Modelling impacts of climate change on the hydrology of a Mongolian catchment using an appropriate permafrost conceptualization

Kor Heerema[1,2], Martijn J. Booij[1], Ric Huting[2] Jord J. Warmink[1], Eelco van Beek[1,3] and Odgarav Jigjsuren[4]

[1] Department of Water Engineering and Management, University of Twente, Enschede, the Netherlands - m.j.booij@utwente.nl
[2] Royal HaskoningDHV, P.O. Box 1132, 3800 BC Amersfoort, the Netherlands
[3] Deltares, P.O. Box 177, 2600 MH Delft, the Netherlands
[4] Institute of Meteorology Hydrology and Environment, Street of Juulchin, Ulaanbaatar-210646, Mongolia

1. Introduction

Mongolia is an example of a country which is particularly vulnerable to climate change. Precipitation is low and highly variable in space and time, and river discharges are largely dependent on the melting of snow and ice. Permafrost conditions prevail in large parts of the country and have a substantial influence on catchment hydrology. Changes in temperature and precipitation may seriously affect the timing, duration and intensity of high and low flows and hence water availablity in downstream areas. The aim of this study is to determine the impacts of future climate change on the hydrology of a Mongolian catchment taking into account permafrost conditions.

2. Study area and data

The study area is the Buyant River basin in western Mongolia (8370 km^2). The basin is dominated by mountains with steep slopes. The climate is semi-arid with annual mean precipitation between 250 mm at high altitudes and less than 100 mm in lowland areas. Annual mean temperatures vary from -6 to -2 °C in mountainous areas and from -3 to -1 °C in lower areas. Daily precipitation, evapotranspiration and discharge data for the period 2000-2009 are used, the first 5 years for model calibration and the second 5 years for model validation.

3. Methods

The conceptual hydrological model HBV (Lindström *et al*., 1997) lumped at the basin scale with a daily time step is used to simulate the discharge. Calibration is carried out using Monte Carlo simulation and a combined objective function *Y* (Akhtar *et al*., 2009) incorporating the relative volume error (*RVE*) and the Nash-Sutcliffe (*NS*) coefficient.

Four different permafrost conceptualizations within HBV are compared to select the most appropriate one. Two conceptualizations take permafrost into account by only calibrating under non-permafrost (summer) conditions and differ in their elevation representation of the catchment (single and multiple elevation zones). The other two conceptualizations explicitly simulate permafrost conditions by adding freezing and melt functions and an ice store to each of the three water stores of HBV.

The impact of climate change on the hydrology is determined by using the outputs of four Global Circulation Models (GCMs) for three SRES emission scenarios. The delta change method is used to translate GCM output to HBV model input for future conditions.

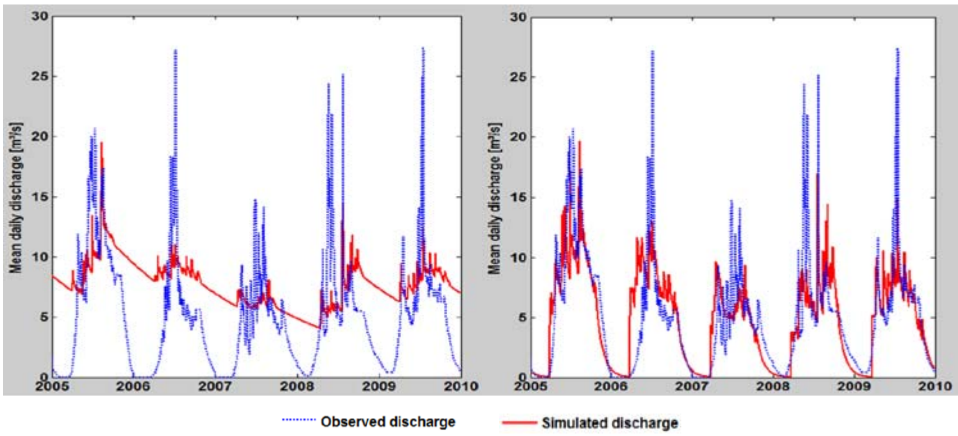

Figure 1 Observed and simulated mean daily discharges at the river gauging point Khovd for the validation period (2005-2009). Permafrost conditions are taken into account in the simulations by only calibrating under non-permafrost (summer) conditions (left) and explicit incorporation of permafrost conditions in the model (right). Both figures are for a model with one elevation zone.

4. Results

Results in the calibration are moderate to good for the conceptualizations with an explicit simulation of permafrost, where the model with one elevation zone performs better in the validation than the model with multiple elevation zones. The other two conceptualizations perform poor to moderate, particularly because groundwater flow persists in winter despite that this period is not considered in the calibration of these cases (see Figure 1). For the period 2080-2100, the discharge of the Buyant River is likely to increase in spring and most probably will decrease in summer and autumn, for some combinations of GCMs and scenarios considerably (see Figure 2).

5. Conclusions

Model conceptualizations with an explicit simulation of permafrost perform better than those implicitly incorporating permafrost conditions through calibration. The HBV model with explicit permafrost simulation and one elevation zone is used for climate change impact assessment. Uncertainties in climate change impacts are large, where the uncertainty due to different GCMs is found to be more important than the uncertainty due to different scenarios. Additionally, uncertainties in downscaling, data and hydrological model structure and parameters can further complicate the analysis of the catchment's response to climate change.

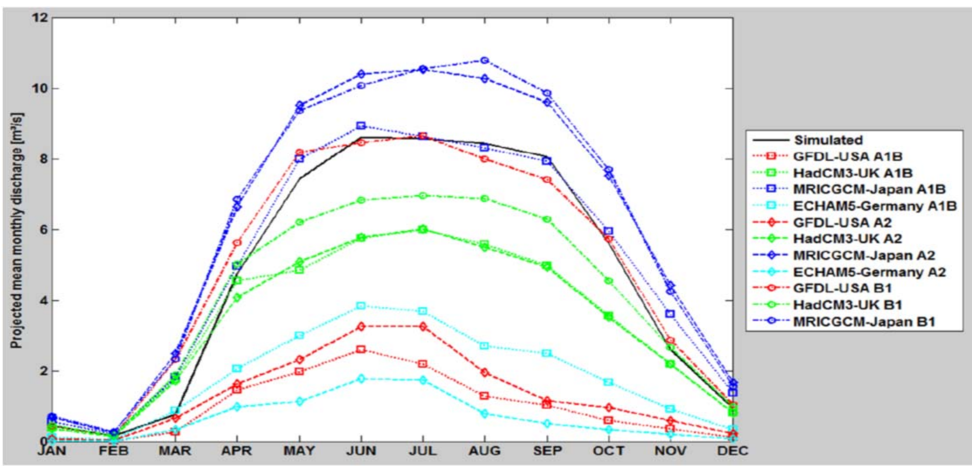

Figure 2 Simulated mean monthly discharge for the current climate and projected mean monthly discharge for 11 climate change scenarios for the period 2080-2100. Discharge simulations have been carried out with the HBV model with explicit permafrost simulation and one elevation zone.

UNIVERSITY OF TWENTE.
Enschede, the Netherlands

Royal HaskoningDHV
Enhancing Society Together

References

Akhtar M, Ahmad N, Booij MJ (2009) *Hydrol. Earth System Sci.* **13**, 1075-1089.

Lindström G, Johansson B, Persson M, Gardelin M, Bergström S (1997) *J. Hydrol.* **201**, 272-288.