Some results of application of flood routing models in the Kherlen river basin

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**Introduction**

- Recent years, the occurrence of floods globally has increased and due to urbanization and growth of population the vulnerability of communities is now greater. By 1990\textsuperscript{th}, the frequency of flood events has increased nearly 6 times since 1960\textsuperscript{th}. Consequently, economic losses and death toll due to flood events are increasing rapidly. Economic losses due to floods only in 2002, is estimated to be about 4.1 billion US dollar (WMO Bulletin, Vol .53, No.1, 2004)

- Similar situation can be observed in Mongolian case. Flood events magnitude has increased and flood duration becomes shorter and more sudden (for example, in the Tuul since 1940\textsuperscript{th}, duration of rainfall floods is shortening for 2-3 days and flood peak has increased annually by 20 cumec , G.Davaa, 2002)

Since establishment of monitoring activities (since mid of 1940th) for river regime in Mongolia, economic losses due to flood event is estimated about 56 billion tugrik and dead several hundreds of people
Therefore flood forecasting becomes an essential research and practical applications in our hydrological studies.

• Several flood routing models were applied since 90\textsuperscript{th} (Linear regression, Single linear reservoir, Muskingum routing, N. Dahsdeleg, 1980, D.Oyunbaatar, G.Davaa, 1994,1999)

• This paper considers results of application of some flood routing models in the Kherlen river basin. Flood routing model are generally used for reconstruction of a missing hydrograph or for prediction of the possible outflow rate at downstream of a specified time interval.
**Brief basin geography and hydrograph**

The Kherlen river takes its origin from southern slope of Khentei mountain range at elevation about 1750 m and drains into Dalai nuur in China. The river basin area in territory of Mongolia is 116455 km² with length of 1090 km

- Generally, surface runoff in the river basin mainly forms from rainfall during the warm period and spring snow melt (56-76 %). By the flow regime classification the Kherlen river belongs to a type with summer rainfall and spring snow melt floods.

- Main portion of runoff of the river forms in upper forest area, until Baganuur station and then starts significant runoff loss along the river through steppe with dominant sandy soil by evaporation and bank infiltration.

Figure 1. Kherlen river basin
Table 1. Basic description of Kherlen river basin and hydrological stations

<table>
<thead>
<tr>
<th>No</th>
<th>River-station</th>
<th>Coordinates</th>
<th>River length, km</th>
<th>Basin area, km²</th>
<th>Basin elevation, m</th>
<th>Record length,</th>
<th>$O_{\text{mean}}$ m³/sec</th>
<th>$Q_{\text{max}}$, m³/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kherlen-Mongenmoryt</td>
<td>48.13</td>
<td>1000</td>
<td>5403</td>
<td></td>
<td>1999</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Kherlen-Baganuur</td>
<td>47.42</td>
<td>940</td>
<td>7350</td>
<td>2200</td>
<td>1943</td>
<td>24.9</td>
<td>1320</td>
</tr>
<tr>
<td>3</td>
<td>Kherlen-Underkhaan</td>
<td>47.19</td>
<td>829</td>
<td>39400</td>
<td>1405</td>
<td>1942</td>
<td>20.8</td>
<td>422</td>
</tr>
<tr>
<td>4</td>
<td>Kherlen-Choibalsan</td>
<td>48.06</td>
<td>390</td>
<td>71500</td>
<td>1280</td>
<td>1942</td>
<td>19.4</td>
<td>261</td>
</tr>
</tbody>
</table>
**Methods**

*a. Linear regression model*

The model based on travel time and concurring discharge (water level) at upper and lower stations. Flood routing and its deformation mainly depend on length of river reach, flow behavior, channel slope and riverbed roughness etc. By estimating mean travel time and related discharges between stations can be derived following regression equations for forecasting or simulating.

\[
Q_{\text{downstream}-\tau} = aQ_{\text{upstream}-t-\tau} + b
\]

\[
Q_{\text{downstream}-\tau} = a Q^2_{\text{upstream}-t-\tau} + b Q_{\text{upstream}-t-\tau} + c
\]

Where: \( \tau \) - travel time
b. Muskingem linear routing model

In the Muskingum is based on simple ideas relating to the storage of floodwater in a river reach.

Storage, $S$, is increased by inflow, $I$, and reduced by discharge, $Q$

$$S = k(I + (1-x)Q)$$

- $k$: storage coefficient, has the dimension of time
- $x$: dimensionless weighting factor

$$Q_{j+1} = C_1 I_j + C_2 I_{j+1} + C_3 Q_j$$

Where: $C \Rightarrow (k \text{ and } x)$
c. Muskingum-Cunge method
The essence of the Cunge’s refinement is that with an appropriate choice of space and time steps, the Muskingum method can provide a good approximation to solution of the linear diffusion equation.

\[ Q_{j+1} = C_1 I_j + C_2 I_{j+1} + C_3 Q_j + C_4 \]

Where: \( C \Rightarrow (k, x, D, c, \alpha, \Delta x, L, Q_p) \)

If the diffusion coefficient is defined as: \( D = \alpha Q_p / L \)

- Parameters of the model estimated by least square (linear regression), graphic and Donnel’s direct optimization methods (Muskingum and Muskingum-Cunge). Such least square fitting automatically takes account of any effect of channel deformation, flow regime, channel geography etc.

\[ C = \left( P^T P \right) P^T Q \]

(O’Donnel, 1985)

Where: \( P \) - \( I_j, I_{j+1} \), \( Q_j \) - rectangular matrix formed by the inflow and outflow series

\( Q \) - \( Q_{j+1} \) - column matrix containing the outflow series beginning from the second value

\( C \) - \( C_i \) - column matrix containing the three coefficients
Results

a. Linear regression model (Method of related discharge or water stage)

• The daily discharge data of the Baganuur, Underkhaan and Choibalsan stations are available for 20 years from 1980 to 2000. For calibration of linear regression model has selected 6 years data that differ by high, mean and low annual flows.

• Travel time between stations were estimated by concurrent flow series at three stations: Baganuur, Underkhaan and Choibalsan. Travel time between Baganuur-Underkhaan and Underkhaan-Choibalsan vary 3-8 and 6-15 days, respectively.
Flood peak attenuation analysis show that flood peak at upper station-Baganuur decrease on average by 40 percent at Underkhaan and 40 percent at Choibalsan. The analysis shows that by passing from forest-steppe into steppe zone, the river runoff lost up to 40-50 percent. For instance, flood peak at Baganuur station decreases by 40 percent at Underkhaan station and by reaching lower Choibalsan station, runoff loss increases up to 60 percent of upper value.

Table 2. Flood peak attenuation along the Kherlen river

<table>
<thead>
<tr>
<th></th>
<th>Baganuur/Underkhaan</th>
<th>Underkhaan/Choibalsan</th>
<th>Baganuur/Choibalsan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.404</td>
<td>0.378</td>
<td>0.612</td>
</tr>
<tr>
<td>Max</td>
<td>0.138</td>
<td>0.152</td>
<td>0.427</td>
</tr>
<tr>
<td>Min</td>
<td>0.633</td>
<td>0.631</td>
<td>0.865</td>
</tr>
</tbody>
</table>
Figure 2. Flood peak attenuation coefficients along the Kherlen river
Flood wave routing along the Kherlen river

Figure 3. Flood wave attenuation
Table 3. Regression equations for forecasting along the Kherlen river

<table>
<thead>
<tr>
<th>River-station</th>
<th>Years</th>
<th>Travel time, days</th>
<th>Forecasting equations</th>
<th>R</th>
<th>Mean error, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kherlen-Baganuur-Underkhaan</td>
<td>Mean-1995,1998</td>
<td>5</td>
<td>( Q_{UKH} = 0.53 Q_{BN} + 13.83 )</td>
<td>0.93</td>
<td>30.0</td>
</tr>
<tr>
<td></td>
<td>Max-1984,1990</td>
<td></td>
<td>( Q_{UKH} = 0.29 Q_{BN} + 47.4 )</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low-1980,1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kherlen-Underkhaan-Choibalsan</td>
<td>Mean-1995,1998</td>
<td>8</td>
<td>( Q_{Choi} = 0.62 Q_{UKH} + 7.54 )</td>
<td>0.90</td>
<td>35.0</td>
</tr>
<tr>
<td></td>
<td>Max-1984,1990</td>
<td></td>
<td>( Q_{Choi} = 0.56 Q_{UKH} + 6.64 )</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low-1980,1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Forecasted hydrograph by regression equation
b. Muskingum linear routing model

- For calibration of Muskingum routing models have been selected 15 years daily discharge along the Kherlen River and several tenth of single flood events.

- The analysis of several flood hydrographs show that routing interval between Baganuur and Underkhaan is estimated to be 72 hours or 3 days.

- Parameters of Muskingum models are estimated by graphic and Donnel’s optimization methods. Several trials for several flood hydrographs give following parameters values for Kherlen-Baganuur-Underkhaan reach: k=8-10 days, x=0.1-02.
<table>
<thead>
<tr>
<th>River-stations</th>
<th>$C_1(I_j)$</th>
<th>$C_2(I_{j+1})$</th>
<th>$C_3(Q_j)$</th>
<th>Error, %</th>
<th>Distance, km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kherlen-Baganuur-Underkhaan</td>
<td>0.23</td>
<td>0.053</td>
<td>0.716</td>
<td>17.3</td>
<td>407</td>
</tr>
<tr>
<td>Kherlen-Underkhaan-Choibalsan</td>
<td>0.027</td>
<td>0.41</td>
<td>0.616</td>
<td>17.2</td>
<td>310</td>
</tr>
</tbody>
</table>

**Figure 5. Muskingum model output**
### c. Muskingum linear routing model

Parameters of Muskingum-Cunge model Bagaruur- Underkhaan

<table>
<thead>
<tr>
<th>Parameters</th>
<th>value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta l$ - routing reach interval</td>
<td>62.4</td>
<td>km</td>
</tr>
<tr>
<td>$c$ - flood speed</td>
<td>0.717</td>
<td>m/sec</td>
</tr>
<tr>
<td>$k$ - travel time parameter</td>
<td>86400</td>
<td>sec</td>
</tr>
<tr>
<td>$\Delta x$ - weighting factor</td>
<td>0.06599</td>
<td></td>
</tr>
<tr>
<td>$C_1$ - coefficient of model equation</td>
<td>0.27714</td>
<td>-</td>
</tr>
<tr>
<td>$C_2$ - coefficient of model equation</td>
<td>0.36142</td>
<td>-</td>
</tr>
<tr>
<td>$C_3$ - coefficient of model equation</td>
<td>0.36142</td>
<td>-</td>
</tr>
<tr>
<td>$Q$ - mean flood peak discharge between upstream and downstream sites</td>
<td>226</td>
<td>m/sec</td>
</tr>
<tr>
<td>$L$ - total length between upstream and downstream sites</td>
<td>312</td>
<td>km</td>
</tr>
</tbody>
</table>
Figure 6. Correlation between observed and simulated hydrograph, Muskingun-Cunge

\[ y = 0.8258x + 2.3972 \]
\[ R^2 = 0.9561 \]

Figure 7. Simulated hydrograph along the Kherlen river, Muskingun-Cunge
Figure 8. Simulated hydrograph along the Kherlen river, Muskingun-Cunge model
The accuracy of a model lies with the goodness of fit between simulated and observed hydrograph can be used as a criterion of accuracy. One such criterion is Nash and Sutcliffe (1970) efficiency criterion defined as:

$$R^2 = 1 - \frac{F^2}{F^2_o}$$

Where:

- $F^2 = \sum (Q_{\text{obs}} - Q_m)^2$ – sum of square error
- $F^2_o = \sum (Q_m - Q_{\text{mean}})^2$ – initial variance of observed discharge
- $Q_{\text{obs}}$ - observed discharge
- $Q_m$ - simulated discharge
- $Q_{\text{mean}}$ - mean of observed discharge
Conclusions

- The results obtained seem to encouraging, but need to be verified
- Linear regression model is recommended to use for forecasting by updating with the derived equations with new inflow
- Muskingum flood routing model provide better simulation results
- The application of the models was limited to a very inadequately gaged river system due to long distances between stations
- For estimation of parameters of Muskingum-Cunge model require more detailed analysis and measurement
Advantages of such simplified routing model are: channel geometry does not need to be defined in details, programming for computer solution is simple, ready integrated with other hydrological models.

Disadvantages: cannot allow velocity changes and backwater, a large amount of measured inflow and outflow data is required to calibrate the parameters and such models sensitive to the time and distance between stations.

<table>
<thead>
<tr>
<th>Models</th>
<th>R</th>
<th>Error, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear regression model</td>
<td>0.87-0.93</td>
<td>30.0</td>
</tr>
<tr>
<td>Muskingum flood routing</td>
<td>0.92-0.95</td>
<td>10.3-15.5</td>
</tr>
<tr>
<td>Muskingum-Cunge</td>
<td>0.89</td>
<td>42.4</td>
</tr>
</tbody>
</table>

Table 5. Comparison of Model results
Thank you for attention