European volcanological supersite in Iceland:
a monitoring system and network for the future

Report

D6.2 Results of field tests of continuous water samplers and protocols for high-frequency river monitoring during periods of volcanic unrest.

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Deliverable:	*Field tests of continuous water samplers; protocols for river monitoring during periods of unrest*	
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Abstract

The aims of WP6, Task 6.6 were to construct and test a new form of geochemical monitoring in Iceland. Two osmotic pumps that provided continuous, electricity-free, time-integrated samples were tested and installed in rivers draining from the subglacial volcano Katla and from the geothermal area beneath west Vatnajökull. The testing and installation was successful, such that individual storm events, glacial melting, and outbursts from underneath geothermal cauldrons could be easily identified. We were also fortunate enough to catch a small glacial flood event (jökulhlaup) from the Skaftár cauldrons, indicating both the robustness and usefulness of the samplers to monitor such phenomena. These results are being used to implement new protocols for eruption response, and prepared for publication in international scientific journals.

Contents

Introduction

Work package 6 was conceived to consider the signals and processes associated with magma migration into shallow environments and the final pre-eruptive stages, with an emphasis on real-time analysis. Part of this work package included advancing the present state of the art in geochemical monitoring of fluid discharges around active volcanoes. Previously, the only monitoring of chemical changes were manual spot samples of river water during and after a flood event. Task 6.6 within this work package is aimed to test and implement novel high-frequency river sampling techniques in order to test geochemical signatures of volcanic rivers as a feasible early warning system of an imminent eruption. To achieve this end, we constructed and tested two osmotic pumps, designed and manufactured by the University of Southampton (Fig. 1). These samplers can continuously sample river water for a month to produce daily integrated samples, and have the benefit of being automatic, electricity-free, and extremely cost effective (Gkritzalis-Papadopoulos et al., 2012a). While proven to work in high pressure abyssal plains (Jannasch et al., 2004) and in weak flowing rivers in England (Gkritzalis-Papadopoulos et al., 2012b), these samplers had never before been tested in such dynamic and occasionally violent systems such as an Icelandic glacial river prone to jökulhlaups.

The specific subtasks of Task 6.6 were to:

1) Produce and install osmotic pumps in rivers affected by Katla/Mýrdalsjökull jökulhlaups (Múlakvísl and Þverkvísl/Skálm), with the intention of completion by milestone MS45 at month 6.
2) Field testing of the osmotic chemical sampling equipment, and design of a protocol for continuous water sampling to identify potential chemical eruption precursor-signals in affected rivers during periods of volcanic unrest.

Figure 1. The osmotic sampler during the laboratory preparation (a) and during the installation in the field (b). Notice the protection housing for the sampler (b) and the inlet filter allowing prefiltration for the sampled water.

Construction and testing of water samplers

The work package began in January 2013. By March 2013, the two osmotic samplers had been built, transported to Iceland, and field tested by Thanos Gkritzalis-Papadopoulos and Morgan Jones. The first field test site was the natural spring near the farm of Selsund to the south of Hekla volcano. The site was chosen because it has a steady flow from the spring that varies little in both chemistry and temperature, and has a very gentle flow (it is the internal water standard from the inductively coupled plasma machine at the University of Iceland). The sampler was installed for a month then recollected for sampling. While the conditions appeared to be well suited for a deployment test, the activity of algae and other organisms in the spring quickly clogged the sampler, rendering the results from this field installation unusable. The second deployment was into the Skálm River (Fig. 2) in mid-April.

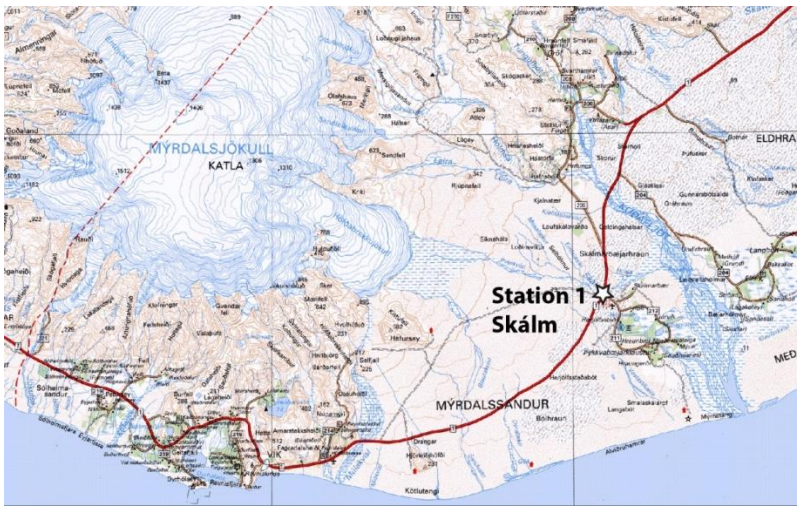

Figure 2 The site for successful osmotic sampler deployment at Skálm river which is draining subglacial Katla volcano.

This river is a sedate spring-fed river during the winter that becomes a more powerful glacially-fed river in summer months. It is also occasionally affected by jökulhlaups originating from Katla/Mýrdalsjökul. This deployment was a great success, and continued until mid-August. The sample tubing was changed every month, and spot samples were taken whenever possible to calibrate and corroborate the readings from the sampler. Data on water stage, temperature, and conductivity were monitored by the hydrological network of the Icelandic Meteorological Office (IMO) at the same location. The summarised results are shown in Fig. 2. It is clear that the osmotic samplers can offer much more information than spot sampling alone. Influxes of discreet events, both from the geothermal sources of Katla (seen as concurrent peaks in Si, Ca, and SO_4), and from storm events bringing sea spray into the catchment (seen as concurrent peaks in Na and Cl), could easily be identified from the continuous sampling results. Spot sampling (the dots in Fig. 3) regularly misses these peaks in element concentrations. These findings were presented at the 2013 Goldschmidt conference in Florence (August 2013; http://goldschmidt.info/2013/abstracts/abstractView?abstractId=3402) and the Volcanic and Magmatic Studies Group (VMSG) meeting in Edinburgh (January 2014; http://www.geos.ed.ac.uk/~jsteven5/VMSG_Edinburgh_abstracts.pdf).

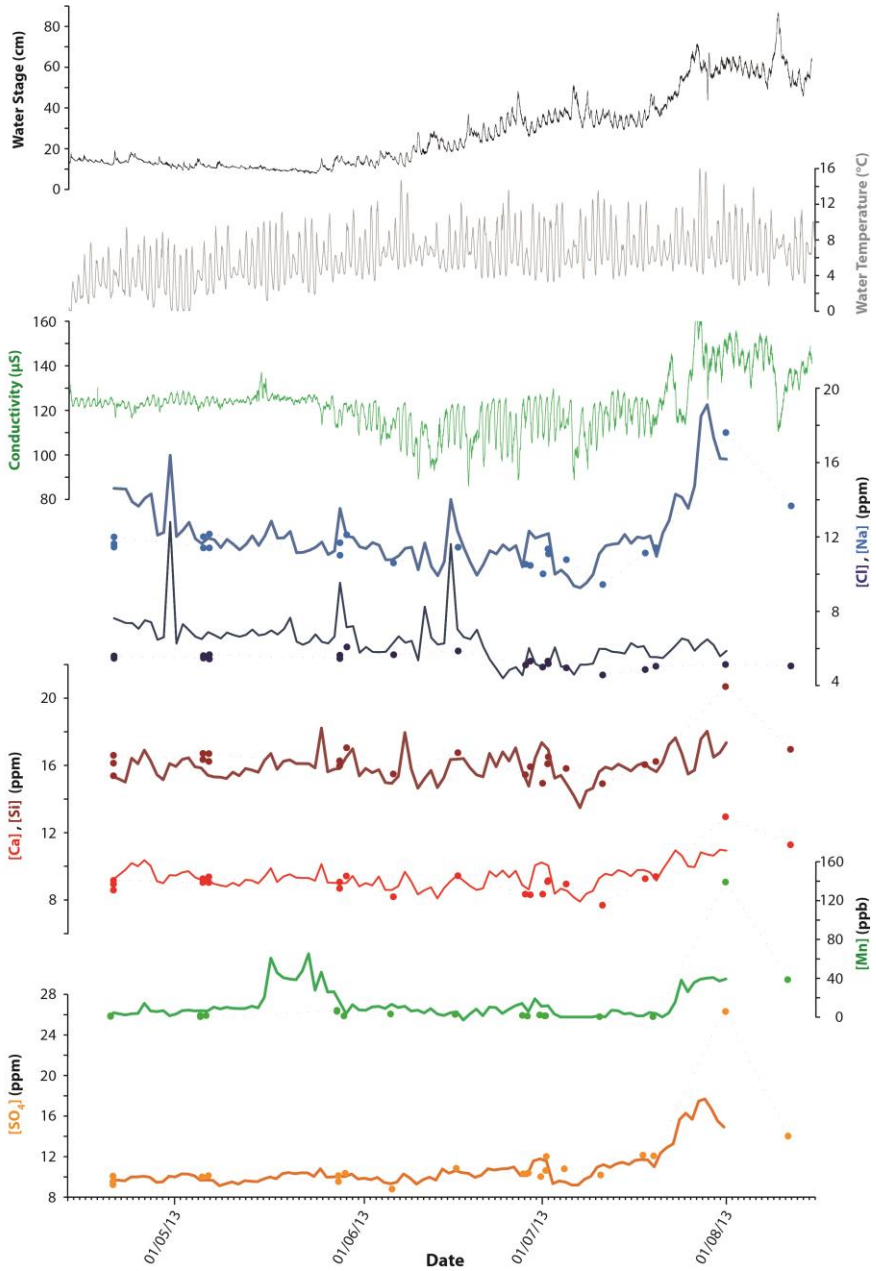

Figure 3. The major element data from the deployment of the osmotic samplers (lines) and spot samples (dots) from Skálm River during the summer of 2013. Conductivity, temperature, and water stage were all measured by a hydrological station in the Icelandic Meteorological Office network, located at the same Skálm locality.

The installation at Skálm was ended when the powerful Leirá River was rechanneled into the Skálm catchment towards the end of July 2013. The installation method we had chosen (bottom anchored) was inundated with more sediment than normal, which buried the sampler. The suspended material can not only bury the sampler but also get into the osmotic pump container, sampling tubing, fitting and inlet filter clogging and deteriorating it. Nerveless, the Skálm installation site served as a proof that the samplers can be installed in glacial rivers and give accurate and extremely informative results. The next sampling station was located at the Skaftá River (Fig. 2 , draining from two subglacial lakes under the Western and Eastern Skaftár cauldrons on the west side of Vatnajökull glacier. Enhanced geothermal activity causes the glacier to melt, with water accumulating in the subglacial lakes underneath the

cauldrons. Periodically these lakes drain in flood (jökulhlaup) events. A glacial outburst was suspected at the end of 2013, based on seismic data monitoring. The glacial flood is a great opportunity to test the sampler, whether it is able to record the chemical signal of the glacial flood. The sampler was installed in Skaftá river in Kirkjubæjarklaustur village (Fig. 4) by Þorsteinn Jónsson and Iwona Galeczka in late November 2013, with spot samples collected periodically in the same location. The Kirkjubæjarklaustur location was chosen instead of the Sveinstindur monitoring station (Fig.4) due to easy access, protection of the sampler from the high discharge stream by the bridge construction (see Fig. 5a), and the possibility to install it on the bridge side wall support (see Fig. 5b). In addition, the installation spot was chosen based on the amount of loaded sediments settling down at the bottom of the river to avoid burying the sampler. Control samples were taken into one liter, high density propylene bottles and stored in the fridge until further treatment in the laboratory. In the laboratory, water from the bottles was filtered through 0.2 µm Millipore cellulose acetate membranes into acid washed, high density polypropylene tubes for cations and trace metal analysis and into low- and high density polyethylene bottles for anions determination. Water samples collected for major and trace element analysis were acidified using Suprapur® 0.5% (v/v) HNO_3. The pH and alkalinity measurements were performed right after the filtration. Dissolved F^-, Cl^-, SO_4^{2-}, NO_3^-, acetate, and formate concentrations were quantified using an IC−2000 Dionex, ion chromatograph. Cations and trace metals were measured using a Spectro Cirus Vision inductive coupled plasma, optical emission spectrometer (ICP−OES), with an in−house standard, and checked against the SPEX Certified Reference Standard. Samples from the osmotic sampler tubing were diluted with dionized water approximately 10-14 times into high density polipropylen tubes and filtrated again, since the filter used directly at the sampler inlet (Fig. 1b) was not efficient enough to fully filter the inflow. The inefficiency of the inlet filter was caused by high amount of particle suspended material in the Skaftá river, especially during the flood event.

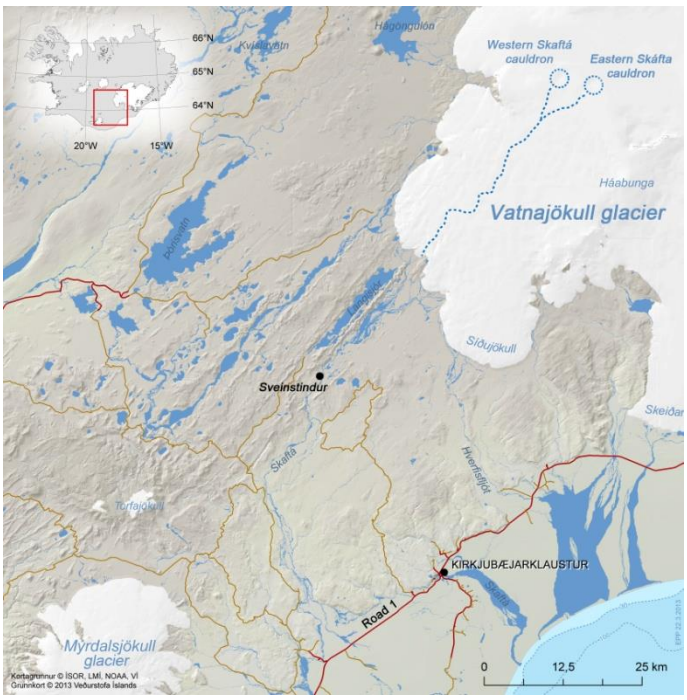

Figure 4. The site for successful osmotic sampler deployment in Skaftá river at Kirkjubæjarklaustur village. The location of the Sveinstindur hydrological station, one of five stations in Skaftá where discharge and conductivity are measured by the Icelandic Meteorological Office, is also indicated.

Figure 5. Installation of the sampler in Skaftá River at Kirkjubæjarklaustur. (*a*) Side view; (*b*) top view.

The first signs of a glacial flood in Skaftá were observed at IMO's Sveinstindur hydrological monitoring station on 18.01.2014 by the increased discharge and conductivity (Fig. 6ab). Sveinstindur is located up river from the Kirkjubæjarklaustur sample site, close to Vatnajökull glacier (Fig. 4). Visual observations on the glacier showed that the flood originated from the Western Skaftá cauldron, which last drained in September 2012. The peak discharge of Skaftá observed at Sveinstindur on 19.1.2014 was 384 m^3/s (Fig. 5a). The peak discharge at Kirkjubæjarklaustur was measured the following day, and it equaled 80 m^3/s. The results of the chemical analyses of the water collected by the osmotic sampler and the river spot samples taken regularly at the sampler location by the farmer, Eyþór Valdimarsson are presented in Fig. 7. Even though the discharge at Kirkjubæjarklaustur was only 20% of the total discharge measured at Sveinstindur, the spot samples and samples collected by the osmotic sampler detected the outburst, which is indicated by increased major cations concentrations which correlate with the increased discharge in Skaftá (compare Fig. 6c and Fig. 7). Increased elemental concentrations contribute to increased conductivity. This pattern is often seen during glacier floods draining geothermal areas (e.g. Galeczka et al., 2014). In addition, the concentrations of major cations in spot samples compare very well with the samples collected by the osmotic sampler, especially at the waning stage of the flood. The major element concentration in samples collected by the osmotic sampler and spot samples also compares well as exemplified in Fig. 8 for SO_4.

Figure 6. Resutls of the hydrological monitoring of Skaftá during the January flood event. Plots (a) and (b) present the discharge (a) and conductivity (b) measured at Sveinstindur and plot (c) shows discharge measured at Kirkjubæjarklaustur.

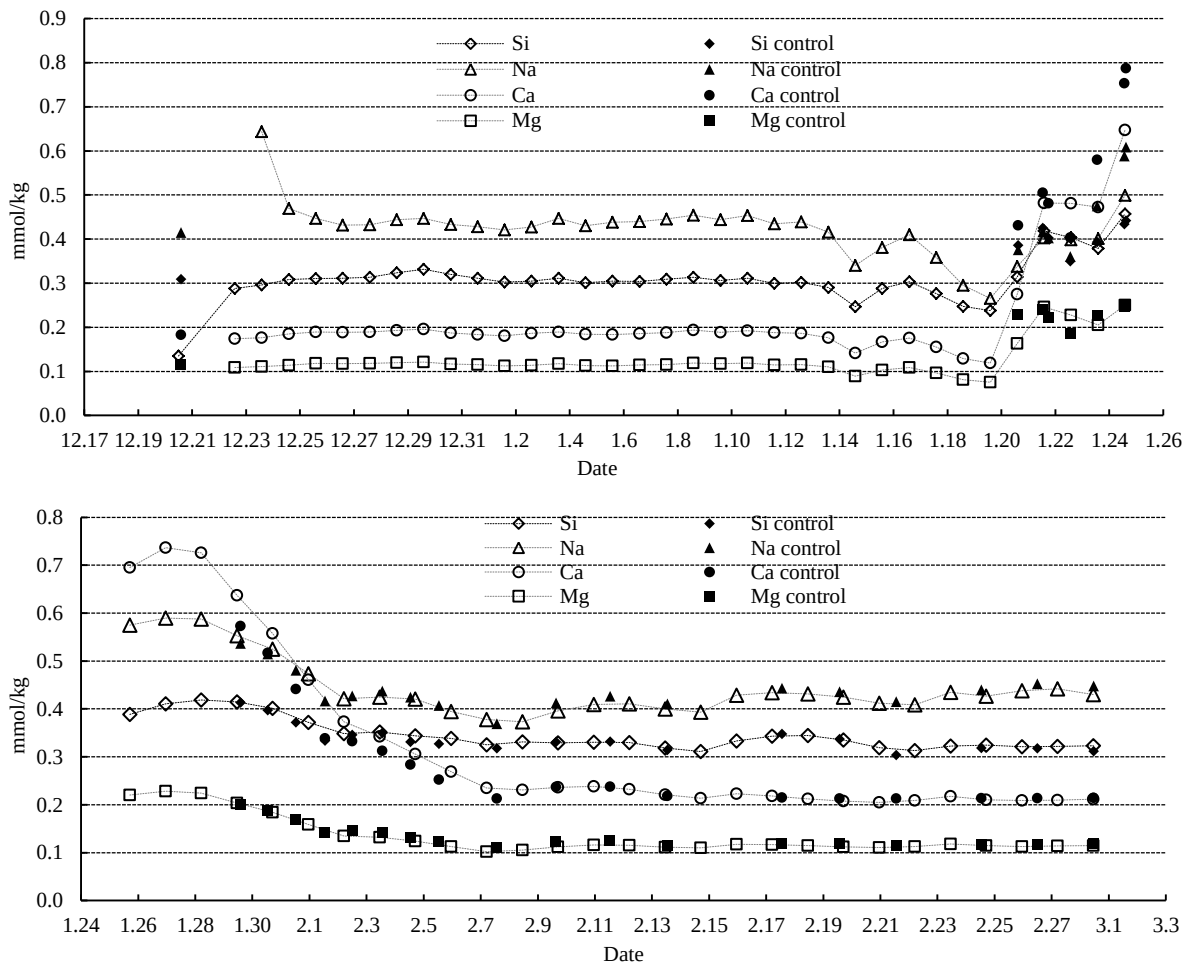

Figure 7. Selected major cation data from the deployment of the osmotic sampler (open symbols) and spot samples (filled symbols) from Skaftá River in December 2013, January and February 2014. The increased cation concentrations correlate with the peak discharge of the glacial flood.

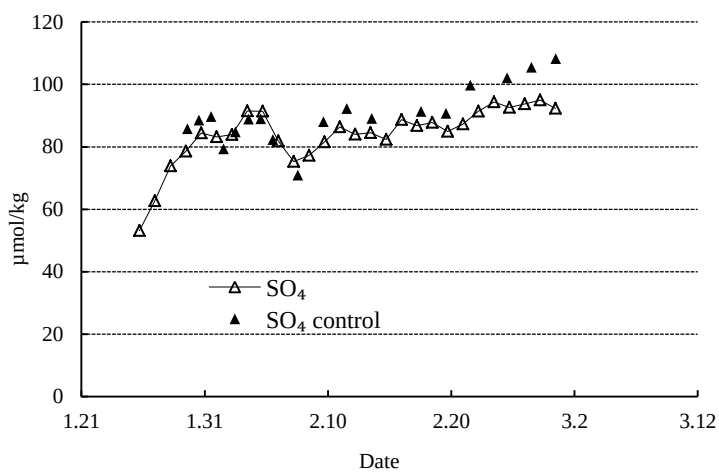

Figure 8. Comparison between SO_4 measured in the samples collected by the osmotic sampler (SO_4 open symbols) and in the spot samples (SO_4 control filled symbols).

The concentration of trace elements, such as Al, Ti and Fe measured in samples collected by the osmotic sampler and in spot samples do not compare as well as major cation concentrations (compare Fig. 7 and Fig. 9). Concentrations of those elements are higher in the samples collected by the osmotic sampler. The reason for the discrepancy might stem from the sampling procedure (filtration) and different conditions during the storing of the samples. Further analyses and investigation of obtained data sets must be performed to reveal this chemical discrepancy. In addition, some adjustment of the osmotic sampler set-up have to done to prevent deterioration of the osmotic chamber by the suspended material carried by high discharge river water.

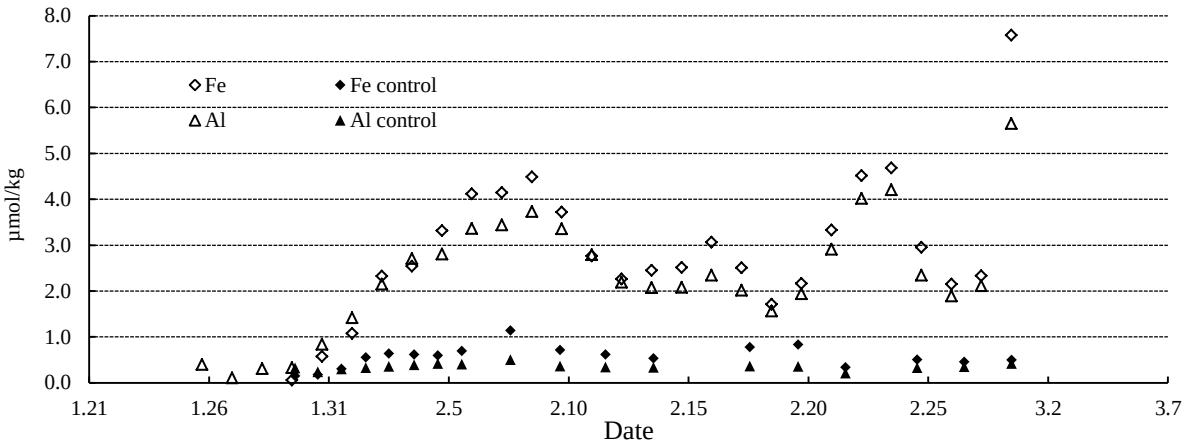

Figure 9. Comparison between SO_4, measured in the samples collected by the osmotic sampler in January and February 2014 (SO_4 open symbols), and in the spot samples (SO_4 control filled symbols).

Even though not all dissolved elements measured in samples taken by the osmotic sampler compare well with those measured in spot samples, the osmotic sampler works well as a tool for continuous monitoring of the rivers in volcanic and geothermal areas. This small jökulhlaup in Skaftá, originating from the Western Cauldron during the time of recording, confirmed its ability to monitor volcanic unrest. Results of this study will be presented in the Journal of Volcanology and Geothermal Research, with the aim of submitting in July/August 2014. The Icelandic Meteorological Office (IMO), University of Iceland and University of Southampton are planning to set up more samplers so that the river monitoring in Iceland can be expanded to other locations that may be affected by volcanic disturbances, but also to locations where geographical setting prevents frequent spot sampling.

Development of protocol during volcanic unrest

With the implementation and testing phase a resounding success, a protocol is now being developed in the event of volcanic unrest. The IMO is currently deciding whether it is possible to invest in more samplers. Meanwhile, the use of osmotic samplers can only be used as a reactionary measure unless we are very fortunate to be monitoring the affected river at the time of the beginning of the unrest. The River Monitoring subgroup (Sigurður Gíslason, Morgan Jones and Iwona Galeczka) will deploy the spare sampler into a river downstream of volcanic unrest at the earliest opportunity, assuming that the conditions are suitable and safe. This will be complimented by spot sampling wherever possible, and more regular changes of the sample tubing in case an eruption washes the sampler away. During periods of heightened volcanic activity, these results will be processed and made publically available as soon as possible (likely within 48 hours).

As shown in previous eruptions, for example in the 1970 and 1991 and 2000 eruptions of Hekla Iceland, surface waters become heavily contaminated by fluorine and some toxic metals following the first rain on volcanic ash in river catchments (Oskarsson 1980; Flaathen and Gislason 2007). The osmotic samplers provide a major step forward in monitoring local pollution of surface waters, after deposition of volcanic ash on river catchments. As shown in Figures 10 and 11, until now, only spots samples have been available, and we have most likely missed the main contamination events because of infrequent sampling. By deploying the osmotic samplers we will gain much better understanding of the magnitude and timing of pollution following explosive volcanic eruptions.

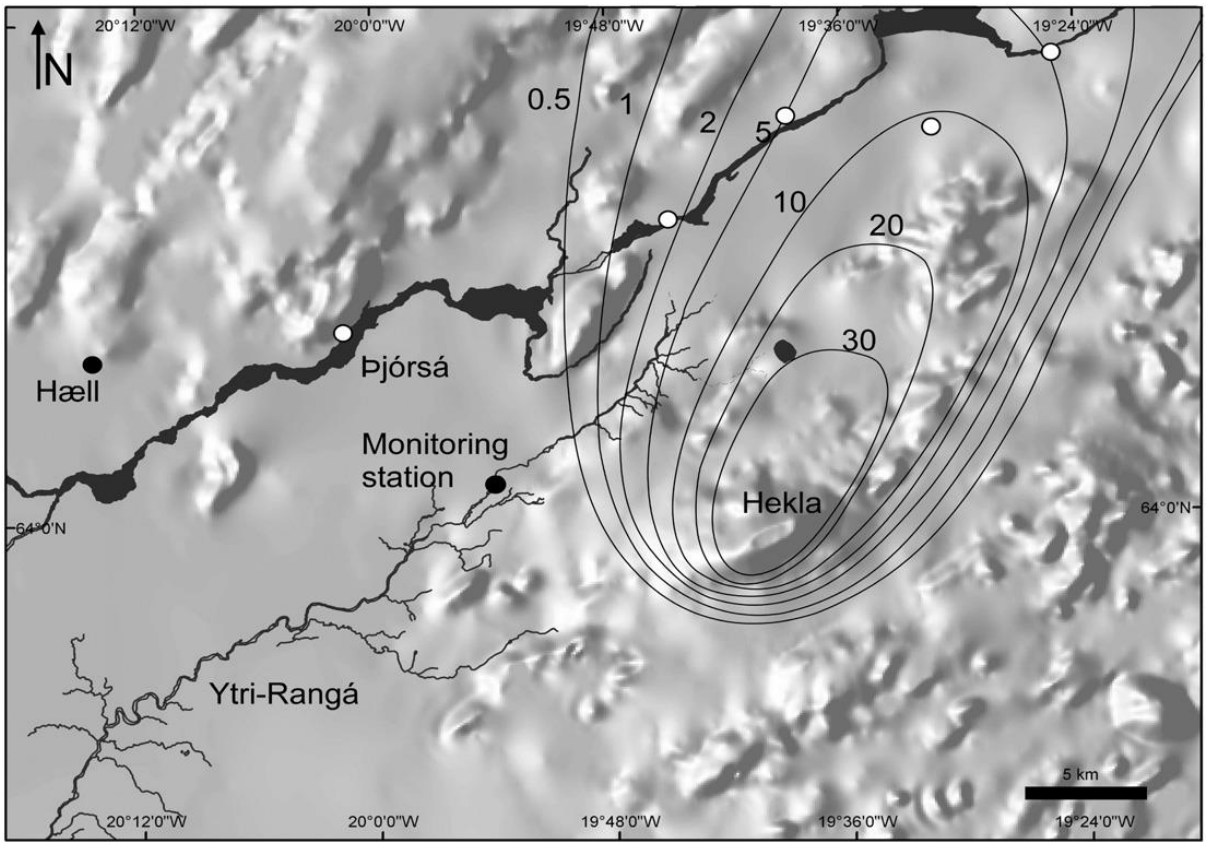

Figure 10. The Hekla volcano and the Ytri–Rangá River in south Iceland (from Flaathen and Gislason 2007). Superimposed on the map are isolines (kg/m^2) of the ash fall after the 2000 eruption (Haraldsson, 2001), the monitoring station in the Ytri–Rangá River, the meteorological station at Haell and the location of snow and ash samples (white circles).

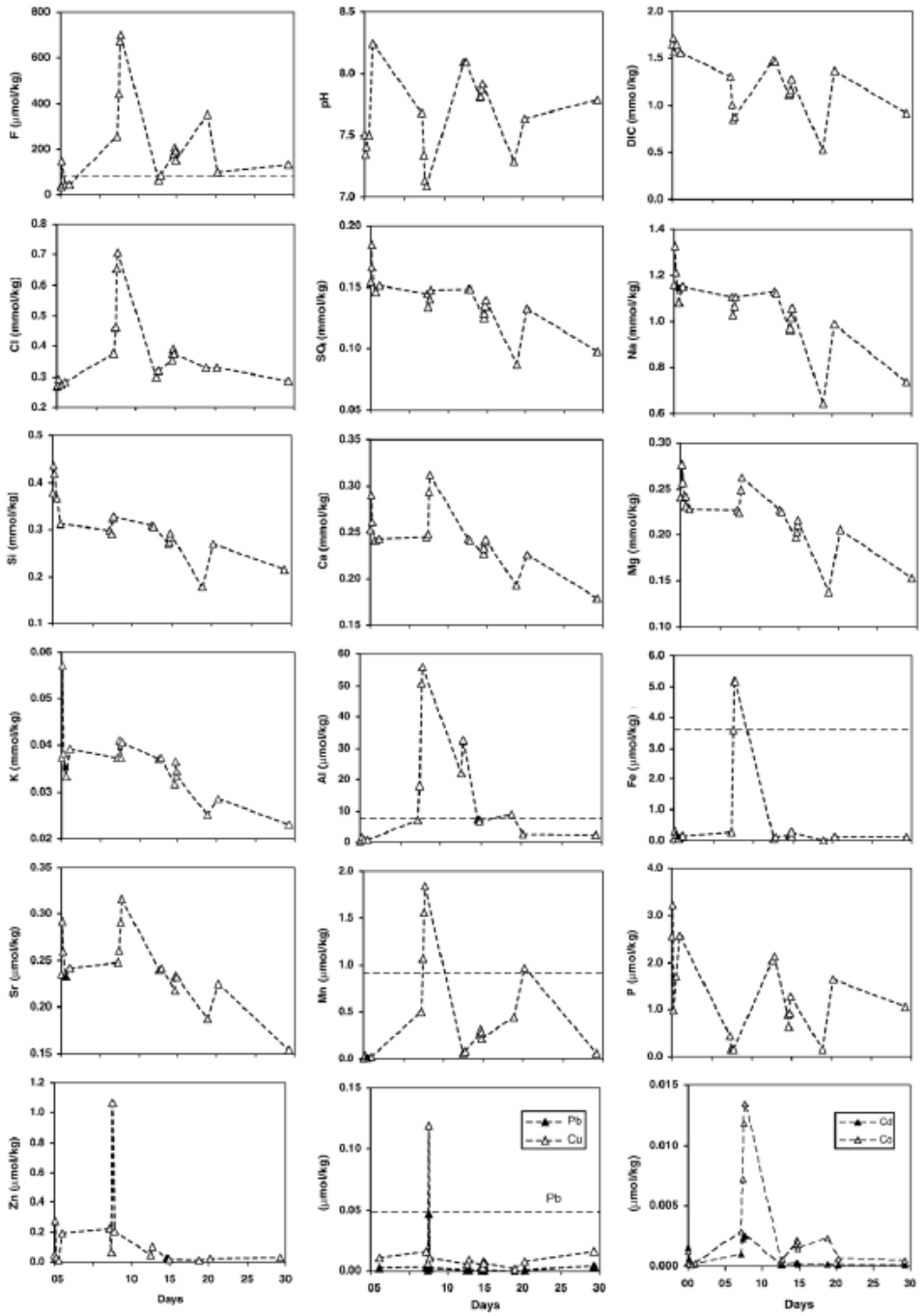

Figure 11. Dissolved constituents in the Ytri–Rangá River versus time during and after the 2000 eruption of Hekla (Flaathen and Gislason 2007). All concentrations are shown for the 30 day period. The hatched horizontal line on some diagrams is the upper limit for drinking water (European communities, 1998). No horizontal line is shown if concentrations were below this upper limit.

Conclusions

The construction and testing of the osmotic pumps has been a resounding success. The samplers continue to work even in turbulent river conditions, making them ideal for monitoring the very changeable Icelandic rivers. Osmotic-

pump continuous sampling provides temporal changes in elemental concentrations that far surpass the data obtained from spot samples. With further investment, these samplers can become an integral part of river monitoring in Iceland, both for hydrological purposes and in response to volcanic unrest.

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