacent open area. Snow depths and water equivalents decreased in the order young forest (highest values) - meadow-old forest. Snow depths and water equivalents at higher elevations were higher than at lower elevations, but the snow density was rather similar. Kulasová (2005) analysed climatic and snow conditions of the winters in the Jizera Mountains (the wettest part of the Czech Republic) in the period 1900-2005. The data indicate that trends towards weaker or stronger winters can not be detected, although the snow heights since the end of the 1980-ties are smaller (Fig. 2). The highest precipitation amount was measured in winter 1911 (889 mm). The coldest winter (mean air temperature - 4.3°C) occurred in 1942. The longest winter was the one in 1944. The duration of snow cover was 198 days (12 November 1943 to 28 May 1944). The highest snow depth (235 cm) was measured in winters 1970 and 2005. Both winters were climatically similar. It indicates that although the period after 1980 is considered to be influenced by the climate change, the strong winters still occur. Actually, since the year of 2000 there were several winters with a lot of snow.

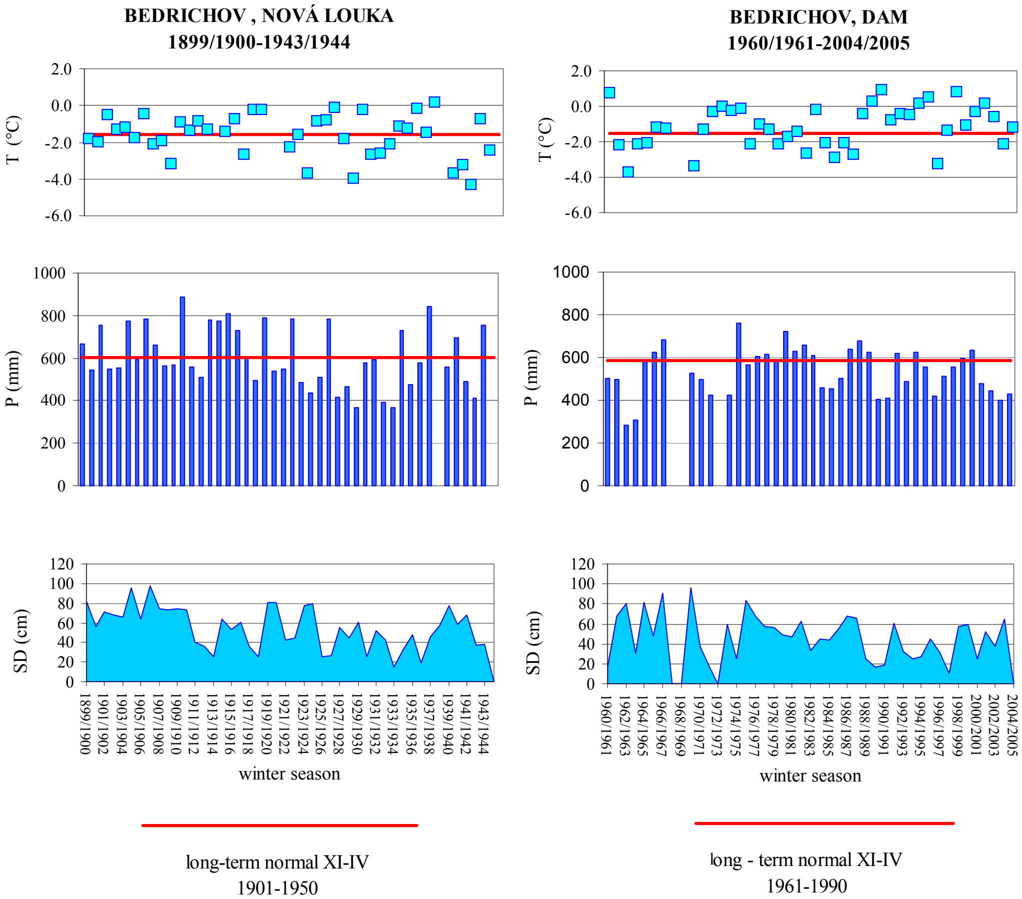

Fig. 2. Climatic characteristics of the Bedřichov station during winter period (November-April); T-mean air temperature, P-precipitation mount, SD-mean snow depth.

Changing environment

Assessment of possible climate and landuse changes impacts was presented in a number of studies. Uhlenbrook et al. (2003) analysed the possible impacts of global change on runoff generation processes of the Brugga catchment, Germany. They concluded that future climatic and land use changes would have significant impact on the recharge of the springs and consequently on quantitative and qualitative characteristics of runoff. They highlighted the importance of the riparian zone and near-stream wetlands for water quality. Herrmann (2004) has worked out some aspects of changes in land use impact on runoff formation process. He argued that although climate warming is supposed to influence runoff regime considerably, runoff generation would be influenced only gradually.

Woronko (2003) and Woronko and Zmudzka (2004) studied the water balance of the Welkie Batorowskie mountain peatland and investigated the influence of changing climatic characteristics. Changes of climatic conditions of the 20th century seemed to favour the future development of the peatland into semi-natural ecosystem. Precipitation trends indicated that water supply of the peatland would continue. Higher spring air temperatures would positively influence the spring-bog water supply.

In a study of the Biebrza wetland in Poland (Nauta et al, 2005) the groundwater model SIMGRO was used to predict consequences of different land use management scenarios. One scenario considered the natural vegetation succession of the peatlands as a serious threat. The second scenario considered a man-made approach, and was designed to check which changes in groundwater levels could be expected by blocking the existing drainage system on the Biebrza riverbanks. The study showed that, with regard to the impact on wetland conditions, the first scenario lead to negative changes in simulated groundwater levels while the second scenario resulted in positive changes.
Physically based model SIMGRO was also used to estimate the impacts of climate-change and drastic land use changes in the world's largest complex of wetlands in Pantanal region, Brasil (Querner et al., 2005). The scenarios were defined to represents the increased rainfall situation, the land use change and mitigation measures. The results indicated that the increase of precipitation would have large effect on the hydrology of the Pantanal. The change in land use would have a very small effect on the discharges.
Pecušová et al. (2004) showed that there was a pronounced decrease of snow water equivalent in the mountainous catchment of the upper Hron river in central Slovakia in the last 40 years (1962-2001). The changes are visible especially in the southern part of the catchment. Highest mountain areas (elevations up to 2000 m a.s.l.) did not exhibit such a pronounced decrease. Holko et al. (2005) suggested that if the climate change follows the scenarios provided by climatologists, the snow water equivalent would be drastically reduced in major part of the catchment.
Holko et al. (2005) revised 40 years of measured runoff data in three small European catchments. They found out that despite the general opinion, the measured data did not indicate a trend towards higher occurrence of high flows in recent years. Similar data was presented by Pekárová et al. (2005) who have analysed long-term water balance data (1965-2004) including runoff regime in several small microcatchments situated in Slovak highlands.

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