Icelandic
Meteorological Office

Veðurstofa Íslands

Available discharge time-series from glacier-covered catchments in Iceland

Bergur Einarsson, Veðurstofu Íslands

Technical report

Veðurstofa Íslands
Bústaðavegur 7–9
IS 150 Reykjavík

+354 522 60 00
vedur@vedur.is

BE/2012-01

Keypage

Technical report no.: BE/2012-01	**Date.:** August 2012	**Public** ☒ **Restricted** ☐ **Provision:**
Report title / including subtitle Available discharge time-series from glacier-covered catchments in Iceland		**No. of copies:** 12 **Pages:** 17
		Managing director: Jórunn Harðardóttir
Author(s): Bergur Einarsson		**Project manager:** Tómas Jóhannesson
		Project number: 4844-0-0004
Project phase:		**Case number:**

Report contracted for:

The Nordic Centre of Excellence SVALI, “Stability and Variations of Arctic Land Ice”.

Prepared in cooperation with:

Summary:

This report documents availability of discharge data in Iceland for study of subglacial hydrology. Selection of ten discharge time-series form glacier-covered catchment is described. Extraction from the hydrological database at the Icelandic Meteorological Office and storage of the selected data is also described. The report describes as well the processing of hydrometric data at the Icelandic Meteorological Office. A preliminary study of the data and an assessment of their potential use is furthermore presented.

Keywords:	**Managing director's signature:**
Discharge time-series, glacier runoff, glacier rivers, glacier hydrology, processing of hydrometric data.	**Project manager's signature:**
	Reviewed by: TJ, SG

Contents

1 Introduction **7**

2 Processing of hydrometric data at the Icelandic Meteorological Office **7**

3 Hydrometric measurements in glacier rivers **8**

4 Discharge data from selected glacier-covered catchments **9**

5 Data extraction and storage **9**

6 Preliminary study and assessment of potential use **12**

7 Conclusion **16**

8 Acknowledgments **16**

9 References **17**

1 Introduction

Glacier runoff is an important part of the hydrology of Iceland. Glaciers cover 11% of the country and store the equivalent of approximately 20 years of precipitation over the whole of Iceland (Björnsson & Pálsson, 2008). Many of the main rivers in Iceland do therefore have a considerable glacial component.

Glacier rivers are important for hydropower harvesting because of a large discharge and large elevation span as glaciers tend to be located in highland areas. This has led to substantial hydrological measurements in glacier rivers in Iceland (Rist, 1990). Decadal long discharge time-series are therefore available from a number of glacier rivers. These series show pronounced signs of glacier influence with a large late-summer discharge peak and diurnal discharge variations.

Glacier rivers bear witness to their source in the glacier. Hydrological measurements in glacier rivers can therefore potentially be used to shed light on the subglacial hydrological system which has gained an increased attention recently. The reason is that variations in the subglacial hydrological system are considered to be the main cause for ice velocity variations that have been observed on many glaciers in recent years in connection with increased surface melting caused by climate warming (Rignot & Kanagaratnam, 2006; Bell, 2008).

The relationship between subglacial hydrology and ice velocity variations is being investigated as a part of the project, Stability and Variations of Arctic Land Ice (SVALI) which is a part of the Nordic Top Research Initiative (TRI). Discharge time-series from selected hydrometric stations operated by the Icelandic Meteorological Office (IMO) will be analysed and modelled to elucidate the development of the subglacial hydraulic system and the subglacial hydraulic pressure. The first task in this study is to select the rivers that will be analysed and to prepare the discharge data for further processing.

This report describes the processing of hydrometric data at the IMO in section two. Problems and shortcomings in the acquisition of hydrometric data in glacier rivers are described in section three. Section four and five are on available discharge data from glacier-covered catchments and the extraction and storage of the selected data. A preliminary study of the data and an assessment of their potential use is then presented in section six.

2 Processing of hydrometric data at the Icelandic Meteorological Office

Discharge of selected rivers in Iceland is monitored by the IMO which operates approximately 200 hydrometric stations. These rivers are monitored either because of a general interest in the water resource by the National Energy Authority and the Ministry of Industry Energy and Tourism or because of particular interests related to the use of the rivers for hydropower or other utilization of the water. The Icelandic Road Authority and the National Power Company of Iceland, Landsvirkjun, are the main organisations that require hydrometric measurements related to particular use of the water resource.

The discharge is normally measured by monitoring the water-level in the river by a pressure transducer located upriver from a stable natural controlling cross section. The water-level is then converted to discharge using a water-level – discharge rating curve that is constructed from discrete water-level and discharge measurements.

The water-level was formerly measured by an analog water-level meter in a special measurement well that was connected to the river by a pipe. These analog meters registered the water-level, measured by a float, onto a paper roll (Rist, 1990). The paper rolls have later been digitized by scanning but only mean daily water-level and discharge are available in a digital database.

During the last two decades, considerable development has taken place in the acquisition of hydrological data. Now most of the hydrometric stations are equipped with digital data loggers that have replaced the analog data loggers. The processing of the measurements has changed according to the switch from analog to digital data acquisition and hourly discharge values are now computed directly from hourly water-level measurements.

The hydrometric data are quality checked and corrected for biases as needed at the end of each hydrological year. Missing data because of instrument breakdown, ice formation or other causes are estimated by use of nearby weather stations or discharge from nearby rivers that have similar discharge characteristics. All estimated data are flagged and can therefore be filtered out if only measured data of high quality are needed. Hydrological data at the IMO are stored in a *Wiski* database from KISTERS. Current version used at the IMO is 7.0, recently upgraded from version 6.6.

Two systems are used to denote hydrometric time-series at the IMO. One number describes the general location of the hydrometric station and a unique number is given for all station that measure the same discharge. This numbering is indicated by VHM and a three digit number. A sub-numbering is used to keep track of relocation and major changes in instrument setup of the hydrometric station. That numbering is indicated by a V and a three digit number. It is for example common for two time-series to have the same VHM numbering but different V number if they are both measuring the same discharge but in different locations because of relocations of the hydrometric station. The first location of hydrometric station is given the same VHM and V number.

3 Hydrometric measurements in glacier rivers

Hydrological measurements in glacier rivers are often difficult. Glaciers erode the underling strata by sliding and create a large amount of sediments that are carried by the rivers. These sediments give glacier rivers their identifying milky color and they create a number of problems in hydrometric measurements. Sensors get buried in sand drifts traveling at the riverbed, silt jams up sensors and measuring pipes and sediment accrual and removal from controlling cross section disturbs water-level – discharge connection. The sediments do also create large alluvial fans and sandur plains causing the rivers to be braided and running in highly erodible channels. This makes good locations for hydrological measurements and stable cross sections hard to find. The magnitude of annual discharge variations does also make measurements harder as same instrument setup must be able to measure few m^3s^{-1} and hundreds of m^3s^{-1}. Continuous discharge measurements are therefore not available from a number of the main Icelandic glacier rivers such as Skeiðará, Gígjukvísl and Jökulsá á Breiðamerkursandi.

The hydropower interest in measuring glacier rivers is a double-edged sword as long discharge time-series may break when hydropower plants are built. A number of series from rivers originating from northern Vatnajökull underwent a pronounced change in 2007 when the 690 MW hydropower plant of Fljótsdalsstöð was built. As a part of the hydropower plant a 57 km^2 reservoir was made for regulation along with drastic diversion of rivers. Two of the three large glacier rivers draining northern Vatnajökull were heavily affected by the project and long time-series from the lower parts of Jökulsá á Dal and Jökulsá í Fljótsdal changed their character.

Many of the hydrometric stations measuring discharge from watersheds with the largest relative glacier cover are located close to the glacier margin far from the coast and at high elevations. Ice formation on the controlling cross-section is therefore common during winter. This causes errors in the water-level discharge relationship that is used to calculate discharge from water-level measurements. The discharge is therefore estimated for a considerable part of the year for many of these rivers. This affects mainly measurements of winter discharge. During cold stable winters the estimations are good because the discharge can safely be assumed to be lowered exponentially to base flow that is know from low flow discharge measurements done on site in late winter (Rist, 1990). For highly variable winters with number of melt events these estimations are harder to conduct and are therefore not as certain.

4 Discharge data from selected glacier-covered catchments

Discharge time-series from up to 40 hydrometric stations are available from rivers with at least some glacier originated water. Despite the abovementioned measurement problems many of these series are long and continuous. The glacier-covered fraction of the watershed is though small for many of these stations.

Ten discharge time-series, with acceptable data coverage, from watersheds with a large glacier cover, were selected for the SVALI study of glacier hydrology. The selected glacier rivers are all from two of the three main glaciers in Iceland, Vatnajökull and Hofsjökull. An overview of the selected rivers is shown in Figure 1 for the ones draining Vatnajökul and in Figure 2 for the ones draining Hofsjökull. The area of the selected watersheds, the glacier-covered area and glacier-covered fraction are given in Table 1. The periods with available daily and hourly discharge data are given in Table 2.

Only daily mean discharge values are stored digitally for older analog data that have been digitized, as mentioned above. This applies to most time-series considered here before 2005. Time-series with sub-daily time resolution are available after the switch to digital data acquisition. Sub-daily time-scales will therefore only be studied for the period after 2005 for most rivers.

5 Data extraction and storage

Discharge time-series for the selected rivers have been extracted from the digital *Wiski* database, two series for each river, one with daily values and another one with hourly values. The time-series are stored in a simple text format that can easily be read into data processing programs like *R* and *Matlab*. The time specified in each record specifies the end time of the day or hour of the respective time period.

The data presented here were extracted from the *Wiski* database using a built in data exporter that makes it possible to export time-series in a comma separated format. The data are in a four

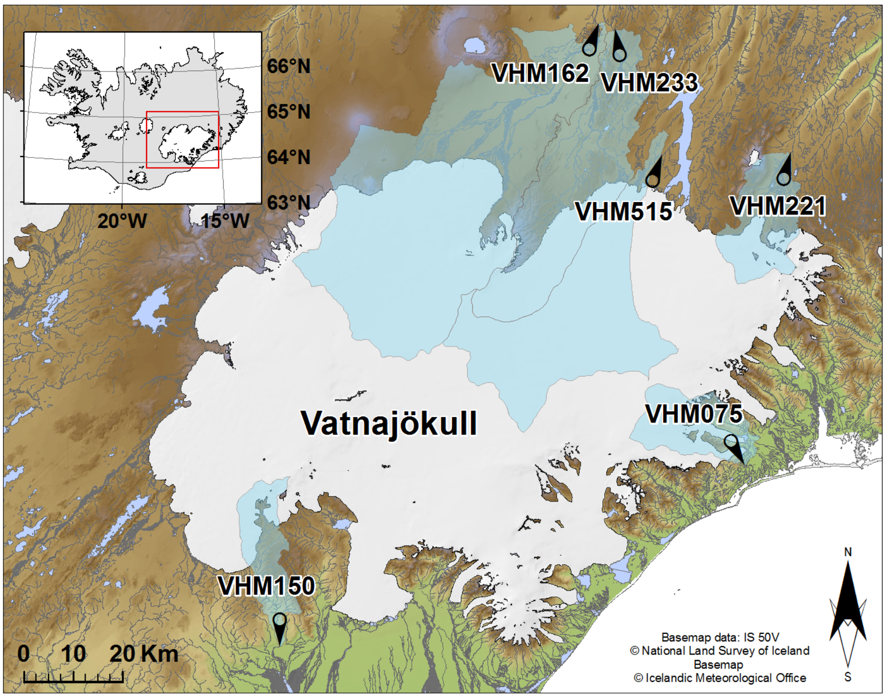

Figure 1. Map of Vatnajökull with location of hydrometric station. The watersheds of the selected hydrometric station are shaded blue.

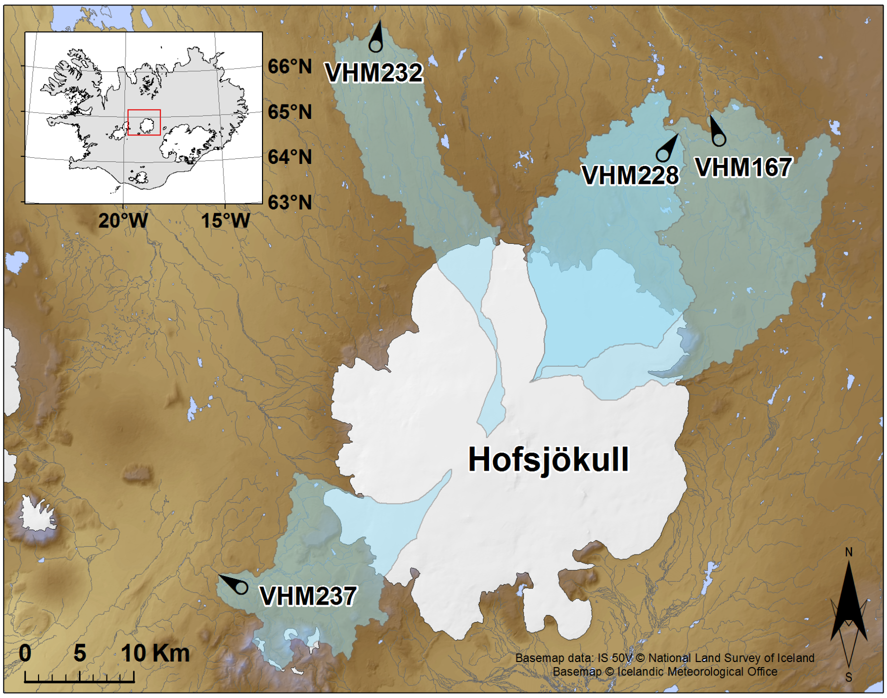

Figure 2. Map of Hofsjökull with location of hydrometric station. The watersheds of the selected hydrometric station are shaded blue.

Table 1. Area, area of glacier-cover and glacier-covered ratio for the watersheds of the selected hydrometric stations.

River name	Gauge number	Watershed area [km^3]	Glacier-covered area [km^3]	Glacier-covered area [%]
Vatnajökull				
Kolgríma	VHM075	264	174	0.66
Djúpá	VHM150	226	84	0.37
Jökulsá á Fjöllum	VHM162	2022	1137	0.56
Kreppa	VHM233	816	287	0.35
Kringilsá	VHM515	919	885	0.96
Jökulsá í Fljótsdal	VHM221	298	127	0.43
Hofsjökull				
Austari-Jökulsá	VHM167	552	134	0.24
Austari-Jökulsá	VHM228	258	95	0.37
Vestari-Jökulsá	VHM232	182	32	0.18
Jökulfall	VHM237	182	41	0.23

Table 2. Periods of available hourly and daily values for the selected hydrometric stations.

River name	Gauge number	Period with daily data	Period with hourly data
Vatnajökull			
Kolgríma	VHM075	1951–1980 and 2005–2010	2005–2010
Djúpá	VHM150	1968–2011	2005–2011
Jökulsá á Fjöllum	VHM162	1972–2011	2005–2011
Kreppa	VHM233	1985–2011	1998–2011
Kringilsá	VHM515	2006–2011	2006–2011
Jökulsá í Fljótsdal	VHM221	1985–2011	1985–2011
Hofsjökull			
Austari-Jökulsá	VHM167	1984–2011	1998–2011
Austari-Jökulsá	VHM228	2007–2011	2007–2011
Vestari-Jökulsá	VHM232	1985–2007	2005–2007
Jökulfall	VHM237	1995–2010	2005–2010

column format which consist of date, time, discharge and a comment. The date is in the format yyyy-mm-dd, the time is given as HH:MM:SS in a 24-hour system and the discharge is given in cubic meters per second. Missing records are given the value of -999. There are five possible comments: (Good), (Estimated), (Suspect), (Unchecked) and (Missing).

Small discontinuities can be caused by relocations and major changes in instrument setup but these possible flaws are ignored in this study and discharge time-series with different V numbers are concatenated to form continuous discharge time-series for location with same VHM number.

The time-series are stored in a designated location for data sets of research projects on the computer system at the IMO. The folder is glacier_tseries under "/vi/datasets/hydro/". Each hydrometric station has it own subfolder identified by the VHM-number of the station. Under each subfolder there are *.csv files named Q_XXX_60.csv and Q_XXX_24.csv for hourly discharge data and daily discharge data, respectively, where XXX stands for the VHM-number of the station. Only the Q_XXX_60.csv file is stored for two station with short time-series, where all data are available as hourly data.

Watershed layout and area were extracted from the geographical hydrological database of IMO for each selected hydrometric station. This hydrological database for the whole of Iceland allows automatic delineation of watersheds for user defined outlets. In addition the glacier-covered area of each watershed was delimitated. The glacier margins used are from 2006 as delineated by Oddur Sigurðsson at IMO (the version included in the Corine land use database from the National Land Survey of Iceland).

6 Preliminary study and assessment of potential use

An overview pdf file was made for each of the selected discharge time-series. For the hourly time-series both mean daily discharge and the difference of minimum and maximum discharge within each day are plotted. One plot is made for each year along a plot with mean seasonal variation for both parameters. Precipitation and temperature from a nearby meteorological station were plotted along with the discharge time-series to facilitate the study of the data. Similar figures were made for the time-series of daily data except that the daily discharge range is not available. In addition are decadal mean seasonal variations, based on the daily data, compared in specific plots.

A number of different phenomena connected to glacier hydrology can be seen in the data. Examples of the typical mean seasonal variation, dominated by late summer glacier melt, are shown in Figure 3. Three rivers with small nuance in seasonal variation are selected. For Kreppa (VHM233, shown in green on Figure 3) the glacier originated discharge is the main and almost only feature in the seasonal discharge variation. The winter discharge is low. For Jökulsá á Fjöllum (VHM162, black) the groundwater fed winter discharge is pronounced and this keeps the winter discharge relatively high. The glacier-covered part is relatively lower for Austari-Jökulsá (VHM167, red) than for the other two. Spring floods originated from snow melt in areas outside the glacier are therefore of similar magnitude as the late summer glacier originated peak. The diurnal variation is pronounced in the data (Figure 4). It emerges in early summer and grows until late summer when its amplitude starts to diminish. The glacier originated diurnal variation is often masked by other variations caused by precipitation, snow melting outside of the glacier or other factors. It is therefore clear that the discharge originating from areas outside the glacier affects the time-series and might masks or disturbs some of the glacier originated phenomena that are sought in this study.

Summer discharge for selected years is shown for three rivers in Figures 5 to 7 to give an overview of the data. The magnitude of the diurnal variation as well as the precipitation and temperature from a nearby meteorological station are shown along with the discharge. The underlying growth and decay of the diurnal variation can be seen for all of the rivers although it is

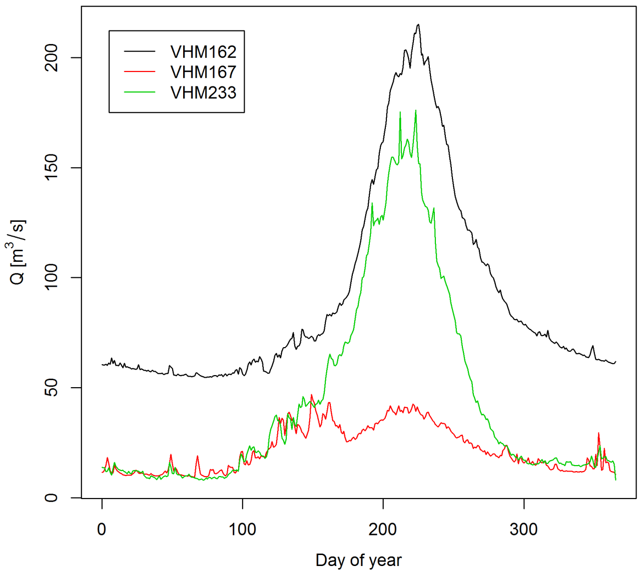

Figure 3. Mean seasonal discharge variation for three typical glacier rivers: Jökulsá á Fjöllum (VHM162), Austari-Jökulsá (VHM167) and Kreppa (VHM233).

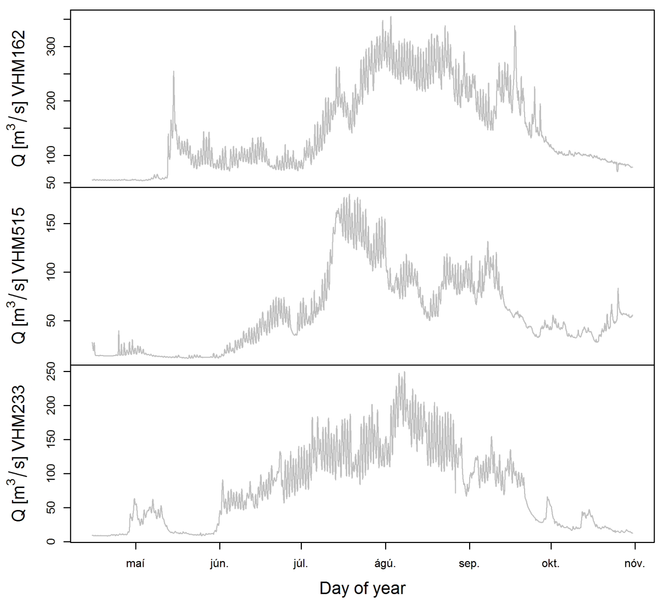

Figure 4. Typical variation of summer discharge for three glacier rivers: Jökulsá á Fjöllum (VHM162), Kringilsá (VHM515) and Kreppa (VHM233). The emergence of diurnal variation in early summer can be seen as well as the broad and voluminous summer peak.

affected by sub-daily discharge variations during the spring melt in areas outside the glacier and fluctuations because of cold spells and precipitation.

Glacier originated events that cannot be explained by meteorological influencing factors can also be seen in the data. An example of a yearly flood in Kolgríma, originated from a glacier dammed marginal lake, is shown in Figure 8. A number of events like this can be found for many other glacier rivers than Kolgríma.

Many interesting phenomena can be seen in the data but the discharge from areas outside the glacier must be subtracted to get a better view of the glacier originated discharge. Better comparison of river discharge and ice-velocity measurements may also be expected if other influencing factors than changes in the subglacial hydrological system are minimized. In addition the data will be better suited for validation of modelling of the development of the subglacial hydraulic system and subglacial hydraulic pressure, if discharge originating outside the glacier is subtracted.

The next step in this study is therefore to calculate the discharge originating from ice-free areas in the selected watersheds with the hydrological model WaSiM. All the selected watersheds have been modelled before with WaSiM except Kolgríma (Jónsdóttir & Einarsson, 2006). All the selected watersheds will nevertheless be remodelled as the use of WaSiM at the IMO has been improved in number of ways in recent years (Einarsson & Jónsson, 2010a; Einarsson & Jónsson, 2010b; Atladóttir, Crochet, Jónsson & Hróðmarsson, 2011; Crochet, 2012) and modelling of number of processes have been added or improved in the WaSiM model itself (Schulla, 2012).

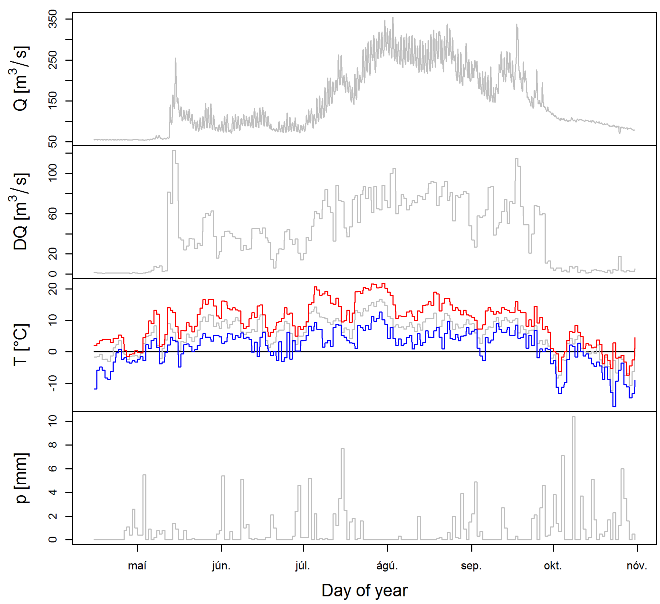

Figure 5. Summer discharge for Jökuslá á Fjöllum (VHM162), for the summer of 2008. The magnitude of diurnal discharge variation are shown in panel 2. Meteorological data from a nearby meteorological station, Grímsstaðir S495 (temperature and precipitation), are shown in the lowest two panels.

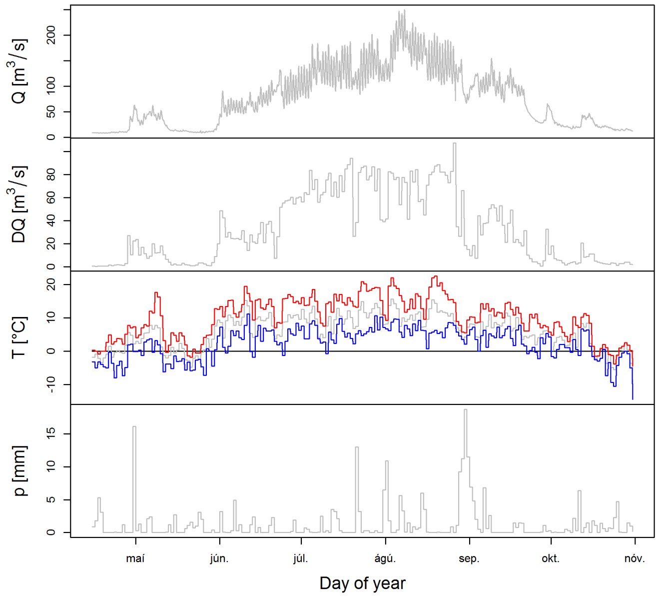

Figure 6. Summer discharge for Kreppa (VHM233), for the summer of 2008. The magnitude of diurnal discharge variation are shown in panel 2. Meteorological data from a nearby meteorological station, Grímsstaðir S495 (temperature and precipitation), are shown in the lowest two panels.

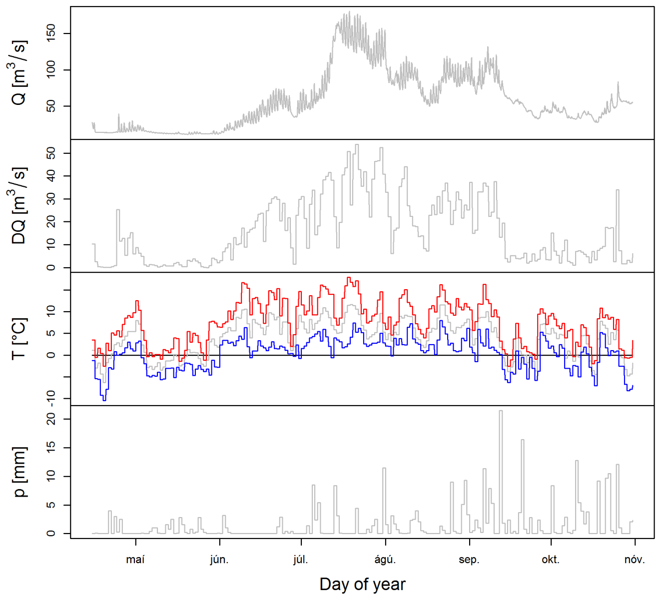

Figure 7. Summer discharge for Kringilsá (VHM515), for the summer of 2007. The magnitude of diurnal discharge variation are shown in panel 2. Meteorological data from a nearby meteorological station, Eyjabakkar S5943 (temperature and precipitation), are shown in the lowest two panels.

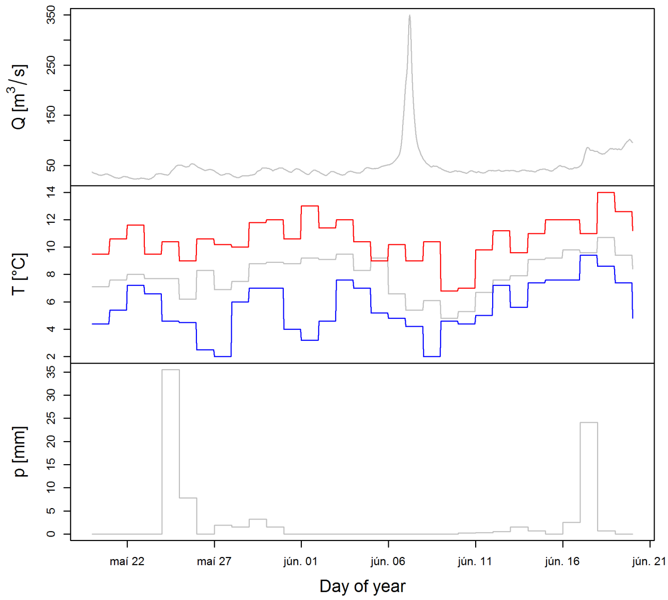

Figure 8. The emptying of a small marginal lake, in 2007, creating a jökulhlaup (glacier outburst flood) in Kolgríma (VHM075) that cannot be explained by meteorological events. Meteorological data from a nearby meteorological station, Hólar í Hornafirði S710 (temperature and precipitation) are shown in the lower two panels.

7 Conclusion

Discharge time-series from a number of partly glacier-covered watersheds are available and show many interesting glacier originated phenomena. Data from selected stations have been exported out of the hydrometric database of the IMO in a convenient format for further processing and long continuous time-series have been constructed from measurements of nearby hydrometric stations that measure the "same" discharge. The exported data along with metadata and geographic information about the layout of the watersheds and their glacier cover part have been collected into a file structure suitable for further analysis. The discharge time-series do need further processing to estimate the glacier originated part of the discharge. The hydrological model WaSiM will for this purpose be used to model discharge from ice-free areas of the watersheds. The resulting estimated glacier discharge time-series should be well suited for comparison with observations of ice-velocity and for validation and calibration of models of the subglacial hydrological system.

8 Acknowledgments

This report is contribution of the Nordic Centre of Excellence SVALI, Stability and Variations of Arctic Land Ice, funded by the Nordic Top-level Research Initiative (TRI). The author is also grateful to Tómas Jóhannesson for helpful revision.

9 References

Atladóttir, A., Crochet, P., Jónsson, S. & Hróðmarsson, H.B. (2011). *Mat á flóðagreiningu með rennslisröðum reiknuðum með vatnafræðilíkaninu WaSiM. Frumniðurstöður fyrir vatnasvið á sunnanverðum Vestfjörðum.* Reykjavík, Icelandic Meteorological Office, Rep. VÍ 2011-008, 41 pp. [In Icelandic].

Bell, R. E. 2008. The role of subglacial water in ice-sheet mass balance. *Nature Geoscience*, **1**(5), 297–304, doi:10.1038/ngeo186.

Björnsson, H. & Pálsson, F. (2008). Icelandic glaciers. *Jökull*, **58**, 365–386.

Crochet, P. (2012). *A semi-automatic multi-objective calibration of the WaSiM hydrological model.* Reykjavík, Icelandic Meteorological Office, Technical report PC/2012-01, 26 pp.

Einarsson, B. & Jónsson, S. (2010a). *Improving groundwater representation and the parameterization of glacial melting and evapotranspiration in applications of the WaSiM hydrological model within Iceland*. Reykjavík, Icelandic Meteorological Office, Rep. VÍ 2010-017, 29 pp.

Einarsson, B. & Jónsson, S. (2010b). *Virkjun grunnvatnshluta vatnafræðilíkansins WaSiM, auk samanburðar við stakar rennslismælingar og stuttar rennslisraðir.* Reykjavík, Icelandic Meteorological Office, Technical report BE/SJ-2010-01, 22 pp. [In Icelandic].

Jónsdóttir, J. F. & Einarsson, B. (2006). *Nýtt mat á afrennsli Íslands, frumniðurstöður*. Reykjavík, National Energy Authority, Hydrological Service, Technical report JFJ-BEE-2006/01, 85 pp. [In Icelandic].

Rist, S. (1990). *Vatns er þörf.* Bókaútgáfa Menningarsjóðs, Reykjavík. [In Icelandic].

Rignot, E. & Kanagaratnam, P. (2006). Changes in the velocity structure of the Greenland Ice Sheet. *Science*, **311**(5763), 986–990.

Schulla, J. (2012). *Model Description WaSiM (Water balance Simulation Model) completely revised version.* Zürich, Hydrology Software Consulting.