

RUNOFF MODELLING IN ICELAND WITH THE HYDROLOGICAL MODEL, WASIM

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ABSTRACT

The distributed hydrological model WASIM has been employed in studies carried out at the Hydrological Service in the past five years. The model has been used to produce a runoff map of Iceland for the decades 1961-1990 and a projection of future runoff for the decades 2071-2100. Modeled runoff data are also being provided as boundary conditions for oceanographic modelling. Further application of the WASIM model in coming years is outlined.

INTRODUCTION

Hydrological quantities are important in many respects: for utilization and management of water resources; as an input to other research fields, e.g. oceanography; as indicators of climate changes and more. But since measurements are sparse in both space and time, models are often used to produce time series for past time periods and ungauged areas. As a part of the joint Nordic research project, CE (Climate and Energy, see <http://www.os.is/ce>) (Fenger, 2007), and the Icelandic sister project VO (Veðurfar og Orka) the WASIM model (Jasper et al., 2002; Jasper & Kaufmann, 2003) was set up and calibrated at the Hydrological Service. The model has been used to make a runoff map for Iceland and a future projection of runoff. The produced data sets on freshwater runoff of Iceland are now being used as a boundary condition in an oceanographic model that computes the ocean's current field, its temperature, salinity and the sea surface elevation.

Further application of the model and development of its use is intended as part of the followup project CES (Climate and Energy Systems, see <http://leirhnukur.orkugardur.is/ces>). The groundwater modulus of WASIM has not been used up to now because of a lack of calibration data, but will be included in our further work. A new calibration of the WASIM model, using precipitation data on a 1x1 km grid is also planned. Up to now

weather data on a 8x8 km grid have been used but orographic precipitation is much better represented on a smaller scale. Further runoff simulations are planned after recalibration and activation of the groundwater modulus.

RUNOFF MAP OF ICELAND FOR 1961-1990 AND FUTURE PROJECTION FOR 2071-2100

The WASIM model was used to make a runoff map of Iceland for the period 1961-1990, which was selected as a reference period in the CE project. A future projection of runoff for the period 2071-2100 was also made. The project was sponsored by: the National Energy Authority, the Icelandic VO project and the joint Nordic CE project. A short description of the project and major results is given below but the reader is referred to Jónsdóttir (2008) for more detailed information.

Data and methods

The WASIM model was calibrated with data from about 70 watersheds covering 1/3 of the country. Data from 30 watersheds were also used for a crude comparison of calculated and measured water balance. Model parameters were evaluated for ungauged watersheds using a division of the country on a catchment scale by hydrological properties.

Meteorological data calculated by Institute of Meteorological Research were used as input in WASIM. Precipitation and other meteorological parameters were calculated on a 8x8 km grid using the PSU/NCAR MM5 numerical weather model (Rögnvaldsson, 2004).

The evaluation of the effects of climate change was based on a climate change simulation from the HIRHAM regional climate model (RCM; Bjørge et al., 2000) with boundary conditions from the HadAM3H global climate model (GCM; Gordon et al., 2000) using A2 and B2 emission scenarios (Nakićenović et al., 2000).

As the volume of glaciers in Iceland is projected to decrease over the next centuries, decreased glacier extent and lower ice surface elevation was accounted for in the scenario calculation for 2071-2100. This was done by using a projection of future glacier geometry for the year 2085 that was made as part of the CE project, produced from a dynamic glacial model for the three largest ice caps in Iceland; Vatnajökull, Langjökull and Hofsjökull, which encompass about 90% of the glaciated area in Iceland (Aðalgeirsdóttir et al., 2006; Bergström et al., 2007).

Results

According to the runoff map (Fig. 1) the mean discharge for the water years 1961-1990 is 4770 m³/s or 1460 mm/year. This is somewhat lower than runoff estimates obtained for earlier periods; which were 5500 m³/s or

1690 mm/year for 1948-1955 (Rist, 1956) and 5150 m³/s or 1590 mm/year for 1951-1980 (Tómasson, 1981). Evapotranspiration was found to be 280 mm/year, whereas Rist (1956) and Tómasson (1981) found values of 100-200 mm/year and 310-414 mm/year respectively.

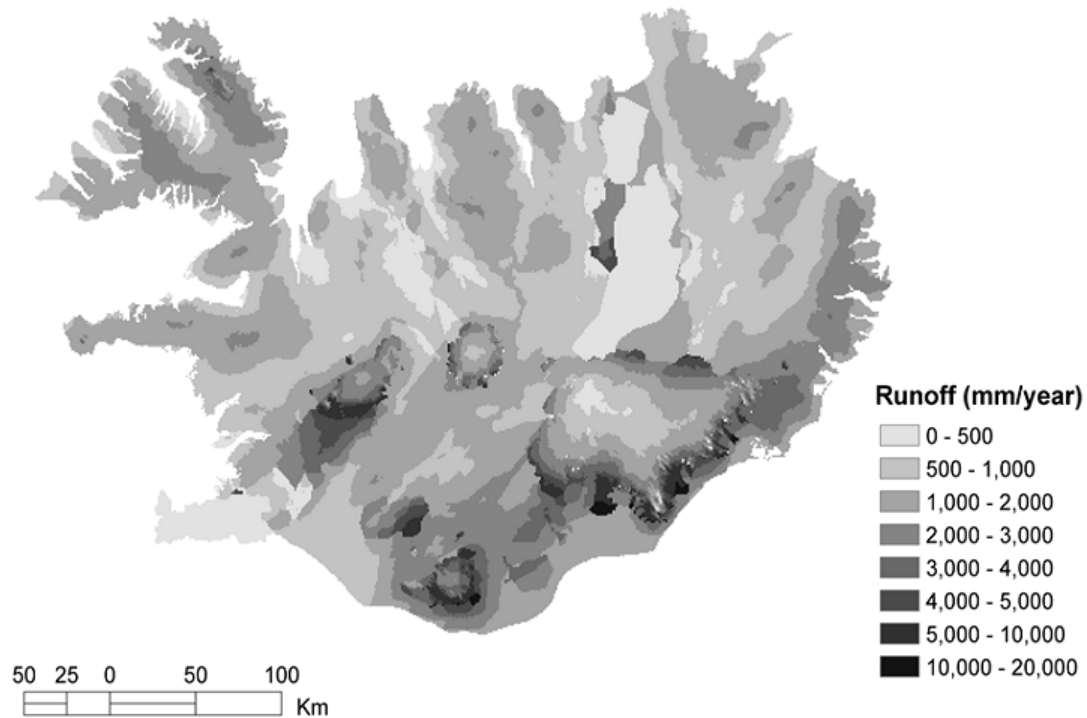


Figure 1. Runoff map of Iceland for the period 1961–1990.

Future runoff was found to become substantially higher in 2071–2100 compared with 1961–1990. According to the runoff projection, the average runoff over the whole country will be 1800 mm/year in the period 2071–2100, which is almost 25% higher than in the reference period 1961–1990 (Fig. 2a). The increase in future runoff is predominantly due to increased glacial melting caused by higher temperatures, which are projected to rise on average by 2.8°C between the two above mentioned periods. Discharge from non-glaciated areas increases by 8%, in part because non-glaciated areas become larger (Fig. 2b), while glacial discharge increases by 90% (Fig. 2c) (Jónsdóttir, 2008).

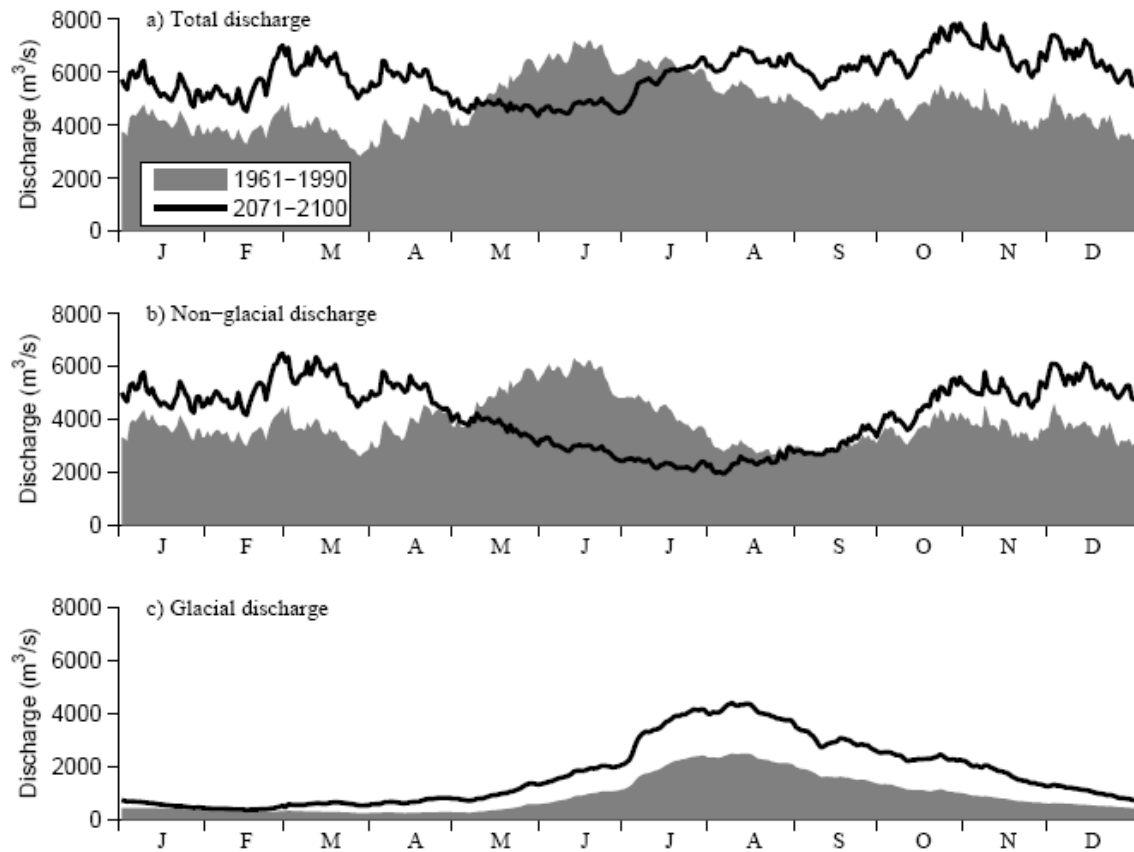


Figure 2. Seasonal variation in mean runoff from Iceland for the reference period 1961-1990 and a future projection for the years 2071-2100. a) Runoff from the entire country. b) Runoff from non-glaciated areas (3% larger area in the future scenario). c) Runoff from glaciated areas (20% smaller area in the future scenario).

FURTHER USE OF THE HYDROLOGICAL MAP

Freshwater runoff influences the salinity field and layering in the coastal waters around Iceland. The freshwater influence is not only present at river mouths, but also over the entire continental shelf. The freshwater inflow causes pressure and density gradients that drive a costal current clockwise around the country (Stefánsson, 1999). The salinity and current fields then affect the biosphere. The effects on the spawning and reproduction of cod have gained most attention, as cod is the most important Icelandic fishing stock. Sediment transportation by river flow is also considered to have influence on nutrient supply in the costal waters.

In this context the total runoff from Iceland over the period 1961-1990 has been routed to the shores. The data on which the runoff map is based are available as daily mean values for zones that are based on the division of the country by hydrological properties on a catchment scale. To route the runoff to the shores the country was divided into 46 watersheds that are assigned to certain parts of the coastline. Runoff was then summed up for

each watershed from the zones and given as mean daily discharge for each watershed. These discharge series are then provided as boundary conditions for oceanographic models used to simulate the oceanic environment. Results from the oceanographic model are then used in biological studies on cod stocks.

The runoff map depicts natural runoff without human-induced changes (which are mainly in the form of damping of summer and spring peaks in river flow due to hydropower plants construction). Thus the modelled runoff data, together with measured time-series of runoff (which show the effects of hydropower harnessing on the discharge), allow us to contribute to studies of the effect of human activities on the biosphere. This is especially interesting for the Þjórsá-Tungnaá river system where five hydropower plants have been built in steps during the last four decades, because one of the main spawning areas of cod in Icelandic waters is close to the mouth of the river.

This is only one example of possible use of the runoff map and associated data. As an example of other uses it has been used for the calculation of gravitational potential power and other hydrological parameters (Jónsdóttir, 2008).

MODEL APPLICATION IMPROVEMENTS

The WASIM model has proven to be a useful tool for: runoff mapping, future projection of runoff and calculation of runoff from ungauged areas. Modelling use can nevertheless still be improved. As a part of the CES project and its planned Icelandic sister project further use and improvements of application of WASIM is intended. It is planned to activate and calibrate the groundwater part of the model and to calibrate the model with new precipitation data on a 1x1 km grid.

Activation and calibration of WASIM's groundwater modulus

Until now the groundwater modulus of WASIM has not been used in efforts to model the runoff of Iceland. Data on groundwater level are sparse and the groundwater modulus proved to be hard to calibrate, therefore a shortcut was taken and groundwater flow was accounted for by scaling the precipitation. On watersheds where groundwater infiltrates and flows out of the watershed the precipitation is scaled down, and likewise the precipitation is scaled up on watersheds where groundwater emerges as spring water. This method keeps the water balance right but makes the calibration of discharge timing more difficult as the river base-flow, which is fed by groundwater, becomes hard to represent. This also gives problems on porous watersheds where snow accumulates during the winter and infiltrates within a short period during the spring thaw, giving high

groundwater levels. In these water systems the precipitation is scaled down on the porous watershed so there is very little snow accumulation during the winter and no peak in infiltration during the spring. This modelling problem (and numerous other smaller ones) shows the importance of representing the groundwater properly by use of the groundwater modulus. This is especially valid for the large areas in central Iceland which are covered with porous postglacial lavas.

One defined subproject within the Icelandic part of CES is to activate and calibrate the groundwater modulus. For this task, we will use maps of hydraulic conductivity and permeability, which have been produced for a substantial part of the country. For the remaining parts, these parameters can be estimated from geological maps. Available data on spring water flow and the sparse data on groundwater level will be used in the calibration efforts.

Recalibration onto new precipitation data

The geographical distribution of precipitation is a key parameter in hydrological modelling. It is important that the effects of mountains and landscape are resolved in precipitation calculations and as the scale in modelling gets smaller landscape is better represented. Therefore it is preferable to use precipitation data on the smallest available scale. As a part of the CE project precipitation was modelled with a model based on linear theory of orographic precipitation on a 1x1 km grid (Jóhannesson et al., 2007). The WASIM model will be calibrated onto these new precipitation data to improve model performance.

DISCUSSION

The WASIM model has proven useful in calculating runoff under Icelandic conditions and a runoff map has been made for the decades 1961-1990. A future projection for 2071-2100 has also been made. The performance of the model and its representation of natural conditions can still be improved and the groundwater modulus will be activated and calibrated for this purpose. The model will also be recalibrated onto new precipitation data sets that are on a finer grid than those that were used previously. After these improvements the model will be used to calculate runoff from Iceland for the period 1957-2007, producing boundary conditions for oceanographic modelling over longer periods than hitherto. The model will also be used to make new future runoff scenarios. These scenarios will be made for the period from present until 2050. Uncertainties and variation in runoff scenarios will also be studied by use of more than one future projection, based on different climate scenarios.

REFERENCES

- Aðalgeirsdóttir, G., T. Jóhannesson, H. Björnsson, F. Pálsson and O. Sigurðsson. 2006. Response of Hofsjökull and southern Vatnajökull, Iceland, to climate change. *J. Geophys. Res.* 111, F03001
- Bergström, S., T. Jóhannesson, G. Aðalgeirsdóttir, A. Ahlström, L. M. Andreassen, J. Andréasson, S. Beldring, H. Björnsson, B. Carlsson, P. Crochet, M. de Woul, B. Einarsson, H. Elvehøy, G. E. Flowers, P. Graham, G. O. Gröndal, S. Guðmundsson, S.-S. Hellström, R. Hock, P. Holmlund, J. F. Jónsdóttir, F. Pálsson, V. Radic, N. Reeh, L. A. Roald, S. Rogozova, J. Rosberg, O. Sigurðsson, M. Suomalainen, Th. Thorsteinsson, B. Vehviläinen and N. Veijalainen. 2007. Impacts of climate change on river runoff, glaciers and hydropower in the Nordic area. *Joint final report from the CE Hydrological Models and Snow and Ice Groups*. Reykjavík, Climate and Energy, Report no. CE-6
- Bjørge, D., Haugen, J. E. & Nordeng, T. E. 2000. Future climate in Norway. Dynamical downscaling experiments within the RegClim project. *Research Report no. 103*, Norwegian Meteorological Institute, Oslo, Norway
- Fenger, J. (ed). 2007. *Impacts of Climate Change on Renewable Energy Sources. Their role in the Nordic energy system*. Copenhagen, Nordic Council of Ministers, Nord 2007:003, ISBN 978-92-893-1465-7, 192 pp
- Gordon, C., Cooper, C., Senior, C. A., Banks, H., Gregory, J. M., Johns, T. C., Mitchell, J. B. F. & Wood, R. A. 2000. The simulation of SST, sea ice extents and ocean heat transport in a version of the Hadley Centre coupled model without flux adjustments, *Clim. Dyn.* 16, 147–168
- Jasper, K., Gurtz, J. & Lang, H. 2002. Advanced flood forecasting in Alpine watersheds by coupling meteorological observations and forecasts with a distributed hydrological model. *J. Hydrol.* 267, 40–52
- Jasper, K. & Kaufmann, P. 2003. Coupled runoff simulations as validation tools for atmospheric models at the regional scale. *Quart. J. Roy. Met. Soc.* 129(588) 673–692
- Jónsdóttir, J. F. 2008. A runoff map based on numerically simulated precipitation and a projection of future runoff in Iceland. *Hydrological Sciences Journal*, 53(1) February 2008
- Jóhannesson, T., Aðalgeirsdóttir, G., Björnsson, H., Crochet, P., Eliasson, E. B., Guðmundsson, S., Jónsdóttir, J. F., Ólafsson, H., Pálsson, F., Rögnvaldsson, Ó., Sigurðsson, O., Snorrason, Á., Sveinsson, Ó. G. B., Thorsteinsson, Th., 2007. *Effect of climate change on hydrology and hydro-resources in Iceland*, Reykjavík, Orkustofnun, OS-2007/011, ISBN 978-9979-68-224-0, 91 pp
- Nakićenović, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grübler, T. Y. Jung, T. Kram, E. L. La Rovere, L.

- Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Riahi, A. Roehrl, H.-H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, N. Victor and Z. Dadi. 2000. *IPCC Special Report on Emissions Scenarios*. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 599 pp
- Rist, S. 1956. Íslenzk vötn. *Icelandic fresh waters*. Raforkumálastjóri, Vatnamælingar, Reykjavík, Iceland
- Rögnvaldsson, Ó., Crochet, P. & Ólafsson, H. 2004. Mapping of precipitation in Iceland using numerical simulations and statistical modeling, *Meteorol. Z.* 13(3), 209–219
- Stefánsson, U., 1999. *Hafið 2nd ed.* Reykjavík, Háskólaútgáfan.
- Tómasson, H. 1981. Vatnsafl Íslands, mat á stærð orkulindar. In: *Orkuþing 81. Erindi flutt á Orkuþingi 9., 10. og 11. júní, 1981*. Vol 2. [in Icelandic]