ORKUSTOFNUN

Vatnamælingar – Hydrological Service

Comparison of HBV models, driven with weather station data and with MM5 meteorological model data

Jóna Finndís Jónsdóttir
Jón Sigurður Þórarinsson

Prepared for the national project,
Climate Water and Energy

2004

OS-2004/017

ORKUSTOFNUN
Hydrological Service

Project no.: 7-690927

Jóna Finndís Jónsdóttir
Jón Sigurður Þórarinsson

Comparison of HBV models, driven with weather station data and with MM5 meteorological model data

Prepared for the national project, Climate Water and Energy

OS-2004/017 **August 2004**

ISBN 9979-68-147-0

ORKUSTOFNUN – HYDROLOGICAL SERVICE

Reykjavík: Grensásvegi 9, 108 Rvk. – Tel.: 569 6000 – Fax: 568 8896
E-mail: vm@os.is – Webpage: http://www.os.is/vatnam

ORKUSTOFNUN
Hydrological Service

Key page

Report no.:	**Date:**	**Distribution**
OS-2004/017	August 2004	☒ Open ☐ Closed

Report name / Main and subheadings:	**Number of copies:**
Comparison of HBV models, driven with weather station data and with MM5 meteorological model data.	30
	Number of pages: 17
Authors: Jóna Finndís Jónsdóttir Jón Sigurður Þórarinsson	**Project manager:** Jóna Finndís Jónsdóttir
Classification of report: Results from hydrological modelling	**Project no.:** 7-690927

Prepared for:

The national project, Climate, Water and Energy

Cooperators:

Abstract:

A comparison of two HBV models is performed, one is driven with weather station data and the other with MM5 meteorological model output data. This was done for three watersheds in Iceland, where HBV models using weather station data have been calibrated earlier. The purpose of the study is to estimate how well the MM5 model evaluates the precipitation in the selected watersheds, both considering the timing of events and the accumulated precipitation over a longer period. The study showed that meteorological output from the MM5 model gives important information for water balance studies in Iceland including prediction of runoff in ungauged watersheds. The correlation between measured discharge and calculated by the MM5 data driven HBV model is generally fairly good and the water balance for each water year was generally improved by using the MM5 data rather than data from the weather stations.

Key words:	**ISBN-number:**
HBV, MM5, hydrological model, Sandá, Norðurá, Hólmsá, vhm 36, vhm 128, vhm 231	9979-68-147-0
	Project manager's signature: Jóna Finndís Jónsdóttir
	Reviewed by: Kristinn Einarsson, Gunnar Orri Gröndal

CONTENTS

1 INTRODUCTION

This report describes a comparison of HBV models, driven with weather station data and with MM5 meteorological model output data. The comparison was made for three watersheds in Iceland, where HBV models using weather station data have been calibrated earlier. The purpose of the study is to estimate how well the MM5 model evaluates the precipitation in the selected watersheds, both considering the timing of events and the accumulated precipitation over a longer period.

The PSU/NCAR MM5 numerical simulation model simulates meteorological parameters on a grid with 8 km horizontal resolution. Downscaling experiments have been done with the MM5 model in order to determine the optimal configuration for climatological downscaling of precipitation in Iceland (Rögnvaldsson and Ólafsson 2002) and simulation for the period 1990 – 2003 has been completed. The setup of the model is described by Rögnvaldsson et al. (2004).

The HBV hydrological watershed model simulates the runoff of a watershed from data on daily precipitation and temperature. In the model, simple equations are used to describe the complicated processes of nature. The Hydrological Service uses the so-called "KARMEN" version, which was developed at Norges vassdrags- og energidirektorat (NVE) together with the University of Oslo. (Sælthun, 1996).

Over 100 parameters are used in the model to convert data on precipitation and temperature into runoff. The parameters are determined by a trial and error method, i.e. the parameters are given a value that is assumed to be reasonable and the model calculates the runoff for a particular time period. The difference between the calculated and measured runoff is then evaluated, the parameters are changed and the model calculates the runoff again, until the correlation between measured and calculated runoff is acceptable.

In this study only time series on temperature and precipitation from the MM5 were used since those are the only two time series that can be used as an input to the HBV model. Other meteorological variables, such as wind and radiation, affect snow melt and evaporation and would be valuable to use in further watershed modeling. The time resolution of the output data from the MM5 model is 6-hours but the values were summed up to daily data for the HBV model.

2 DATA

2.1 Discharge data

Icelandic rivers are generally divided in to three categories by their origin:

- Glacial rivers originate at the glacier when the snow and glacier is melting. Their discharge is correlated with air temperature and their discharge in the summertime may become some degrees of magnitude larger in the summer than during the winter. They also have a large daily variation in discharge in the summer time, since the melting occurs primarily during the daytime.
- Direct runoff rivers originate in many small creeks that accumulate into a river. They appear where the soil or rocks have a low permeability and precipitation

or melt water does not infiltrate into the ground to a large degree. The discharge of these rivers is usually highest in the spring when the snow is melting.

- Springfed rivers originate in areas with a high permeability, for example where lave fields are vast and are often connected to tectonic faults and fractures. The groundwater aquifers are rather large and the discharge of the rivers is fairly even throughout the year.

This division of rivers by origin can often be done easily be comparing their seasonal profile. Fig. 1 shows the profile of three rivers of different origin. The direct runoff river is largest during springfloods, the springfed river has an approximately even flow throughout the year. The glacier river has very low flow during the winter but a high flow from the time of the spring floods and throughout the summer, when the snow and glacier is melting.

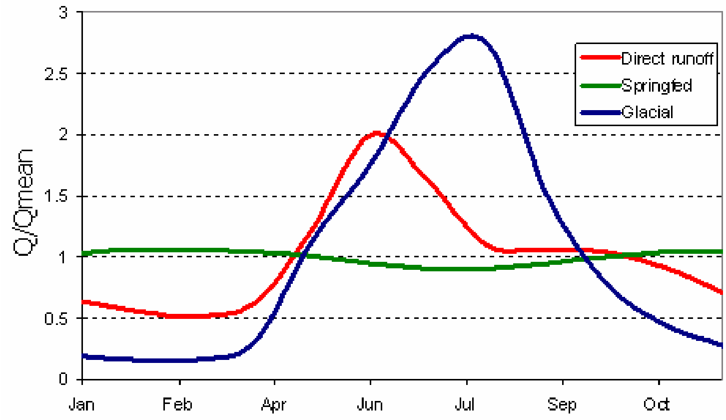

Figure 1. *Seasonal profiles of rivers of three different origins, direct runoff, springfed and glacial.*

With these three profiles in mind, one can often determine the origin of different rivers by looking at their seasonal profile, also a knowledge of the geology of the watershed is valuable. Many rivers have however more than one "origin" and some rivers run through lakes that smooth out variations in their seasonal profile.

The three watershed in this study are in different parts of the country (Fig. 2). They have somewhat different characteristics, where one of the rivers, Hólmsá (vhm 231) is groundwater fed with a large glacier component while the two others, Norðurá (vhm128) and Sandá (vhm 26) are directly fed by precipitation and snowmelt. The size of the watersheds at the gauge location is: Hólmsá 241 km^2, Sandá 263 km^2 and Norðurá 507 km^2.

These three watersheds have all been modelled earlier by HBV, using meteorological data from neighbouring weather stations. Those models are described in the reports by Gröndal (2000, 2002) and Gísladóttir (1997). During this study results from those models were compared to the models with MM5 input meteorological data.

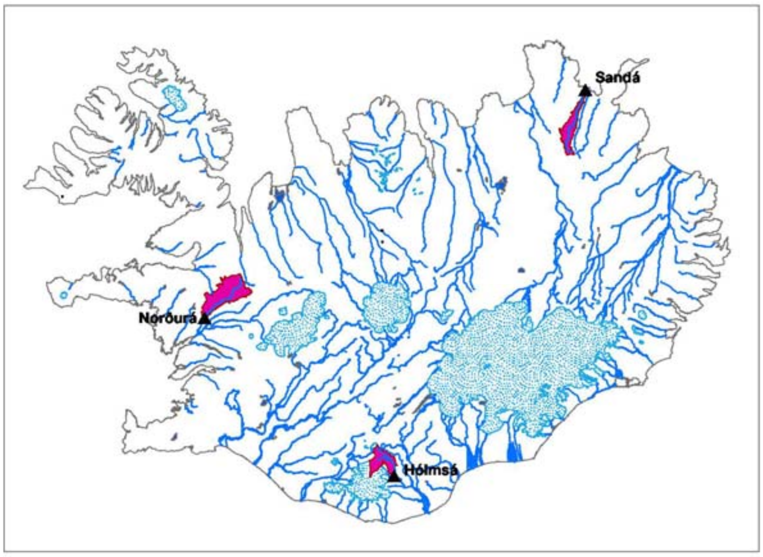

Figure 1. *The location of the three watersheds used in the study.*

2.1.1 Sandá in Þistilfjörður

The watershed of Sandá lies in the north-eastern part of Iceland. The river originates in Mórilludalur valley and reaches 50 km to the ocean in north east. One discharge gauge (vhm 26) has been operated in the river since 1965. The gauge is at 20 m a.s.l. and the area of the watershed at the gauge is 263 km^2. The watershed reaches up to 967 m a.s.l. (Gröndal 2002).

As can be seen on the seasonal profile (Fig. 3) of the river, the discharge of the river is highest in May and June but low during the last six months of the year. The profile indicates that the discharge of the river is predominantly from direct runoff and snowmelt but the river also has a considerable groundwater component. Floods are most common during the snow melt season in the spring, while rain floods in the fall are also common. Droughts are quite common in the river when ice dams the river or snow drift fills up the channel, floods follow the droughts when the ice breaks up but those floods are almost always smaller than the largest spring floods. (Jónsson et al. 1999).

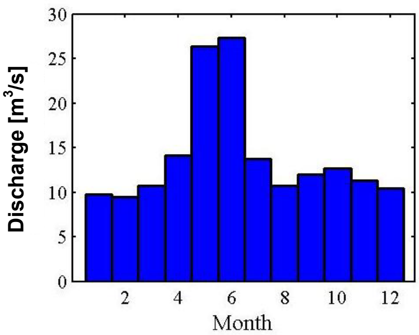

Figure 3. *The seasonal profile of Sandá, monthly discharge averages for 1965-2003.*

During the winter the water level data from the gauge are often interrupted by ice. Data appearing to be interrupted have been adjusted according to discharge measurements and meteorological data. The adjusted data are not used to calibrate the

HBV model. A new stage-discharge curve was adopted for the year 1997 and onwards.

2.1.2 Hólmsá in Skaftártunga

River Hólmsá is located in south Iceland and originates southeast of the glacier Torfajökull. Several rivers that originate in Mýrdalsjökull glacier merge with the river and the runoff is a combination of groundwater, glacial melt water and direct runoff. The seasonal profile of the river is shown in Fig. 4, it shows that in the early spring the runoff is at its lowest, the snowmelt starts contributing to the runoff in May and June and glacier melt continues until in the fall.

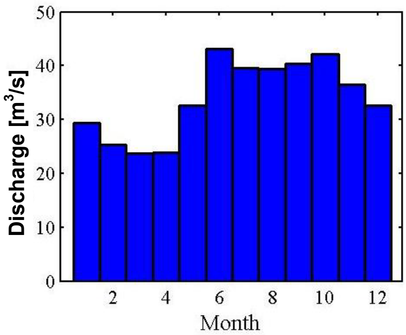

Figure 4. *The seasonal profile of Hólmsá, monthly discharge averages for 1984-2003.*

The discharge gauge (vhm 231) has been operated since September 1984. The gauge is at 170 m a.s.l. but the watershed reaches up to 1400 m on Mýrdalsjökull. The area of the watershed is 241 km^2 of which the glaciers Mýrdalsjökull and Torfajökull cover 49 km^2 and 1.5 km^2 respectively.

The modelling of this watershed is difficult with HBV since geothermal areas beneath the glaciers generate a glacial melt component that is independent of air temperature. Another complicating factor is that the ground is very permeable and frozen ground may block infiltration to groundwater, resulting in changes in the precipitation to runoff relationship. Additionally there has been some disturbances at the discharge gauge due to sand accumulation. (Gröndal 2000)

2.1.3 Norðurá in Borgarfjörður

Norðurá in Borgarfjörður is in west Iceland. The river originates in Holtavörðuheiði and reaches 60 km to the southwest through Norðurárdalur until it merges with Hvítá. The discharge gauge (vhm 128) has been operated since August 1965, the gauge is at 18 m a.s.l. and the area of the watershed at the gauge is 506 km^2.

The seasonal profile of the river is shown in Fig. 5, Norðurá is predominantly a direct runoff and snowmelt river. The runoff is highest in the spring during snow melt and increases again during the fall when the precipitation in the area is high. The floods of Norðurá are quite large and winter floods are most common (Oct-Feb), those are rain- and snowmelt floods on frozen ground or slush floods. (Jónsson et al. 1999).

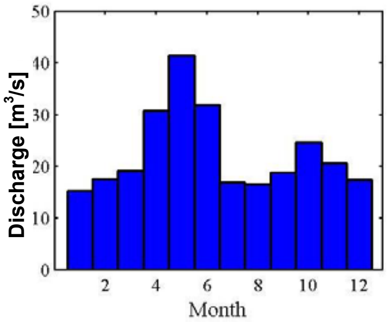

Figure 5. *The seasonal profile of Norðurá, monthly discharge averages for 1971-2003.*

2.2 Meteorological data

The MM5 model has been run for the period February 1990 until April 2003. The meteorological data for the hydrological years 1990-2001 were therefore available for analysis. The output data were extracted from the MM5 output files using IDL software. The mean daily temperature at 2 m elevation was extracted as well as the accumulated daily precipitation. For a precipitation value, convective and nonconvective rain was summed up. Convective rain is associated with movement of moist air when the air heats/cools down, while non-convective rain is associated with frontal boundaries, troughs, and low-pressure systems.

The MM5 output is given on an 8km*8km grid cells in a projected coordinate system. The coordinates of the grid points were projected to the official Icelandic Lambert (Ísnet93) coordinate system and compared to the extent of the watersheds. Values for all grid points within and neighbouring the specific watersheds were extracted. The resulting text files are separate files for each grid point for each hydrological year. The text files are named according to the number of the grid point and the year. Within each file there are five columns, the first three columns are the date, the fourth column is the daily precipitation, and the fifth column corresponds to the daily mean temperature at 2m above ground.

3 METHODS

During the study an effort was made to perform the study of the three watersheds in a similar way for all the watersheds and the method of study is described here. Details, specific to each of the watersheds are however discussed in the subchapters.

The data from the MM5 model were used as input data into the HBV model for the three watersheds. The HBV models were calibrated on the first seven hydrological years and the other 5 years of data were used for comparison.

The HBV model can use up to 25 data series with precipitation and four time series of temperature. For these three watersheds, the intersecting grid cells were never more than 25, therefore all the precipitation series were used. The weight of the grid cells as precipitation stations was defined according to the proportion of the cell intersecting the watershed (Figure 6a). Only four time series of temperature were allowed and those central to the watersheds were selected. The weight of the grid cells as temperature stations was defined by creating Theissen polygons around the four grid points selected as temperature stations and intersecting those with the watershed (Figure 6b).

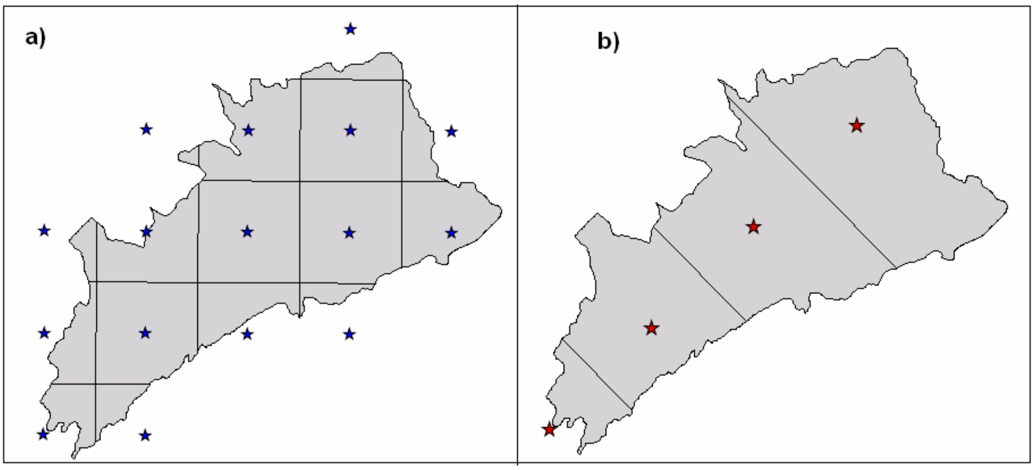

Figure 6. *The watershed of Norðurá at vhm128 and the grid points from the MM5 model used in the HBV model. a) 16 grid points were used as precipitation stations, weight of each station defined according to the grey areas b) Four grid points were used as temperature stations.*

The precipitation gradient in HBV (PGRAD) is defined as the percentage change in precipitation between 100 m intervals. This is described by (1) where p_y is precipitation at elevation y (measured in meters) and p_0 is precipitation at elevation y_0.

$$p_y = p_0 \cdot (1 + PGRAD)^{(y-y_0)/100} \tag{1}$$

$$\log(p_y) = \log(p_0) + \left(\frac{y - y_0}{100}\right) \cdot \log(1 + PGRAD) \tag{2}$$

Equation (2) is derived from (1) and shows that if $\log(p_y)$ is plotted against y/100, the gradient equals log(1+pgrad).

The precipitation gradient model in HBV (eq. 1) was fitted to the MM5 data in order to evaluate PGRAD. Accumulated precipitation for the hydrological years from 1991 to 1996 was extracted from all the MM5 grid point data series and plotted as a function of the elevation of the grid points, as explained in eq. 2., the slope of the graph then revealed the PGRAD. The data did however not fit this model well in every case and it may turn out to be better to use models where the meteorological data are not forced to be represented by gradients applying for the whole watershed.

The temperature gradient in HBV is given as °C change per 100 m. The gradient is different for days with (TVGRAD) and without (TTGRAD) precipitation. A seasonal profile of the temperature gradient can be specified by one value per month from January to December. This profile is normalized against TTGRAD and TVGRAD (Sælthun, 1996). The temperature gradients were calculated from the data series of the same grid points as were used as precipitation stations. At maximum four temperature data series could be used directly into the HBV model. The hydrological years 1992 and 1994 were used for the calculation of temperature gradients.

In this study, the HBV model was run with and without the precipitation/temperature gradients defined by the MM5 data.

There are two parameters in the HBV model that correct precipitation from weather stations. All precipitation is adjusted by the parameter PKORR which accounts for losses in precipitation at the gauge as well as rain that is not presented by precipitation stations. The adjustment parameter SKORR is used when temperature indicates that precipitation falls as snow rather than rain and accounts for larger catch losses with snow.

While using the MM5 data into the HBV model, there was no reason to adjust for losses at the gauge. No adjustment of rain or snow was therefore done at first. When the water balance did not appear to fit the precipitation and discharge data, the PKORR parameter was used to adjust the precipitation from the MM5 model.

Some additional HBV parameters were then changed from the original HBV model of each watershed, trying to get a good fit for the model. The fit of the model was judged by on one hand the water balance and on the other hand by the R2 and R2log, Nash efficiency criterion.

3.1 Sandá in Þistilfjörður

An earlier HBV model described by Gröndal (2002) was able to model the base flow of Sandá fairly well. The model did however have difficulties in estimating floods, the calculated flood peaks were usually either under or over estimated. This earlier model was calibrated on discharge data from the water years 1988 – 1994. The data used for calibration of that model are no longer valid since the discharge curve used to convert water level into discharge has been re-evaluated.

Two models using the data from the MM5 model were calibrated, one using the same discharge series as the earlier HBV model was calibrated on, the other using the discharge series that is valid today. No major difference appeared between the results of the models and only the one calibrated on valid discharge data will be discussed here.

The model was calibrated on the discharge series of the water years 1990-1995 and calculated discharge was then compared to measured discharge for the water years 1996-2001. The parameters from the earlier model were used for this model, except for temperature gradients, precipitation gradients and precipitation correction. The temperature gradient of the MM5 data was evaluated and used. The precipitation gradient was set to zero which means that precipitation was evenly distributed over the watershed, this was done since if another gradient was used in the HBV model, the accumulated precipitation from the model was different from the precipitation evaluated straight from the MM5 data. This results however in a wrong distribution of snow and may cause wrong timing of floods. This method is therefore not recommended.

3.2 Hólmsá in Skaftártunga

An earlier HBV model described by Gröndal (2000) is not regarded liable because of a bad fit during the water years used for comparison. The model had difficulties simulating the runoff during years with high runoff which may imply that the weather stations did not represent the watershed well enough. The model was calibrated on the water years 1983-1990.

A model using the data from the MM5 model was calibrated. Originally the parameter set from the earlier model was used but some parameters were modified to adjust it to the new set of input data. The temperature gradients were given the values calculated from the MM5 dataset, PKORR was adjusted to correct the mean water balance and the precipitation gradient was given the value that gave the best fit to observed runoff. Finally parameters that describe the snow submodel were adjusted. The model was calibrated on the water years 1990-1996.

3.3 Norðurá in Borgarfjörður

An earlier model by Gísladóttir (1997) proved to be quite successful in simulating the discharge of Norðurá. The model was composed of two sub models since meteorological data were not available for the same set of weather station for the period of simulations. The water years 1972-1984 were used for calibration of the model. An older verison of HBV was used for this model and the parameter file does not seem to be compatible with this version of HBV (KARMEN). This reduces the possibilities of comparing the two models.

Since discharge data are not available for the water years of 1990-1991, the MM5 data driven model was calibrated on the water years 1992-1996. The water years 1997-2002 were used for comparison. The temperature gradients were given values calculated from the MM5 dataset as well as the precipitation gradient. Precipitation was adjusted for a good fit of water balance and parameters describing the snow and soil sub models were adjusted according to the Nash efficiency criterion.

4 RESULTS

4.1 Sandá in Þistilfjörður

Precipitation from the MM5 dataset was increased by 5% to make the mean water balance for the water years 1990-1995 fit to measured data.

Tables 1-2 show some of the results from the comparison of the two models. Results from the earlier model by Gröndal (2000) is shown in italics and the other one where the MM5 data are used, is on the right side. The period used for calibration of the MM5 data driven model is above the thick line.

Water Year	*Original HBV model, Gröndal 2000*				HBV model with MM5 data			
	Q_{mes} [m^3/s]	*Q_{calc} [m^3/s]*	*Proportional difference*	*Q_{tot} [m^3/s]*	Q_{mes} [m^3/s]	Q_{calc} [m^3/s]	Proportional difference	Q_{tot} [m^3/s]
1990/91	*13.7*	*13.5*	*-2 %*	*13.2*	14.5	14.4	-1 %	14
1991/92	*12.8*	*13.5*	*5 %*	*13.1*	13.5	13.8	2 %	13.4
1992/93	*16.8*	*17.8*	*6 %*	*14.8*	17.5	16.2	-7 %	13.8
1993/94	*18.3*	*14.4*	*-22 %*	*11*	18.9	16.5	-13 %	12.4
1994/95	*18.3*	*20.8*	*14 %*	*15.8*	19.1	20.2	6 %	15.6
1995/96	*10.5*	*8.54*	*-19 %*	*8.5*	11.2	12.8	14 %	12.3
1996/97	*15.4*	*15.3*	*0 %*	*11.6*	15.6	15.8	1 %	11.9
1997/98	*14.2*	*13.8*	*-3 %*	*13*	14.2	13.2	-7 %	12.4
1998/99	*20.3*	*16.2*	*-20 %*	*13.4*	20.3	18	-11 %	15.2
1999/00	*16.2*	*17.3*	*7 %*	*13.5*	16.1	13.4	-17 %	10.7
2000/01	*15.2*	*12*	*-21 %*	*11.3*	15.2	13.7	-9 %	12.4
2001/02	*16.2*	*13.7*	*-15 %*	*13.3*	15.6	12.8	-18 %	12.4

Table 1. *Comparison of Sandá water balance using weather station data (on the left) and MM5 data (on the right). Above the black line is the period of the calibration for MM5 data driven model.*

Period (water years)	*Original HBV model (Gröndal 2000)*			HBV model with MM5 data		
	R2	*R2log*	*Water balance*	R2	R2log	Water balance
1990/91-1995/96	*0.63*	*0.63*	*-2 %*	0.49	0.57	0 %
1996/97-2001/02	*0.62*	*0.52*	*-11 %*	0.54	0.44	-11 %

Table 2. *Comparison of Nash efficiency criterion for Sandá. using weather station data (on the left) and MM5 data (on the right).*

Both of the models do a fair job of simulating the discharge of Sandá. Neither of the models is able to simulate the mean runoff for each year well but the average mean for a period of time is fairly good. Both of the models show a water balance deviation of 11% during the period 1996-2001. This may be caused by unstable conditions at the discharge gauge (a new rating curve is valid from 1.1.1997). Another reason may be that climatological/hydrological conditions were somewhat different during the second period and that the HBV model fails to simulate the effect of those conditions.

The weather station data driven model seems to simulate the daily runoff better (higher R2 and R2 log values), however the MM5 data driven model seems to be somewhat better at simulating the mean runoff for each water year.

4.2 Hólmsá in Skaftártunga

Precipitation from the MM5 dataset was increased by 16% to make the mean water balance for the water years 1990-1996 fit to measured data.

The precipitation gradient was changed in order to get the best fit. The final setting of those was PGRAD 0.02 and for elevations above 800 m, PGRAD1 0.09. According to the MM5 data the corresponding values would be PGRAD 0.02 and above 680 m a.s.l. PGRAD1 0.12. This shows that the best fitted precipitation gradient was very close to the one determined by the MM5 dataset.

In Tables 3-4 some results from both of the models are shown. The earlier model by Gröndal (2003) is shown in italics and the other one where the MM5 data are used, is on the right side. The period used for calibration of the MM5 data driven model is above the thick line. Both of the models have trouble simulating floods as can be seen from a low value of R2 in Table 4. The timing of floods is especially poor for MM5 data driven model during the period used for comparison. This problem may be connected to the discharge gauge since the stilling well has proved to react slowly to changes in discharge.

Water Year	*Original HBV model (Gröndal 2003)* Q_{mes} $[m^3/s]$	Q_{calc} $[m^3/s]$	*Proportional difference*	Q_{tot} $[m^3/s]$	HBV model with MM5 data Q_{mes} $[m^3/s]$	Q_{calc} $[m^3/s]$	Proportional difference	Q_{tot} $[m^3/s]$
1990/91	*35.8*	*31.4*	*-12 %*	*31.1*	35.8	32.6	-9 %	32.3
1991/92	*33.5*	*38.4*	*15 %*	*37.7*	33.5	32.9	-2 %	32.6
1992/93	*35.3*	*35.9*	*2 %*	*32.7*	35.3	38.2	8 %	34.8
1993/94	*36*	*35*	*-3 %*	*34.1*	36	38.5	7 %	37.5
1994/95	*32*	*37.1*	*16 %*	*35.3*	32	34	6 %	31.9
1995/96	*31.3*	*34.5*	*10 %*	*34.2*	31.3	34.6	11 %	34.3
1996/97	44.6	36	-19 %	32.9	44.6	37.2	-17 %	34.1
1997/98	*40.3*	*31.6*	*-22 %*	*30.8*	40.3	39.7	-2 %	38.6
1998/99	*35.7*	*35.3*	*-1 %*	*34.8*	35.7	36.7	3 %	36.2
1999/00	*47.9*	*38*	*-21 %*	*33.6*	47.9	46.3	-3 %	33.6
2000/01	*33.2*	*32.8*	*-1 %*	*31.4*	33.2	40.9	23 %	40.4
2001/02	*37.9*	*37.6*	*-1 %*	*36.1*	37.9	39.5	4 %	37.4

Table 3. *Comparison of Hólmsá water balance using weather station data (on the left) and MM5 data (on the right). Above the black line is the period of the calibration for MM5 data driven model.*

Period (water years)	*Original HBV model (Gröndal 2003)* *R2*	*R2log*	*Water balance*	HBV model with MM5 data R2	R2log	Water balance
1984/85-2001/02	*0.34*	*0.47*	*0 %*			
1990/91-1996/97	*0.18*	*0.32*	*0 %*	0.32	0.37	0 %
1997/98-2001/02	*0.16*	*0.19*	*-8.9%*	-0.19	0.18	4.7%

Table 4. *Comparison of Nash efficiency criterion for Hólmsá. using weather station data (on the left) and MM5 data (on the right).*

The HBV model is generally not capable of modelling watersheds with a large groundwater component. Hólmsá river has a large groundwater component and neither of these HBV models can be regarded as a good model for the simulation of runoff in Hólmsá. Still the latter one, driven by the data from the MM5 models proves to be better at simulating the long term water balance. There, fewer years have large deviations from the accumulated measured runoff than in the model driven with meteorological data from weather stations (Table 4).

4.3 Norðurá in Borgarfjörður

Precipitation from the MM5 dataset was decreased by 16% to make the mean water balance for the water years 1990-1996 fit to measured data.

The precipitation gradient was set to 16% increase for every 100m increase in elevation. This value should have been 11% but was not calculated correctly from the MM5 data. A short examination of the effects of the wrong precipitation gradient showed a somewhat better fit with the correct value but the water balance remained the same.

Table 5 shows the water balance for each water year for the MM5 data driven model. The period used for calibration of the MM5 data driven model is above the thick line. Table 6 shows the fit of the models for various periods, unfortunately the models could not be run for the same period.

Water Year	HBV model with MM5 data Q_{mes} [m^3/s]	Q_{calc} [m^3/s]	Proportional difference	Q_{tot} [m^3/s]
1992/93	36.3	33	-9 %	26.7
1993/94	23	25.9	12 %	23.1
1994/95	27.2	29.5	9 %	24.5
1995/96	23	22.3	-3 %	20.5
1996/97	27.3	25.1	-8 %	21.1
1997/98	21.2	21.9	3 %	20
1998/99	26.2	22.9	-13 %	19.6
1999/00	36.2	34	-6 %	27.9
2000/01	15.9	15.3	-4 %	13.9
2001/02	28.1	24.1	-15 %	22

Table 5. *Norðurá water balance using MM5 data. Above the black line is the period of the calibration for MM5 data driven model.*

Period (water years)	*Original HBV model (Gísladóttir 1997)* R2	*R2log*	*Water balance*	HBV model with MM5 data R2	R2log	Water balance
1972/73-1984/85	*0.7*	*0.75*	*9 %*			
1970/71-1989/90	*0.66*	*0.7*	*3 %*			
1972/73-1984/85	*0.72*	*0.73*	*7.9%*			
1950/51-1984/85	*0.71*	*0.72*	*8.8%*			
1992/93-1996/97				0.56	0.54	0.0%
1997/98-2001/02				0.47	0.58	-7.5%

Table 6. *Comparison of Nash efficiency criterion for Norðurá. using weather station data (on the left) and MM5 data (on the right).*

Table 5 shows that the water balance fit is fairly similar between years. It seems however that according to the validation years the precipitation should not have been reduced as much as it was. According to the Nash efficiency criterion (Table 6) the earlier model was able to simulate the discharge of Norðurá better that the new model.

5 DISCUSSION

The purpose of this study was to estimate how well the MM5 model evaluates the precipitation in the selected watersheds, both considering the timing of events and the accumulated precipitation over a longer period. Precipitation and discharge are connected through natural processes but not all precipitation on the watershed becomes discharge, evaporation has to be accounted for as well as the groundwater flow to and from the watershed. Boundaries of groundwater aquifers do not necessarily coincide with the watershed of a river. Evaporation can not be determined accurately since few measurements are available. Evaporation can however be evaluated from the MM5 model output data, and the seasonal distribution of evaporation according to the model should be studied further. Therefore, even though the precipitation from the MM5 model had to be reduced/increased to fit the discharge of the rivers, further study covering more watersheds is necessary to determine whether the precipitation according to the MM5 model is too low or high.

Meteorological measurements for large areas in Iceland, especially the highland are lacking. When the data from the meteorological stations are used, the precipitation has to be scaled to account for losses due to wind. This scaling is substantial especially for snow. When the meteorological station input data were used for the HBV models of the three watersheds the measured precipitation was multiplied by an average of 1.7

for rain and 2.2 for snow. This is much greater scaling than we had to do with the MM5 data where the precipitation was scaled by a maximum of 16%.

The meteorological stations are generally close to the ocean. Only one meteorological station is above 500 m a.s.l. whereas 50% of the country is above that elevation. Therefore, information of how precipitation increases with altitude is scarce. The MM5 model of precipitation over Iceland has been calibrated using available mass balance from glaciers and should be capable of evaluating precipitation better than can be done by simply using lowland precipitation stations.

The correlation between measured discharge and calculated by the MM5 data driven HBV model is generally fairly good. The correlation is however usually better in the original models that used data from nearby weather stations. The reason for this may be that more model parameters were adjusted to the weather station data and more time was spent on calibrating the original models.

The water balance for each water year was generally improved by using the MM5 data rather than the weather stations. This may reflect that fewer parameters have to be determined by calibration where the MM5 data are used since the MM5 data give additional information on precipitation and temperature gradients. Another reason may be that the MM5 meteorological data represent variations of climate in the watershed better than the weather stations that may be located quite far away.

The study shows that meteorological output from the MM5 model gives important information for water balance studies in Iceland including prediction of runoff in ungauged watersheds. The HBV model does however not use all the information supplied by the MM5 model. The distribution of meteorological variables within the watershed and through time is simplified in the HBV model. Instead of using the gridded data, gradients are determined that should represent the whole watershed. Also other meteorological variables than temperature and precipitation, such as radiation and wind, affect snow melt and evaporation and would be valuable to use in further watershed modeling.

REFERENCES

Gunnar Orri Gröndal. 2000. *Hólmsá í Skaftártungu. Gerð HBV-rennslislíkans af vhm 231* 14159 Orkustofnun, Vatnamælingar OS-2000-042

Gunnar Orri Gröndal. 2002. *Sandá í Þistilfirði : gerð HBV-rennslislíkans af vhm 026* 14378 Orkustofnun, Vatnamælingar OS-2002/036

Jón Sigurður Þórarinsson, Jóna Finndís Jónsdóttir. 2003. *Samanburður á HBV-líkönum í Sandá í Þistilfirði, vhm 26, með tvenns konar veðurgögnum* 3403 OST GRG JSTH/JFJ-2003/01

Jón Sigurður Þórarinsson, Jóna Finndís Jónsdóttir. 2003. *Samanburður á HBV-líkönum í Hólmsá í Skaftártungu, vhm 231, með tvenns konar veðurgögnum* 3434 OST GRG JSTH-JFJ-2003/02

Jón Sigurður Þórarinsson, Jóna Finndís Jónsdóttir. 2003. *Samanburður á HBV-líkönum í Norðurá, Norðurárdal, vhm 128, með tvenns konar veðurgögnum* 3435 OST GRG JSTH-JFJ-2003/03

Ólafur Rögnvaldsson, Haraldur Ólafsson. 2002. *Downscaling experiments with the MM5 model : determining an optimal configuration for climatological downscaling studies of precipitation in Iceland.* http://www.os.is/~or/rev/urkoma.pdf.

Ólafur Rögnvaldsson, Philippe Crochet, Haraldur Ólafsson. 2004. Mapping of precipitation in Iceland using numerical simulations and statistical modeling. *Meteorologische Zeitschrift,* **13**(3), 209-219

Pálína Gísladóttir. 1997. *Norðurá*. Orkustofnun, Vatnamælingar. Unpublished

Páll Jónsson, Eve Bourgault, Kristinn Guðmundsson, Heiðrún Guðmundsdóttir, Svanur Pálsson. 1999. *Flóð íslenskra vatnsfalla. Flóðagreining rennslisraða.* Orkustofnun, Vatnamælingar OS-99100.

Sælthun, Nils Roar. 1996. *The "Nordic" HBV model-version developed for the project "Climate Change and Energy Production"*. NVE Publication no.7, Norwegian Water Resources and Energy Administration, Oslo.