Groundwater runoff separation—test of applicability of a simple separation method under varying natural conditions

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Abstract Groundwater runoff was computed for five European basins using the method based on the relationship between the groundwater table and stream discharge. The results highlight the active role of groundwater in basin runoff formation. At least 49% of total basin runoff was contributed by groundwater on average and the groundwater contributions were high also during flood events. Evaluation of separated groundwater runoff using knowledge gained from experimental hydrological research in the basins including tracer studies and hydrometric studies indicated that the results are reasonable.

Key words groundwater runoff; hydrograph separation; groundwater table–stream discharge relationship

INTRODUCTION

Groundwater runoff is an important indicator of available water resources. The separation method introduced by Kliner & Knezek (1974) is a simple but well justified method of groundwater runoff determination based on the relationship between groundwater table and stream discharge using the following principles: considering hydraulic connections between rivers and aquifers, a close relationship between groundwater and stream water levels should exist. Daily groundwater runoff can then be determined by plotting corresponding values of daily discharge vs groundwater table. The upper limit of the points in the graph usually makes it possible to draw an envelope line representing the flux formed by groundwater runoff (Fig. 1(a)). This line can be used to calculate groundwater runoff for any measured groundwater table.
Groundwater runoff calculated according to the envelope line represents minimum groundwater runoff that occurred for a particular measured groundwater table. Typically, the envelope line consists of three sections as shown in Fig. 1(a). It is assumed that sections 1–3 represent different runoff components (groundwater, shallow groundwater plus soil water and the near-surface or overland flow, respectively). Querner (1997) assumes that section 1 can be regarded as the regional flow component (baseflow), section 2 is groundwater flow to shallow drains or ditches and section 3 represents subsurface drains.

If groundwater table and discharge data span a period of several years, the envelope lines can either be constructed separately for individual years, or the whole data set can be used to determine the master envelope line. The differences between the master envelope line and envelope lines determined for a few single hydrological years in the Lange Bramke basin are shown in Fig. 1(b).

**BASINS AND DATA**

The above described groundwater runoff separation method was applied in five basins in Germany (Lange Bramke, Brugga), Luxembourg (Alzette), The Netherlands

<table>
<thead>
<tr>
<th>Basin</th>
<th>Area (km²)</th>
<th>Elevation (m a.s.l.)</th>
<th>Geology</th>
<th>Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lange Bramke</td>
<td>0.76</td>
<td>543–700</td>
<td>Quartzites, sandstones, slates</td>
<td>Spruce 90%, grassland 10%</td>
</tr>
<tr>
<td>Brugga</td>
<td>40</td>
<td>438–1493</td>
<td>Gneiss, drift</td>
<td>Forest (spruce) 75%, grassland 22%, urban areas 2%</td>
</tr>
<tr>
<td>Alzette at Livange</td>
<td>233</td>
<td>200–539</td>
<td>Marls, sandstone, limestone</td>
<td>Arable land 29%, forest (mainly deciduous) 25%, grassland 23%</td>
</tr>
<tr>
<td>Hupselse Beek</td>
<td>6.5</td>
<td>24–33</td>
<td>Sands, till, marine clays</td>
<td>Grassland 70%, arable land 20%, forest 8%</td>
</tr>
<tr>
<td>Jalovecky creek</td>
<td>46</td>
<td>570–2178</td>
<td>Granodiorite, schists, glacio-fluvial sediments, flysch</td>
<td>Forest (spruce) 26%, dwarf pine 16%, arable land 29%, grassland 24%, urban areas 5%</td>
</tr>
</tbody>
</table>
(Hupselse Beek) and Slovakia (Jalovecky creek). Selected characteristics of the basins are given in Table 1. Three of the five basins are situated in mountains, the Hupselse Beek and Alzette basins represent lowland conditions. Envelope lines were determined from the plots of stream discharges vs groundwater tables measured in observation wells. In the Brugga basin, groundwater tables were substituted by discharges from two springs representing deep and shallow groundwater runoff.

It is obvious that a crucial point in the applied separation method is the representativity of the groundwater table regime measured in the observation well. Groundwater tables should be representative for the part of the basin where the main drainage occurs. Groundwater table data from several points measured approximately once per two weeks were available in the Hupselse Beek basin. Therefore, the mean of measurements at observation wells was used to derive the envelope line for this basin.

RESULTS AND DISCUSSION

Separation of groundwater runoff


![Fig. 2 Lange Bramke: (a) master envelope line, (b) distribution of groundwater contributions calculated using master (columns) and single years (line) envelope lines, and (c) examples of separations for hydrological year 1995.](image-url)
Fig. 3 Brugga: (a) envelope lines based on the spring Zipfeldobel (deep groundwater) and Zänglelhof-2 (shallow groundwater), (b) distribution of groundwater contributions (sum of deep and shallow groundwater runoff), and (c) example of separation for hydrological year 1996. 1, total runoff; 2, deep groundwater; 3, sum of deep and shallow groundwater.

Fig. 4 Alzette: (a) envelope line, (b) distribution of groundwater contributions, and (c) example of separation for hydrological year 2000.
According to separations, groundwater is an important component of the total runoff in all basins. Figures 2–6 show the envelope lines, histograms of calculated groundwater contributions, as well as selected hydrographs (total and groundwater runoff) for each basin. Contribution of groundwater, as a % of total runoff, was calculated for each day and used to construct the histograms shown in the figures. Since the data series in the basins differ, histograms of groundwater contributions show relative frequencies. In Lange Bramke, two envelope lines were applied in each hydrological year—the master envelope line and the envelope line determined from data measured during that particular year. Thus, two distributions of groundwater contributions shown in Fig. 2(b) were obtained.

The highest mean contributions of groundwater to total basin runoff were calculated for the Lange Bramke basin with the envelope lines determined separately for every single year (mean 77%). At the same time, the variation of groundwater contributions as characterized by the coefficient of variation (standard deviation divided by arithmetic mean) was not very high ($C_v 0.195$). Using the master envelope line (determined from all the data, i.e. the same line for every single year), the mean groundwater contribution was substantially lower (54%) and the variation of groundwater contributions as measured by the coefficient of variation ($0.315$) was higher.

As mentioned above, two springs were used instead of groundwater tables in the Brugga basin. Thus, two groundwater components could have been separated. The mean contribution of deep groundwater was 53% and the coefficient of variation was 0.213. This component represents the “true” flow of groundwater from the saturated zone into the stream. Mean contribution of deep plus shallow groundwater representing flow from the saturated zone and soil water was 69% ($C_v 0.184$).

High groundwater runoff was calculated also for the Alzette basin (mean 65%) with coefficient of variation 0.338. The Alzette basin is rather large and the results cannot be considered to be valid for the basin as a whole, but are relevant for the alluvium of the Alzette River at Livange. The results indicate that the groundwater contribution to river runoff is important at the measured river profile and that the data from the observation well used in this study reasonably represent the overall groundwater regime in the area drained down to the measured river profile.

In the Hupselse Beek basin, it was shown that the separation method provides reasonable results also for the groundwater table data measured only once per one or two weeks. The mean groundwater contribution was 55% and the coefficient of variation 0.409. It is obvious that the envelope line based on the data measured once per week would differ from the envelope line based on daily data. The difference may be basin-dependent. To have an idea on the differences, we used the data from the Lange Bramke basin and determined two envelope lines for the hydrological year 1995. One envelope line was based on daily data while another was based on weekly data. Groundwater runoff calculated from both lines did not differ significantly, though the runoff estimated from the weekly-based envelope line was higher during some events.

The lowest groundwater contributions (however, reaching 49% on the average) and the highest variability in groundwater contributions were calculated for the Jalovecky creek basins ($C_v 0.429$).
Fig. 5 Hupselse Beek: (a) envelope line, (b) distribution of groundwater contributions, and (c) example of separation for 1 November 1983–31 October 1984.

Fig. 6 Jalovecky creek: (a) envelope line, (b) distribution of groundwater contributions, (c) example of separation for hydrological year 1990.
Comparison of results with other data

Experimental hydrological research is carried out in four of five basins described in this study. We could therefore compare the results of the Kliner-Knezek separation with the results of other studies.

Results of environmental isotope (e.g. Herrmann et al., 1989) and other separation techniques performed in the Lange Bramke basin indicate that the results of the Kliner-Knezek separation are realistic and the method can be used to analyse the behaviour of the groundwater system. Application of the more expensive tracer techniques can be restricted to justification of the results. More details on the results in this basin were given by Holko et al. (2001). Previous experimental investigations in the Brugga basin (including hydrometric and tracer studies) showed that two indirect components exist in the basin: deep and shallow groundwater (e.g. Uhlenbrook et al., 2000). The significant contribution of groundwater calculated by the envelope method is in line with the tracer results. Spring discharge can be successfully used to represent the groundwater regime given that the selection of the spring is based on a good knowledge, or proper estimate, of the hydrogeological conditions in the basin. The use of a non-representative spring or observation well could lead to wrong results. Groundwater runoff calculated for the Jalovecky creek basin was lower than the pre-event water contribution (contribution of water stored in the basin before the event) calculated from isotopic runoff separation in the upstream, mountain part of the basin. It is important to point out that the pre-event water given by isotopic separation is not exactly the same component as the groundwater runoff estimated from the envelope line. Nevertheless, it can be concluded for the Jalovecky creek basin that the calculated groundwater runoff is higher than previously expected and that the active role of groundwater in basin runoff is in agreement with the results of isotopic separation. About 60% of the annual discharge in the Hupselse Beek basin is contributed by pre-event water (Seuna & Lepistõ, 1997). Mean groundwater runoff estimated by the Kliner-Knezek method is similar. For the Alzette basin, no comparison with other data is currently possible due to the absence of previous studies on hydrograph separation techniques. Nonetheless, the Kliner-Knezek method gives very plausible results. The high groundwater contribution (65%) for the period 1999–2000 reflects the high permeability of the alluvium in the study area.

CONCLUSIONS

Separations of groundwater runoff performed in five European basins with different physiographic conditions showed that the results of the simple method based on the groundwater table (spring discharge)–stream discharge relationships are acceptable. This was confirmed by additional results from four experimental basins. The separation method provides daily estimates of groundwater runoff. Consequently, it is most suitable to provide the long-term characteristics of the groundwater contributions. However, because it provides realistic results on hydrograph components as well, it seems to be a suitable tool for preliminary assessment of groundwater runoff dynamics in the hydrological praxis, too.
REFERENCES


Querner, E. P. (1997) Description and application of the combined surface and groundwater flow model MOGROW. *J. Hydrol.* 192, 158–188.
