FLOOD WARNING LEVEL FORECASTING FOR UNGAUGED CATCHMENTS BY MEANS OF A COMBINED API-STORAGE CONCEPT

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Abstract

The knowledge of the expected dimension of the flood peak is of major importance for security and warning services to take preventive measures. In this paper the authors want to introduce the concept of the Antecedent Precipitation Index (API) as a possible variable to estimate runoff warning classes. The aim was (a) to define API warning classes which correspond to runoff warning classes at a certain runoff gauge and (b) apply the method to ungauged basins. To consider time and state dependent rainfall losses a spatially distributed linear storage concept was applied to intercept the actual rainfall. The 3-parameter API function was fitted to several flood events at observed gauges within the district of lower Austria and lead to a set of optimized parameters. Through extreme value statistics the 1, 5 and 30 years API extremes were derived and set into correlation to the corresponding flood events. These API extremes together with the optimized API parameters were spatially interpolated and thus transferred to ungauged basins. The calculated flood events had the tendency to underestimate the smaller flood frequencies whereas the extreme flood classes could be reliably performed.

Keywords: API, flood forecasting, ungauged catchments, warning classes.

1 INTRODUCTION

Flood forecasting with sparse data availability is still a great challenge to hydrologists. This is especially the case when a forecast should be made at an ungauged catchment. There already exist different methods to transfer model parameters from gauged to ungauged catchments by linking them to catchment characteristics like slope, geology, landuse etc. (Xu, 1999; Lowe & Nathan, 2006). But still the uncertainty is high when trying to forecast real hydrographs. Most frequently disaster prevention services deal with warning levels corresponding with flood frequencies. These warning levels are linked to certain measures. In this case the knowledge of the flood dimension and consequently the warning class would be very helpful to take preventive measures (Harum et al., 2005). Additionally through forecasting warning classes the forecast uncertainty in comparison to forecasting hydrographs is diminished through the range in which the flood peak can be located. By using the API model, warning classes could be forecasted by only using precipitation as input data. It is an attempt to directly transform irregular rainfall into runoff warning classes.
2 STUDY REGION AND DATA

Lower Austria is the largest province in Austria and is located in the Northeast of the country. In the North it borders on the Czech Republic and in the East on the Slovak Republic. The City of Vienna is enclosed by Lower Austria (see Figure 1). The landscape reaches from mountainous areas in the South with mountains up to 2000 m a.s.l. over soft hills in the North to rather flat areas in the East. South and North are divided by the Danube River. The geology is dominated by limestone in the mountainous Southwest whereas in the Northwest mostly granite is found. Forrest and agriculture are the dominant landuse.

For analysis, precipitation and discharge data since 1990 were used. For calibration 31 gauges have been chosen. Precipitation data in hourly resolution from about 84 rain gauges were used for interpolating catchment mean values.

Figure 1: Austria and Lower Austria
3 METHODOLOGY

The traditional concept of the API refers to precipitation on daily basis. It describes the declining impact of past precipitation in time (Linsley et al., 1958). The API can be interpreted as a kind of runoff disposition in the catchment (Holzmann & Nachtnebel, 2002). With a higher temporal resolution of available precipitation data also the API has to be adapted to a higher resolution as the runoff disposition changes with every precipitation element. In this study data with an hourly resolution were used. Runoff losses were considered by a linear storage reservoir. The depletion of the reservoir, which corresponds to factors like basin size, hydrogeology or soil moisture redistribution, was described by a retention factor. Only the precipitation excess of the storage ($P_{eff}$) contributes to the API computation (see Figure 2). This leads to a better correlation between discharge and API, which is of importance for deriving API warning classes that should correspond to flood warning classes (Holzmann & Lehmann, 2007).

![Figure 2: Linear storage](image)

$$P_{eff} = P - (S_{max} - S_{act})$$

$$S_{act,i} = S_{act,i-1} \cdot e^{-\frac{1}{S_{val}}}$$

$$API_i = API_{i-1} \cdot e^{\frac{-1}{24dt*akvri}}$$

- $P$ precipitation
- $P_{eff}$ effective precipitation
- $S_{max}$ maximum storage capacity
- $S_{act}$ actual storage content
- $S_{val}$ retention factor
- $akvri$ API coefficient
- $dt$ factor for temporal resolution (1 for hourly calculations)
- $API$ Antecedent Precipitation Index
- $i$ timestep
4 RESULTS

The storage parameters like maximum capacity ($S_{\text{max}}$) and retention constant ($S_{\text{val}}$) as well as the API coefficient ($akvri$) were optimized until the best statistical accordance between the API function and the observed hydrograph was achieved. As the evaluation criteria the correlation coefficient has been used. This process was repeated for several flood events at all gauged catchments and led to a set of optimized parameters for each catchment. Thereby the correlation of the peak values was of major importance. This means a good correspondence between the temporal occurrence of runoff peaks and API peaks was aimed. Through the implementation of the linear reservoir this task could be satisfactory performed (see figures below).

![Figure 3](image3.png)

Figure 3: Comparison between discharge (black, solid) and API without storage (red, dashed)

![Figure 4](image4.png)

Figure 4: Comparison between discharge (black, solid) and API with storage (red, dashed)
In above figures the discharge (black) is shown in comparison to the API (red) at
gauge Hofstetten. It is apparent that through the use of the storage (Figure 4) the
correlation between discharge and API is much better. The occurrence time of the
peaks is well expressed and higher discharge peaks meet with higher API peaks.
This is an important fact for the definition of API warning classes that should
correspond to the HQ warning classes.

4.1 Derivation of warning classes

From the optimized parameter sets of each catchment, the mean values were
chosen as the characteristical catchment values. Eventually API timeseries for each
catchment have been created from a 15 year precipitation period (1990 – 2005).
From these timeseries the 1, 5 and 30 years frequencies events have been deduced
as the three different warning levels. For this purpose the Gumbel distribution has
been used. Then the API warning levels have been related to the 1, 5 and 30 years
flood frequencies at the correspondent catchment. At this point the API extremes did
not meet the flood extremes in a good manner. Especially the smaller events like the
1 years flood frequencies were underestimated in all catchments. Therefore the API
extremes have been reduced by 20% until they reached a good accordance with the
flood extremes. At this stage the flood events could be reliably forecasted by the API
values, although there still was an underestimation of smaller flood events, especially
the 1 years frequencies events. As an example, Table 1 shows the forecasting
results at several catchments.

<table>
<thead>
<tr>
<th>ID</th>
<th>Number of events</th>
<th>Too low</th>
<th>Correct</th>
<th>Too high</th>
</tr>
</thead>
<tbody>
<tr>
<td>170</td>
<td>19</td>
<td>5</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>171</td>
<td>18</td>
<td>5</td>
<td>11</td>
<td>2</td>
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<td>173</td>
<td>18</td>
<td>5</td>
<td>12</td>
<td>1</td>
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<tr>
<td>174</td>
<td>18</td>
<td>9</td>
<td>9</td>
<td>0</td>
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<td>19</td>
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<tr>
<td>180</td>
<td>20</td>
<td>8</td>
<td>11</td>
<td>1</td>
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<tr>
<td>188</td>
<td>19</td>
<td>9</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>193</td>
<td>14</td>
<td>4</td>
<td>10</td>
<td>0</td>
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<tr>
<td>194</td>
<td>20</td>
<td>7</td>
<td>13</td>
<td>0</td>
</tr>
</tbody>
</table>

At e.g. catchment 170, from a total of 19 flood events, 12 were classified in the
correct warning class, two events were overestimated (too high) and 5 were
underestimated (too low). Most frequently the underestimated events have been 1
years flood events. This outlines the difficulties with that kind of events. A further
decreasing of the 1 years warning level led to a higher overestimation rate. So it is
better to underestimate small events than making false estimation at higher events.

4.2 Transfer warning levels and API parameters to ungauged catchments

After the process of calibration at gauged sites, the API parameters and warning
levels have been transferred to ungauged catchments by using Ordinary Kriging.
In the following the quality of the interpolation for the 1, 5 and 30 years extremes that
refer to the three warning levels is presented. For validation purposes some of the
known gauges were assumed to be unknown and be used as interpolation targets.
The interpolated values obtained through Kriging were then compared to the values obtained through calibration. One example of the many possible constellations is presented subsequently.

Example:
In Figure 6 an excerpt of the available gauges is shown. The green marked gauges have been pretended to be known and used for Kriging. The ones marked red were intended to be forecasted. The following tables show the comparison between the kriged values and the values achieved through calibration for these basins. Table 2 shows the interpolation results for the 1, 5 and 30 years flood frequencies that are correspondent to the three warning levels (API_WL_1, API_WL_2, API_WL_3). Table 3 refers to the storage parameters $S_{\text{max}}$, $S_{\text{val}}$ and $\text{akvri}$ and Table 4 provides the classification results of different flood events from the period 1990 – 2005. API values are in [mm].

![Figure 5: API warning level interpolation](image)

Table 2: Comparison API warning level calibration – kriging

<table>
<thead>
<tr>
<th>Id</th>
<th>Name</th>
<th>API_WL_1</th>
<th>API_WL_2</th>
<th>API_WL_3</th>
<th>API_WL_1</th>
<th>API_WL_2</th>
<th>API_WL_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>172</td>
<td>Atzenbrugg</td>
<td>22,54</td>
<td>53,62</td>
<td>89,09</td>
<td>26,68</td>
<td>61,89</td>
<td>103,68</td>
</tr>
<tr>
<td>173</td>
<td>Siegersdorf</td>
<td>24,96</td>
<td>62,41</td>
<td>105,53</td>
<td>26,68</td>
<td>60,33</td>
<td>97,93</td>
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<tr>
<td>177</td>
<td>Fahrafeld</td>
<td>25,65</td>
<td>66,33</td>
<td>113,44</td>
<td>26,68</td>
<td>66,56</td>
<td>115,42</td>
</tr>
</tbody>
</table>

Table 3: Comparison API storage parameters calibration – kriging

<table>
<thead>
<tr>
<th>Id</th>
<th>Name</th>
<th>Smax</th>
<th>Sval</th>
<th>akvri</th>
<th>Smax</th>
<th>Sval</th>
<th>akvri</th>
</tr>
</thead>
<tbody>
<tr>
<td>172</td>
<td>Atzenbrugg</td>
<td>15,00</td>
<td>50,50</td>
<td>1,45</td>
<td>13,17</td>
<td>47,75</td>
<td>2,22</td>
</tr>
<tr>
<td>173</td>
<td>Siegersdorf</td>
<td>13,30</td>
<td>49,25</td>
<td>1,90</td>
<td>12,86</td>
<td>48,35</td>
<td>2,22</td>
</tr>
<tr>
<td>177</td>
<td>Fahrafeld</td>
<td>12,90</td>
<td>46,75</td>
<td>1,30</td>
<td>14,12</td>
<td>44,37</td>
<td>2,22</td>
</tr>
</tbody>
</table>
The classification results provided in Table 4 are really promising. In comparison to Table 1, the results shown in Table 4 indicate that in this case the Kriging interpolation is an acceptable method to use.

In the following four figures, the Kriging interpolation results are demonstrated graphically. The first and second figure correspond to the API storage parameters $S_{val}$ and $S_{max}$. The third and fourth figure refer to the warning levels. Warning level 1 (1 years flood frequency) and the storage parameter akvri have been left out since spatial difference was very low in this case. The graduation of the parameter bands is shown in different colours. Green means low values and purple refers to high values of the accordant parameter.

Every figure shows the same detail of Lower Austria and hast the same extent. In the northern part the landscape is rather flat whereas in the South it is hillier. Here, most of the flood events are caused by intensive rainfall of short duration. In the North the flood levels are lower and floods are rather causes by long duration rainfall. This leads to lower storage capacities but higher retention constants than in the South. The hydrographs in the southern part are steeper and the flood events are of shorter duration. Consequently the API storage has to drain faster which results in a lower retention constant.

![Figure 6: Spatial distribution of retention constant (Sval)](image)

<table>
<thead>
<tr>
<th>ID</th>
<th>Number of events</th>
<th>Too low</th>
<th>Correct</th>
<th>Too high</th>
</tr>
</thead>
<tbody>
<tr>
<td>172</td>
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<td>0</td>
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<tr>
<td>173</td>
<td>18</td>
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<td>13</td>
<td>1</td>
</tr>
<tr>
<td>177</td>
<td>19</td>
<td>9</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4: Classified flood events when using interpolated values
Figure 7: Spatial distribution of maximum storage capacity (Smax)

Figure 8: Spatial distribution of 5 years flood frequency (warning level 2)
5 Conclusions

The API in combination with the linear storage is a possible concept for forecasting warning levels in ungauged catchments. It is an easy to use method to classify and forecast flood frequencies (warning levels). It only requires precipitation as input data. Higher flood events such as events around the 10 or 30 years floods could be reliably forecasted. Difficulties exist at forecasting small events like 1 years flood frequencies. Here the threshold between precipitation that causes a flood and precipitation that causes no flood is hard to define. But after all the method provided promising results that need further investigation in terms of storage parameter estimation and linking the storage parameters to catchment characteristics.

References