The implications of glacial fluctuations on the shallow proglacial groundwater systems of two SE Icelandic glaciers

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Introduction

Groundwater significantly impacts the ecohydrology, biogeochemistry and water resources of glaciated basins[1]. In addition to that, river-aquifer exchange forms an important control on in-stream physicochemical parameters and habitats[2]. However, the understanding of proglacial river-aquifer exchange processes and vulnerability to climate change is very limited[3].

Figure 1. Groundwater monitoring at the Skaftafellsjökull margin.

This project aims to investigate the impacts of changes in catchment glaciation on shallow proglacial groundwater systems (figure 1). A key objective is a comparison of the quantity, intensity and spatial heterogeneity of river-aquifer exchange between two contrasting proglacial sites: A large proglacial outwash plain (sandur) and the margin of a temperate valley glacier (fig. 2,3).

Figure 2. The retreating margin of the Skaftafellsjökull glacier. The hydrology of glaciated basins contains water sourced from snow, ice, and groundwater.

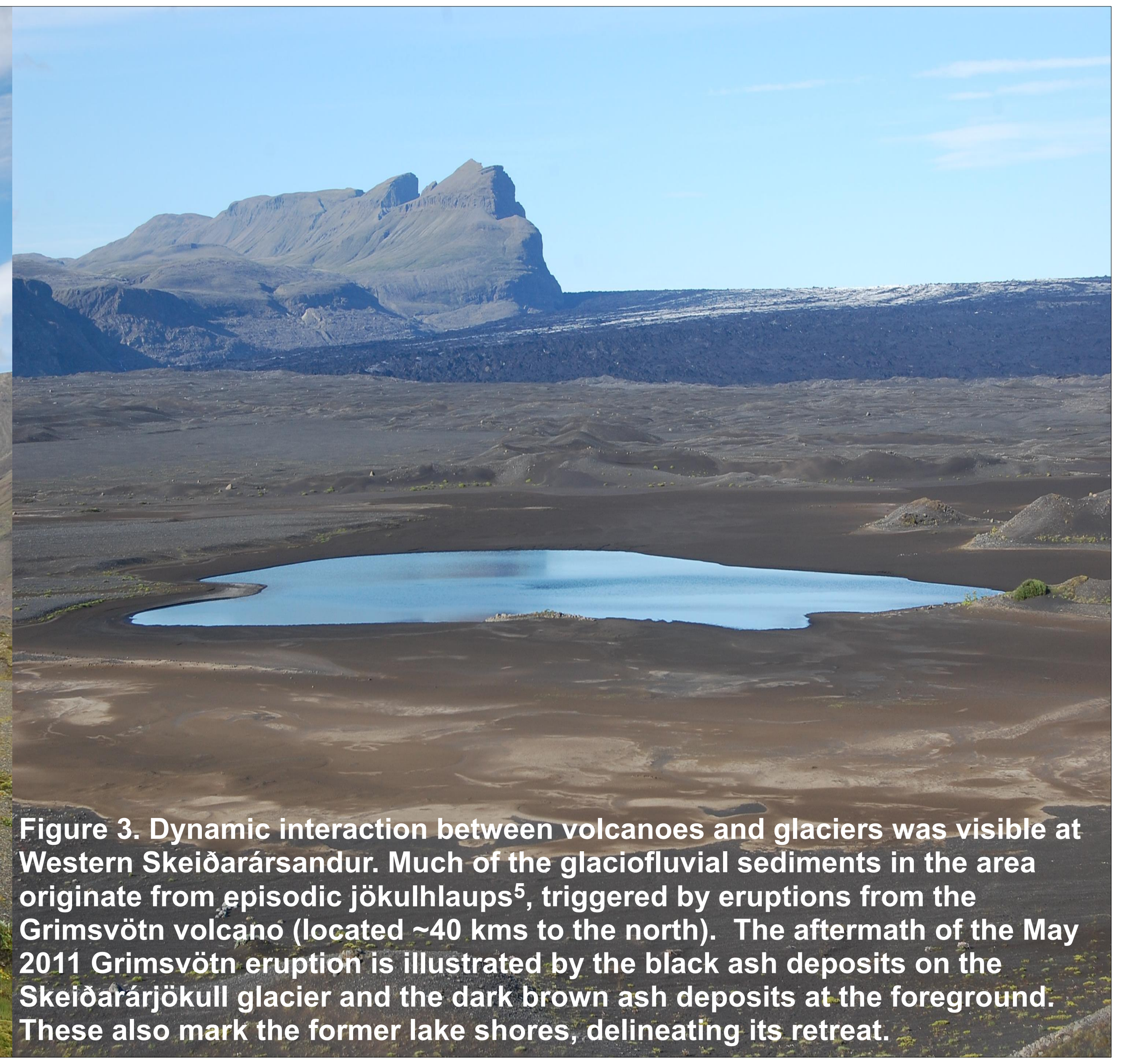

Figure 3. Dynamic interaction between volcanoes and glaciers was visible at Western Skeiðarársandur. Much of the glaciofluvial sediments in the area originate from episodic jökulhlaups[5], triggered by eruptions from the Grimsvötn volcano (located ~40 kms to the north). The aftermath of the May 2011 Grimsvötn eruption is illustrated by the black ash deposits on the Skeiðarárjökull glacier and the dark brown ash deposits at the foreground. These also mark the former lake shores, delineating its retreat.

Field sites: The field sites are located in the proglacial areas of two outlet glaciers of the Vatnajökull ice cap, SE Iceland (fig. 4). Groundwater level, temperature and EC were automatically monitored with Solinst data loggers between 07/07/2011–12/08/2011. These were placed in seven 40mm diameter shallow wells [GW] (fig. 1), located across two contrasting proglacial sites (fig. 2,3,4 [B,C]):

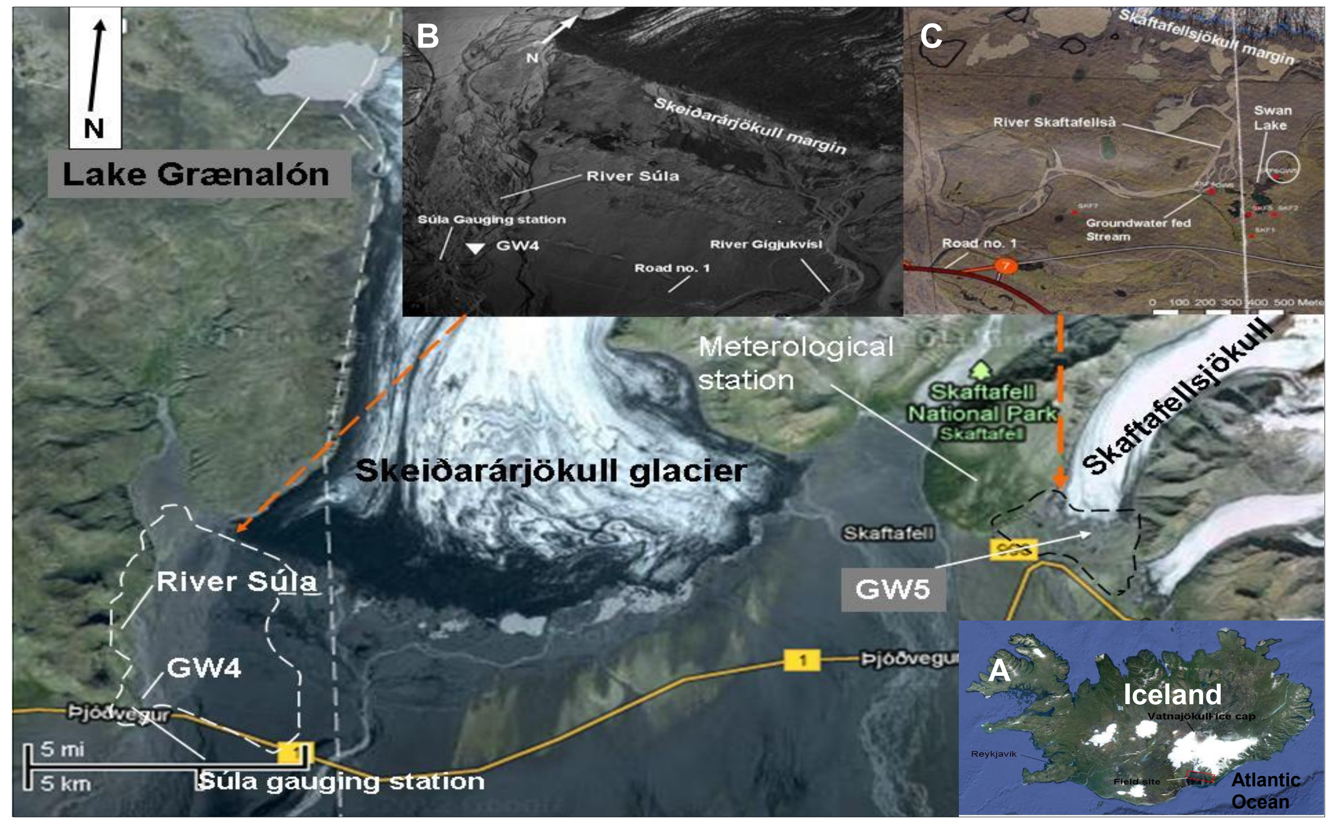

Figure 4. Field site location[6]. The dashed areas denote the main research sites. The figure also shows general site location in Iceland[6] and the locations of GW4 (inset B)[7] and GW5 (inset C)[8], whose data is presented.

1. Skeiðarársandur (fig. 3)

- The world's largest active proglacial outwash plain (sandur) [~1,000m^2].
- The area is significantly impacted by the interaction between glacial and volcanic activities.
- The sandur is underlain by 100-250m thick aquifer, composed of glaciofluvial deposits[4, 5].
- Episodic outbursts from Lake Grænalón are believed to significantly impact the level of the river Súla (fig. 4).

2. The Skaftafellsjökull margin (fig. 2)

- A retreating, temperate valley-glacier margin. This site provides a suitable example of an Alpine proglacial margin.
- The site is dominated by moraines, confined channels and higher vegetation cover than Skeiðarársandur.
- Sediment mobility is lower than on the sandur.
- Groundwater seepages provide important ecological nichés at both sites.

Comparing river-aquifer exchange between a proglacial outwash plain (sandur) and a temperate valley glacier

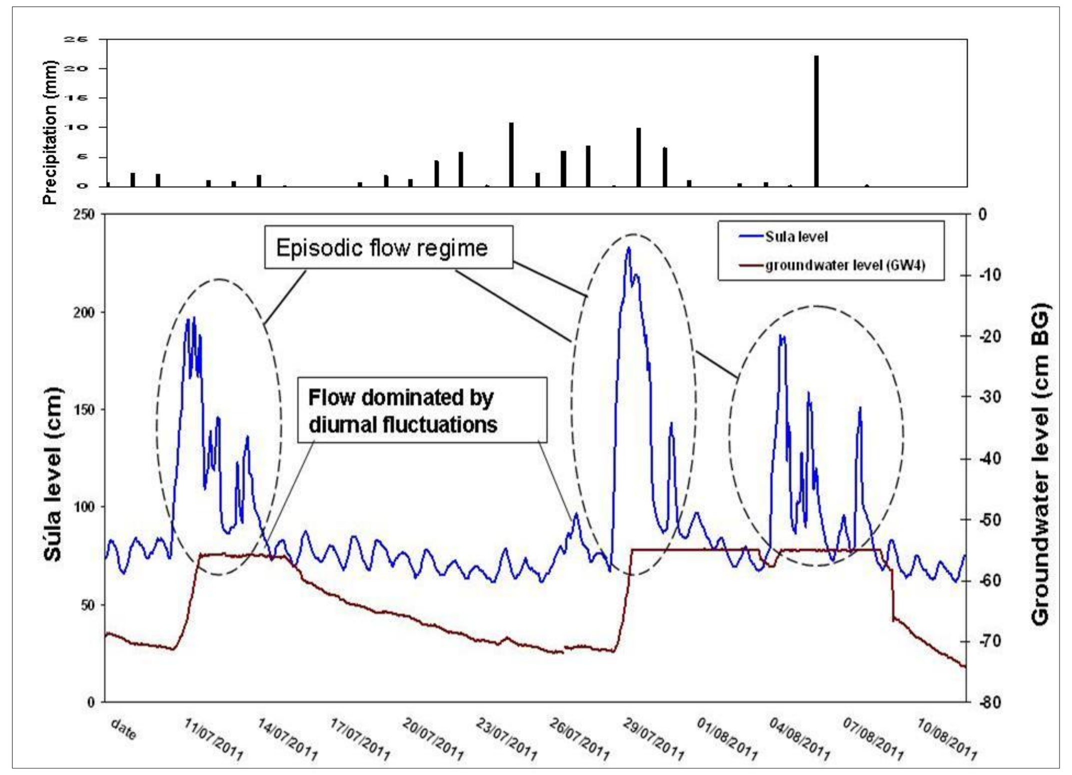

Figure 5. River Súla water levels, GW4 groundwater levels and precipitation. The wells have not been yet levelled to a single datum. Therefore, groundwater levels are measured in cm below the ground (cm BG). The Súla level is dominated by two distinctive controls: diurnal fluctuations in melt and episodic increases in level (dashed ellipses). The latter are suspected to be caused by jökulhlaups from Lake Grænalón (fig. 4).

River-aquifer exchange in a proglacial sandur

River-aquifer exchange in Skeiðarársandur was monitored at GW4, a shallow well located ~200m from the river Súla (fig. 4). The river levels during the monitoring period followed two distinct flow regimes[9]. A diurnal flow regime (fig. 5), controlled by fluctuations in melt, was observed at the start of monitoring and between 15-29/07. However, levels were also dominated by three events of significant rises in the Súla level (episodic flow regime, fig. 5). An analysis between river level, air temperature, and wind speed[10] (an important control on the removal of ash from Skeiðarárjökull) did not suggest that these variables had a significant control on Súla levels. Therefore, the increasing Súla levels were possibly attributed to jökulhlaups from Lake Grænalón (fig. 4). This hypothesis is supported by the negative correlation (r = -0.4497) between river level and temperature (fig. 6). During the diurnal flow regime, groundwater levels receded gradually. However, during the episodic flow regime, groundwater levels also rose rapidly [~15cm/12hours] (fig. 6). This suggests strong coupling between the aquifer and the river. However, despite of increasing groundwater levels during the episodic flows, groundwater temperatures did not decrease (fig. 6). Therefore, the hypothesis that the Súla at this section was a losing stream is not fully supported by the groundwater data.

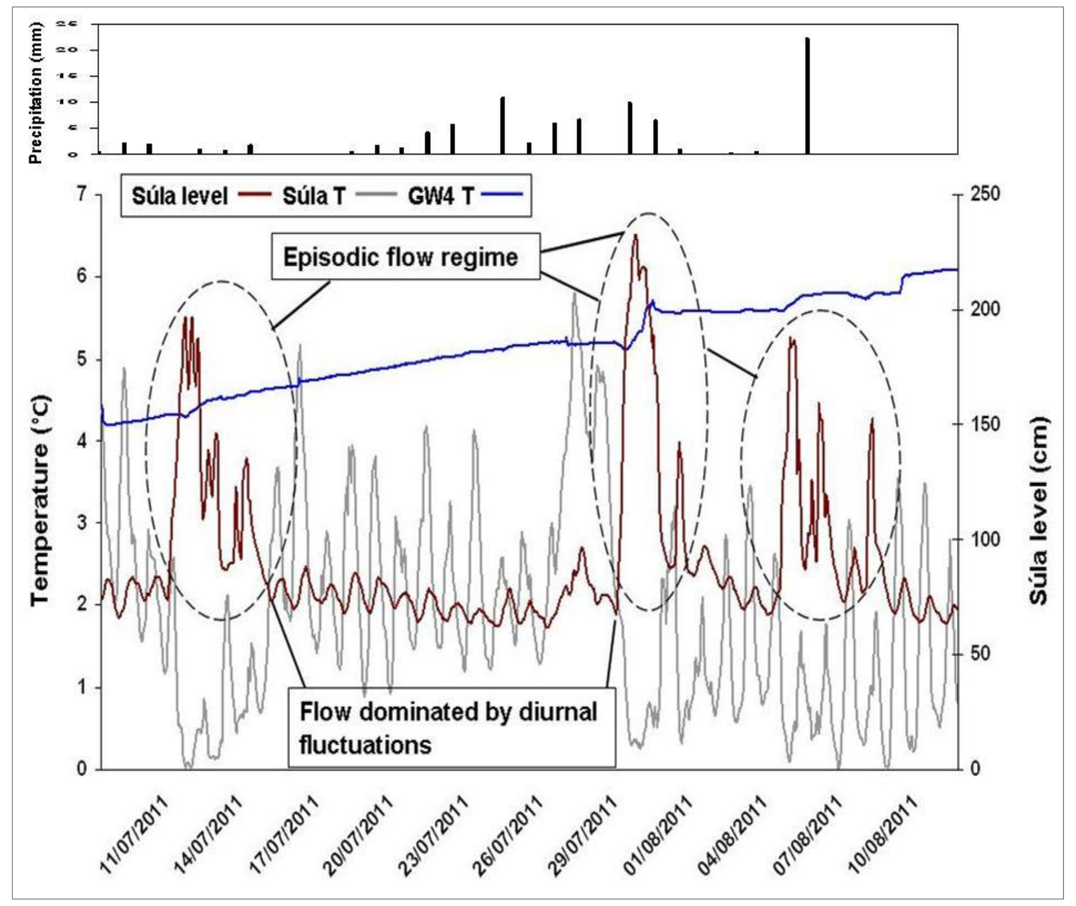

Figure. 6. Time series of the river Súla level and temperature (T)[9] and groundwater temperature at GW4.

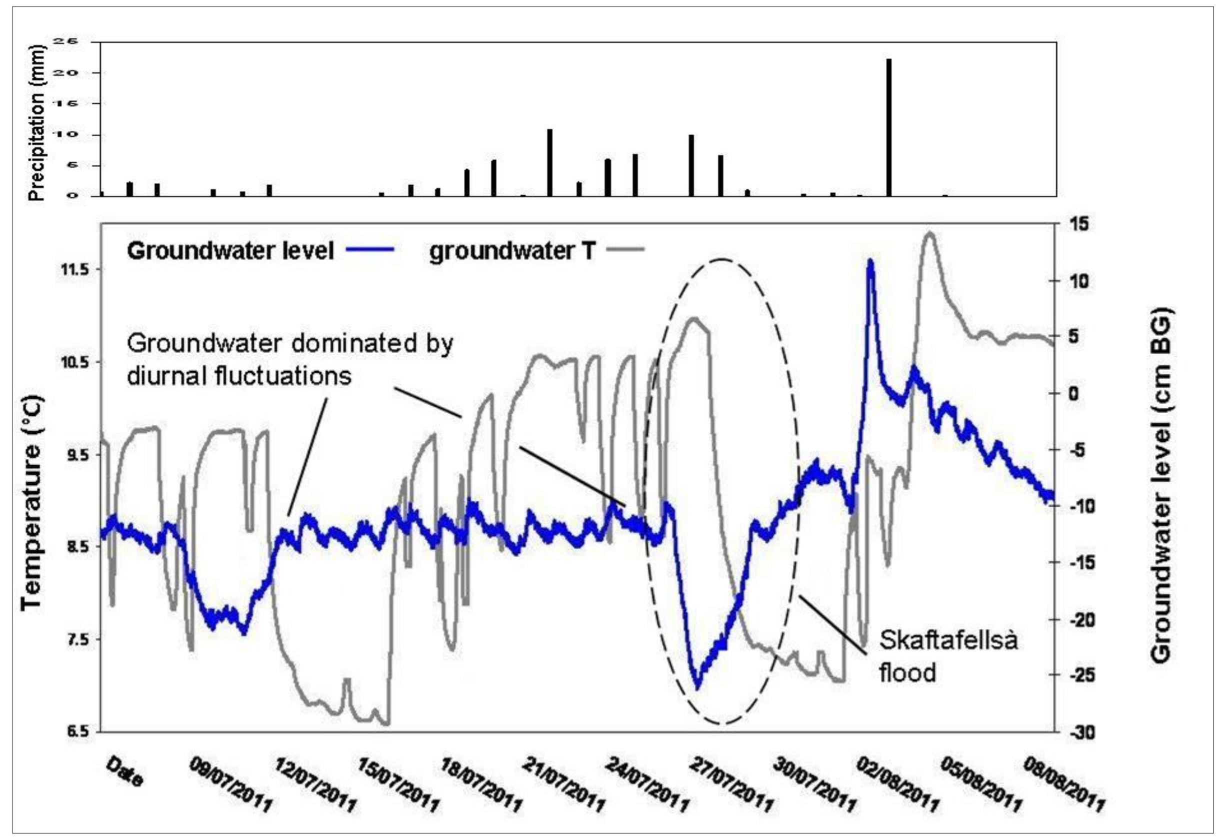

Figure 7. Groundwater level and temperature at GW5. Diurnal fluctuations are controlled by hourly/daily variations in melt. Unfortunately, it was not possible to obtain level data for the Skaftáfellsa. The wells have not been yet levelled to a single datum. Therefore, groundwater levels are presented in cm below ground (cm BG).

River-aquifer exchange at the margin of a temperate valley glacier

River-aquifer exchange at the Skaftafellsjökull margin was monitored at GW5, located between a large groundwater-fed lake (Swan Lake) and the glacial-fed river Skaftáfellsa (fig. 4c). The start of the monitoring period (until 13/07) was dominated by a slow decline in groundwater levels and strong temperature fluctuations (~2°C). This possibly suggests dynamic river-aquifer exchange, with groundwater being sourced from both the Skaftáfellsa and Swan Lake. The period 13-27/07 was characterized by diurnal oscillations of groundwater level (~5cm), mainly driven by fluctuations in melt. Groundwater temperatures during this stage fell to their lowest levels (~6°C) and then gradually rose, although the oscillations still varied around 2°C (fig. 7).

At the end of July, groundwater level and temperature were dominated by a significant flood at the Skaftáfellsa (fig. 8). From 27/07, groundwater levels began to rise. Following ~24hours delay, groundwater temperatures significantly dropped (~3°C) [fig. 7]. This negative correlation between level and temperature during the flood (r = -0.6484) suggests a reversal of the hydraulic gradient and an infiltration of cold river water into the aquifer.

Figure 8. Intrusion of glacial melt water into a groundwater-fed stream during the Skaftáfellsa flood. The intrusion was detected by measurements of water temperature and EC and observations of water colour.

Conclusions

- Dynamic river-aquifer exchange were detected at both wells.
- Groundwater levels at GW4 were colder than at GW5 by about 2°C. Temperatures at this site steadily increased during the monitoring period.
- Increasing groundwater levels during episodic flow regime of the Súla suggest an infiltration of river water into the aquifer. However, groundwater temperatures did not drop during these episodes.
- Therefore, the groundwater data from GW4 does not fully support the hypothesis that the Súla is a losing stream at this location.
- The temperature variability at GW5 was higher than at GW4 (reaching up to 3°C), both at the diurnal and seasonal time scales.
- Groundwater level and temperature at GW5 were dominated by diurnal patterns.
- However, during a flood event in the Skaftáfellsa, groundwater levels rose and temperature significantly dropped. This suggests an infiltration of river water into the aquifer.

Further work

- Tracing patterns and processes of river-aquifer exchange using high resolution temperature monitoring obtained by fibre optic Distributed Temperature Sensing (DTS). This will be done in June 2012 near GW4 and at the Skaftafellsjökull margin (fig. 9). The output will be used to define boundary conditions for numerical modelling of the impact of changes in catchment glaciation on proglacial river-aquifer exchange.
- Field and laboratory testing of hydrogeological (recharge, hydraulic conductivity), geochemical and isotopic parameters from both sites.
- Conceptual and numerical modelling of the impact of changes in catchment glaciation on river-aquifer exchange in proglacial environments.

Figure 9. Sharp temperature and EC gradients (~5° and 100 μS/cm/50 metres) were measured at this confluence between a spring-fed stream and the river Skaftáfellsa. It is planned to use fibre optic DTS* at this site in order to investigate proglacial groundwater-river exchange and ecohydrological conditions.

References: 1. Crossman, J., Bradley, C., Boomer, I. and Milner, A. M. (2011). Water Flow Dynamics of Groundwater-Fed Streams and Their Ecological Significance in a Glacierized Catchment. *Arctic, Antarctic and Alpine Res.*, Vol. 43 is. 3, pp. 364-379. 2. Krause, S., Hannah, D. M., Fleckenstein, J. H., Heppell, C. M., Kaeser, D., Pickup, R., Pinay, G., Robertson, A. L. and Wood, P. J. (2011). Inter-disciplinary perspectives on processes in the hyporheic zone. *Ecohydrology,* vol. 4, iss. 4, pp. 481-499. 3. Boucher, J., and Carey, S. (2010). Exploring runoff processes using chemical, isotopic and hydrometric data in a discontinous permafrost catchment. *Hydrology Res.*, V. 41, is. 6, pp. 508-519. 4. Guðmundsson, M., Bonnel, A. and Gunnarsson, K. (2002) Seismic soundings of sediment thickness on Skeiðarársandur, SE Iceland. *Jökull V.* 51, pp. 53-64. 5. Robinson, Z., Fairchild, I., and Spiro, B. (2009). The sulphur isotope and hydrochemical characteristics of Skeiðarársandur, Iceland: identification of solute sources and implications for weathering processes. *Hyrological Processes*, V. 23, is. 15, pp.2212-2224. 6. Google Earth. Online (2012) 7. The Icelandic Geodetic Survey, Landmælinger Íslands (LMÍ), August 1997. 8. Af stad photomap GPS. Skaftafell. Published by Loftmyndir ehf, Iceland. 9. The Icelandic Meteorological Office. Delivery of data from the Hydrological database, no. 2011-10-09/01. 10. The Icelandic Meteorological Office, personal correspondence.

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