Report

P-19-08

October 2019

Hydrological monitoring in Forsmark – surface waters, ground moisture and ground temperature

October 1, 2017 – September 30, 2018

Kent Werner

SVENSK KÄRNBRÄNSLEHANTERING AB

SWEDISH NUCLEAR FUEL
AND WASTE MANAGEMENT CO

Box 3091, SE-169 03 Solna
Phone +46 8 459 84 00
skb.se

SVENSK KÄRNBRÄNSLEHANTERING

ISSN 1651-4416
SKB P-19-08
ID 1613615

October 2019

Hydrological monitoring in Forsmark – surface waters, ground moisture and ground temperature

October 1, 2017 – September 30, 2018

Kent Werner, EmpTec

Keywords: Stream, Pond, Lake, Gauging station, Flume, Water level, Discharge, Electrical conductivity, Temperature, Moisture, AP SFK-10-083, AP SFK-17-035.

This report concerns a study which was conducted for Svensk Kärnbränslehantering AB (SKB). The conclusions and viewpoints presented in the report are those of the author. SKB may draw modified conclusions, based on additional literature sources and/or expert opinions.

Data in SKB's database can be changed for different reasons. Minor changes in SKB's database will not necessarily result in a revised report. Data revisions may also be presented as supplements, available at www.skb.se.

Summary

This document reports the monitoring of water level, which is used to calculate water depth, EC (electrical conductivity), temperature, and water-depth based calculations of discharge at four gauging stations in four streams in Forsmark during the hydrological year 2017/2018 (October 1, 2017 – September 30, 2018). SKB's HMS (Hydro Monitoring System) was used to collect and store all data. Quality-controlled, high-resolved data on water level, EC and temperature were transferred from HMS to SKB's primary database Sicada. Moreover, hourly average discharge was calculated based on quality-controlled water-level data and delivered separately to Sicada.

During the 2017/2018 hydrological year the average discharge for the four stations was c 20–50 L/s. The average EC and temperature of the stream water were c 25–40 mS/m and 8–12 °C, respectively. It is noted that the statistics for the hydrological year 2017/2018 presented in the report are affected by some data gaps, in particular due to refurbishment of the PFM002667 station. Flumes and observation wells have been levelled annually during the period 2012–2017, and it is recommended to repeat the annual levelling also in the future. The validity of stage-discharge relationships and associated parameters has been checked by independent discharge measurements in 2004–2006, and recently in 2013–2017. Independent discharge measurements need to be performed also in the future.

The report also presents an overview of and uses some results from other hydrology-related monitoring, for which data gathering and quality control are not part of the present work. The objective is to provide illustrative examples of integrated evaluations that may provide insight into near-surface hydrological interactions. Specifically, the overview and the integrated evaluations include data from meteorological monitoring and monitoring/observations of "winter parameters" (snow depth and ice coverage), data from surface-water level and temperature monitoring in lakes and ponds, and data from monitoring of ground temperature and water content.

Sammanfattning

Denna rapport beskriver övervakning av vattennivå, som används för beräkning av vattendjup, EC (elektrisk konduktivitet), temperatur samt vattendjupsbaserade beräkningar av vattenföring vid fyra vattenföringsstationer i fyra bäckar i Forsmark under det hydrologiska året 2017/2018 (1 oktober 2017 – 30 september 2018). SKB:s HMS (Hydro Monitoring System) användes för att samla in och lagra alla data. Kvalitetskontrollerade, högupplösta data på vattennivå, EC och temperatur överfördes från HMS till SKB:s primärdatabas Sicada. Timmedelvärden på vattenföring beräknades utifrån kvalitetskontrollerade vattennivådata och levererades separat till Sicada.

Under det hydrologiska året 2017/2018 var den genomsnittliga vattenföringen vid de fyra stationerna cirka 20–50 l/s). Bäckvattnets genomsnittliga EC och temperatur var cirka 25–40 mS/m respektive 8–12 °C. Det hydrologiska året 2017/2018 innehåller några dataluckor, speciellt till följd av ombyggnad av stationen PFM002667. Mätrännor och observationsrör har avvägts årligen under perioden 2012–2017, och rekommendationen är årliga avvägningar även i framtiden. Giltigheten för avbördningsekvationer och tillhörande parametrar har kontrollerats genom oberoende vattenföringsmätningar 2004–2006 och 2013–2017. Oberoende vattenföringsmätningar behöver genomföras även i framtiden.

Rapporten presenterar även en översikt över och använder resultat från annan hydrologirelaterad övervakning, för vilken datainsamling och -granskning inte ingår i detta arbete. Syftet är att illustrera hur integrerade utvärderingar kan ge insikt om hydrologiska processer i ytsystemet. Översikten och de integrerade utvärderingarna inkluderar meteorologisk övervakning, mätningar/observationer av ”vinterparametrar” (snödjup och istäckning), övervakning av ytvattennivå och -temperatur i sjöar och gölar, samt övervakning av marktemperatur och markvattenhalt.

Contents

1 Introduction and objectives 7

2 Equipment 9
2.1 Gauging stations 9
2.2 Data-collection systems 10
2.3 Practical experiences, field inspections and independent discharge measurements 11
2.4 Completed and planned refurbishments and reconstructions 12
2.4.1 Completed refurbishments and reconstructions 12
2.4.2 Refurbishment and reconstruction of the PFM002667 station 12

3 Execution 19
3.1 General 19
3.2 Field work 19
3.3 Data handling and post processing 19
3.3.1 Water-level calibration 19
3.3.2 Controls of EC and temperature 20
3.3.3 Recording interval 21
3.3.4 Calculation of discharge 21
3.4 Quality control 22
3.4.1 Regular quality control 22
3.4.2 Quality control of the 2017/2018 dataset 22
3.4.3 Flume and well levelling: Results and influence on discharge calculations 24
3.5 Nonconformities 24

4 Results 25
4.1 General 25
4.2 Water level 25
4.3 Calculated discharge 25
4.4 Electrical conductivity 26
4.5 Temperature 26

5 Evaluation of other hydrology-related monitoring 27
5.1 General 27
5.2 Overview of meteorological and other hydrology-related monitoring 27
5.2.1 Meteorological monitoring and monitoring of winter parameters 27
5.2.2 Surface-water level and temperature monitoring 28
5.3 Integrated evaluation of surface-water level and stream-discharge monitoring data 30
5.4 Evaluation of surface-water temperature monitoring 37
5.5 Monitoring of soil moisture and soil temperature 40

References 47

Appendix 1 Tables 51

Appendix 2 Water level 57

Appendix 3 Calculated discharge 63

Appendix 4 Electrical conductivity 65

Appendix 5 Temperature 69

Appendix 6 PFM002667 CAD and WinFlume drawings 73

Appendix 7 Soil temperature and soil moisture 75

1 Introduction and objectives

This document reports the monitoring of water level, EC (electrical conductivity), temperature, and water-level based calculations of discharge at four gauging stations (Figure 1-1 and Table 1-1) in four streams in Forsmark during the hydrological year October 1, 2017 – September 30, 2018. The report also provides an overview of and uses some results from other hydrology-related monitoring in Forsmark. The monitoring and discharge calculations provide data and information for various types of conceptual and quantitative modelling, such as water and mass balances, which in turn form the basis for site descriptions, assessments of long-term radiological safety and environmental impact assessments. A hydrological year is characterised by approximately equal storages of water in the beginning and in the end of the year, facilitating terrestrial water-balance studies. In Sweden, the turn of the month September/October is typically chosen as breakpoint (August/September in northern Sweden), when there normally are no or very small storages of water in the form of snow and ice (Bergström 1993).

Previous monitoring and discharge calculations are reported in Johansson and Juston (2007, 2009, 2011a, b) for the period April 2004 – December 2010, and in Werner (2014a, b, 2015a, 2017, 2018a, b) for the period January 1, 2011 – September 30, 2017. The monitoring was carried out in accordance with relevant parts of activity plans AP SFK 10-083 and AP SFK-17-035 (Table 1-2), which are SKB-internal controlling documents. Table 1-2 also lists reports that present the performance of regular quality control of water-level data (see further details in Section 3.4.1). Quality control was performed on four occasions during the data period of this report.

SKB's HMS (Hydro Monitoring System) was used to collect and store all data. From HMS quality-controlled data were transferred to SKB's primary database Sicada, where they are traceable by the activity plan number (cf. Table 1-1). Only data in Sicada are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. If data errors are found, data in databases are revised but will not necessarily result in a revision of the report, although the normal procedure is that major data revisions entail a report revision.

If not stated otherwise, coordinates in this report are given in the coordinate systems SWEREF 99 18 00 (X, Y) and RH 2000 (Z), i.e. vertical (Z) coordinates are expressed in terms of elevation (m) above the RH 2000 datum (0 m elevation). Note that the coordinate systems RT 90 2.5 gon V/0:15 (X, Y) and RHB 70 (Z) were used in previous monitoring reports. Times are in HMS stored in the time zone GMT+1 (no DST), and this system is used also in this report.

In connection to Table 1-1 and Figure 1-1, it is noted that the catchment-area boundaries (SDEADM.POS_FM_VTN_5441) for PFM002667 and PFM002668 were updated in December 2006, and therefore do not match the boundaries shown in the original installation report (Johansson 2005). Also note that the catchment area of stream-gauging station PFM005764 (AFM001267) includes the upstream catchment area AFM001268, which in turn includes the upstream AFM001269 catchment area. The catchment-area boundaries are determined based on a DEM (digital elevation model) with a horizontal resolution of 10 m (Brunberg et al. 2004). It is recommended to revise catchment-area boundaries when a new DEM is available, supported by field checks of road culverts. Culverts conduct water across road embankments, acting as catchment-area boundaries along road stretches without culverts.

Table 1-1. Catchment areas of the four gauging stations (Johansson and Juston 2011b).

Gauging station id	Catchment area id	Size of catchment area (km^2)
PFM005764	AFM001267	5.59
PFM002667	AFM001268	3.01
PFM002668	AFM001269	2.28
PFM002669	AFM001270	2.83

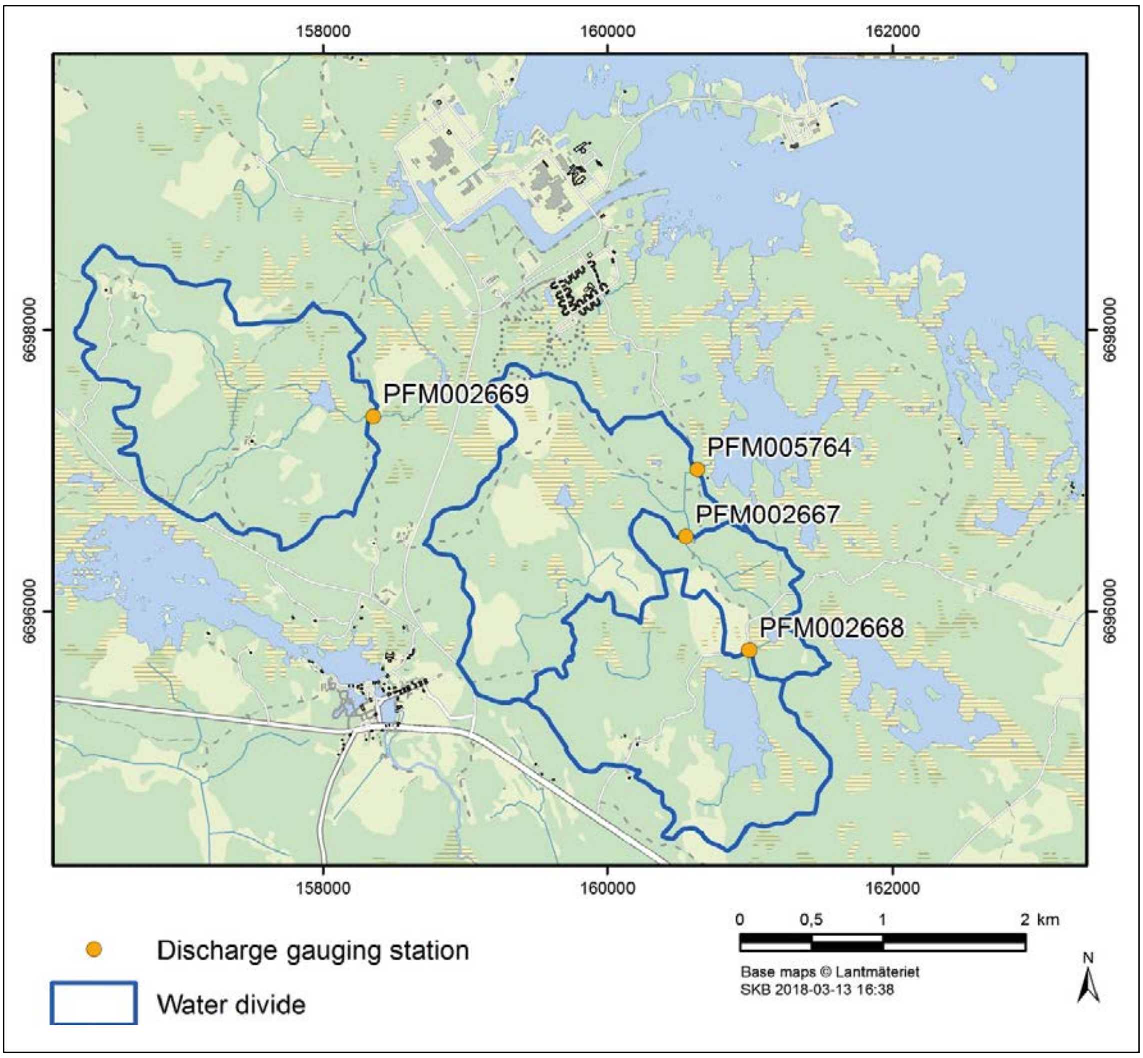


Figure 1-1. Locations and associated catchment areas of the four stream-gauging stations. The PFM005764 catchment area includes the PFM002667 catchment area, which in turn includes the PFM002668 catchment area.

Table 1-2. Controlling internal documents and quality-control documents for the activity.

Activity plan	SKBdoc id, version
AP SFK 10-083 – Hydrologisk och hydrogeologisk monitering, Platsförvaltning Forsmark 2015–2017	1464444 ver 2.0
AP SFK 17-035 – Hydrologisk och hydrogeologisk monitering, Platsförvaltning Forsmark 2018–2020	1613111 ver 1.0
Projekt Kärnbränsleförvaret, quality-control reports	
Monitering Forsmark och SFR: Kvalitetskontroll av yt- och grundvattenmonitering Juni – oktober 2017	1683244 ver 1.0
Monitering Forsmark och SFR: Kvalitetskontroll av yt- och grundvattenmonitering Oktober 2017 – januari 2018	1680333 ver 1.0
Monitering Forsmark och SFR: Kvalitetskontroll av yt- och grundvattenmonitering Januari – juni 2018	1695319 ver 1.0
Monitering Forsmark och SFR: Kvalitetskontroll av yt- och grundvattenmonitering Juli – oktober 2018	1704943 ver 1.0

2 Equipment

2.1 Gauging stations

As described in Johansson (2005), long-throated flumes were selected for water-level monitoring and associated discharge calculations, mainly due to the limitations set by the flat landscape, the need for accurate measurements, and the desire to avoid fish-migration obstacles. This type of flume provides accurate measurements over relatively wide discharge ranges and works under a high degree of submergence (Robinson 1966, 1968, Kilpatrick and Schneider 1983, Clemmens et al. 2001).

At three of the gauging stations, two different types of flumes were installed to obtain good accuracy over a wide range of discharge in the intervals < 20 L/s and > 20 L/s (see details below). The flumes are made of stainless steel. Five of the totally seven flumes use standard factory designs (Plasti-Fab, Inc.), whereas two are custom made using the design software WinFlume (Wahl et al. 2000). The flume designs are presented in Johansson (2005), whereas further details on technical installations at the gauging stations are shown in Werner (2014a) (Appendix 1).

The gauging stations are equipped as follows:

- **PFM005764 –** There are two flumes, one small and one large, of standard factory designs at this gauging station. The flumes were originally installed in November 2003, and measurements were initiated in March 2004. Due to damming problems at high discharge, the station was reconstructed and the flumes were reinstalled in October 2004 (Johansson 2005). The station was refurbished and reconstructed in August 2014, including replacement of the small flume (Werner 2015a). On January 10, 2018, a water-level bubbler (YSI Waterlog Amazon Bubbler) was installed in the observation well connected to the large flume. The intention is to measure water level using the bubbler in parallel with pressure-sensor measurements.
- **PFM002667 –** There are two flumes, one small and one large, at this gauging station. The small flume has a standard factory design, whereas the large flume is designed using the WinFlume software. The flumes were installed in October 2004, and measurements were initiated in December 2004. In August 2018, the station was refurbished and reconstructed and the two flumes were replaced by a single flume (see Section 2.4.2).
- **PFM002668 –** There is a single, large flume at this gauging station, designed using the WinFlume software. The flume was installed in October 2004, and measurements were initiated in December 2004.
- **PFM002669 –** There are two flumes, one small and one large, at this gauging station. The small flume has a standard factory design, whereas the large flume is designed using the WinFlume software. The flumes were installed in October 2004, and measurements were initiated in December 2004. The small flume was stolen in July 2007. It was replaced and both flumes (and also the observation wells) were reinstalled in November 2007. The station was refurbished and reconstructed in August–September 2015 (Werner 2017).

As illustrated in Werner (2014a) (Appendix 1), water levels in flumes are measured by vented pressure sensors (see Section 2.2) installed in observation wells located alongside each flume. At the stations PFM002667–68, EC and temperature sensors are mounted on the outside of screened tubes located in the streams (all sensors were installed inside the tubes up to March 2012; see Werner 2014a). As part of the PFM005764, PFM002669 and PFM002667 refurbishments and reconstructions in 2014, 2015 and 2018, respectively, the tubes hosting the EC and temperature sensors were moved to the grating, and the sensors were again installed inside the tubes. In their new position, the tubes communicate with the stream water not only through the tube screen but also through the open tube bottom (see example in Figure 2-5). Moreover, in December 2014 – January 2015 the EC and temperature sensors at PFM002668 were moved, in order to avoid the rapid that is formed on the downstream side of the flume (Werner 2015a).

Table A1-1 in Appendix 1 presents geographical positions of the gauging stations and elevations of upstream edges of flume bottoms and of top of observation wells, used for calculation and adjustment of water levels and water depth-based calculation of stream discharges (Johansson and Juston 2011b).

As described in Section 3.4.3, 2012–2017 levelling campaigns indicate that all flumes may have moved vertically since they were installed, including movements during the period 2012–2017. However, the levelling performed at time of the original flume installations had less accuracy compared to the 2012–2017 levelling, which implies that actual vertical movements subsequent to flume installations are uncertain. The influence of vertical flume movements on discharge calculations, and reduction of potential errors by manual water-depth measurements, are described in Section 3.4.3 and in Werner (2014a) (Appendix 2).

Table 2-1 presents flume-specific, recommended discharge intervals and discharge equations, i.e. equations and associated parameters that are used to convert water depths to stream discharges. The recommended equations, parameters and discharge intervals are derived using the WinFlume software, including flumes of standard factory designs (i.e. equations, parameters and intervals provided by the manufacturer are not used). The applicability of equations and parameters have been investigated by independent discharge measurements (see Section 2.3). As shown in the table, the upper discharge limit for the small flumes is 20 L/s, which corresponds to a water depth of c 0.23 m. According to Johansson (2005), the mathematical errors associated with the discharge equations, i.e. their deviations from the exact mathematical solution, are less than ± 2 % for all flumes.

Table 2-1. Stage-discharge relationships (discharge equations) for the flumes and associated recommended discharge ranges. Q = discharge (L/s), h = water depth (m).

Id	Discharge eq.	Recommended range (L/s)
PFM005764 **Nov. 27, 2003 – Oct. 1, 2004**		
Small flume (QFM1:1)	$Q = 864.9 \cdot h^{2.576}$	0–20
Large flume (QFM1:2)	$Q = 1.175 \cdot h^{2.15}$	20–70
Oct. 5, 2004–		
Small flume (QFM1:1)	$Q = 864.9 \cdot h^{2.576}$	0–20
Large flume (QFM1:2)	$Q = 2.298 \cdot (h + 0.03459)^{2.339}$	20–1 400
PFM002667 **Dec. 8, 2004 – Aug. 16, 2018**		
Small flume (QFM2:1)	$Q = 864.9 \cdot h^{2.576}$	0–20
Large flume (QFM2:2)	$Q = 2.001.5 \cdot (h + 0.02660)^{2.561}$	20–500
PFM002668		
QFM3	$Q = 979.1 \cdot h^{2.574}$	0–250
PFM002669		
Small flume (QFM4:1)	$Q = 864.9 \cdot h^{2.576}$	0–20
Large flume (QFM4:2)	$Q = 1.117.6 \cdot (h + 0.02727)^{2.604}$	20–920

2.2 Data-collection systems

The data collecting system, which is part of SKB's HMS (Hydro Monitoring System) consists of a computer that collects data from a large number of data loggers and associated sensors. The computer is connected to the SKB Ethernet LAN. All data were collected by means of pressure, EC and temperature transducers (sensors) connected to Mitec Sat60 GSM data loggers, connected on-line by means of GSM telephony. As part of the 2014 and 2018 refurbishments and reconstructions, Mitec data loggers were switched to a dataTaker DT85 data logger at PFM005764 (Werner 2015a) and a Cube300S data logger at PFM002667 (Section 2.4.2).

At stations equipped with Mitec data loggers, the measured water level must be compensated for temperature. This report uses temperature-compensated water levels available in so called HBV channels (previously denoted BH) in HMS, from which data are transferred to the Sicada database. Uncompensated water levels, which are available in HMV channels (previously denoted MH) in HMS, not transferred to the Sicada database, were used in previous discharge calculations (Johansson and Juston 2007, 2009, 2011a, b) for the period April 2004 – December 2010. Differences in compensated and uncompensated water levels are discussed as part of the evaluation of the PFM005764 refurbishment and reconstruction (Werner 2015a). However, no systematic analysis has yet been performed on the difference in calculated discharge using compensated or uncompensated water levels. The plan is to switch the Mitec data loggers to other logger types during 2019.

Water levels at the upstream edge of flumes were measured using vented Druck PTX 1830 pressure sensors (full scale pressure range 1.5 m w.c., accuracy 0.1 % of full scale). EC (electrical conductivity) was measured by GLI 3442 sensors, range 0–200 mS/m, accuracy 0.1 % of full scale, whereas temperature was measured using Mitec MSTE106 (range 0–120 °C) and Sat60 (range −40 to +120 °C). In connection to the PFM002667 refurbishment and reconstruction in 2018, the Druck pressure sensor was replaced by a LevelTroll 700 pressure sensor, whereas the EC and temperature sensors were replaced by a single Aqua TROLL 200 sensor (Section 2.4.2).

2.3 Practical experiences, field inspections and independent discharge measurements

For summaries of practical experiences, field inspections and independent discharge measurements up to the end of the 2016/2017 hydrological year, the reader is referred to previous data reports (Werner 2014a, b, 2015a, 2017, 2018a, b) and reports from independent discharge measurements (Bergqvist 2014a, b, c, Werner 2015b, Ryman and Strömbeck 2016). With few exceptions, independent discharge measurements have only been performed when the prevailing discharge is above the discharge interval for the small flumes, as it is practically difficult to perform measurements when discharges are small.

Using the salt-dilution method (e.g. Moore 2005), independent discharge measurements (Ryman and Strömbeck 2018) were performed on November 27, 2017 (all gauging stations) and on January 10, 2018 (PFM005764 only). Based on previous measurements (Ryman and Strömbeck 2016) it was judged that this method works reasonably well for the conditions at all gauging stations. A single salt-dilution measurement has an estimated uncertainty of ± 5 %, whereas the estimated uncertainty is ± 10 % at PFM002667 due to backwater conditions and downstream damming (prior to station refurbishment and reconstruction, cf. Section 2.4.1). The results of the independent discharge measurements in 2017 and 2018 are summarised in Table 2-2. As can be seen in the table, two salt-dilution measurements were performed per gauging station on each measurement occasion.

Table 2-2. Results of independent discharge measurements in 2017 and 2018 (Ryman and Strömbeck 2018).

	PFM005764	PFM002667	PFM002668	PFM002669
Measurement on November 27, 2017:				
Salt dilution no. 1 (L/s)	140.4	77.7	51.2	77.3
Salt dilution no. 2 (L/s)	140.1	89.1	51.3	77.8
Average of the above (L/s)	140.2	83.4	51.3	77.6
Water depth at upstream edge of flume (m)	0.266	0.258	0.324	0.366
Calculated discharge (L/s); cf. Table 2-1	138.1	80.1	53.8	80.0
Diff. between salt-dilution average and the calc. discharge (%)	+1.6	+4.1	−4.6	−3
Measurement on January 10, 2018:				
Salt dilution no. 1 (L/s)	131.6	-	-	-
Salt dilution no. 2 (L/s)	135.1	-	-	-
Average of the above (L/s)	133.3	-	-	-
Water depth at upstream edge of flume (m)	0.260	-	-	-
Calculated discharge (L/s); cf. Table 2-1	131.8	-	-	-
Diff. between salt-dilution average and the calc. discharge (%)	+1.1	-	-	-

Hence, at prevailing discharges independent measurements differ 1–4 % compared to calculated discharges at PFM005764 and PFM002667 (prior to station refurbishment and reconstruction), and they are 3–5 % lower than calculated discharges at the other two stations. As part of the measurements, Ryman and Strömbeck (2018) noted that the large flume at PFM005764 has a small transverse inclination (the water depth is slightly higher on one side at the upstream end of the flume). Moreover, they also noted erosion on the sides of the small flume at PFM002667 and likely bypass of flow if the water depth in the small flume exceeds 0.20 m. Experiences, inspections and other investigations have led to the conclusion that the gauging stations need to be refurbished and reconstructed to improve their performance, accuracy of measurements and to make them more stable and thereby suitable for long-term monitoring. In accordance with this conclusion, refurbishments and reconstructions of the PFM005764 station (Werner 2015a) and the PFM002669 station (Werner 2017) were done during August 2014 and August–September 2015, and the PFM002667 station was refurbished and reconstructed in August 2018 (Section 2.4.1). Due to the refurbishment, additional independent discharge measurements need to be performed at the PFM002667 station.

2.4 Completed and planned refurbishments and reconstructions

2.4.1 Completed refurbishments and reconstructions

Werner (2018b) provides a continued follow-up of the PFM005764 refurbishment and reconstruction. Based on the analysis, it was recommended to investigate whether temperature, air pressure and/or moisture conditions inside the cottage above the large flume may influence measurements using a vented pressure sensor. It was suggested to install e.g. a water-level bubbler, or some other type of sensor, to measure the water-level in the large flume in parallel with the current Druck pressure sensor.

On January 10, 2018, a water-level bubbler (YSI Waterlog Amazon Bubbler) was installed in the observation well connected to the large flume (Ryman and Strömbeck 2018). The intention is to measure water level using the bubbler in parallel with pressure-sensor measurements. For an initial monitoring period, Figures A2-9 and A2-10 compare water-level time series for the pressure sensor and the water-level bubbler. As can be seen in these plots, due to installation issues the water-level bubbler provided unreliable data during the first months after installation, whereas data are more reliable from April 2018 and onwards. The ”straight line” in Figure A2-10 likely represents the lower measurement limit of the water-level bubbler. Further data evaluation will be done as part of the forthcoming 2018/2019 monitoring-data report when longer time series are available.

2.4.2 Refurbishment and reconstruction of the PFM002667 station

Due to the flat landscape the large flume at PFM002667 generally yields realistic discharge values only up to c 55 L/s (e.g. Werner 2018b). If the downstream wetland is not filled up, it probably also works satisfactory also at higher discharges in the rising phase of a flow peak. Moreover, the small flume may cause converging, supercritical flow and turbulence that disturb the inflow to the large flume, and regular submergence of the small flume or even the whole gauging-station area (see example in Figure 2-1) leads to erosion damages on the gravel bed that forms its foundation. An additional drawback with two flumes with different discharge ranges (0–20 and 20–500 L/s) is the occurrence of short-term, artificial discharge fluctuations during periods with transitions between the small and the large flume, i.e. when the discharge calculated for the small flume fluctuates around 20 L/s.

It has previously been concluded that despite an inevitably flat landscape, some of the above-mentioned issues may be resolved if the current two flumes at PFM002667 are replaced with a single flume (e.g. Werner 2018b). Specifically, a replacement would imply that only one flume needs to be calibrated and maintained, and it would also remove occurrences of artificial, short-term discharge fluctuations. Werner (2018a) provides input for the design of a single flume as a potential replacement for the two current flumes, as flume design is always a balance between its accuracy at low discharges and its maximum discharge capacity. A refurbishment and reconstruction of the PFM002667 station was conducted during the period August 20–30, 2018. As part of this project, the two flumes were replaced with a single flume (Bergqvist 2018). The refurbishment and reconstruction comprises the following:

- Removal of the existing flumes and the hoses connected to the LPG heating system.
- Installation of a new gravel bed and a concrete foundation (length 4 m, width 1 m and depth 0.25 m) for the new flume (Figure 2-2).
- Installation of the flume on its foundation.
- Excavation of a small pond upstream of the flume to reduce the approach flow velocity and reduce risks for turbulence (Figure 2-2).
- Attachment of a boat-cover canvas to the front and along the sides of the flume to reduce risks of water bypass and erosion damages (Figure 2-1 and Figure 2-3).
- Looping of a copper pipe, connected to the LPG heater, for heating and insulation of the pipe connecting the flume to the observation well (Figure 2-4).
- Installation of the grating upstream of the pool, and attachment of the tube hosting an EC and temperature sensor (Aqua TROLL® 200) on the grating (Figure 2-5). In this position, the tube communicates hydraulically with the stream water not only through the tube screen but also via the open tube bottom.
- Installation of a pressure sensor (LevelTroll 700) inside the observation well, and replacement of the Mitec data logger with an In-Situ® Cube300S GSM data logger. The LevelTroll 700 has a pressure range of 11 m w.c. and an accuracy of 0.05 % (of full range).
- The station has been prepared for construction of a small cottage above the flume.

The new flume is designed using the WinFlume software (Wahl et al. 2000, Bergqvist 2018). The discharge range of the flume is 0–250 L/s, whereas the discharge equation is applicable for the discharge range 0–150 L/s. According to WinFlume calculations, the measurement error of the new flume is ± 2.5 % at 20 L/s and ± 4 % at 1 L/s (Bergqvist 2018). For CAD and WinFlume drawings of the flume, see Appendix 6. Levelling of the new flume subsequent to the PFM002667 refurbishment and reconstruction is presented in Hermansson (2019).

Figure 2-1. *Submerged flumes at gauging station PFM002667 on April 23, 2013 (Werner 2014b).*

***Figure 2-2.** Front, side and rear views of the new flume. The front and rear views show the pool that was excavated upstream of the flume.*

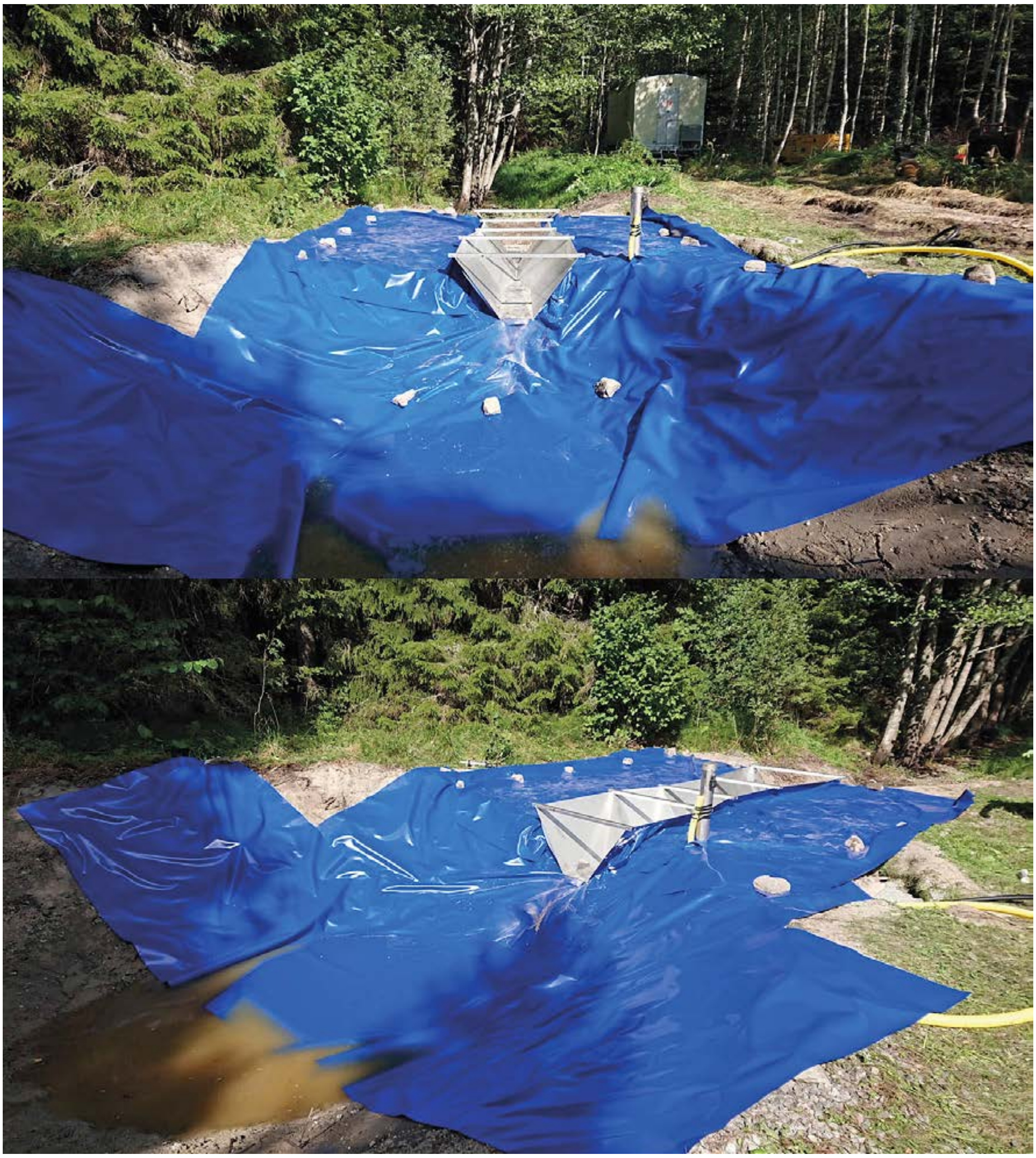


Figure 2-3. *Front and side views of the boat-cover canvas attached to the new flume to reduce water bypass and erosion damages. As shown in the lower image, the canvas is glued onto the sides of the flume.*

Figure 2-4. *The pipe connecting the flume to the observation well, and close ups of the insulation and copper pipe for heating, looped around the connection pipe.*

2018/08/23

Figure 2-5. *Upstream grating and tube hosting the EC and temperature sensor. As can be seen in the picture, the tube is mounted to the grating and communicates with the stream water not only through the tube screen but also through the open tube bottom.*

3 Execution

3.1 General

Data on water levels, electrical conductivities and temperatures were collected to and stored in HMS as described in Chapter 2, and quality-controlled data were transferred to the Sicada database. Hourly average discharge values were calculated based on the quality-controlled water-level data and flume-bottom levels (cf. Table A1-1 in Appendix 1) and also transferred to Sicada.

3.2 Field work

According to the activity plan (see Table 1-2) the gauging stations are to be inspected at least once a week. If needed, the stations and the stream reaches immediately upstream and downstream of the stations are to be cleaned from debris, vegetation, snow and ice. Moreover, manual measurements of the water depth at the upstream edge of each flume are to be done at least every second week, and EC and temperature are to be measured manually once per month. Note that such measurements are not possible when water levels are low or flumes are dry, which implies that actual measurement intervals may be longer than stipulated.

During the hydrological year October 1, 2017 – September 30, 2018, manual measurements of the water depth at the upstream edge of each flume using a folding rule were possible on 2–7 occasions (varying between 2 occasions at the small flume at PFM002667 and 7 occasions at the large flume at PFM005764). EC and temperature measurements, using a hand-held instrument (HACH HQ 14D), were possible on 2–4 occasions (the number of occasions varies between stations). Hence, frequencies of actual measurements were lower during the 2017/2018 hydrological year than stipulated (see Appendices 2, 4 and 5).

The results of the manual measurements were stored in Lodis, which is SKB's database for manual measurements. Lodis data on water depths were regularly transferred to HMS (but not to Sicada), where they were automatically transformed to water levels based on flume-bottom levels (cf. Table A1-1 in Appendix 1). Specifically, manually measured water levels (based on measured water depths) were used for comparison with automatically measured water levels (see further details in Section 3.3.1).

3.3 Data handling and post processing

3.3.1 Water-level calibration

As mentioned in Section 2.1, water levels in the flumes are measured by pressure sensors installed in observation wells located alongside of each flume. The pressure data from the data loggers were converted to water levels by a linear equation. As part of the regular quality control (Section 3.4.1), water depths in the flumes were regularly measured using a folding rule. Hence, water-level calibration is not done based on manual sounding in the observation wells, which implies that the level of the top of the observation wells (Table A1-1 in Appendix 1) is not important. However, in order to provide a basis for evaluations of water-depth measurements, manual sounding of observation wells has also been done in parallel with the water-depth measurements since July 2013.

As part of the regular quality control, water levels measured automatically in observation wells were compared to manually measured water levels (flume-bottom level + water depth), and adjusted in case of poor fit (difference of a few millimetres or more) to manual measurements. Specifically, the linear equation for each flume involves a flume-specific calibration constant, which also includes a flume-independent factor for conversion from water pressure to water level. The calibration constant was adjusted in cases of two or more subsequent mismatches, at a point in time approximately midway between the manual measurements. Hence, calibration constants were not adjusted as a result of a single mismatch.

Table 3-1 lists those dates at which the flume-specific calibration constants have been adjusted from initiation of water-level measurements up to the end of 2018 at each gauging station. As can be seen in the table, calibration constants have regularly been adjusted in order to maintain fits between manual and automatic water-level measurements. In particular, flumes were reinstalled and taken into new operation at PFM005764 and PFM002669 in October 2004 and November 2007 (the PFM002669 observation wells were also reinstalled), respectively, and the PFM005764 small-flume observation well was reinstalled (lowered) in September 2006. As seen in Table A1-1 in Appendix 1, irrespective of the PFM005764 well reinstallation (September 2006), the PFM002669 flume and well reinstallation (November 2007), and irrespective of results of repeated levelling campaigns, originally measured flume-bottom levels have been kept as reference levels. Instead, these deliberate or naturally caused well and flume movements have been handled by calibration-constant adjustments. Moreover, temperature compensations of Mitec loggers (introduced in December 2005) are noted in the HMV channels of HMS, but have not rendered any calibration-constant adjustments.

Table 3-1. Water-level calibration-constant adjustments at each gauging station, from initiation of water-level measurements up to the end of 2018. Temperature compensations of Mitec loggers ("temp. comp.", introduced in December 2005) are noted in the HMV channels of HMS, but have not rendered any calibration-constant adjustments.

Gauging station and flume	Adjustment dates (YYYY-MM-DD)
PFM005764	
Small flume	2004-03-01, 2004-08-06, 2004-10-07 (reinstallation of flume), 2005-07-01, 2005-08-01, 2005-10-22, 2005-12-13 (temp. comp.), 2006-04-15, 2006-05-01, 2006-09-13 (reinstallation of obs. well), 2006-12-19, 2007-04-15, 2007-06-15, 2007-08-01, 2007-09-01, 2007-11-01, 2009-01-16, 2009-07-01, 2009-09-01, 2010-07-01, 2010-08-01, 2011-12-01, 2012-01-01, 2013-03-01, 2013-07-01, 2014-08-26 (refurbishment, switch from Mitec to dataTaker logger), 2015-06-27, 2015-07-06, 2016-01-01, 2016-07-01, 2017-12-07, 2017-12-11, 2018-05-04
Large flume	2004-03-01, 2004-08-06, 2004-10-07 (reinstallation of flume), 2005-01-11, 2005-10-22, 2005-12-13 (temp. comp.), 2007-09-24, 2007-12-01, 2008-01-15, 2008-08-09, 2009-03-10, 2009-05-01, 2009-09-01, 2011-09-01, 2011-10-01, 2014-08-26 (refurbishment, switch from Mitec to dataTaker logger), 2016-04-14, 2017-01-27, 2017-05-24
PFM002667	
Small flume	2004-10-01, 2005-12-15 (temp. comp.), 2006-10-20, 2006-12-15, 2007-09-06, 2008-08-01, 2008-11-01, 2009-03-12, 2010-06-01, 2010-07-01, 2011-11-10, 2012-03-08, 2012-05-10, 2012-09-01, 2012-10-01, 2013-09-01, 2014-02-01, 2014-11-11, 2015-02-11, 2015-03-25, 2015-06-25, 2017-03-15, 2017-04-26, 2018-10-25
Large flume	2004-10-01, 2005-02-14, 2005-04-01, 2005-05-01, 2005-12-15 (temp. comp.), 2006-12-15, 2007-01-01, 2007-09-06, 2007-11-01, 2008-01-01, 2008-08-09, 2008-09-01, 2008-11-15, 2009-03-12, 2009-07-01, 2009-08-01, 2009-10-26, 2010-05-01, 2010-09-01, 2012-05-16, 2012-07-16, 2013-04-15, 2013-06-01, 2017-03-15, 2017-05-15, 2018-10-25
PFM002668	2004-10-01, 2005-07-22, 2005-12-15 (temp. comp.), 2006-08-20, 2006-10-23, 2008-08-09, 2009-07-01, 2009-11-01, 2010-05-15, 2010-06-15, 2011-12-10, 2012-01-10, 2013-07-01, 2013-12-01, 2014-06-01, 2014-10-01, 2015-10-02, 2017-06-26
PFM002669	
Small flume	2004-10-01, 2005-08-05, 2005-12-15 (temp. comp.), 2006-02-10, 2006-02-23, 2007-11-12 (reinstallation of flume and obs. well), 2008-07-02, 2008-08-09, 2008-09-01 (no change of cal. const.), 2008-12-01, 2009-03-02, 2009-09-01, 2010-02-01, 2011-11-01, 2011-12-01, 2012-03-01, 2012-04-01, 2015-09-15 (refurbishment), 2017-11-28
Large flume	2004-10-01, 2005-02-14, 2005-08-05, 2005-12-15 (temp. comp.), 2006-02-10, 2006-10-25, 2007-06-30 (reinstallation of flume and obs. well), 2008-02-12, 2009-03-04, 2009-03-27, 2009-07-01, 2009-08-01, 2012-11-01, 2011-12-01, 2012-07-01, 2012-10-01, 2012-10-08, 2013-01-08, 2013-04-15, 2013-06-01, 2014-06-01, 2014-11-01, 2015-09-15 (refurbishment)

3.3.2 Controls of EC and temperature

As mentioned in Section 2.1, EC and temperature sensors are mounted on the outside of the PFM002668 screened tube (downstream of the flume), and inside the screened tubes upstream of the flumes at the other stations (after refurbishments). Linear equations were used also to convert data from the EC and temperature sensors. As part of the regular quality control (Section 3.4.1), EC and temperature were measured outside of tubes using a hand-held instrument. The only changes of calibration constants have been in connection to the PFM005764 and PFM002667 refurbishments and reconstructions in August 2014 and 2018, respectively.

3.3.3 Recording interval

Recording intervals were very irregular, generally varying between 1 minute and 1 hour (2 hours for EC and temperature). The water-level data recording interval is set to 1 hour, whereas the scanning frequency is once per minute; a water-level datum is recorded if the water-level change is larger than 1–2 mm. For EC and temperature, the recording interval is set to 2 hours, whereas a datum is recorded if the EC change is > 0.1 mS/m and the temperature change > 0.1 C, respectively (the scanning frequency is once per minute).

3.3.4 Calculation of discharge

Discharge was calculated for each flume using water levels stored in the HBV channels (previously denoted BH) in HMS. The calculation procedure consisted of the following steps:

- Quality control of the October 1, 2017 – September 30, 2018 water-level dataset, based on high-resolved water-level data (see Section 3.4.2).
- Calculation of hourly average water levels, based on the high-resolved, screened dataset.
- Calculation of hourly average discharges for each flume, based on hourly average water levels, using the discharge equations shown in Table 2-1 and the bottom level at the upstream edge of each flume shown in Table A1-1 in Appendix 1.

If the hourly average water level is at or below the zero-discharge levels for the small flumes in Table 3-2, the discharge is set to zero (Johansson 2005). Specifically, these levels represent the levels of the connections between pipes and observation wells, which due to installation issues are above the bottom of the upstream edge of three of the four small flumes. As can be seen in Table 3-2, this issue has been resolved at the small flumes of the refurbished gauging stations; the PFM005764 small-flume observation well was also reinstalled in September 2006.

There is a single flume at gauging station PFM002668, whereas there are two flumes at the other stations with given discharge ranges (cf. Table 2-1). For these gauging stations, a single discharge time series for each station was obtained according to the station-specific description below. It is noted that PFM005764 data gaps were reduced by using the discharge calculated for the small flume, even when the small-flume discharge was (slightly) > 20 L/s and the calculated large-flume discharge was < 16 L/s (few occasions). However, the discharge calculated for the large flume was used when the small-flume discharge was much higher than 20 L/s and the large-flume discharge was < 16 L/s.

Moreover, the large-flume discharge was used when there were missing data for the small flume. The PFM002667 discharge was set equal to the small-flume discharge when the small-flume discharge was (slightly) > 20 L/s and there were missing data for the large flume. For the PFM002669 station, the small-flume discharge was used when the calculated small-flume discharge was > 20 L/s and the large-flume discharge was < 20 L/s (few occasions).

- PFM005764 and -2667:
  - The discharge was set equal to the discharge calculated for the small flume if the small-flume discharge was less than 20 L/s.
  - The discharge was set equal to the discharge calculated for the large flume if the small-flume discharge was above 20 L/s and if the large-flume discharge was above 16 L/s.
- PFM002669:
  - The discharge was set equal to the discharge calculated for the small flume if the small-flume discharge was less than 20 L/s.
  - The discharge was set equal to the discharge calculated for the large flume if both small- and large-flume discharges were above 20 L/s.

Table 3-2. Levelled small-flume bottom elevations and elevations to signify zero discharge. Note that the single flume at PFM002667 is levelled in the coordinate system RH 2000 (Hermansson 2019). Elevation in the RHB 70 system is calculated as RH 2000 – 0.185 m.

Gauging station	Bottom elevation (m, RHB 70) of upstream edge	Elevation (m, RHB 70) signifying zero discharge
PFM005764 (up to Aug. 25, 2014)	0.903	0.903 (0.990 prior to Sep. 13, 2006, when the observation well was lowered)
PFM005764 (from Aug. 26, 2014)	0.924	0.924 (station refurbished)
PFM002667 (up to Aug. 16, 2018)	1.502	1.518
PFM002667 (single flume, from Aug. 30, 2018)	1.580	1.580
PFM002668 (single flume)	4.287	4.296
PFM002669 (up to Sep. 14, 2015)	5.852	5.872
PFM002669 (from Sep. 15, 2015)	5.441	5.441 (station refurbished)

In some cases, the rules stated above lead to short-term, artificial discharge fluctuations. Specifically, such fluctuations occur during periods with transitions between the small and the large flume, i.e. when the discharge calculated for the small flume fluctuates around 20 L/s. It is noted that days with missing discharge data are not filled in, as such data filling is not an objective of the hydrological monitoring. It is also noted that the large flume at gauging station PFM002667 generally yields realistic discharge values up to c 55 L/s, but it probably works satisfactory also at higher discharges in the rising phase of a flow peak, if the downstream wetland is not filled up (Johansson 2005). Hence, discharge values > 55 L/s should be used with caution for the PFM002667 station. In August 2018, the station was refurbished and reconstructed and the two flumes were replaced by a single flume (see Section 2.4.2).

3.4 Quality control

3.4.1 Regular quality control

The regular quality control concerns water-level data, but neither EC nor temperature data (cf. quality-control reports in Table 1-1) are included. Once every week, it was checked that loggers were sending data and that all sensors were in function. Another check was performed four times during the data period of this report. Moreover, calibration constants were corrected (Table 3-1) in order to match automatically and manually measured water levels (i.e. water depths plus flume-bottom levels). At those occasions when water depths were measured manually (see further below), the status of the equipment was also checked and maintained if needed. The field maintenance included, for instance, removal of snow and ice and cleaning of EC sensors using hydrochloride.

- **PFM005764:**
  - Small flume: Water-level data are considered uncertain and have not been approved February 1 – May 3, 2018, at which time the pressure transducer was replaced. Water-level data are approved to (and including) Sep. 30, 2018.
  - Large flume: Water-level data are considered uncertain and have not been approved March 6 – April 4, 2018. Water-level data are approved to (and including) Sep. 30, 2018.
- **PFM002667–2669:** Water-level data for all flumes are approved to (and including) Sep. 30, 2018.

3.4.2 Quality control of the 2017/2018 dataset

Apart from the regular quality control described above, an additional quality control was done of the whole 2017/2018 dataset, including EC and temperature data. Tables 3-3 to 3-5 summarise the outcome of this quality control, in terms of data periods excluded from the HMS to Sicada data transferral, and reasons for the exclusions. Note that the quality control was performed on high-resolved data.

Table 3-3. Water-level data excluded from the HMS to Sicada data transferral, as a result of the quality control of the 2017/2018 dataset.

Gauging station (flume)	Dates and times (YYYY-MM-DD hh:mm)	Reason for exclusion (WL = water level)
PFM005764 (large flume)	2018-07-06 12:15 – 2018-07-11 12:00	WL large flume > WL small flume (likely "frozen" data values for large flume)
PFM005764 (large flume)	2018-07-15 22:00 – 2018-08-02 09:00	As above
PFM005764 (large flume)	2018-08-21 10:00 – 2018-08-22 01:00	As above
PFM005764 (large flume)	2018-08-28 13:00 – 21:00	As above
PFM002667 (large flume)	2018-04-12 04:50 – 08:50	Unexplained peak values
PFM002667 (large flume)	2018-05-31 14:00 – 2018-08-16 14:00	WL large flume > WL small flume (likely "frozen" data values for large flume)
PFM002668	2018-02-21 22:00 – 2018-02-22 02:30	Unexplained peak values
PFM002668	2018-03-27 23:00 – 2018-03-29 10:20	As above
PFM002669	No data excluded	

Table 3-4. EC data excluded from the HMS to Sicada data transferral, as a result of the quality control of the 2017/2018 dataset.

Gauging station	Dates and times (YYYY-MM-DD hh:mm)	Reason for exclusion
PFM005764	2018-07-12 21:39 – 2018-08-03 14:10	Low/negative EC values (likely due to low water level)
PFM005764	2018-09-15 17:12 – 2018-09-30 23:00	As above
PFM002667	2018-06-08 17:50 – 2018-08-06 17:00	As above
PFM002668	2018-06-04 05:50 – 2018-06-22 03:40	As above
PFM002668	2018-06-28 01:30 – 2018-07-29 16:30	As above
PFM002668	2018-07-31 16:00 – 2018-08-02 16:20	Negative EC values (likely due to low water level)
PFM002668	2018-08-11 14:50 – 2018-08-12 06:10	As above
PFM002668	2018-08-14 02:40 – 2018-09-30 23:00	As above
PFM002669	2018-06-16 03:00 – 2018-06-22 06:30	Low/negative EC values (likely due to low water level)
PFM002669	2018-06-29 23:50 – 2018-08-04 16:10	Negative EC values (likely due to low water level)
PFM002669	2018-08-08 14:30 – 2018-09-30 23:00	As above

Table 3-5. Temperature data excluded from the HMS to Sicada data transferral, as a result of the quality control of the 2017/2018 dataset.

Gauging station	Dates and times (YYYY-MM-DD hh:mm)	Reason for exclusion
PFM005764	2018-07-12 00:05 – 2018-08-03 23:35	High/fluctuating temperature values (likely due to low water level)
PFM005764	2018-09-15 01:00 – 2018-09-30 23:30	As above
PFM002667	2018-06-07 00:20 – 2018-08-15 23:50	As above
PFM002668	2018-07-11 00:00 – 2018-08-03 23:00	As above
PFM002669	2018-07-05 00:00 – 2018-08-11 23:50	As above

3.4.3 Flume and well levelling: Results and influence on discharge calculations

The gauging stations have been exposed to surface-water flow, debris and ice since 2004, which likely have influenced the stability of the flumes. In particular, the level of the bottom of the upstream edge of each flume, which is used to calculate the discharge, was levelled at time of installation. In order to check whether these levels are still valid, new levelling was done in June, September and October 2012 (Edvardson 2012), in June, August and September 2013 (SWECO 2014), in May and June 2014 (Edvardson 2015), in June 2015 (Edvardson 2016), in May 2016 (Ohrzén 2016), and in May–June 2017 (Hermansson 2017). The results of the levelling at time of flume and well installations and at the 2012–2017 levelling campaigns, which have a stated level accuracy of ± 2 mm, are shown in Table A1-2 and Table A1-3 in Appendix 1. As mentioned in Section 2.1, the levelling performed at time of installations had less accuracy compared to the recent levelling campaigns. This implies that actual vertical movements during the period from flume and well installations to subsequent levelling campaigns are uncertain.

As can be seen in Table A1-2 and Table A1-3 in Appendix 1, flume and well movements since the original levelling seem to be particularly large for gauging station PFM002667 (both flumes have raised c 0.06 m and both wells c 0.08–0.09 m). The large vertical movements at PFM002669 are due to that both flumes wells were reinstalled in 2007. For some flumes (e.g. PFM005754 and -2669) the 2012–2015 levelling results indicate back-and-forth movements. This is primarily due to somewhat dubious results of the 2013 levelling campaign, an issue which is related to the actual inaccuracies of the levelling. It is therefore recommended that evaluations of levelling methods and associated accuracies are integrated parts of continued levelling campaigns.

As discussed further in the corresponding 2011–2012 and 2013 dataset reports (Werner 2014a, b), potential flume movements raises the question of the validity of the discharge equations and their associated parameters. It was shown that vertical flume movements likely have small effects on discharge calculations, provided that manual water-depth measurements in the flumes are done regularly and with high accuracy (Werner 2014a). Adjustments of calibration constants to fit automatic and manual water-level measurements reduce potential errors due to vertical flume movements. The validity of discharge equations and associated parameters due to e.g. unlevelled flumes perpendicular to the stream-flow direction can be checked by independent discharge measurements (cf. Section 2.3).

3.5 Nonconformities

The activity plans (Table 1-2) state that manual water-depth measurements are to be performed at least every second week. However, due to low water levels or dry flumes such measurements were only possible on 2–7 occasions during the period October 1, 2017 – September 30, 2018 (Section 3.2). It is important that sufficient resources are allocated so that routines stated in activity plans can be followed also in the future.

4 Results

4.1 General

The results are stored in SKB's primary database Sicada where they are traceable by the Activity Plan number. Only data in databases are accepted for further interpretation and modelling.

4.2 Water level

Water level data are stored in Sicada as Sicada Activity Type HY096-HMS monitoring surf. w level-small flume and HY097-HMS monitoring surface w level-big flume. During the period of this report, there are some water-level data gaps, i.e. data are missing in HMS, in particular for the gauging station PFM005764. Note that the regular quality control (Section 3.4.1) and the quality control of the 2017/2018 dataset (Section 3.4.2) also result in some further data gaps, apart from data missing in HMS.

- **PFM005764:**
  - Small flume: There is a water-level data gap February 1 – May 3, 2018. During this period, water-level data have not been approved due to large scatter and unreasonable water levels (Section 3.4.1). A new pressure transducer was installed on May 4, 2018.
  - Large flume: There is a water-level data gap March 6 – April 4, 2018. During this period, water-level data have not been approved due to large scatter (Section 3.4.1).
- **PFM002667:** There are no water-level data gaps.
- **PFM002668:** There are no water-level data gaps.
- **PFM002669:** There are no water-level data gaps.

Appendix 2 presents high-resolved water-level data from the four gauging stations during the 2017/2018 period. It is reminded that natural or deliberate flume movements are handled by calibration-constant adjustments, aiming to match manually measured in-flume water depths. Hence, the presented water levels are more or less incorrect in absolute terms.

4.3 Calculated discharge

Data on calculated discharge are stored in Sicada as Sicada Activity Type HY098-HMS stream flow rate – hourly data. Appendix 3 presents hourly average (screened) discharge data from the four gauging stations during the 2017/2018 period, calculated based on the discharge equations of Table 2-1. Due to large scatter and/or unreasonable water levels, hourly average discharge data are missing for 9 % of the time for the PFM005764 station during the period October 1, 2017 – September 30, 2018. Moreover, discharge data are missing for 12 % of the time for the PFM002667 station due to station refurbishment, whereas data are missing for 1 % of the time for the PFM002668 station. Average, minimum and maximum discharges, affected by these data gaps, are shown in Table 4-1.

Table 4-1. Average, minimum and maximum discharges (screened data, rounded to integers) during the hydrological year October 1, 2017 – September 30, 2018. The statistics are affected by data gaps, in particular for the PFM005764 and -2667 stations.

	PFM005764	PFM002667	PFM002668	PFM002669
Average discharge (L/s)	49	30	20	29
Min. discharge (L/s)	0	0	0	0
Max. discharge (L/s)	222	127	78	116
Missing hourly values (%)	9	12	1	0

4.4 Electrical conductivity

Electrical-conductivity data are stored in Sicada as Sicada Activity Type HY094-HMS Monitoring surface water EC. Appendix 4 presents high-resolved EC data from the four gauging stations during the 2017/2018 period, whereas average, minimum and maximum EC values (based on screened data) are shown in Table 4-2. As a result of the quality control of the 2017/2018 dataset (Section 3.4.2), EC data were excluded from the HMS to Sicada data transferral during periods with low or negative EC values.

Table 4-2. Average, minimum and maximum EC (screened data, rounded to integers) during the hydrological year October 1, 2017 – September 30, 2018. For the PFM002667 station, data are only available up to August 16, 2018 due to station refurbishment.

	PFM005764	PFM002667	PFM002668	PFM002669
Average EC (mS/m)	39	28	27	33
Min. EC (mS/m)	2	18	2	14
Max. EC (mS/m)	65	49	62	43

4.5 Temperature

Temperature data are stored in Sicada as Sicada Activity Type HY093-HMS Monitoring river water temperature. Appendix 5 presents high-resolved water-temperature data from the four gauging stations during the 2017/2018 period, whereas average, minimum and maximum temperature values (based on screened data) are shown in Table 4-3. As a result of the quality control of the 2017/2018 dataset (Section 3.4.2), temperature data were excluded from the HMS to Sicada data transferral during periods with high or fluctuating temperature values. This includes a high-temperature period for gauging station PFM002668 (Appendix 5), which explains the relative low maximum temperature for that station.

Table 4-3. Average, minimum and maximum temperature (screened data, rounded to integers) measured at the gauging stations PFM005764, -2667, -2668 and -2669 during the hydrological year October 1, 2017 – September 30, 2018. The statistics are affected by data gaps. For the PFM002667 station, data are only available up to August 16, 2018 due to station refurbishment. The actual maximum temperature at PFM002668 (c 27 °C) was measured during a period that was screened due to low water levels and fluctuating temperatures (cf. Appendix 5).

	PFM005764	PFM002667	PFM002668	PFM002669
Average temp. (°C)	12	8	10	9
Min. temp. (°C)	0	0	0	−1
Max. temp. (°C)	26	26	20	27

5 Evaluation of other hydrology-related monitoring

5.1 General

The stream monitoring described in this report is part of an extensive programme for monitoring of the rock and the surface system in Forsmark (SKB 2007). The monitoring provides data and information for various types of conceptual and quantitative modelling, which in turn form the basis for site descriptions, assessments of long-term radiological safety and environmental impact assessments. The present report and previous stream-monitoring reports (see Chapter 1) are focused on data reporting, i.e. to report and summarise the gathered monitoring data, and to draw attention to data gaps, data uncertainties and required/performed changes of monitoring methods or installations. Moreover, recurrent monitoring-data evaluations are important for maintenance of the site understanding, and as a basis for identification of potential anthropogenic disturbances (Berglund and Lindborg 2017).

The following sections provide an overview of and use some results from other hydrology-related monitoring in Forsmark, as illustrative examples of integrated evaluations that may provide insight into near-surface hydrological interactions. Similar integrated evaluations were presented in the 2015, 2015/2016 and 2016/2017 monitoring-data reports (Werner 2017, 2018a, b). For instance, these previous evaluations showed that stream discharge and ground- and surface-water levels increased in response to precipitation and/or minor snow-melt events during autumn and winter. It was also observed increasing stream discharge during early spring in response to snow and ice melt, and that increasing evapotranspiration during late spring and onwards led to gradually decreasing responses of discharge and ground- and surface-water levels to precipitation events. Note that apart from stream-discharge data, the data presented in this chapter are obtained from the Sicada database, and that data gathering and quality control are not parts of the present work.

5.2 Overview of meteorological and other hydrology-related monitoring

5.2.1 Meteorological monitoring and monitoring of winter parameters

Meteorological parameters are monitored by SKB at the Labbomasten automatic meteorological station (PFM006281, see Figure 5-1), which is operated by SMHI (Swedish Meteorological and Hydrological Institute). The monitoring comprises precipitation, air temperature, barometric pressure, wind direction and wind speed, relative humidity and global radiation. The monitoring also includes calculated parameters, specifically precipitation corrected for e.g. wind losses and calculation of potential evapotranspiration. For redundancy and quality control, the Labbomasten station is also equipped with instruments that were moved when the previously operated Högmasten station (PFM010700) was decommissioned in June 2015. The present report uses results of meteorological monitoring reported in Jones and Björck (2018, 2019).

Monitoring of winter parameters is conducted by SKB and comprises regular measurements of snow depth and snow weight, and observations of ice freeze and ice breakup (Figure 5-1). Specifically, snow depth and snow weight are measured at three locations (Figure 5-1) representing open land (AFM000071) and forest glades (AFM000072 and AFM001172 at Jungfruholm). Moreover, ice-freeze and ice-breakup observations comprise Lake Eckarfjärden (AFM000010), a pond (AFM001426), and two sea bays (AFM000075 and AFM001449). The present report uses results of monitoring of winter parameters reported in Wass (2018).

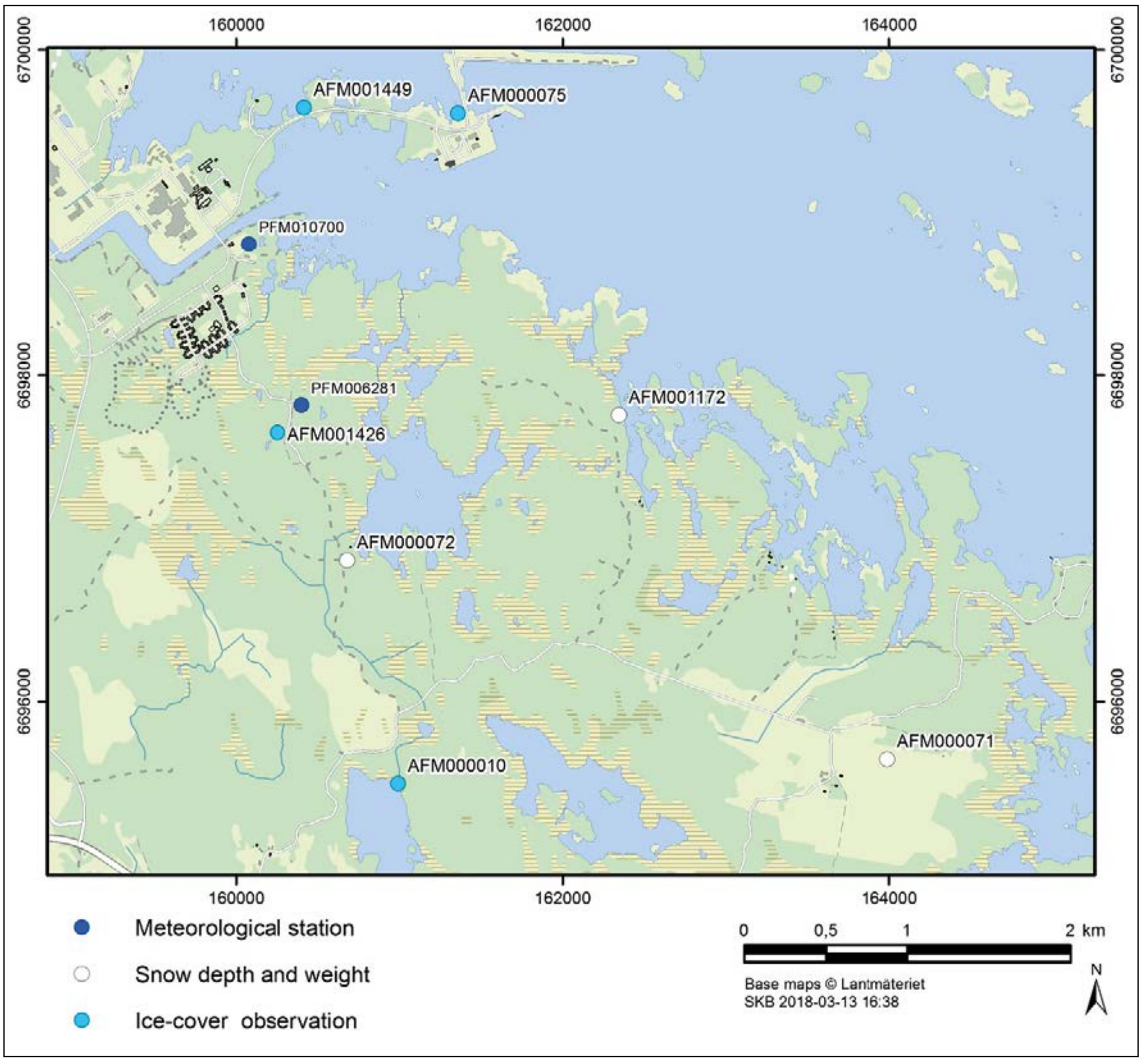


Figure 5-1. *Locations of meteorological stations and winter-time observations of snow depth/weight and ice cover.*

5.2.2 Surface-water level and temperature monitoring

The surface-water level monitoring at Forsmark comprises the surface-water level gauges listed in Table 5-1 (see overview map in Figure 5-2). The present report uses results of monitoring reported in Wass (2019). In addition, automatic water-temperature monitoring was done in natural and constructed ponds during the periods Apr.–Oct. 2016, 2017 and 2018. For further details on the water-temperature monitoring, see Section 5.4.

Table 5-1. List of surface-water level gauges (dates are given as YYYY-MM-DD).

Gauge id	Initiation of monitoring	Comments
PFM010038	2003-05-22	SKB sea-level gauge
PFM010039	2003-01-01	SMHI sea-level gauge (data not shown in this report)
SFM0039	2003-04-30	Lake Norra Bassängen
SFM0040	2003-05-16	Lake Bolundsfjärden
SFM0041	2003-04-29	Lake Eckarfjärden; terminated 2011-02-28, gauge removed and replaced by SFM000127
SFM0042	2004-02-05	Lake Fiskarfjärden
SFM0043	2003-04-28	SKB sea-level gauge; terminated 2005-11-07, gauge destroyed by ice
SFM0064	2004-04-21	Lake Gällsboträsket

Gauge id	Initiation of monitoring	Comments
SFM0066	2004-05-06	Lake Lillfjärden; terminated 2006-12-04, gauge destroyed by ice
SFM000111	2009-04-28	Pond 7 (AFM001428)
SFM000113	2009-04-28	Pond 14 (AFM001444),Norra Labbofjärden
SFM000115	2009-04-28	Pond 16 (AFM001426) (no data available for the period of this report)
SFM000117	2009-04-30	Pond 18 (AFM001427), Kungsträsket
SFM000119	2009-05-07	Lake Tjärnpussen
SFM000127	2011-03-03	Lake Eckarfjärden; replacement for SFM0041
SFM000128	2012-06-29	Constructed pond 11f (AFM001419)
SFM000129	2012-06-29	Constructed pond 11g (AFM001420)
SFM000130	2012-06-29	Constructed pond 19a (AFM001421)
SFM000131	2012-06-29	Constructed pond 66a (AFM001422)
SFM000136	2014-05-20	Constructed pond 6b (AFM001442)
SFM000137	2014-05-20	Constructed pond 17a (AFM001443)
PFM004513	2009-03-20	Man. gauging scale on well SFM000118 (no data available for the period of this report)
SFM000156	2016-03-15	Pond 12 (AFM001453)

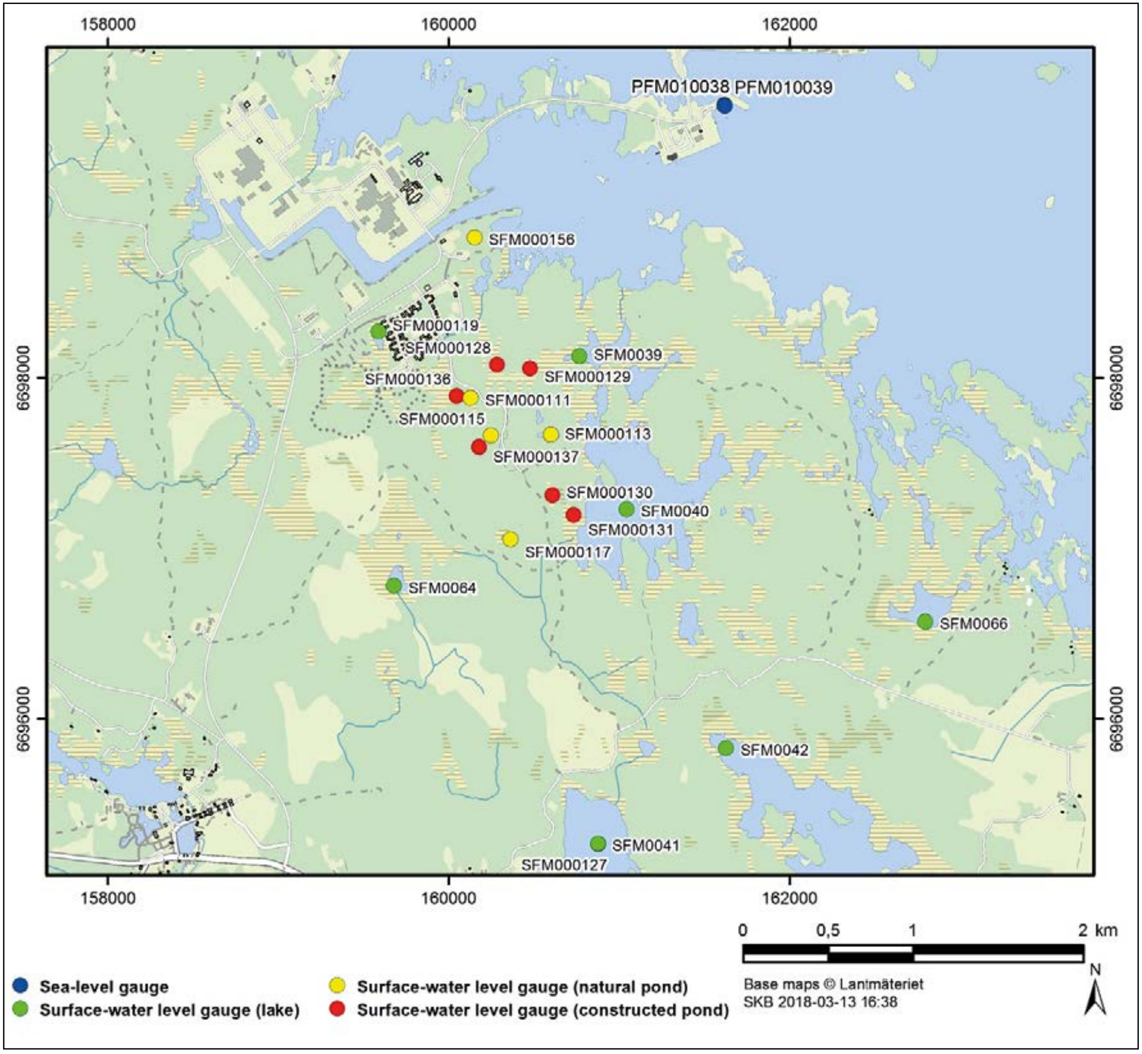


Figure 5-2. Locations of surface-water level gauges in lakes and natural and constructed ponds, and SKB's (PFM010038) and SMHI's (PFM010039) sea-level gauges. Note that the terminated sea-level gauge SFM0043 (sea bay Kallrigafjärden) was located outside of the map.

5.3 Integrated evaluation of surface-water level and stream-discharge monitoring data

Figure 5-3 and Figure 5-4 plot daily average surface-water levels for all gauges listed in Table 5-1, including sea level measured at the SKB gauging station. Data for the SMHI sea-level gauge are not shown, as the SKB and SMHI gauges demonstrate identical variations (e.g. Werner 2018b). The overall variation pattern of this figure is rising surface-water levels during autumn, early winter and early spring, and decreasing levels during late spring and summer. It is also noted that the sea level may rise above thresholds and influence surface-water levels of near-coastal lakes and ponds (e.g. SFM0039 in Lake Norra Bassängen and SFM000156 in pond 12).

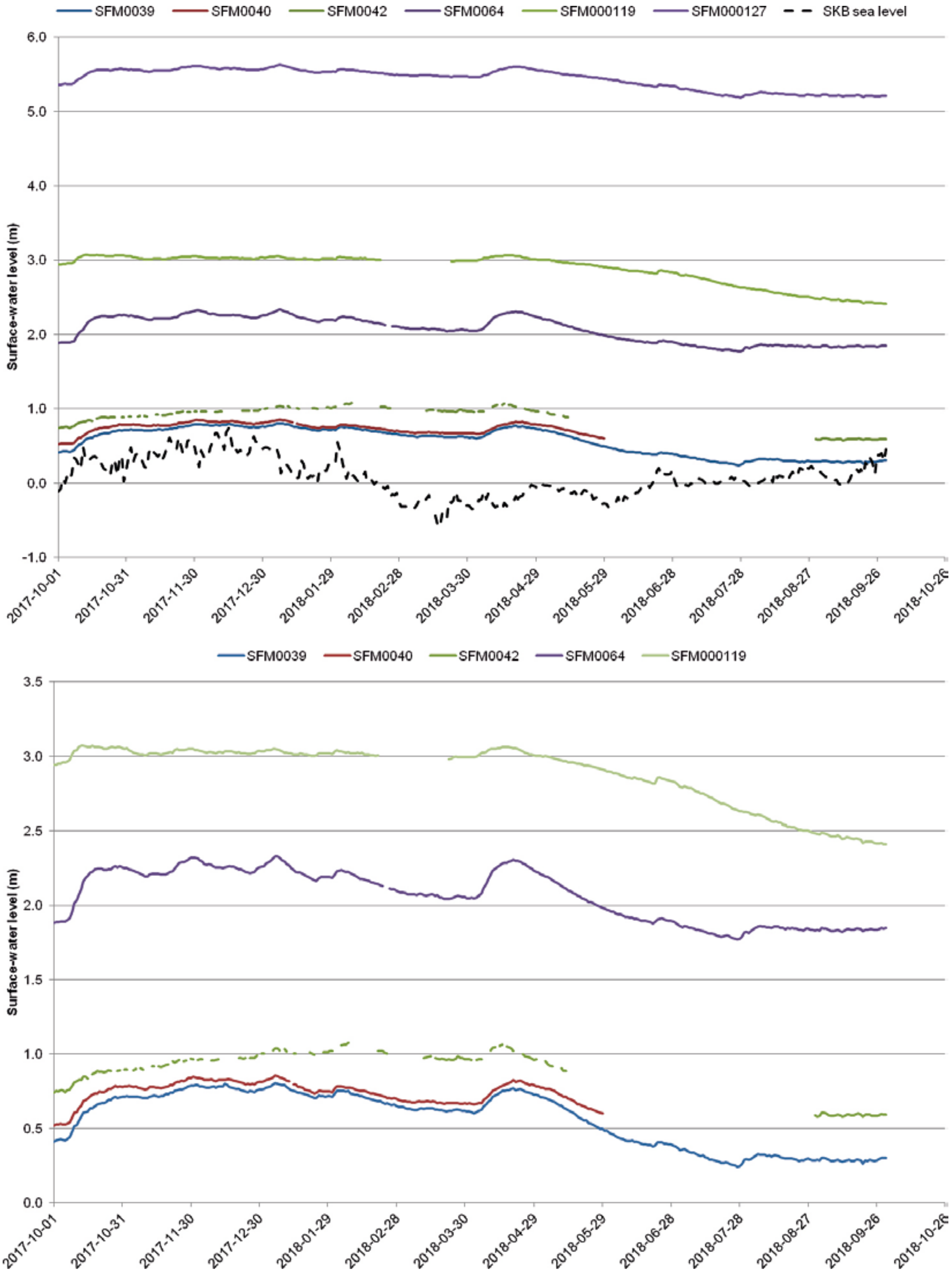


Figure 5-3. *Daily average surface-water levels (m, RH 2000). Upper figure: Surface-water levels in lakes and sea level measured at the SKB gauging station (cf. Table 5-1). Bottom figure: Surface-water levels in lakes, excluding the SFM000127 gauge (Lake Eckarfjärden) for improved clarity.*

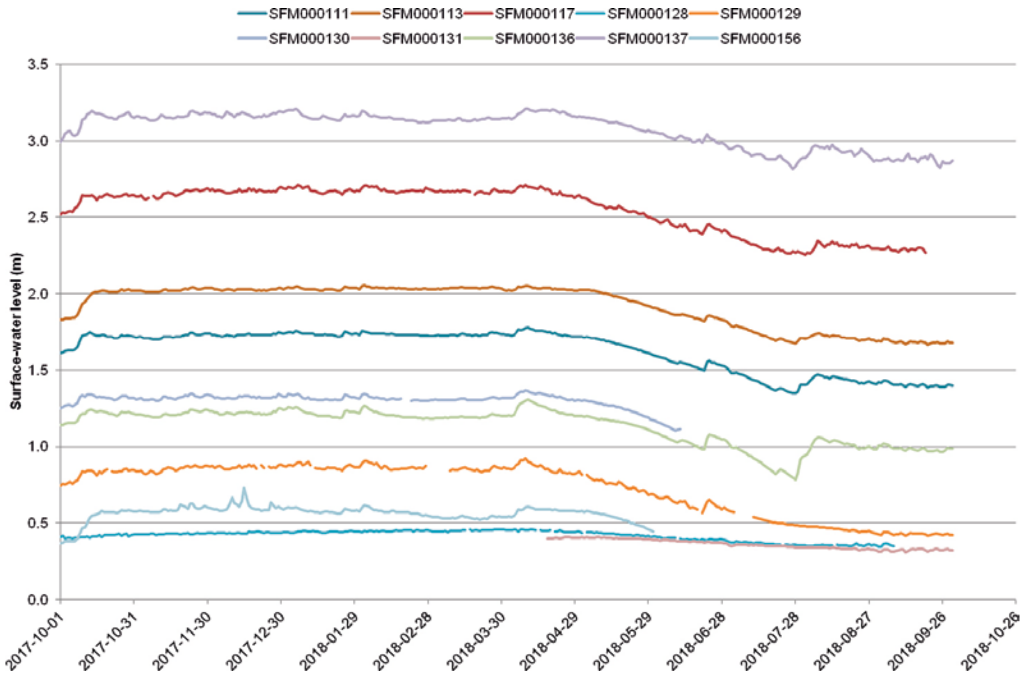


Figure 5-4. *Daily average surface-water levels (m, RH 2000) in natural and constructed ponds (no data are available for surface-water level gauge SFM000115 for the period of this report).*

Figure 5-5 plots daily average surface-water level in Lake Eckarfjärden (PFM000127) and stream discharge at gauging station PFM002668, located downstream from the lake. This figure shows a high degree of co-variation between surface-water levels and stream discharge, with rising surface-water level and stream discharge during autumn, early winter and early spring, and decreasing level and discharge during late spring and summer. The influence of precipitation events and periods on surface-water levels and stream discharge is illustrated in Figure 5-6 and Figure 5-7. Specifically, the figure shows that surface-water levels and stream discharge rise during periods of increasing cumulative precipitation sums. Note that precipitation data are missing for the period May 17 – June 29, 2018.

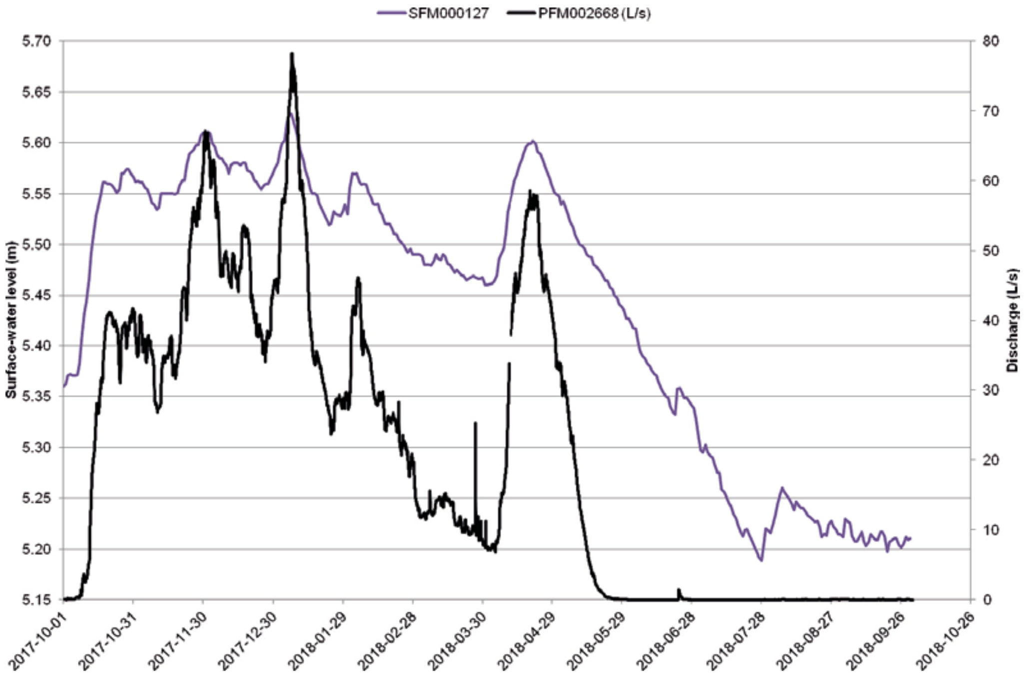


Figure 5-5. *Daily average surface-water level (m, RH 2000) at PFM000127 in Lake Eckarfjärden (upstream from stream-gauging station PFM002668) and discharge (L/s) at PFM002668.*

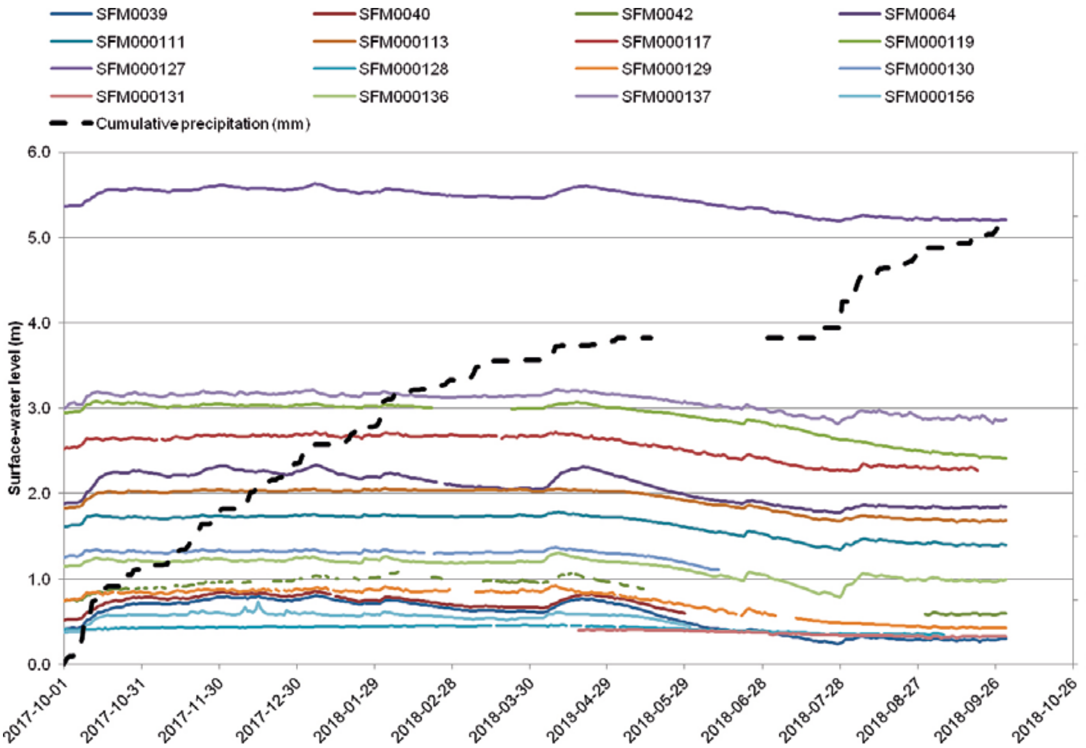
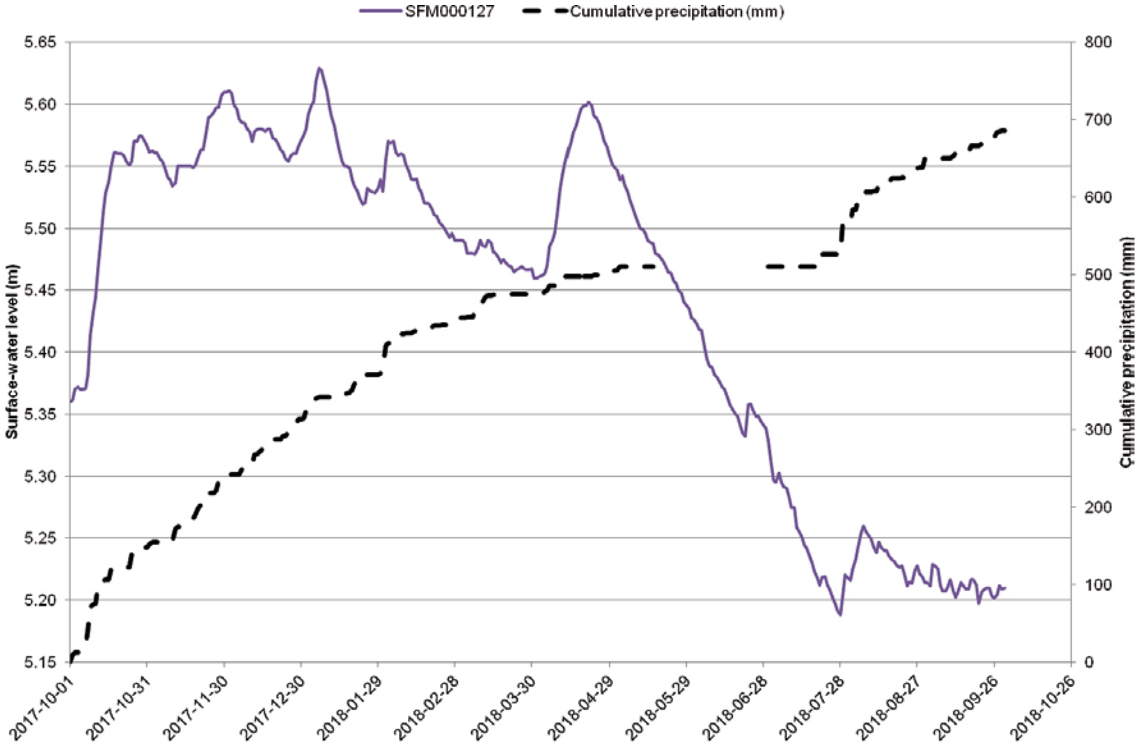


Figure 5-6. *Daily average surface-water levels (m, RH 2000) and cumulative sum of corrected precipitation (mm) at the Labbomasten meteorological station (data are missing for the period May 17–June 29, 2018).*



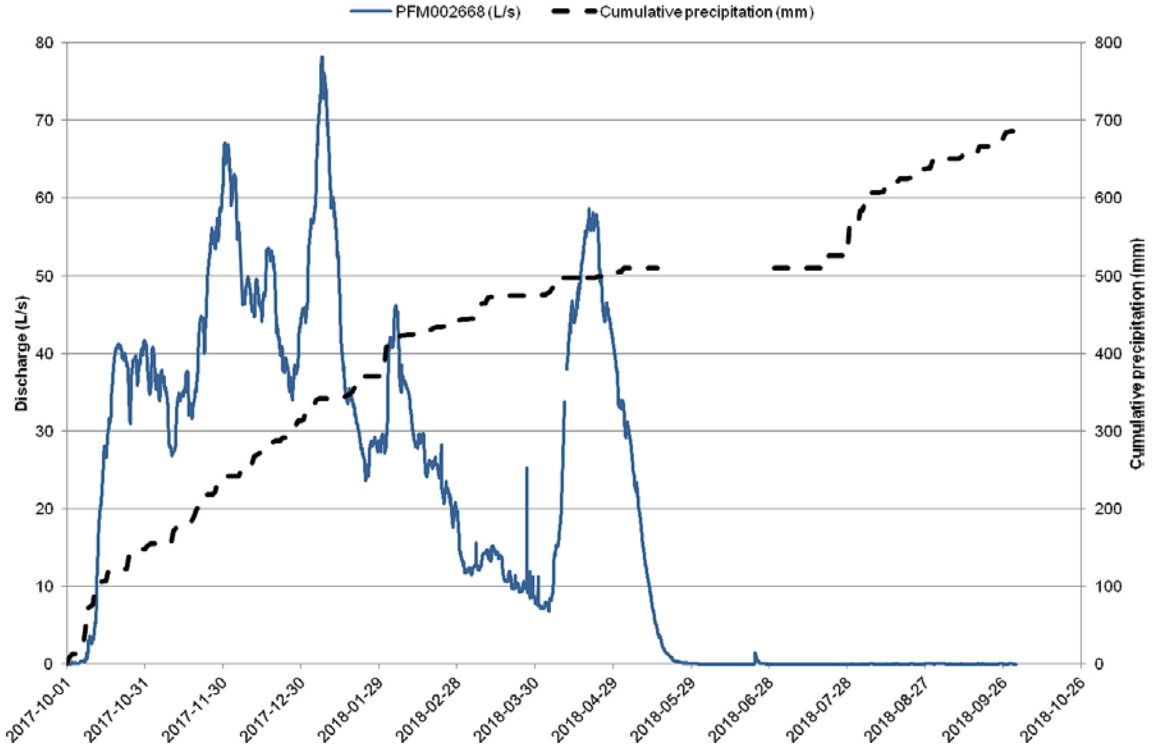


Figure 5-7. *Upper figure: Daily average surface-water level (m, RH 2000) at PFM000127 in Lake Eckarfjärden (upstream from stream-gauging station PFM002668) and cumulative sum of corrected precipitation (mm) at the Labbomasten meteorological station. Bottom figure: Daily average stream discharge (L/s) at gauging station PFM002668 and cumulative sum of corrected precipitation.*

The large influence of ice and snow melt on surface-water levels and stream discharge is shown in Figure 5-8 and Figure 5-9. The figures indicate the ice-covered period in Lake Eckarfjärden (upstream of PFM002668), whereas Figure 5-9 also shows the average snow depth (see Section 5.2.1). For instance, the PFM002668 stream discharge and the surface-water level in Lake Eckarfjärden have a spring peak in the end of the ice- and snow-covered period in the middle of April (Figure 5-9), when precipitation is relatively modest (cf. Figure 5-6). As shown in Figure 5-10, surface-water levels and stream discharge decrease during late spring (after the end of the spring-melt period) and during summer. During this period, evapotranspiration processes become gradually more active, driven by day temperatures of some 10–20 °C during May and June, and around 15–25 °C during July and August.

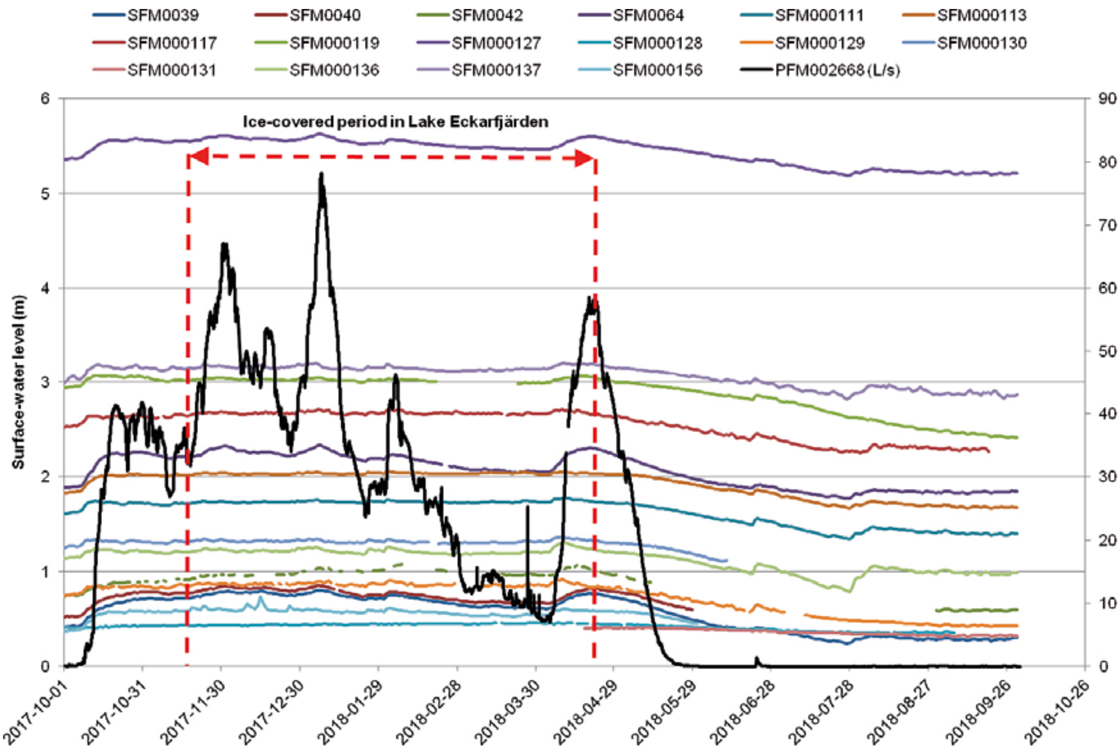


Figure 5-8. *Daily average surface-water levels (m, RH 2000) and discharge at stream-gauging station PFM002668 (L/s). The figure also indicates the ice-covered period in Lake Eckarfjärden (upstream of PFM002668).*

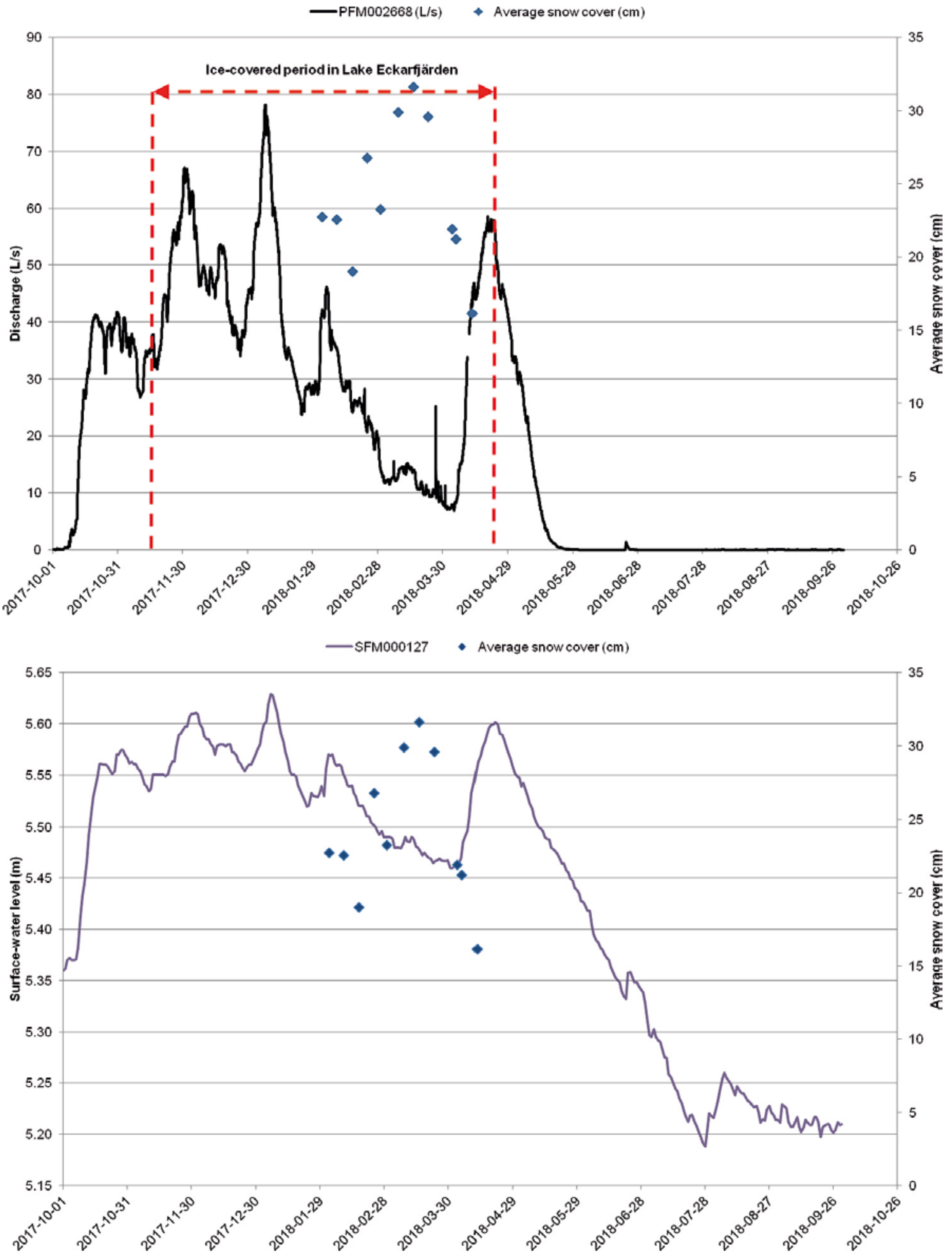
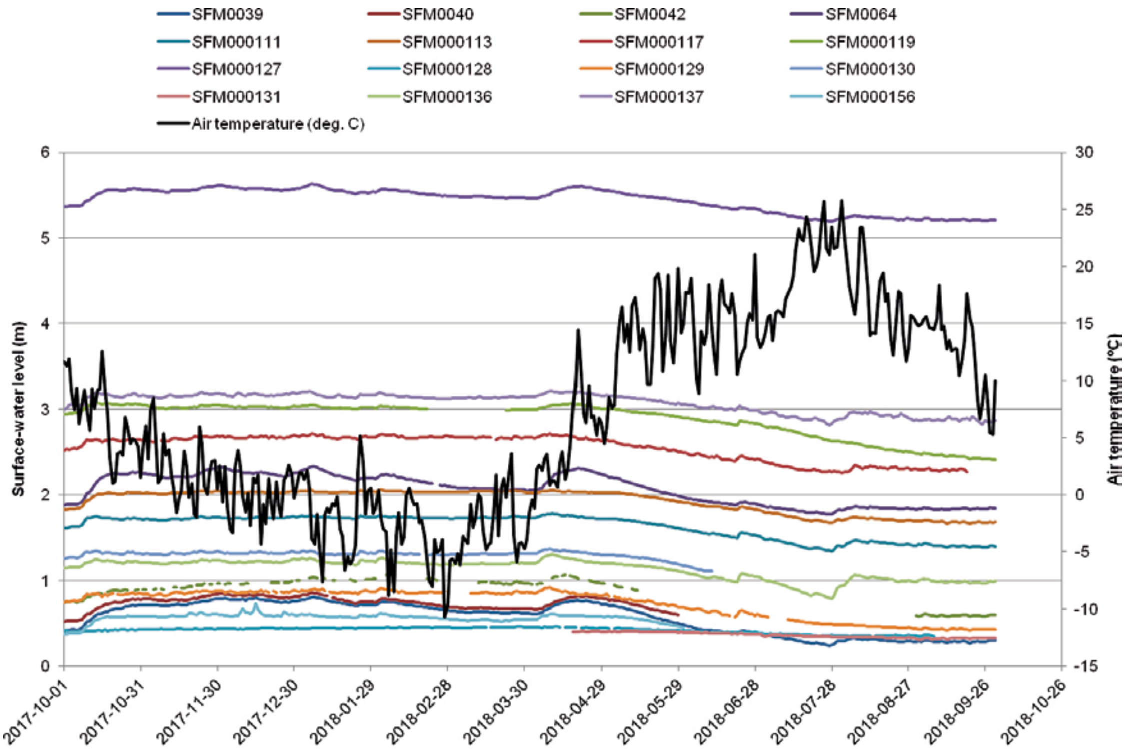


Figure 5-9. *Upper figure: Daily average stream discharge (L/s) at gauging station PFM002668 (downstream from Lake Eckarfjärden), ice-covered period in Lake Eckarfjärden and average snow cover (cm). Bottom figure: Daily average surface-water level (m, RH 2000) at PFM000127 in Lake Eckarfjärden and average snow cover.*



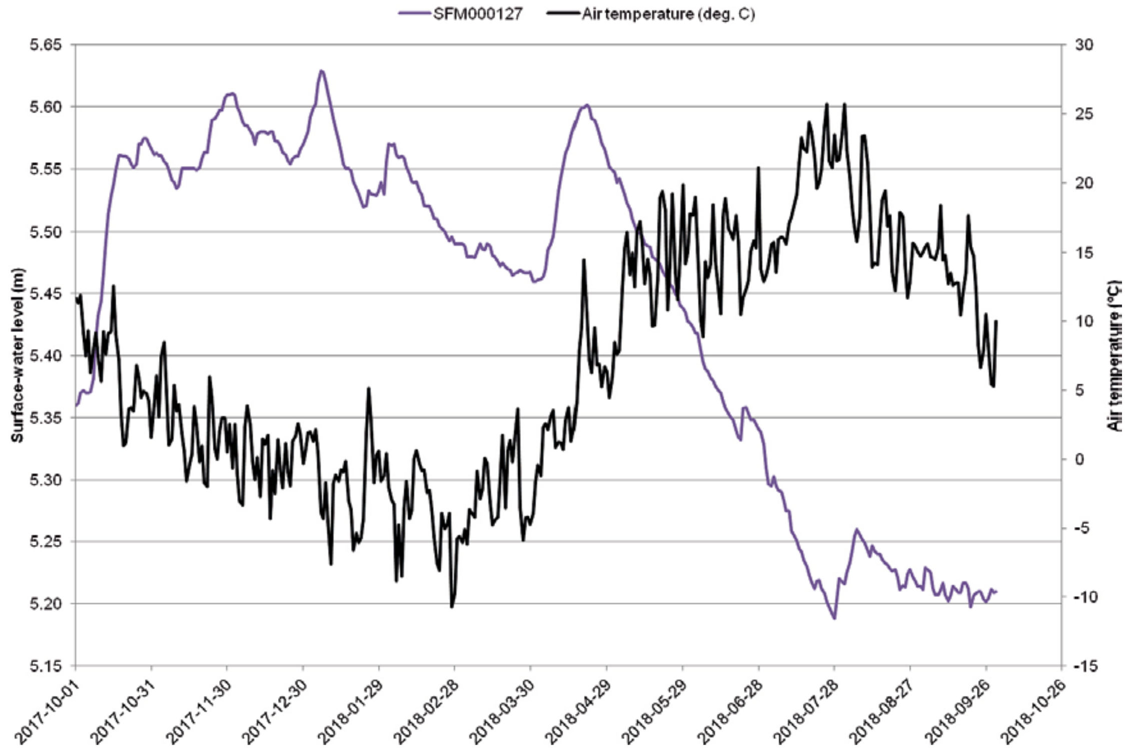


Figure 5-10. *Upper figure: Daily average surface-water levels (m, RH 2000) and daily average air temperature (°C) at the Labbomasten meteorological station. Lower figure: Daily average surface-water level at SFM000127 in Lake Eckarfjärden and daily average air temperature.*

5.4 Evaluation of surface-water temperature monitoring

Automatic water-temperature monitoring was done in natural and constructed ponds during the period April–October 2018 (Borgiel et al. 2019), see Figure 5-11. Similar measurements, in partly different sets of ponds, were conducted during the periods Apr.–Oct. 2016 (Borgiel et al. 2017) and Apr.–Oct. 2017 (Borgiel et al. 2018). For summaries and evaluations of these previous measurements, see Werner (2018b). Measurements and evaluations of water temperatures are part of the background information required to evaluate the suitability of the monitored ponds for pool-frog reproduction from a water-temperature perspective.

The 2018 measurements are summarized in Table 5-2 and Table 5-3. Water temperatures were measured automatically (once per hour) in 15 natural and constructed ponds using temperature sensors with integrated data loggers (Mini-Diver), at a constant depth of 0.05 m below the water surface. As mentioned above, somewhat different sets of ponds have been monitored during the 2016–18 monitoring campaigns (Table 5-2). Specifically, PFM007870–73 (Lake Tjärnpussen, and ponds 12, 15 and 18) were added in the 2017 monitoring campaign, whereas PFM007764 (pond 7), PFM007768 (one location in pond 14) and PFM007769 (pond 16) were not monitored in 2017. In Table 5-3, it is noted that the end of the 2018 monitoring campaign is subsequent to the end of the 2017/2018 hydrological year.

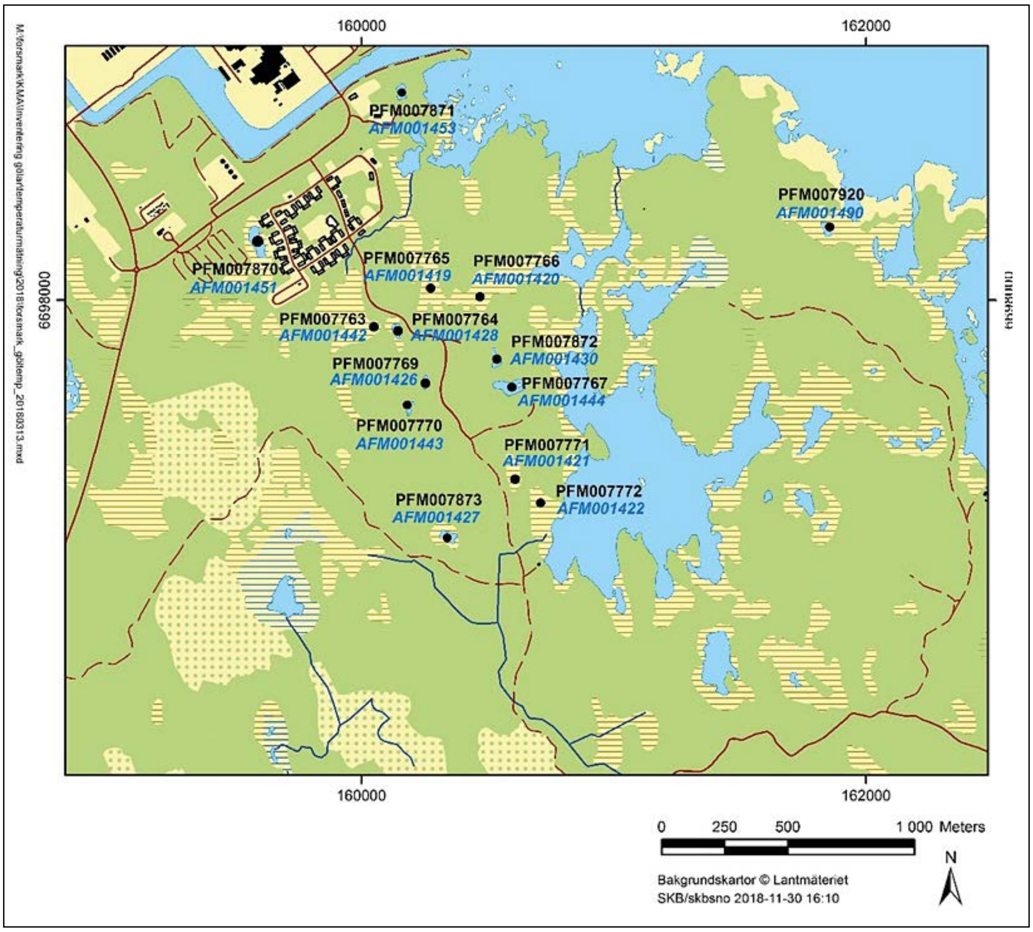


Figure 5-11. Locations of automatic water-temperature measurements during 2018 (Borgiel et al. 2019).

Table 5-2. Automatic water-temperature monitoring in natural and constructed ponds during the period Apr.–Oct. 2018 (Borgiel et al. 2019).

Location id (automatic water-temp. meas.)	Pond id (alias)	Comments
PFM007763	AFM001442 (6b), pond constructed in 2014	Also monitored during 2016 and 2017
PFM007764	AFM001428 (pond 7)	Also monitored during 2016
PFM007765	AFM001419 (11f), pond constructed in 2012	Also monitored during 2016 and 2017
PFM007766	AFM001420 (11g), pond constructed in 2012	As above
PFM007767	AFM001444 (14), natural pond	As above
PFM007769	AFM001426 (16), natural pond	Also monitored during 2016
PFM007770	AFM001443 (17a), pond constructed in 2014	Also monitored during 2016 and 2017
PFM007771	AFM001421 (19a), pond constructed in 2012	As above
PFM007772	AFM001422 (66a), pond constructed in 2012	As above
PFM007870	AFM001451 (8), natural Lake Tjärnpussen	Also monitored during 2017
PFM007871	AFM001453 (12), natural pond	As above
PFM007872	AFM001430 (15), natural pond	As above
PFM007873	AFM001427 (18), natural pond	As above
PFM007920	AFM001490 (318), natural pond	Not monitored before

Table 5-3. Summary of results of automatic water-temperature measurements in ponds. Av. = average, std. dev. = standard deviation, time frac. = fraction of time, deg. hrs. = degree hours (temperatures above 19 °C), r = correlation coefficient (referring to the Labbomasten meteorological station). *Constructed pond.

Location id (PFM00-) (pond id)	Data period	Temp. (°C)				Temp. > 19 °C	
		Av.	Max	Min	Std. dev.	Time frac., full data period	Deg. hrs. (°C·h), May 15 – Sep. 30
7763 (6b*)	2018-04-20– 2018-10-06	18.25	31.75	4.80	5.35	0.47	6 838
7764 (7)	As above	18.19	34.41	2.25	5.78	0.46	7 536
7765 (11f*)	2018-04-20– 2018-05-25, 2018-06-12– 2018-10-06	17.92	33.42	1.68	5.90	0.44	6 549
7766 (11g*)	2018-04-20– 2018-10-06	18.26	32.90	2.84	5.69	0.47	7 396
7767 (14)	As above	19.26	34.46	1.92	6.05	0.56	10 029
7769 (16)	As above	17.29	33.78	0.56	5.74	0.39	5 823
7770 (17a*)	As above	18.92	33.42	5.82	5.63	0.51	8 558
7771 (19a*)	As above	18.23	34.16	2.66	5.76	0.46	7 423
7772 (66a*)	As above	18.62	32.29	5.51	5.65	0.50	8 131
7870 (8)	As above	18.45	30.21	0.56	5.56	0.51	7 392
7871 (12)	As above	18.30	32.62	6.11	5.25	0.47	6 836
7872 (15)	As above	17.98	36.43	2.79	5.84	0.44	7 405
7873 (18)	As above	18.75	33.66	2.42	5.85	0.50	8 654
7920 (318)	As above	18.61	31.60	5.97	5.38	0.51	7 662

According to Table 5-3, the ponds demonstrate rather similar temperature characteristics in terms of overall average temperatures (c 17–19 °C), maximum temperatures (c 30–34 °C) and standard deviations (c 5.2–6.1°C), whereas there is a rather broad range in terms of minimum temperatures (c 0.5–6 °C). During the 2018 period, the average water temperature was highest in the natural pond AFM001444 (pond 14) and lowest in the natural pond AFM001426 (pond 16), see Figure 5-12. It is noted that the constructed ponds demonstrate average water temperatures with no marked deviations from those of the natural ponds. The fraction of time with water temperatures above 19 °C (threshold for pool-frog egg/tadpole development) and the cumulative degree-hours sum (degrees above 19 °C times time in hours, specifically for the period May 15 – Sep. 30; see Figure 5-13) demonstrate some inter-pond variations (c 45–55 % and c 5 800–10 000 °C·h , respectively).

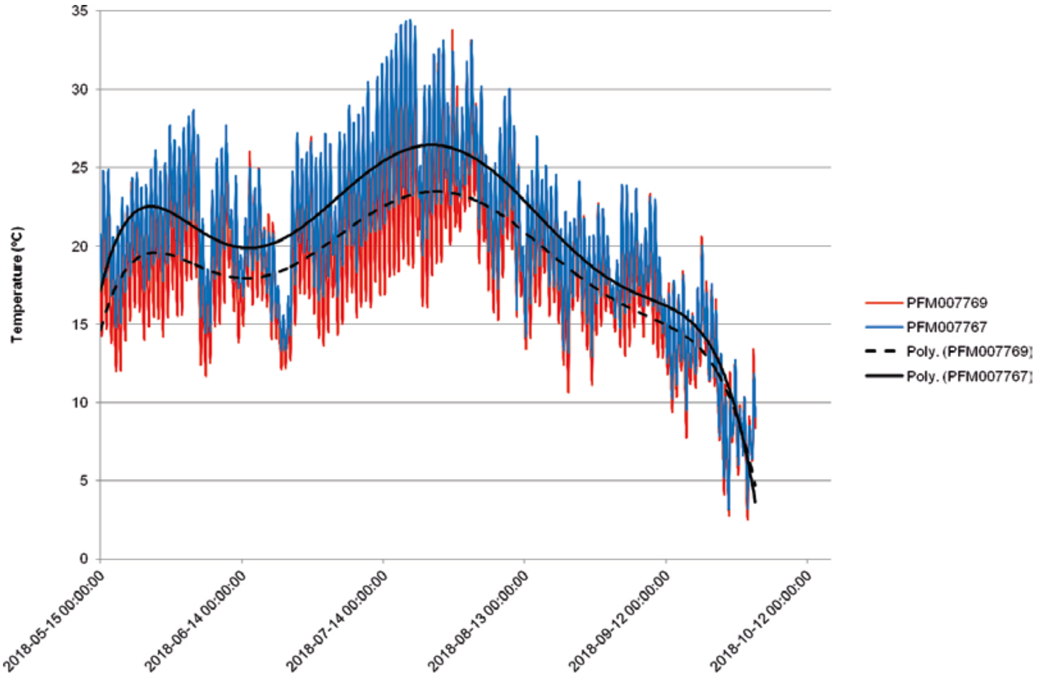


__Figure 5-12.__ Water temperatures (°C) measured in pond 14 (PFM007767) and pond 16 (PFM007769) during the period May 15–Sep. 30, 2018. In order to visualize temperature variations and differences during the summer season, a polynomial (of degree 6) is fitted to each high-resolved dataset.

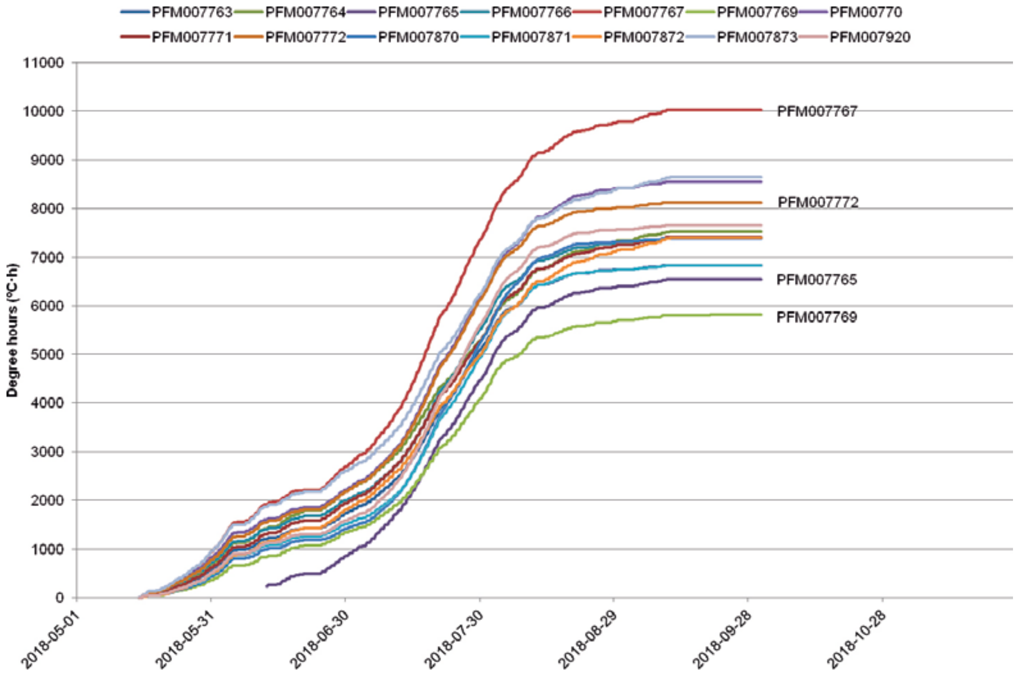


__Figure 5-13.__ Cumulative degree-hours sum (degrees above 19 °C times time in hours) for automatically measured water temperatures during the period May 15–Sep. 30, 2018.

The summer of 2018 was long and warm, with an average air temperature during the period June–August of 17.3 °C. In comparison, the corresponding average for the period June–August 2017 was 14.9 °C. Accordingly, water temperatures were higher during the 2018 measurement period than during the corresponding 2016 and 2017 measurement periods. For example, the cumulative degree-hours sum (degrees above 19 °C, threshold for pool-frog egg/tadpole development, times time in hours) for the period May 15 – Sep. 30, 2018 was c 10 000 °C·h in the warmest pond (pond AFM001444/14).

During the corresponding periods in 2016 and 2017, cumulative degree-hours sums were c 5 700 and 4 700 °C·h, respectively, in that pond. Among the ponds in which measurements took place also in 2016 and 2017, one natural pond (AFM001444/14) and one constructed pond (AFM001143/17a) were the warmest.

5.5 Monitoring of soil moisture and soil temperature

During the summer of 2017 sensors for soil moisture and soil temperature monitoring were installed in regolith at different depths below the ground surface at four locations (Figure 5-14 and Table 5-4), representing different regolith and evapotranspiration conditions (Hargelius et al. 2018, Werner 2018b): (1) Wetland (PFM007874–7875), (2) coniferous forest (PFM007876–7877), (3) coniferous forest on lime-rich soil (PFM007878–7879, and (4) open land (PFM007880–7881). The installed sensors (CS650 Soil Water Content Reflectometer, Onset Computer Corp.) measure volumetric soil-water content (water volume per unit volume of soil; Bilskie 2001) based on TDR (time domain reflectometry) technique. The sensors also measure EC and temperature, and they are connected to CR300 data loggers (Campbell Scientific Inc.).

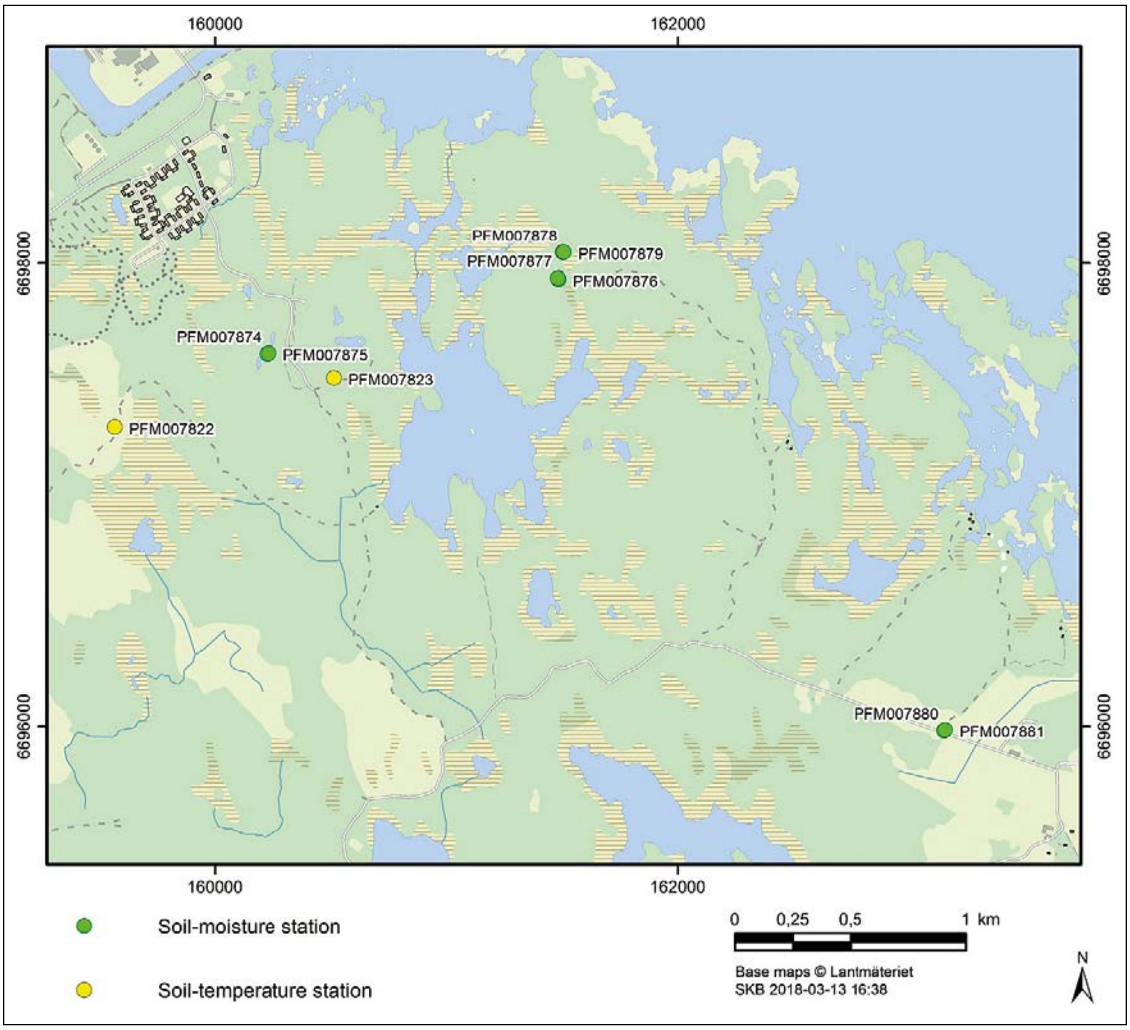


Figure 5-14. Locations of sensors for soil-moisture (TDR technique; these sensors also measure soil temperature and EC) and soil-temperature monitoring.

In addition, during the summer of 2017 sensors (TMC6-HD and TMC20-HD, Onset Computer Corp.) for soil-temperature monitoring were installed in regolith at different depths below the ground surface at two locations, see Figure 5-14: (1) A clay area in the vicinity of a wetland (PFM007822; 8 sensors 0–140 cm below ground), and (2) a till-dominated area (PFM007823; 8 sensors 0–200 cm below ground). The sensors are connected to U12-008 data loggers (Onset Computer Corp.).

Table 5-4. Installed soil moisture and temperature probes (Hargelius et al. 2018).

Location/station id	Regolith stratigraphy	Installation depth (m b gs)	Regolith type at installation depth
Wetland (station 4415)			
PFM007874	0–0.25 Humus	0.15	Humus
	0.25–0.65 Till	0.25	Till
	0.65– Clay	0.60	Clay
		0.75	Clay
PFM007875	0–0.15 Humus	0.15	Humus
	0.15–0.50 Clay	0.30	Cay
	0.50– Silty till	0.45	Clay
		0.65	Silty till
Coniferous forest (station 4413)			
PFM007876	0–0.15 Humus	0.07	Humus
	0.15– Sandy till	0.10	Humus
		0.25	Sandy till
		0.45	Sandy till
PFM007877	0–0.15 Humus	0.20	Sandy till
	0.15– Sandy till	0.35	Sandy till
		0.50	Sandy till
		0.80	Sandy till
Coniferous forest on lime-rich soil (station 4414)			
PFM007878	0–0.15 Humus	0.10	Humus
	0.15–0.40 Sandy-silty till	0.42	Sandy-silty-gravelly-clayey till
	0.40– Gravelly-sandy-silty-clayey till	0.70	Clayey-sandy-silty-gravelly till
		0.85	Clayey-sandy-silty-gravelly till
PFM007879	0–0.20 Humus	0.25	Humus
	0.20– Gravelly-sandy-silty-clayey till	0.40	Sandy-silty-gravelly-clayey till
		0.55	Clayey-sandy-silty-gravelly till
		0.75	Clayey-sandy-silty-gravelly till
Open land (station 4416)			
PFM007880	0–0.10 Humus	0.10	Humus
	0.10–0.40 Sandy-gravelly till	0.40	Sandy-gravelly till
	0.40– Silty-clayey-gravelly till	0.70	Silty-clayey-gravelly till
		0.90	Silty-clayey-gravelly till
PFM007881	0–0.10 Humus	0.05	Humus
	0.10–0.30 Sandy-gravelly till	0.50	Silty-clayey-gravelly till
	0.30– Silty-clayey-gravelly till	0.70	Silty-clayey-gravelly till
		1.00	Silty-clayey-gravelly till

Appendix 7 presents soil-moisture and soil-temperature data retrieved so far, representing an initial test period, and some preliminary interpretations of the data. Table 5-5 summarizes soil-temperature data (soil-temperature sensors; Sicada activity type GT063 Temperature at different depth in the ground). Moreover, Table 5-6 provides a summary of soil-moisture and soil-temperature data (TDR sensors; Sicada activity type HY008 Soil moisture content (TDR)).

Table 5-5. Summary of results of soil-temperature monitoring 2016–2018 (temperatures in °C). The measurement frequency is 3 hours.

Location id	Depth (m b gs)	Monitoring period	Average	St. dev.
PFM007822	0.00	2017-07-14–2018-11-13	8.97	9.10
	0.10	2016-11-14–2018-11-13	5.55	4.86
	0.20	As above	5.72	4.20
	0.35	As above	5.80	3.72
	0.50	As above	5.89	3.33
	0.80	As above	5.88	2.67
	1.10	As above	6.01	2.24
	1.40	As above	5.99	1.98
PFM007823	0.00	2017-07-14–2018-11-13	8.97	9.10
	0.20	As above	9.07	6.68
	0.40	As above	8.97	5.77
	0.75	As above	8.78	5.09
	1.00	As above	8.69	4.69
	1.25	As above	8.59	4.35
	1.50	As above	8.44	4.03
	2.00	As above	8.23	3.46

Table 5-6. Summary of results of soil moisture- and temperature monitoring 2017–2018. Freq. = measurement frequency, SWC = soil water content. Note that there are coherent data gaps during the period August–November 2017.

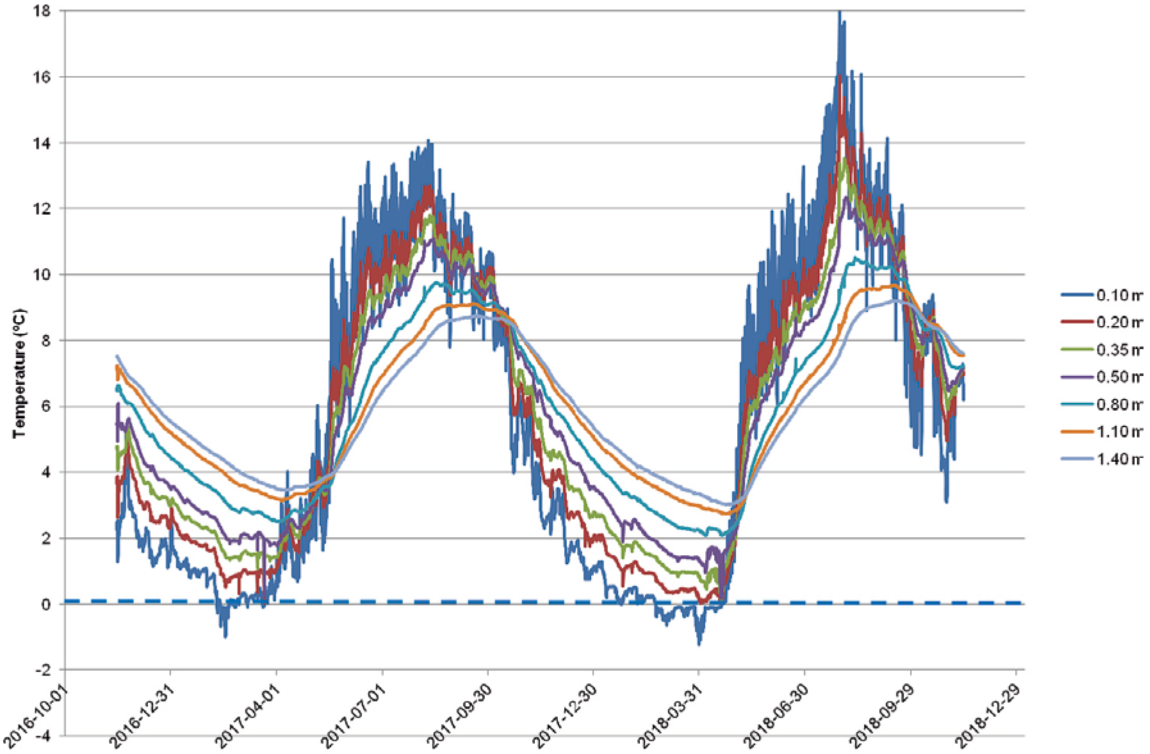
Location id	Monitoring period	Freq.	Depth (m b gs)	Average		St. dev.	
				Temp. (°C)	SWC (%)	Temp. (°C)	SWC (%)
PFM007874	2017-06-19–2018-11-12	10 mins	0.15	7.92	40.82	4.57	7.72
			0.25	7.74	9.20	4.06	2.60
			0.60	7.42	44.58	3.57	5.67
			0.75	7.44	47.43	3.38	2.54
PFM007875	2017-06-19–2018-11-12	10 mins	0.15	8.18	44.78	4.69	17.70
			0.30	7.90	44.91	4.18	3.57
			0.45	7.66	48.60	3.81	2.13
			0.65	7.49	52.21	3.48	0.29
PFM007876	2017-06-19–2018-11-12	1 h	0.07	7.67	18.86	4.65	15.65
			0.10	7.59	17.34	4.44	15.81
			0.25	7.39	16.39	3.99	17.52
			0.45	7.23	23.89	3.68	12.29
PFM007877	2017-06-19–2018-11-12	1 h	0.20	7.73	9.79	5.04	7.39
			0.35	7.45	18.97	4.40	13.23
			0.50	7.41	23.03	4.24	14.86
			0.80	7.23	17.59	3.80	6.29
PFM007878	2017-06-21–2018-11-12	1 h	0.10	7.93	12.73	4.64	7.01
			0.42	7.62	19.59	3.67	3.86
			0.70	7.49	20.51	3.31	4.71
			0.85	7.43	24.55	3.29	0.68

Location id	Monitoring period	Freq.	Depth (m b gs)	Average		St. dev.	
				Temp. (°C)	SWC (%)	Temp. (°C)	SWC (%)
PFM007879	2017-06-21–2018-11-12	1 h	0.25	7.87	14.98	4.36	8.73
			0.40	7.71	23.73	4.03	7.14
			0.55	7.58	26.46	3.76	14.04
			0.75	7.56	23.99	3.54	0.66
PFM007880	2017-07-04–2018-11-12	10 mins	0.10	9.63	20.97	7.64	11.68
			0.40	9.12	16.67	6.45	9.31
			0.70	8.73	24.46	5.45	5.23
			0.90	8.56	23.92	5.16	4.65
PFM007881	2017-07-04–2018-11-12	10 mins	0.05	9.60	23.13	7.58	12.16
			0.50	8.74	16.79	5.82	5.64
			0.70	8.48	18.75	5.23	4.24
			1.00	8.34	21.38	4.81	4.19

As exemplified in Figure 5-15 to Figure 5-17 (cf. Appendix 7), measured soil temperatures demonstrate expected seasonal variations, with increasing temperatures during spring and decreasing temperatures during autumn. In addition, heating and cooling in response to seasonal air-temperature variations are faster close to the ground surface than at depth (Figure 5-16). In relation to near-surface soil temperatures, soil temperatures at depth show a time lag in response to seasonal air-temperature variations. Moreover, vertical soil-temperature gradients switch direction during the year. From autumn (say, end of September) to late spring (say, end of March) soil temperatures at depth are higher than near-surface temperatures (the temperature gradient is directed upwards). On the contrary, the temperature gradient is directed downwards during the approximate period April–September (near-surface temperatures are higher than temperatures at depth).

According to soil-temperature data, ground frost (soil temperatures equal to or below 0 °C) at the monitored locations was modest during the 2017/2018 winter season. Specifically, at four of the locations (PFM007822–23 and PFM007880–81) ground frost penetrated slightly below ground surface (depth 0.05–0.20 m) from the beginning of January (from the beginning of March at PFM007822) to the beginning or middle of April 2018. At PFM007823, PFM007880 and PFM007881, the lowest measured soil temperatures during the 2017/2018 winter season were close to but not quite 0 °C.

Near-surface soil temperatures demonstrate large temporal variations in response to short-term air-temperature variations, whereas soil temperatures at depth are more stable. As shown in Appendix 7, the same phenomenon is observed in terms of soil moisture, with generally larger temporal moisture variability close to the ground surface in response to short-term wetting (precipitation and snow melt) and drying (evapotranspiration) processes. At the TDR stations PFM007880 and -7881, the highest soil-water contents close to the ground surface are associated with soil-water temperatures slightly above 0 °C, likely attributed so melting of snow and ice. At the same time, the lowest soil-water temperatures are close to but not quite 0 °C (see above). This may be due to the so called zero-curtain effect (e.g. Kelley and Weaver 1969), which implies that release of latent heat slows down the phase transition from water to ice when air temperatures falls below zero.



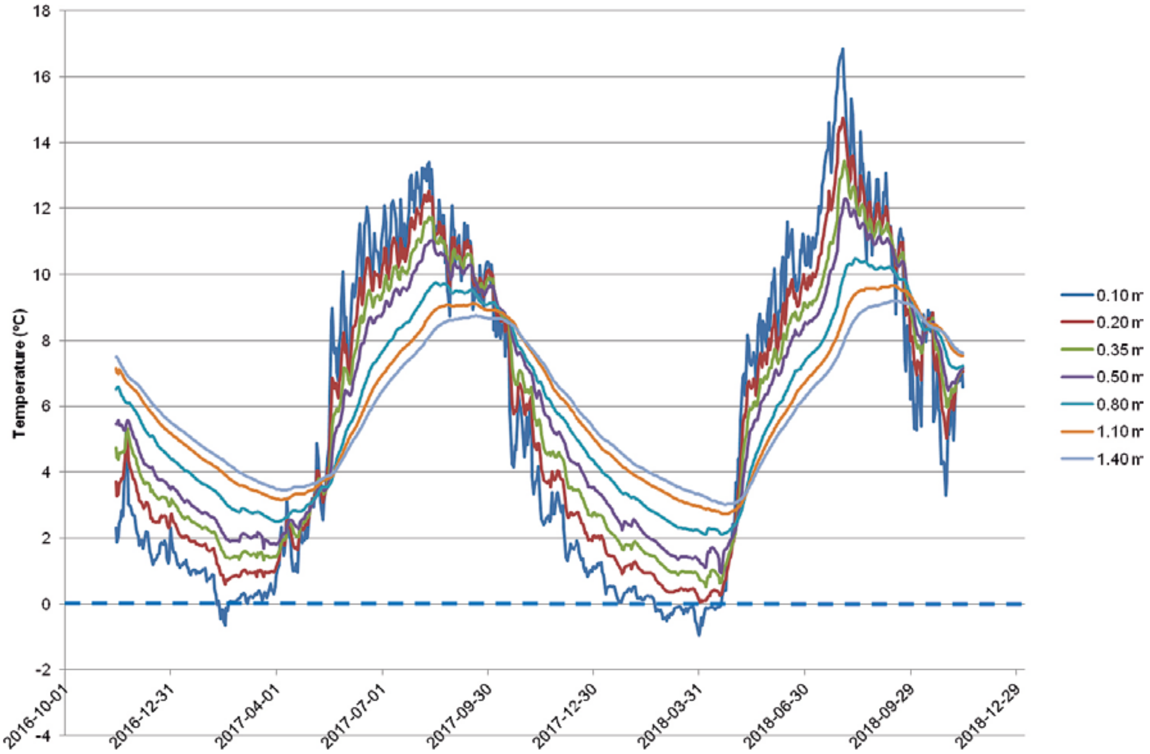


Figure 5-15. *Soil temperature (°C) at different depths below ground in PFM07822. Upper plot: High-resolved data (measurement interval 3 hours). Lower plot: Daily averages. 0 °C is marked with a dashed line.*

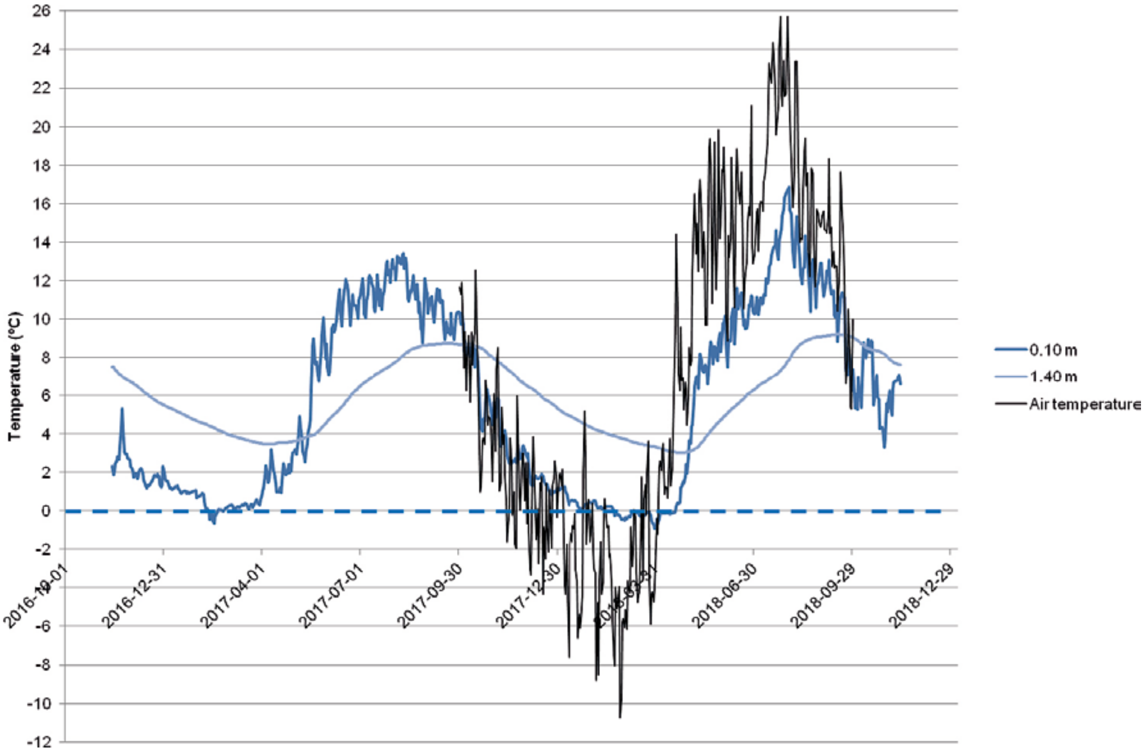


Figure 5-16. *Daily average soil temperatures (°C) at depths 0.10 and 1.40 m below ground surface at PFM07822. 0 °C is marked with a dashed line. For reference, the plot also shows daily average air temperature at the Labbomasten meteorological station (PFM006281) during the 2017/2018 hydrological year.*

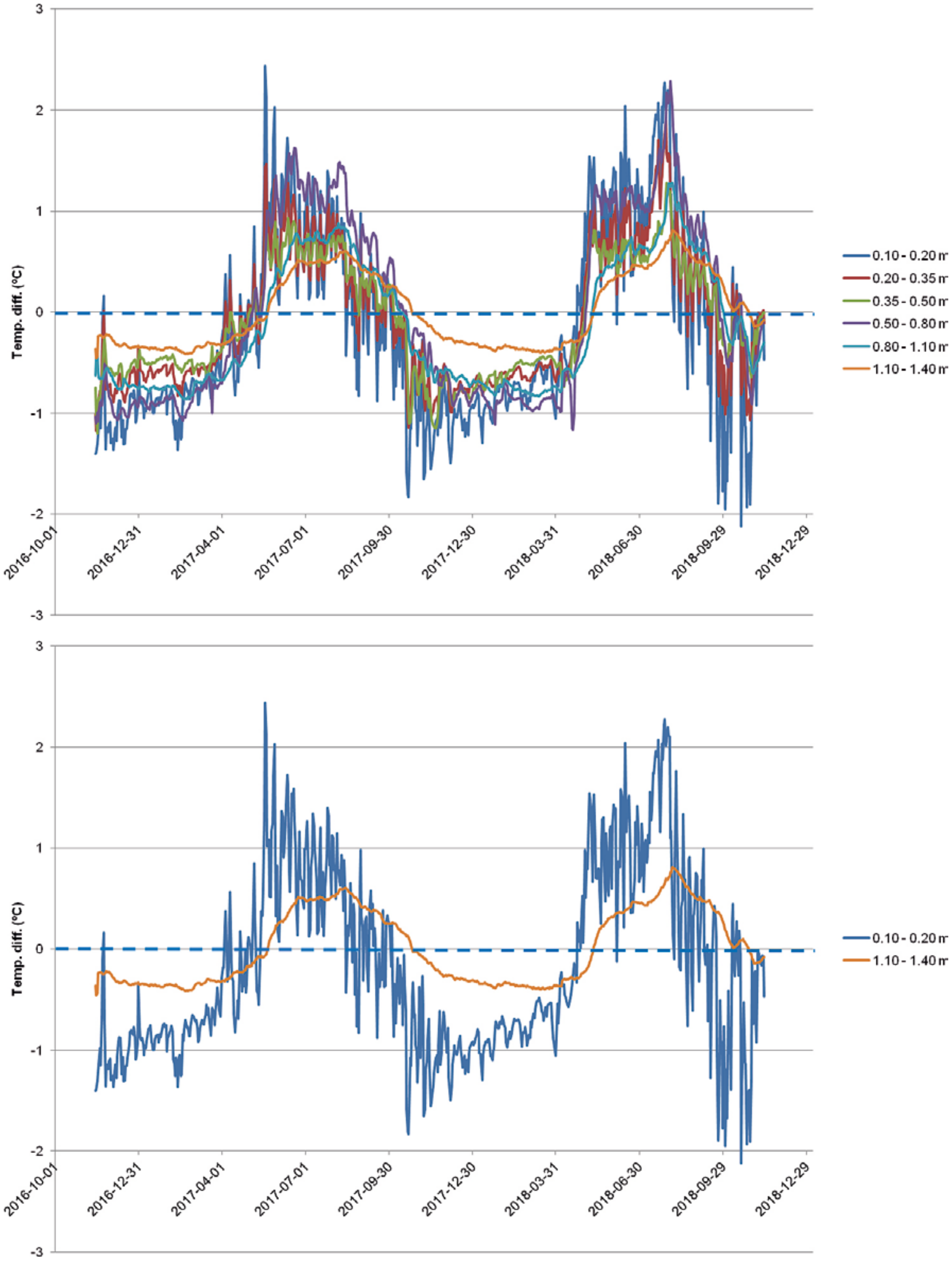


Figure 5-17. *Daily average soil-temperature differences (°C) between adjacent measurement depths below ground in PFM07822. Upper plot: All depths. Lower plot: Top and bottom measurement depths. 0 °C is marked with a dashed line.*

References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications.
SKBdoc documents will be submitted upon request to document@skb.se.

Berglund S, Lindborg T (eds), 2017. Monitoring Forsmark – evaluation and recommendations for programme update. SKB TR-15-01, Svensk Kärnbränslehantering AB.

Bergqvist N, 2014a. Kontrollmätning Forsmark VP3 2013-12-16. SKBdoc 1445903 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Bergqvist N, 2014b. Kontrollmätning Forsmark VP3 2013-05-03. SKBdoc 1445923 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Bergqvist N, 2014c. Rapport från flödesmätning av mätrännor vecka 17 2014. SKBdoc 1445896 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Bergqvist N, 2018. Byte mätränna vid mätstation PFM002667 augusti 2018. SKBdoc 1699158 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Bergström S, 1993. Sveriges hydrologi – grundläggande hydrologiska förhållanden. Norrköping: SMHI. (In Swedish.)

Bilskie J, 2001. Soil water status: content and potential. App. Note 2S-I, Campbell Scientific, Inc., Logan, UT.

Borgiel M, Wallin A, Qvarfordt S, 2017. Mätning av ytvattentemperatur i gölar i Forsmark, 2016. SKB P-17-01, Svensk Kärnbränslehantering AB. (In Swedish.)

Borgiel M, Qvarfordt S, Wallin M, 2018. Mätning av ytvattentemperatur i gölar i Forsmark, 2017. SKB P-17-43, Svensk Kärnbränslehantering AB. (In Swedish.)

Borgiel M, Qvarfordt S, Wallin M, 2019. Mätning av ytvattentemperatur i gölar i Forsmark, 2018. SKB P-19-01, Svensk Kärnbränslehantering AB. (In Swedish.)

Brunberg A-K, Carlsson T, Blomqvist P, Brydsten L, Strömgren M, 2004. Forsmark site investigation. Identification of catchments, lake-related drainage parameters and lake habitats. Revised December 2007. SKB P-04-25, Svensk Kärnbränslehantering AB.

Clemmens A J, Wahl T L, Bos M G, Replogle J A, 2001. Water measurement with flumes and weirs. ILRI Publ. 58, International Institute for Land Reclamation and Improvement, The Netherlands.

Edvardson K, 2012. SKB avvägning jordrör/bäckrännor. Uppföljande avvägning av 14 jordrör, nybestämning av åtta jordrör samt lägen på sju bäckrännor. SWECO Infrastructure AB. SKBdoc 1395324 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Edvardson K, 2015. SKB höjdkontroll GV-rör, bäckrännor. Uppföljande höjdbestämning av 28 jordrör och sju bäckrännor, nybestämning av sju jordrör samt inmätning av strandlinjen i två nya gölar. SWECO Civil AB. SKBdoc 1444516 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Edvardson K, 2016. SKB höjdkontroll GV-rör, bäckrännor. Uppföljande höjdbestämning av 30 grundvattenrör och fem bäckrännor. SWECO Civil AB. SKBdoc 1593195 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Hargelius M, Orbe R, Petrone J, 2018. Installation och och drift av fyra stationer för mätning av markvattenhalt i Forsmark. SKBdoc 1582426 ver 2.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Hermansson N, 2017. Kontrollerande höjdbestämning av jordrör och bäckrännor i Forsmark 2017. SKBdoc 1601610 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Hermansson N, 2019. Kontrollerande höjdbestämning av jordrör och bäckrännor i Forsmark 2018. SKBdoc 1858639 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Johansson P-O, 2005. Forsmark site investigation. Installation of brook discharge gauging stations. SKB P-05-154, Svensk Kärnbränslehantering AB.

Johansson P-O, Juston J, 2007. Forsmark site investigation. Monitoring of brook levels, water electrical conductivities, temperatures and discharges from April 2004 until March 2007. Revised May 2010. SKB P-07-135, Svensk Kärnbränslehantering AB.

Johansson P-O, Juston J, 2009. Forsmark site investigation. Monitoring of brook water levels, electrical conductivities, temperatures and discharges from April 2007 until December 2008. SKB P-09-68, Svensk Kärnbränslehantering AB.

Johansson P-O, Juston J, 2011a. Forsmark site investigation. Monitoring of brook water levels, electrical conductivities, temperatures and discharges January–December 2009. SKB P-10-44, Svensk Kärnbränslehantering AB.

Johansson P-O, Juston J, 2011b. Forsmark site investigation. Monitoring of brook water levels, electrical conductivities, temperatures and discharges January–December 2010. SKB P-11-12, Svensk Kärnbränslehantering AB.

Jones J, Björck E, 2018. Meteorological monitoring at the Labbomasten station in Forsmark January–December 2017. SMHI. SKBdoc 1682756 ver 1.0, Svensk Kärnbränslehantering AB.

Jones J, Björck E, 2019. Meteorological monitoring at the Labbomasten station in Forsmark January–December 2018. SMHI. SKBdoc 1863352 ver 1.0, Svensk Kärnbränslehantering AB.

Kelley J J, Weaver D F, 1969. Physical processes at the surface of the arctic tundra. Arctic 22, 425–437.

Kilpatrick F A, Schneider V R, 1983. Use of flumes in measuring discharge. Techniques of Water-Resources Investigations of the United States Geological Survey. Book 3 – Applications of hydraulics. Chapter A14. Washington: USGS.

Moore R D, 2005. Introduction to salt dilution gauging for streamflow measurement. Part III: Slug injection using salt in solution. Streamline Watershed Management Bulletin 8, 1–6.

Ohrzén S, 2016. SKB höjdkontroll GV-rör, bäckrännor. Uppföljande höjdbestämning av 40 grundvattenrör, fyra bäckrännor och en sjötröskel. SWECO Civil AB. SKBdoc 1552488 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Robinson A R, 1966. Water measurement in small irrigation channels using trapezoidal flumes. Transaction of the ASAE 9, 382–388.

Robinson A R, 1968. Trapezoidal flumes for measuring flow in irrigation channels. ARS 41-140, Agricultural Research Service, United States Deptartment of Agriculture.

Ryman M, Strömbeck N, 2016. Luode teknisk delrapport. Redovisning av utförda flödesmätningar i naturliga vattendrag vid SKB's mätstationer utanför Forsmark. Luode Consulting Oy. SKBdoc 1538578 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Ryman M, Strömbeck N, 2018. Luode teknisk rapport. Redovisning av installation av mätutrustning samt utförda flödesmätningar i naturliga vattendrag vid SKB´s mätstationer utanför Forsmark. Luode Consulting Oy. SKBdoc 1858240 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

SKB, 2007. Forsmark site investigation. Programme for long-term observations of geosphere and biosphere after completed site investigations. SKB R-07-34, Svensk Kärnbränslehantering AB.

SWECO, 2014. SKB avvägning jordrör/bäckrännor. Uppföljande mätning av 29 jordrör, lägen på sju bäckrännor samt sju strandlinjer. SWECO Infrastructure AB. SKBdoc 1417299 ver 2.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Wahl T L, Clemmens A J, Replogle J A, Bos M G, 2000. WinFlume – Windows-based software for the design of long-throated measuring flumes. In 4th Decennial National Irrigation Symposium, American Society of Agricultural Engineers, Phoenix, Arizona, 14–16 November 2000.

Wass E, 2018. Snow depth and snow depth measurements and ice cover during the winter 2017/2018. SKBdoc 1686159 ver 1.0, Svensk Kärnbränslehantering AB.

Wass E, 2019. Monitoring Forsmark. Hydro Monitoring Program. Report for October 2017 – September 2018. SKBdoc 1864943 ver 1.0, Svensk Kärnbränslehantering AB.

Werner K, 2014a. Monitoring hydrology in Forsmark 2011–2012. Projekt Kärnbränsleförvaret, Slutförvarsanläggning för använt kärnbränsle. Monitoring of streams: Water level, discharge, electrical conductivity and temperature 2011–2012. SKBdoc 1437594 ver 2.0, Svensk Kärnbränslehantering AB.

Werner K, 2014b. Monitoring hydrology in Forsmark 2013. Monitoring of streams: Water level, discharge, electrical conductivity and temperature 2013. SKBdoc 1449116 ver 1.0, Svensk Kärnbränslehantering AB.

Werner K, 2015a. Monitoring hydrology in Forsmark 2014. Monitoring of streams: Water level, discharge, electrical conductivity and temperature 2014. SKBdoc 1520285 ver 1.0, Svensk Kärnbränslehantering AB.

Werner K, 2015b. Flödesmätningar i bäckar i Forsmark – mätningar med saltutspädningsmetoden 2014-12-09. SKBdoc 1467666 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Werner K, 2017. Monitoring hydrology in Forsmark 2015. Monitoring of streams: Water level, discharge, electrical conductivity and temperature. SKB P-17-27, Svensk Kärnbränslehantering AB.

Werner K, 2018a. Monitoring hydrology in Forsmark. Hydrological year October 1, 2015 – September 30, 2016. Monitoring of streams: Water level, discharge, electrical conductivity and temperature. SKB P-17-29, Svensk Kärnbränslehantering AB.

Werner K, 2018b. Hydrological monitoring in Forsmark – surface waters, ground moisture and ground temperature October 1, 2016 – October 1, 2017. SKB P-17-44, Svensk Kärnbränslehantering AB.

Appendix 1

Tables

Table A1-1 presents flume and observation-well coordinates, whereas Table A1-2 and Table A1-3 show results of levelling of flume-bottom levels and top of casing of observation wells, respectively.

Table A1-1. Flume and observation-well coordinates (Northing and Easting: RT 90 2.5 gon W 0:-15; elevation: RHB 70) used for calculation and adjustment of water levels and calculation of stream discharges (see also Section 3.4.3). Flume and/or well movements are handled by calibration-constant adjustments (cf. Table 3-1). Note that after refurbishment in 2018, the PFM002667 station is levelled in the coordinate system RH 2000 (Hermansson 2019). Elevation in the RHB 70 system is calculated as RH 2000 – 0.185 m.

Id	Northing (m)	Easting (m)	Elevation (m)
PFM005764 (Nov. 27, 2003 – Oct. 1, 2004)			
Small flume			
Top of obs. well	6698745.4	1631660.4	1.701
Flume bottom, upstream edge	6698747.6	1631658.9	0.577
Large flume			
Top of obs. well	6698752.1	1631666.5	1.740
Flume bottom, upstream edge	6698753.1	1631665.1	0.551
PFM005764 (Oct. 5, 2004 – Aug. 25, 2014)			
Small flume			
Top of obs. well	6698745.4	1631660.9	2.190 (orig. levelling; lowered to 2.050 in Sep. 2006, handled by cal.- const. adjustment; Table 3-1)
Flume bottom, upstream edge	6698747.3	1631659.1	0.903
Large flume			
Top of obs. well	6698751.8	1631667.2	2.117
Flume bottom, upstream edge	6698753.0	1631666.0	0.895
PFM005764 (Aug. 26, 2014–)			
Small flume			
Top of obs. well	6698746.5	1631657.3	2.085
Flume bottom, upstream edge	6698747.8	1631656.0	0.924
Large flume			
Top of obs. well	6698754.1	1631666.6	2.131
Flume bottom, upstream edge	6698755.4	1631665.1	0.893
PFM002667 (Oct. 1, 2004 – Aug. 16, 2018)			
Small flume			
Top of obs. well	6698263.0	1631595.5	2.679
Flume bottom, upstream edge	6698264.1	1631593.5	1.502
Large flume			
Top of obs. well	6698270.2	1631598.4	2.721
Flume bottom, upstream edge	6698271.0	1631596.5	1.511
PFM002668			
Top of obs. well	6697474.9	1632066.9	5.482
Flume bottom, upstream edge	6697475.5	1632065.7	4.287

Table A1-1. Continued.

Id	Northing (m)	Easting (m)	Elevation (m)
PFM002669 (Nov. 10, 2003 – Sep. 14, 2015)			
Small flume			
Top of obs. well	6699047.4	1629371.7	6.994 (orig. levelling; reinstalled in Nov. 2007, handled by cal.-const. adjustment; Table 3-1)
Flume bottom, upstream edge	6699046.6	1629371.2	5.852 (orig. levelling; reinstalled in Nov. 2007, handled by cal.-const. adjustment; Table 3-1)
Large flume			
Top of obs. well	6699045.9	1629379.9	6.901 (orig. levelling; reinstalled in Nov. 2007, handled by cal.-const. adjustment; Table 3-1)
Flume bottom, upstream edge	6699043.9	1629379.1	5.843 (orig. levelling; reinstalled in Nov. 2007, handled by cal.-const. adjustment; Table 3-1)
PFM002669 (Sep. 15, 2015–)			
Small flume			
Top of obs. well	6699048.1	1629370.3	6.607
Flume bottom, upstream edge	6699048.9	1629370.6	5.441
Large flume			
Top of obs. well	6699047.3	1629379.5	6.501
Flume bottom, upstream edge	6699045.6	1629378.5	5.431

Table A1-2. Results of the levelling of bottom levels (m) of upstream edges of flumes at time of flume installations (2004) and in 2012–2017. Using the notation of the levelling reports, points B and C refer to each flume-bottom corner (D and B in the 2018 levelling). The flumes at PFM002669 were reinstalled in 2007, and the PFM005764, PFM002669 and PFM002667 stations were refurbished in Aug. 2014, Aug.–Sep. 2015 and Aug. 2018, respectively. The results of the 2013 levelling are somewhat dubious. Note that PFM002667 was not included in the 2016 levelling campaign, and that PFM002668 was not included in the 2016 and 2017 campaigns. The data in the table are not stored in the Sicada database. Dates are given as YYYY-MM-DD.

Gauging station and flume)	Point B (RHB 70)	Point C (RHB 70)	Average (RHB 70)	Level change (m)
PFM005764				
Original levelling (2004-04-30):				
Small flume	0.577	Used for discharge calc. 2003-11-27–2004-10-01		
Large flume	0.551	As above		
Levelling after reconstruction (2004-11-09):				
Small flume	0.903	Station reconstructed in Oct. 2004 Used for discharge calc. 2004-10-05–2014-08-25 and as ref. level for man. meas. in HMS 2004-11-03–2014-08-25 (obs. well ToC was used up to 2004-11-03)		
Large flume	0.895	As above		
2012:				
Small flume	0.911	0.908	0.910	-
Large flume	0.889	0.896	0.893	-
2013:				
Small flume	0.894	0.892	0.893	−0.017 (level change since 2012)
Large flume	0.885	0.890	0.888	−0.004 (as above)
2014:				
Small flume	0.909	0.908	0.909	−0.002 (as above)
Large flume	0.891	0.898	0.895	+0.002 (as above)

Gauging station and flume)	Point B (RHB 70)	Point C (RHB 70)	Average (RHB 70)	Level change (m)
Levelling after reconstruction (2015):				
Small flume	0.924	0.923	0.924	Refurbished Aug. 2014 Used for discharge calc. and as ref. level for man. meas. in HMS 2014-08-26–
Large flume	0.889	0.897	0.893	As above
2016:				
Small flume	0.924	0.923	0.924	0 (level change since refurbishment)
Large flume	0.889	0.896	0.893	0 (as above)
2017:				
Small flume	0.928	0.927	0.928	+0.004 (as above)
Large flume	0.893	0.899	0.896	+0.004 (as above)
PFM002667				
Original levelling (2004-11-09):				
Small flume	1.502	Used for discharge calc. 2004-12-08– and as ref. level for man. meas. in HMS 2004-11-03– (the obs. well ToC was used up to 2004-11-03)		
Large flume	1.511	As above		
2012:				
Small flume	1.565	1.564	1.565	-
Large flume	1.566	1.569	1.568	-
2013:				
Small flume	1.570	1.570	1.570	+0.005 (level change since 2012)
Large flume	1.572	1.576	1.574	+0.006 (as above)
2014:				
Small flume	1.568	1.568	1.568	+0.003 (as above)
Large flume	1.570	1.573	1.572	+0.004 (as above)
2015:				
Small flume	1.566	1.566	1.566	+0.001 (as above)
Large flume	1.567	1.570	1.569	+0.001 (as above)
2017:				
Small flume	1.569	1.568	1.569	+0.004 (as above)
Large flume				+0.004 (as above)
PFM002668				
Original levelling (2004-11-10):				
	4.287	Used for discharge calc. 2004-12-08– and as ref. level for man. meas. in HMS 2004-11-03 (the obs. well ToC was used up to 2004-11-03)		
2012:				
	4.282	4.278	4.280	-
2013:				
	4.286	4.282	4.284	+0.004 (level change since 2012)
2014:				
	4.283	4.279	4.281	+0.001 (as above)
2015:				
	4.282	4.278	4.280	0 (as above)

Table A1-2. Continued.

Gauging station and flume)	Point B (RHB 70)	Point C (RHB 70)	Average (RHB 70)	Level change (m)
PFM002669				
Original levelling (2004-11-10):				
Small flume	5.852	Used for discharge calc. 2004-12-08–2015-09-14 and as reference point in HMS 2004-11-03–2015-09-14 (obs. well before that)		
Large flume	5.843	As above		
2012:				
Small flume	5.438	5.439	5.439	-
Large flume	5.425	5.431	5.428	-
2013:				
Small flume	5.443	5.444	5.444	+0.005 (level change since 2012)
Large flume	5.433	5.440	5.437	+0.008 (as above)
2014:				
Small flume	5.440	5.441	5.441	+0.002 (as above)
Large flume	5.427	5.435	5.431	+0.002 (as above)
Levelling after refurbishment (2016):				
Small flume	5.441	5.441	5.441	Refurbished Aug.–Sep. 2015
Large flume	5.428	5.433	5.431	Used for discharge calc. and as ref. level for man. meas. in HMS 2015-09-15–
2017:				
Small flume	5.442	5.443	5.443	+0.001 (level change since refurbishment)
Large flume				Not levelled

Table A1-3. Results of the levelling of top of casing of observation wells (m) at flumes in 2012–2017. Using the notation of the levelling reports, point I refer to the well ToC (point A in the 2018 levelling). The wells at PFM002669 were reinstalled in 2007, and the PFM005764, PFM002669 and PFM002667 stations were refurbished in Aug. 2014, Aug.–Sep. 2015 and Aug. 2018, respectively. The results of the 2013 levelling and the 2012 levelling of PFM002668 (likely measurement error) are somewhat dubious. Note that PFM002667 was not included in the 2016 levelling campaign, and that PFM002668 was not included in the 2016 and 2017 campaigns. Unless stated otherwise, data are not stored in Sicada. Dates are given as YYYY-MM-DD.

Gauging station and well	Original levelling	Comment on original levelling
	Point I (RHB 70)	Level change since original levelling (m)
PFM005764		
Original levelling (2004-04-30):		
Small flume	1.701 (stored in Sicada)	Used as ref. level for man. meas. in HMS 2003-03-01–2004-10-04
Large flume	1.740	As above
Levelling after reconstruction (2004-11-09):		
Small flume	2.190 (stored in Sicada)	Station reconstructed in Oct. 2004 Used as ref. level for man. meas. in HMS 2004-10-05–2004-11-02 (flume-bottom level is used after 2004-11-02)
Large flume	2.117	As above
Levelling after lowering of well (2006-09-13):		
Small flume	2.050 (stored in Sicada)	Well lowered to eliminate the zero-discharge issue (cf. Table 3-2)
2012:		
Small flume	2.059	-
Large flume	2.141	-

Gauging station and well	**Original levelling**	**Comment on original levelling**
	Point I (RHB 70)	**Level change since original levelling (m)**
2013:		
Small flume	2.064	+0.005 (level change since 2012)
Large flume	2.147	+0.006 (as above)
2014:		
Small flume	2.058	−0.001 (as above)
Large flume	2.144	+0.003 (as above)
Levelling after refurbishment (2015):		
Small flume	2.085 (stored in Sicada)	Station refurbished in Aug. 2014
Large flume	2.131	Station refurbished in Aug. 2014
2016:		
Small flume	2.085	0 (level change since refurbishment)
Large flume	2.132	+0.001 (as above)
2017:		
Small flume		Not levelled
Large flume	2.133	+0.002 (level change since refurbishment)
PFM002667		
Original levelling (2004-11-09):		
Small flume	2.679 (stored in Sicada)	Used as ref. level for man. meas. in HMS 2004-10-01–2004-11-02 (flume-bottom level is used after 2004-11-02)
Large flume	2.721	As above
2012:		
Small flume	2.769	-
Large flume	2.804	-
2013:		
Small flume	2.787	+0.018 (level change since 2012)
Large flume	2.823	+0.019 (as above)
2015:		
Small flume	2.770 (stored in Sicada)	+0.001 (as above)
Large flume	2.804	0 (as above)
2017:		
Small flume		Not levelled
Large flume		Not levelled
PFM002668		
Original levelling (2004-11-10):		
	5.482 (stored in Sicada)	Used as ref. level for man. meas. in HMS 2004-10-01–2004-11-02 (flume-bottom level is used after 2004-11-02)
2012:		
	5.128 (likely measurement error)	-
2013:		
	5.497	-
2015:		
	5.479 (stored in Sicada)	−0.003 (level change since 2012)

Table A1-2. Continued.

Gauging station and well	Original levelling	Comment on original levelling
	Point I (RHB 70)	Level change since original levelling (m)
PFM002669		
Original levelling (2004-11-10):		
Small flume	6.994 (stored in Sicada)	Used as ref. level for man. meas. in HMS 2004-10-01–2004-11-02 (flume-bottom level is used after 2004-11-02)
Large flume	6.901	As above
2012:		
Small flume	6.605 (well reinstalled in 2007)	-
Large flume	6.509 (as above)	-
2013:		
Small flume	6.631	+0.026 (level change since 2012)
Large flume	6.532	+0.023 (as above)
2014:		
Small flume	6.609	+0.004 (as above)
Large flume	6.510	+0.001 (as above)
Levelling after refurbishment (2016):		
Small flume	6.607	Refurbished Aug.–Sep. 2015
Large flume	6.501	Refurbished Aug.–Sep. 2015
2017:		
Small flume		Not levelled
Large flume		Not levelled

Appendix 2

Water level

Figures A2-1 to A2-8 show water level time-series plots for the flumes at gauging stations PFM005764, -2667, -2668 and -2669 for the period September 1, 2017 – September 30, 2018 (water-level data October 1, 2018 and forward were not yet approved at time of this report). The plots also show manually measured water levels (flume-bottom elevation + manually measured water depth), and data periods excluded (SCREEN) as a result of the quality control of the 2017/2018 water-level dataset. Note that water levels for September 2017 are shown for reference only. Figures A2-9 and A2-10 compare water-level time series for the pressure sensor and the water-level bubbler installed in the observation tube at the large flume at gauging station PFM005764.

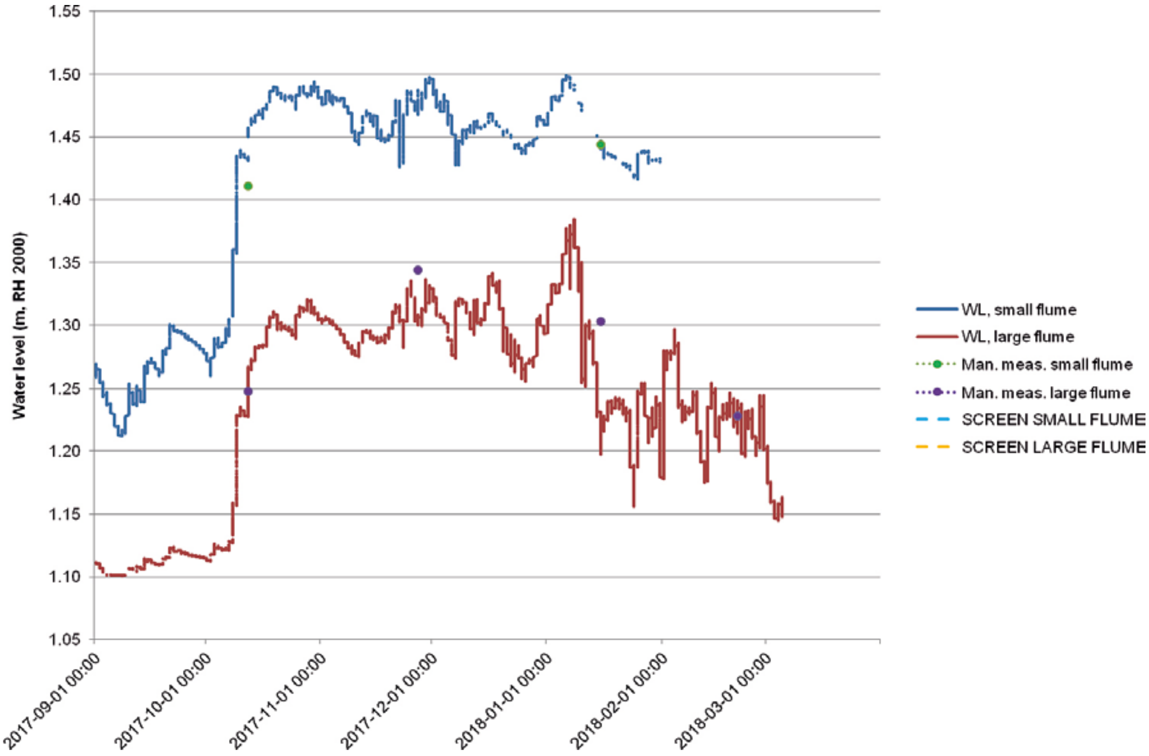


Figure A2-1. Water-level time series for the flumes at gauging station PFM005764 for the period Sep. 1, 2017 – Mar. 31, 2018.

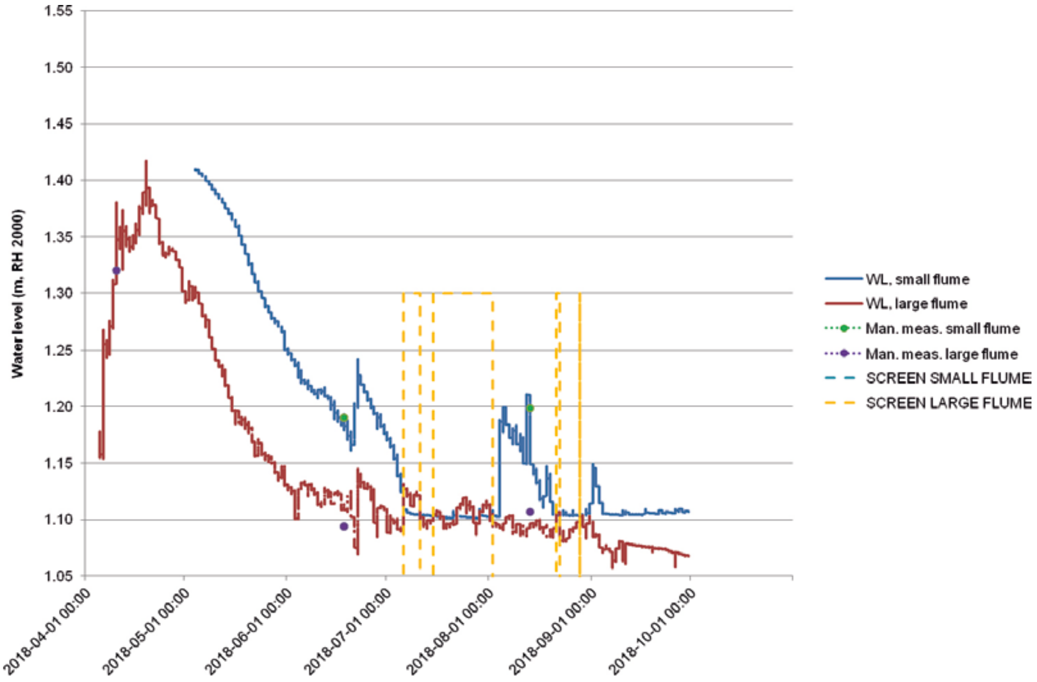


Figure A2-2. *Water-level time series for the flumes at gauging station PFM005764 for the period Apr 1 – Oct. 31, 2018 (data are approved up to Sep. 30, 2018).*

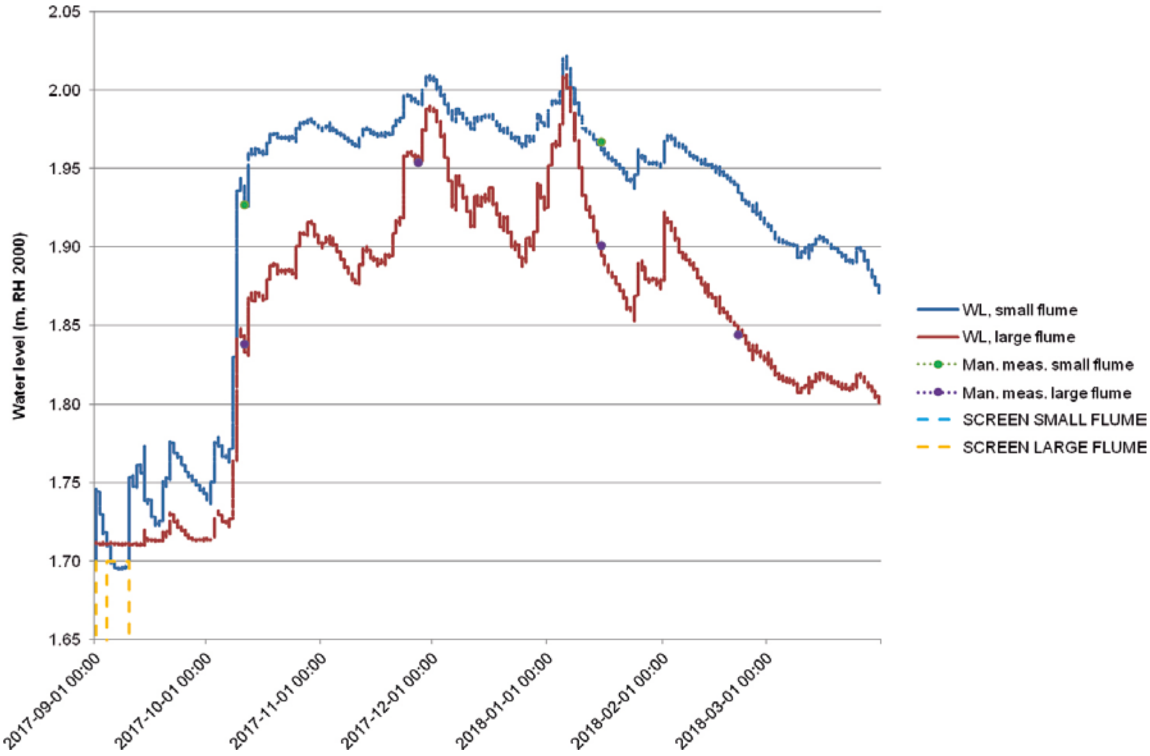


Figure A2-3. *Water-level time series for the flumes at gauging station PFM002667 for the period Sep 1, 2017 – Mar. 31, 2018.*

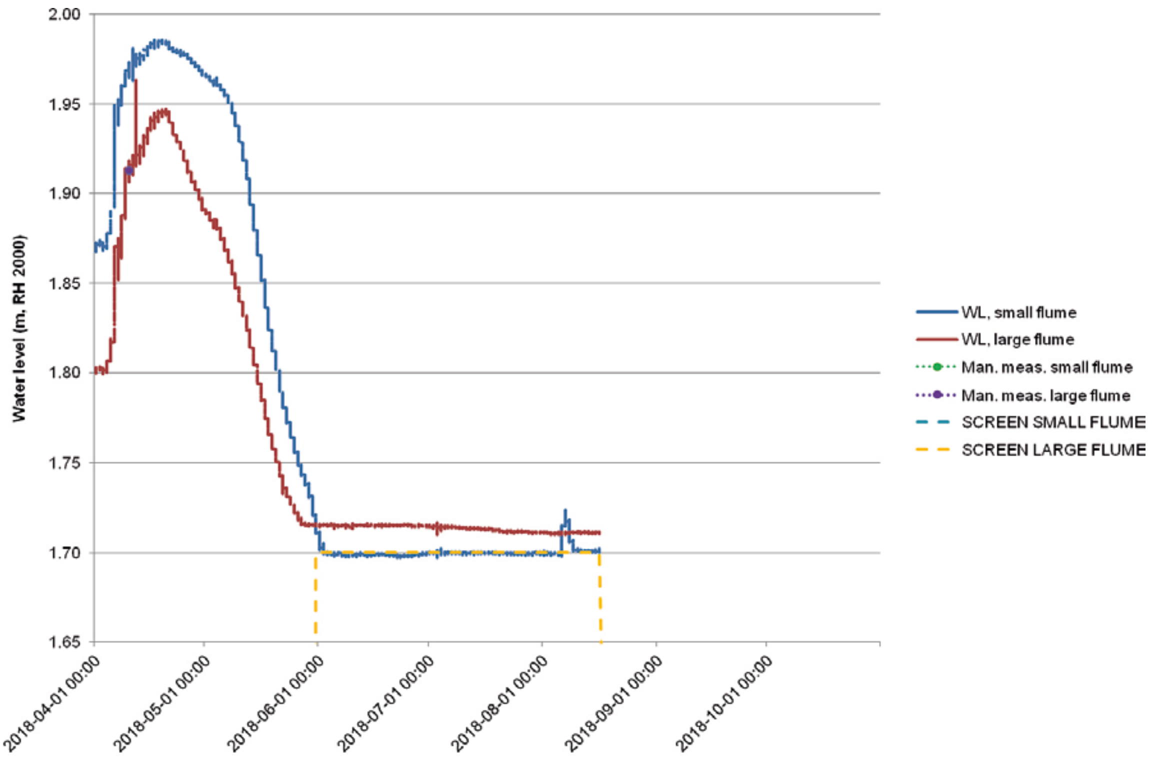


***Figure A2-4.** Water-level time series for the flumes at gauging station PFM002667 for the period Apr. 1 – Oct. 31, 2018 (data are available up to Aug. 16, 2018, when the station was refurbished and reconstructed).*

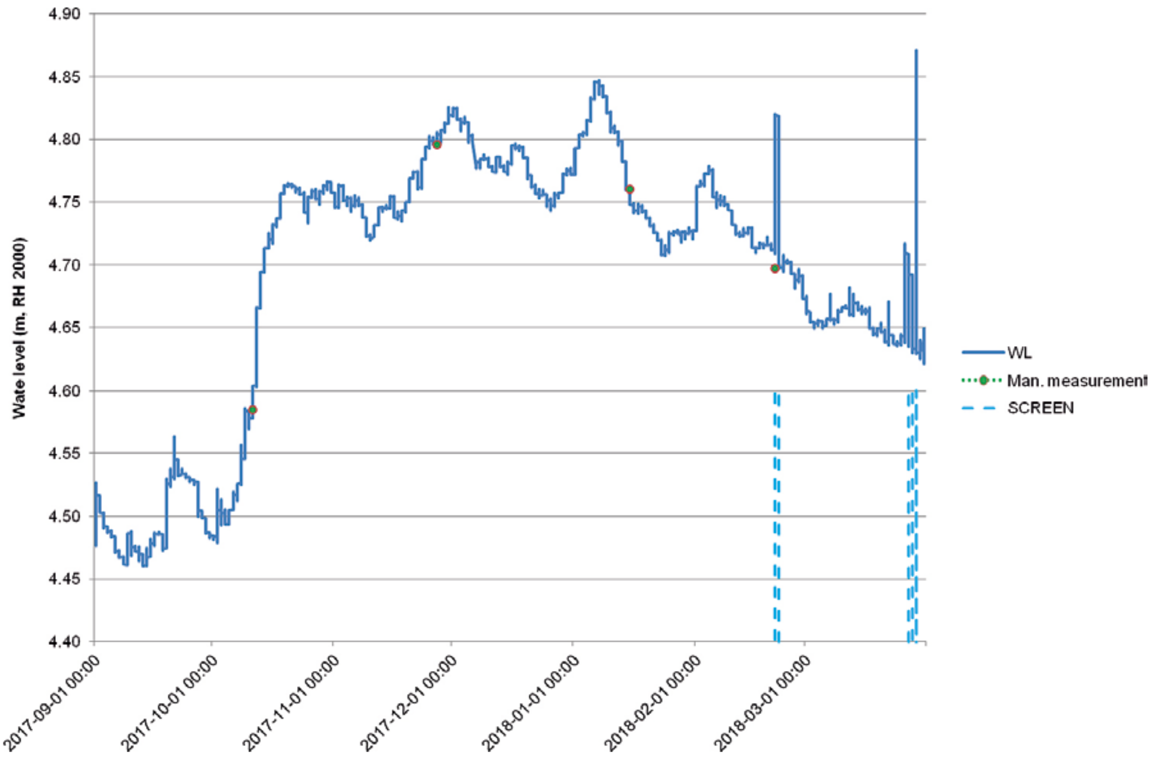


***Figure A2-5.** Water-level time series for the flume at gauging station PFM002668 for the period Sep. 1, 2017 – Mar. 31, 2018.*

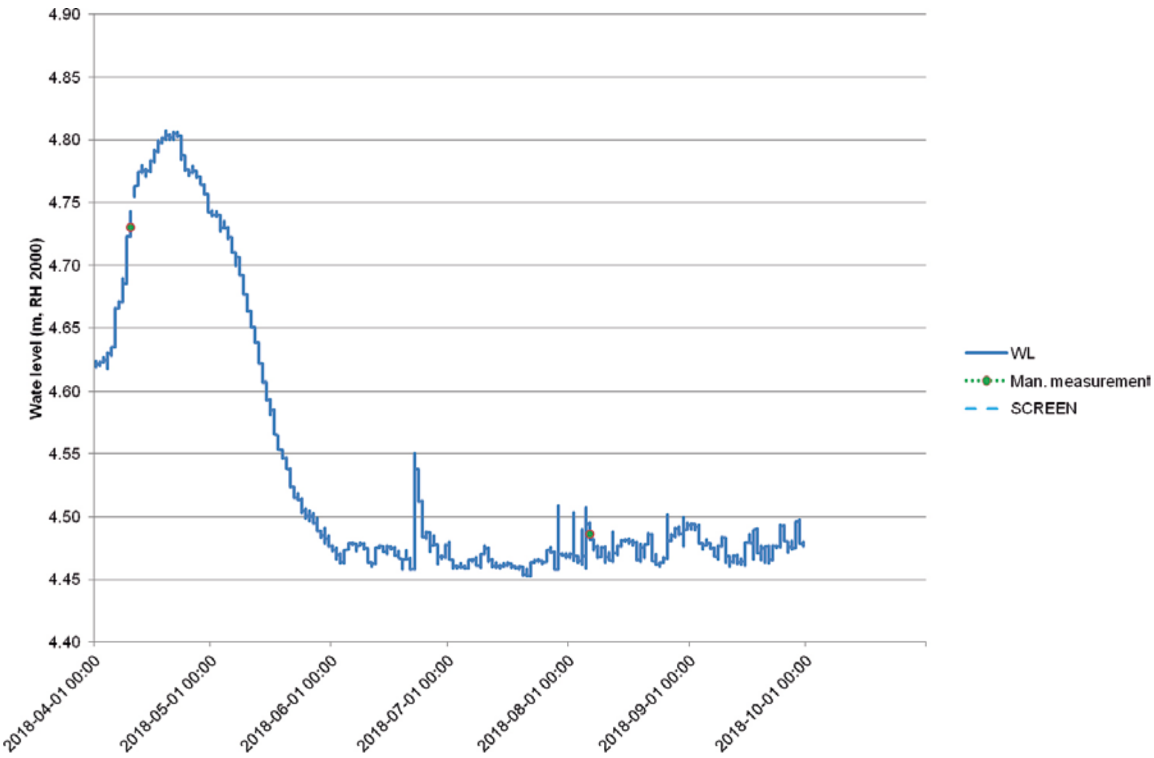


Figure A2-6. *Water-level time series for the flume at gauging station PFM002668 for the period Apr. 1 – Oct. 31, 2018 (data are approved up to Sep. 30, 2018).*

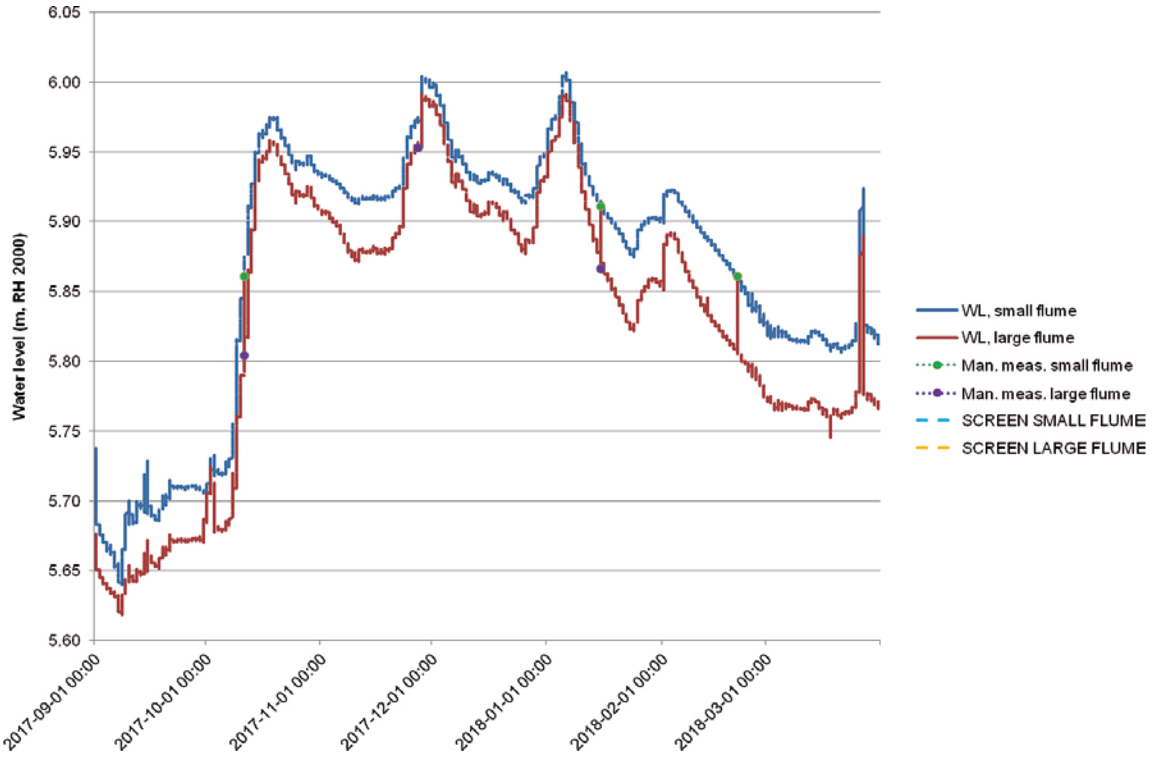


Figure A2-7. *Water-level time series for the flumes at gauging station PFM002669 for the period Sep. 1, 2017 – Mar. 31, 2018.*

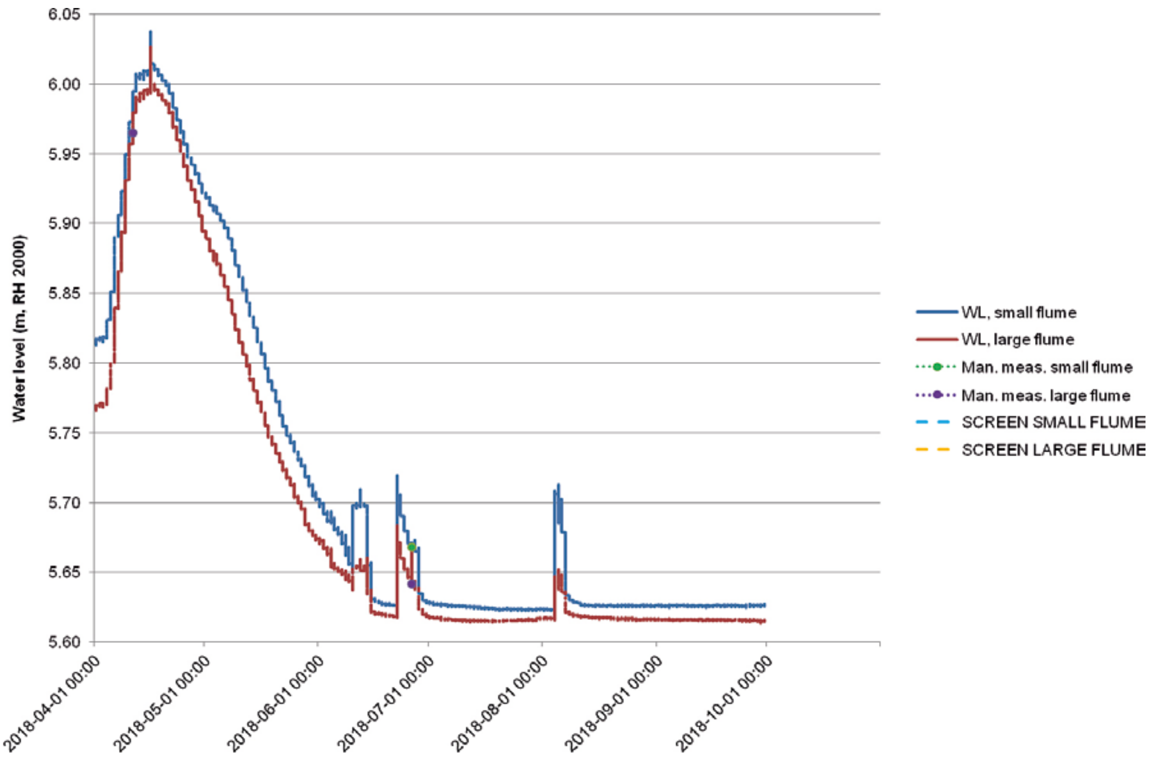


Figure A2-8. *Water-level time series for the flumes at gauging station PFM002669 for the period Apr. 1 – Oct. 31, 2018 (data are approved up to Sep. 30, 2018).*

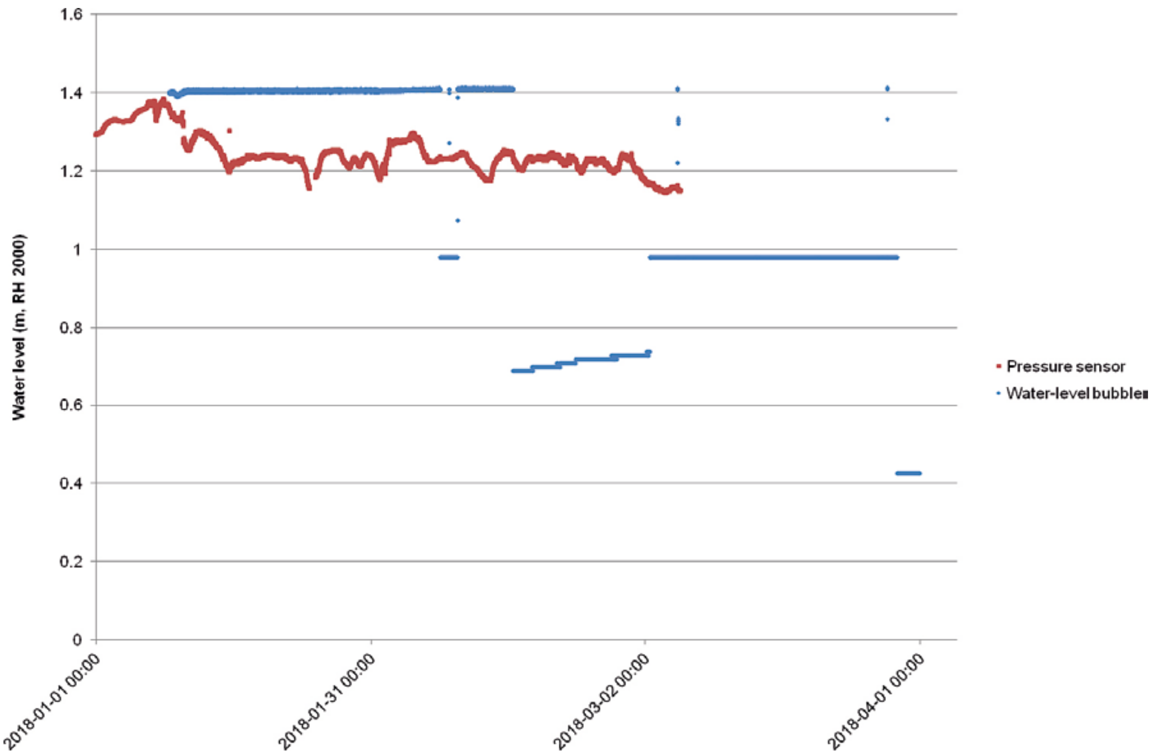


Figure A2-9. *Comparison between water-level time series for the pressure sensor and the water-level bubbler installed in the observation tube at the large flume at gauging station PFM005764, for the period January 1 – Mar. 31, 2018. Note that bubbler data are not approved, whereas pressure-sensor data are approved up to Sep. 30, 2018.*

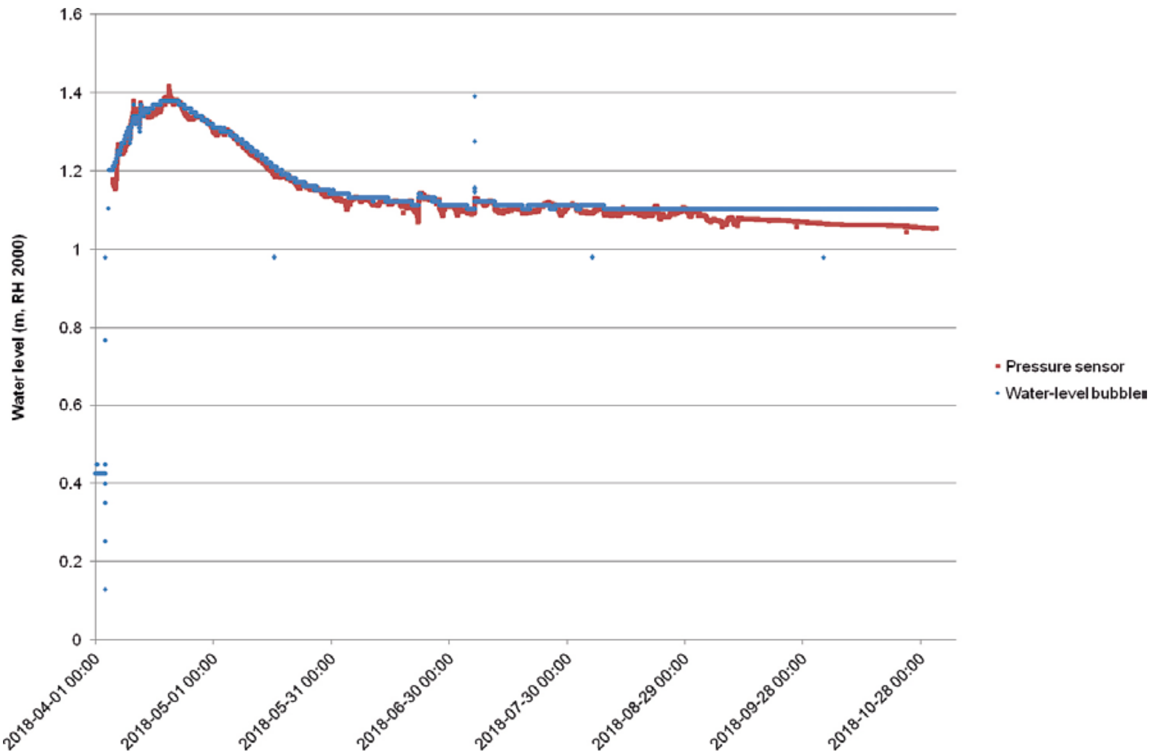


Figure A2-10. *Comparison between water-level time series for the pressure sensor and the water-level bubbler installed in the observation tube at the large flume at gauging station PFM005764, for the period Apr. 1 – Oct. 31, 2018. Note that bubbler data are not approved, whereas pressure-sensor data are approved up to Sep. 30, 2018.*

Appendix 3

Calculated discharge

Figures A3-1 to A3-4 show time-series plots of calculated hourly average stream discharges at gauging stations PFM005764, -2667, -2668 and -2669 for the hydrological year October 1, 2017 – September 30, 2018. Hourly averages are calculated without the data periods excluded as a result of the regular quality control and the quality control of the 2017/2018 water-level dataset (Appendix 2).

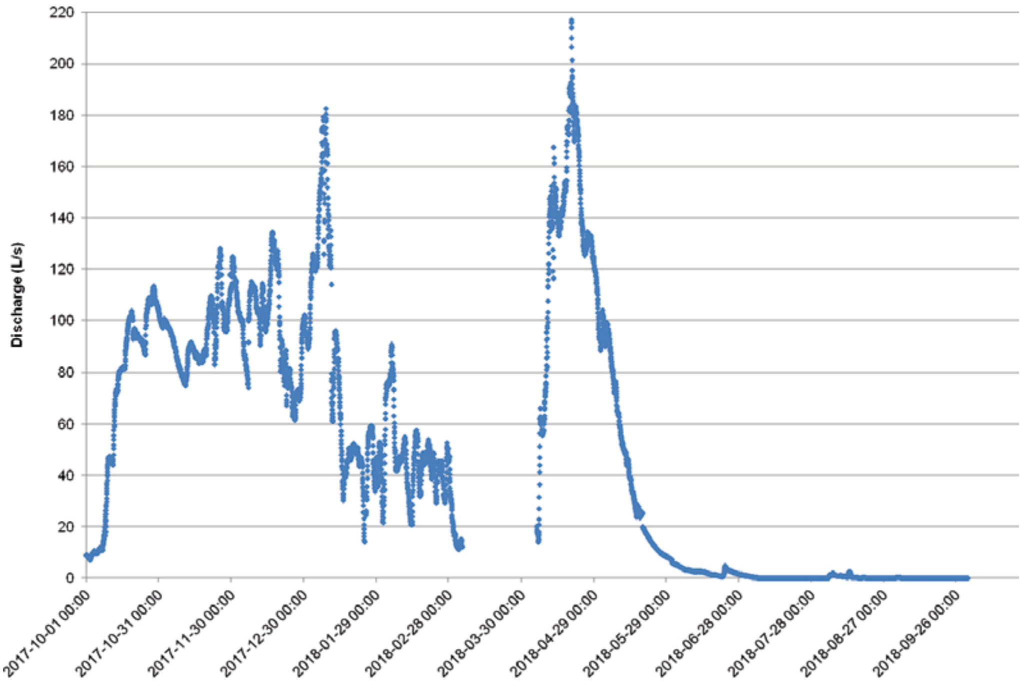


Figure A3-1. *Hourly average stream discharge at gauging station PFM005764 for the period Oct. 1, 2017 – Sep. 30, 2018.*

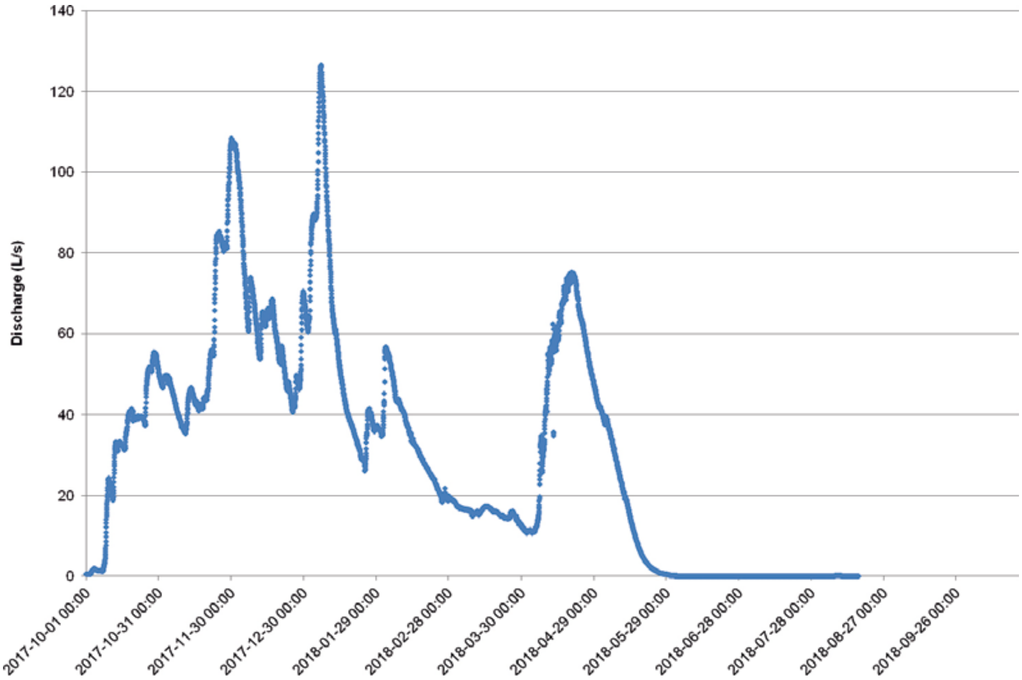


Figure A3-2. *Hourly average stream discharge at gauging station PFM002667 for the period Oct. 1, 2017 – Sep. 30, 2018.*

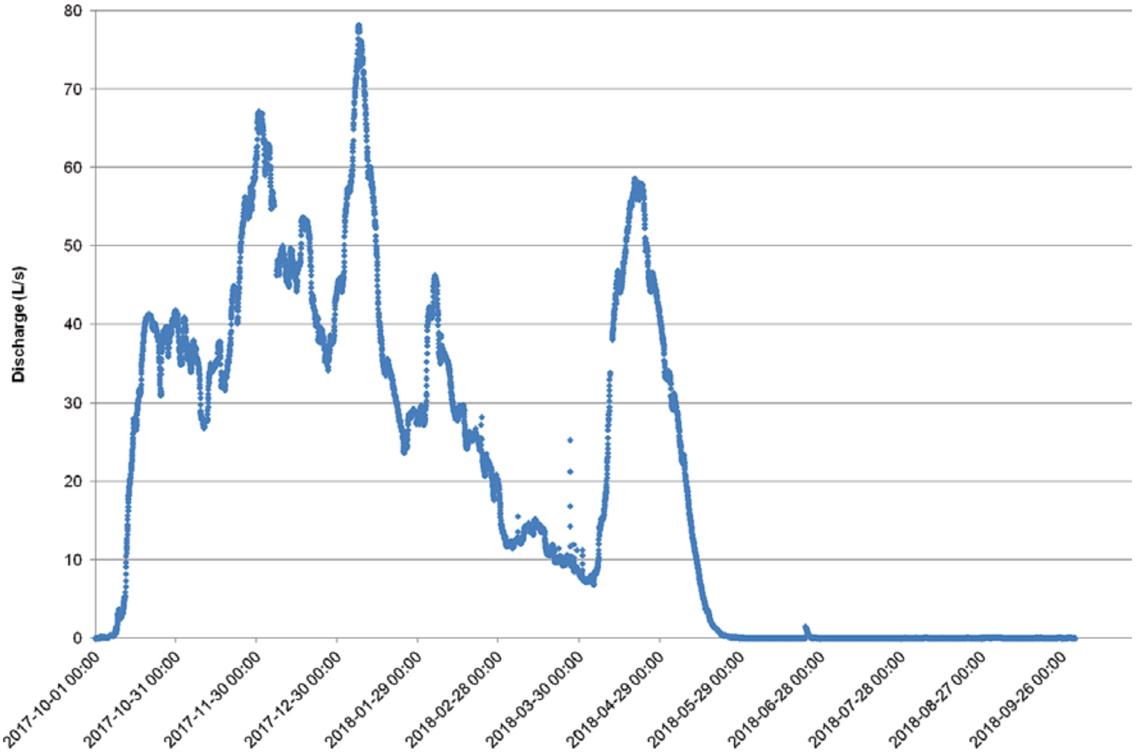


Figure A3-3. *Hourly average stream discharge at gauging station PFM002668 for the period Oct. 1, 2017 – Sep. 30, 2018.*

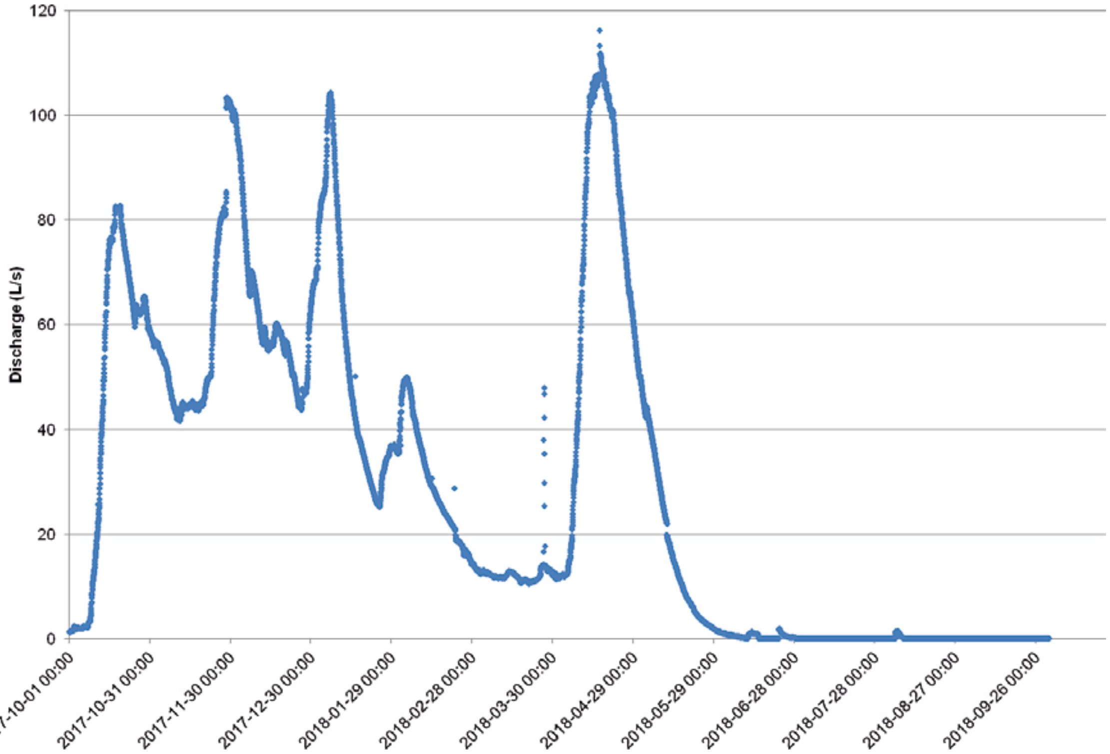


Figure A3-4. *Hourly average stream discharge at gauging station PFM002669 for the period Oct. 1, 2017 – Sep. 30, 2018.*

Appendix 4

Electrical conductivity

Figures A4-1 to A4-8 show EC time-series plots for gauging stations PFM005764, -2667, -2668 and -2669 for the period September 1, 2017 – October 31, 2018. The plots also show manually measured EC values and data periods excluded (SCREEN) as a result of the quality control of the 2017/2018 EC dataset. Note that EC values for September 2017 and October 2018 are shown for reference only.

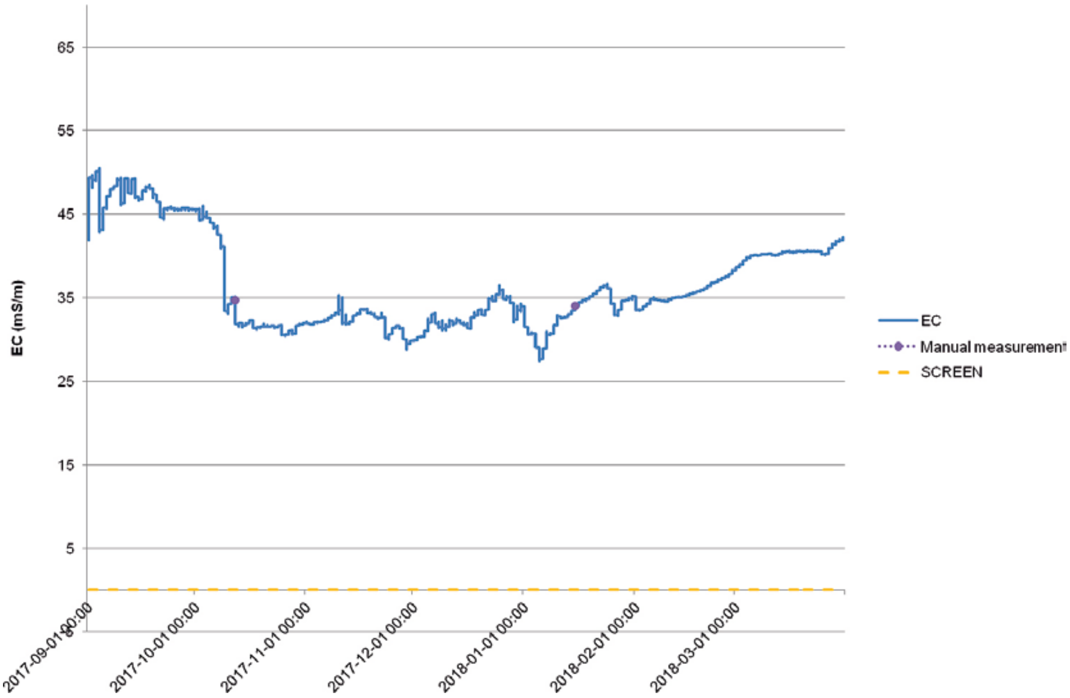


***Figure A4-1.** EC time series for gauging station PFM005764 for the period Sep. 1, 2017 – Mar. 31, 2018.*

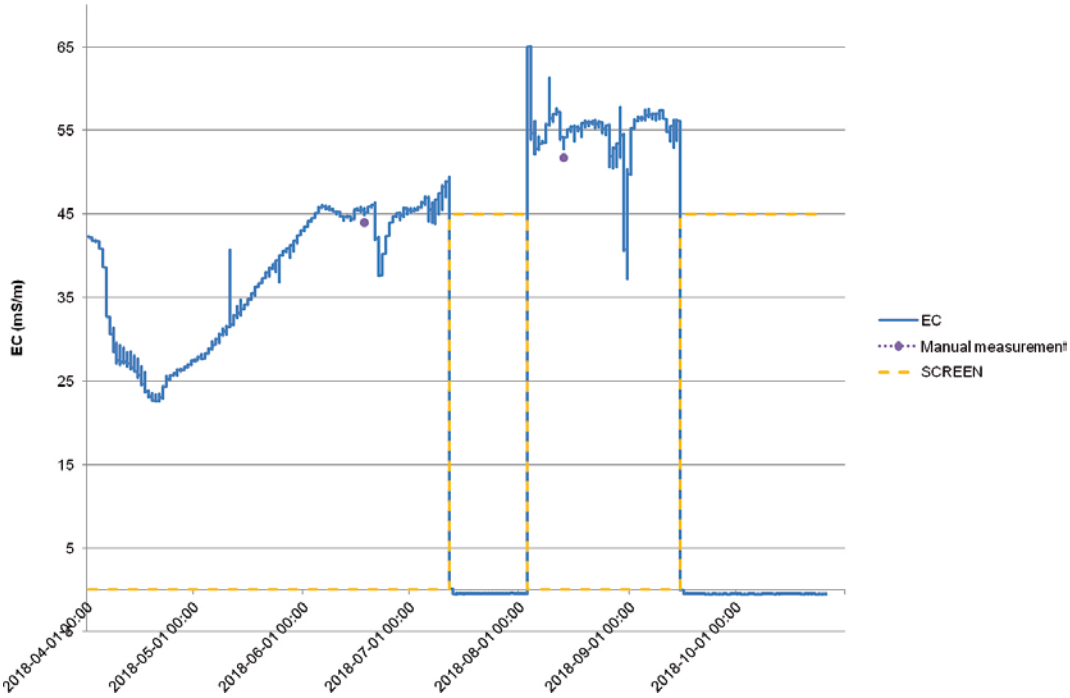


***Figure A4-2.** EC time series for gauging station PFM005764 for the period Apr. 1 – Oct. 31, 2018.*

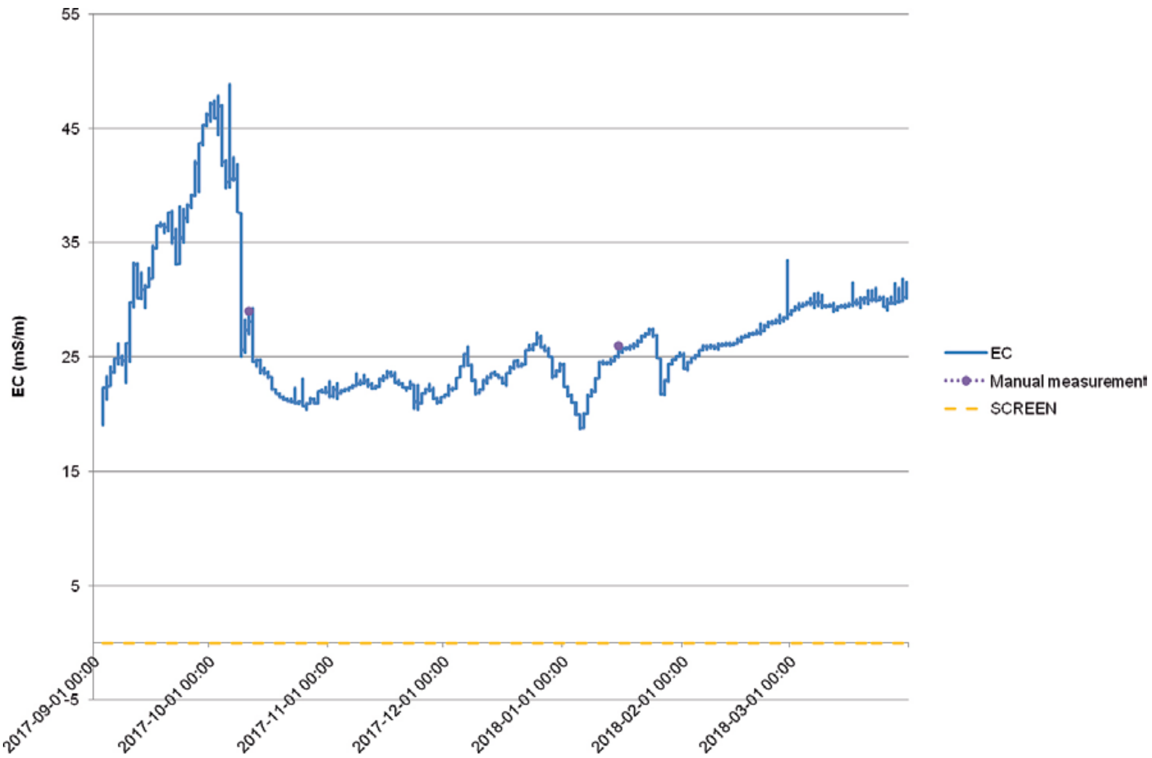


Figure A4-3. EC time series for gauging station PFM002667 for the period Sep. 1, 2017 – Mar. 31, 2018.

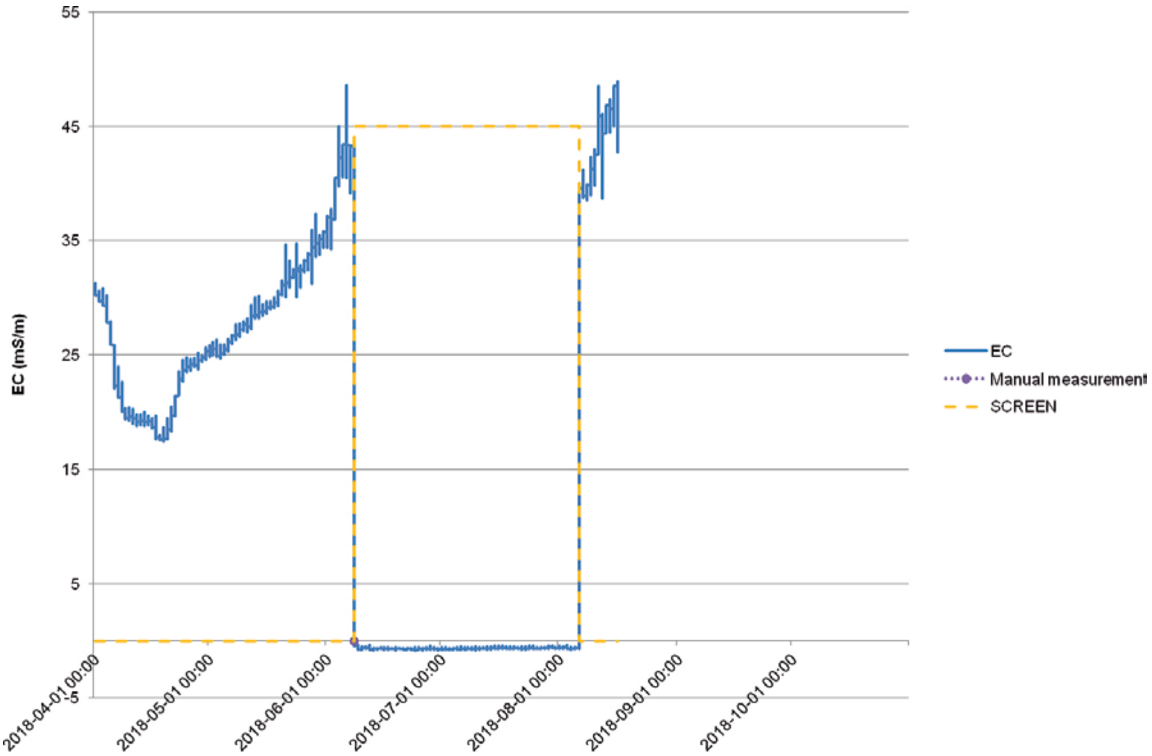


Figure A4-4. EC time series for gauging station PFM002667 for the period Apr. 1 – Oct. 31, 2018.

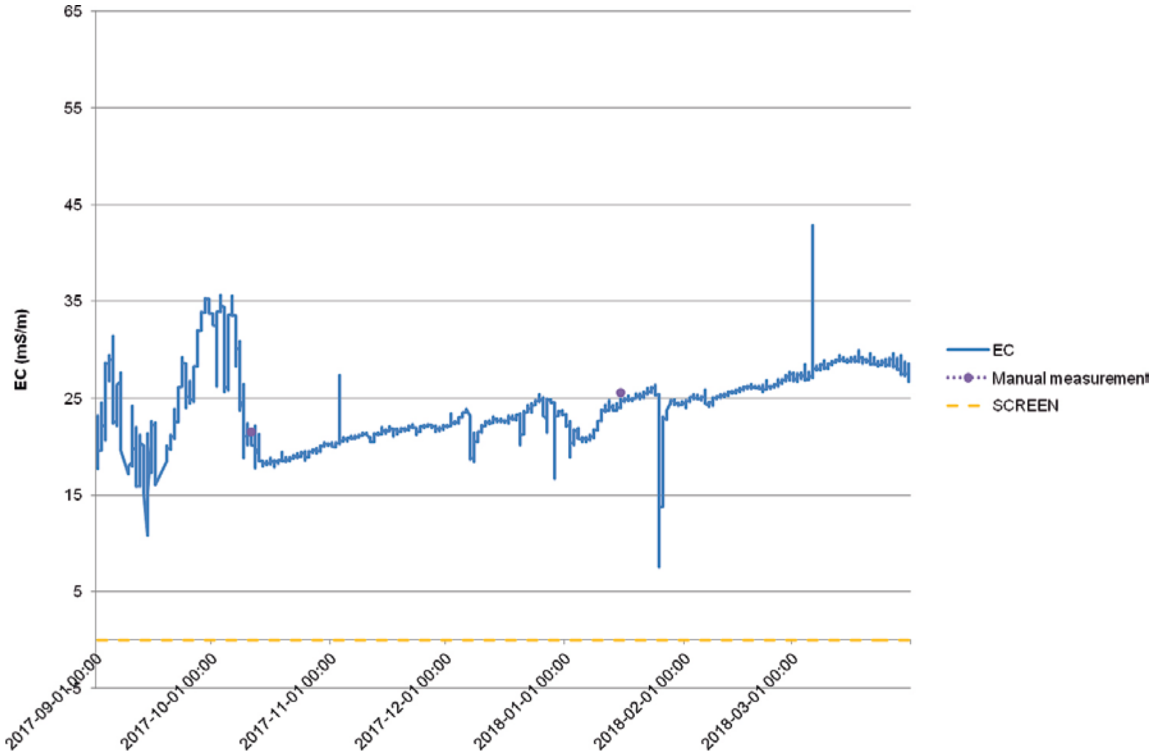


Figure A4-5. *EC time series for gauging station PFM002668 for the period Sep. 1, 2017 – Mar. 31, 2018.*

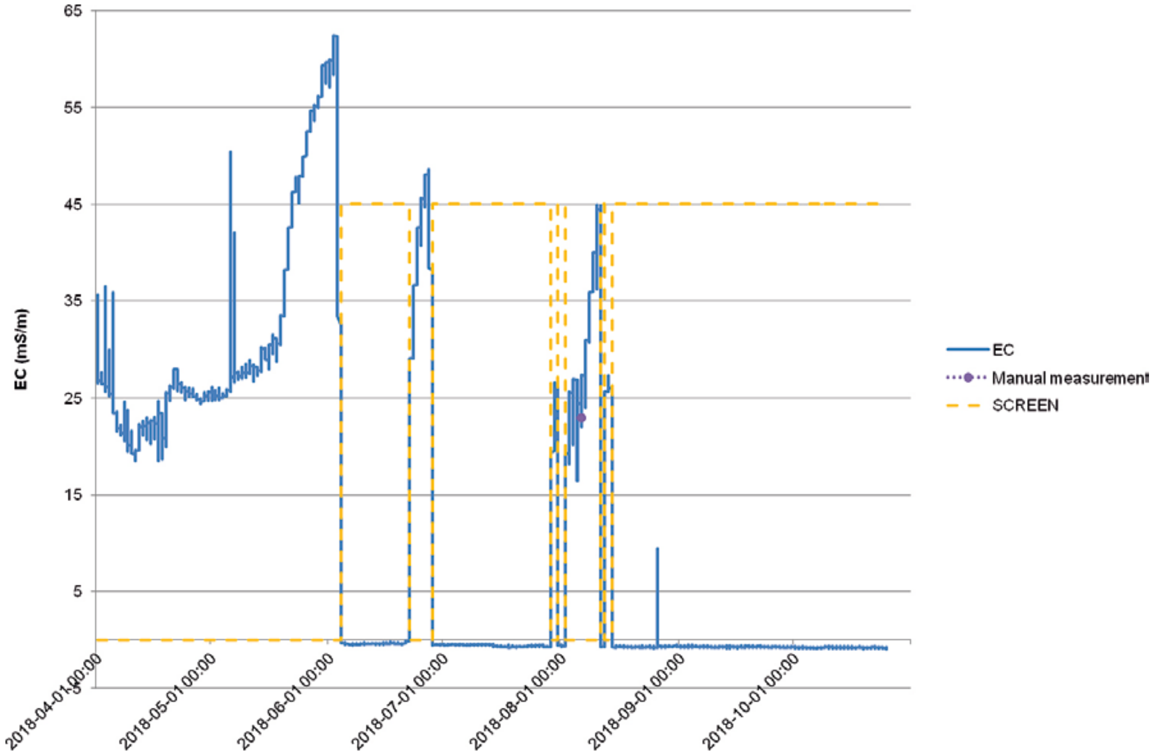


Figure A4-6. *EC time series for gauging station PFM002668 for the period Apr. 1 – Oct. 31, 2018.*

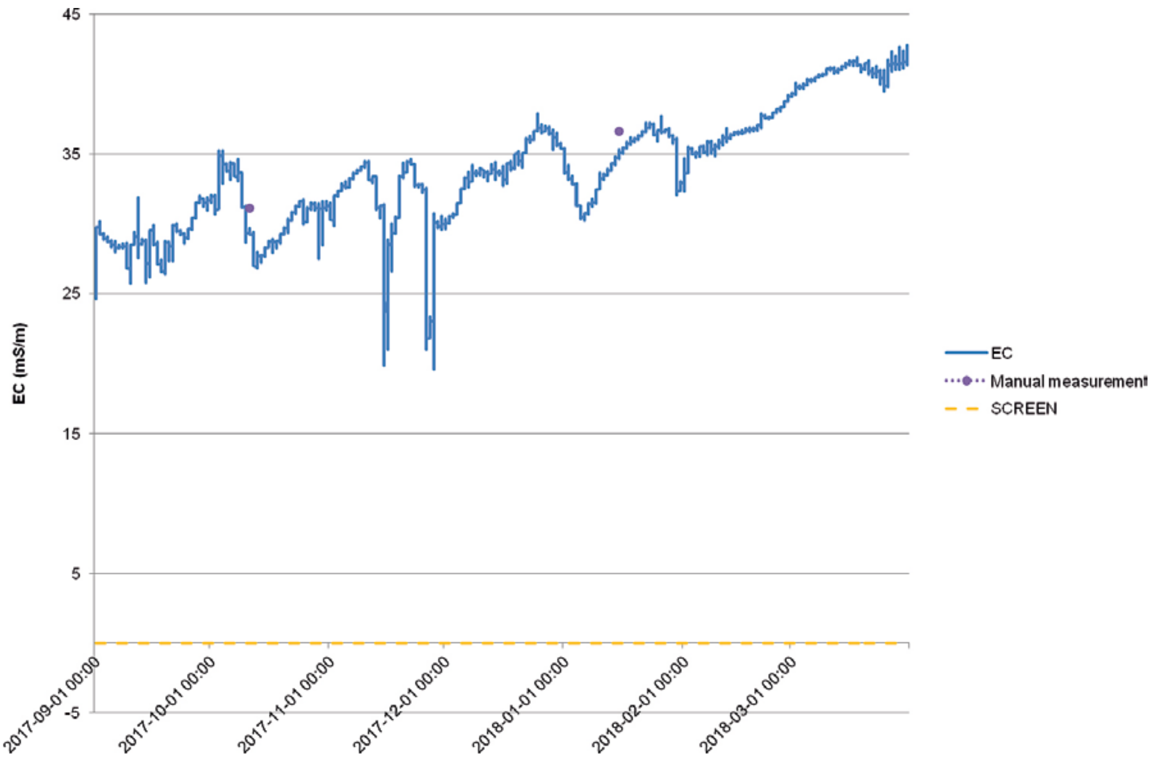


***Figure A4-7.** EC time series for gauging station PFM002669 for the period Sep. 1, 2017 – Mar. 31, 2018.*

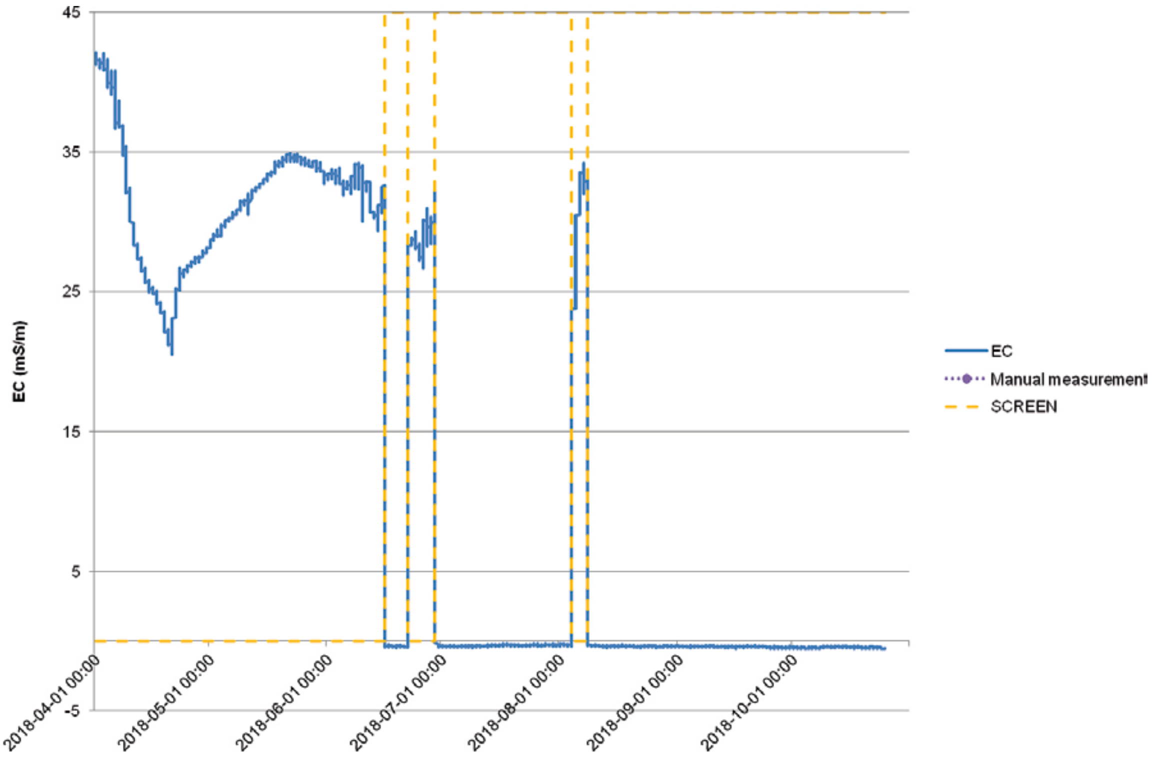


***Figure A4-8.** EC time series for gauging station PFM002669 for the period Apr. 1 – Oct. 31, 2018.*

Appendix 5

Temperature

Figures A5-1 to A5-8 show temperature time-series plots for gauging stations PFM005764, -2667, -2668 and -2669 for the period September 1, 2017 – October 31, 2018. The plots also show manually measured temperature values and data periods excluded (SCREEN) as a result of the quality control of the 2017/2018 temperature dataset. Note that temperature values for September 2017 and October 2018 are shown for reference only.

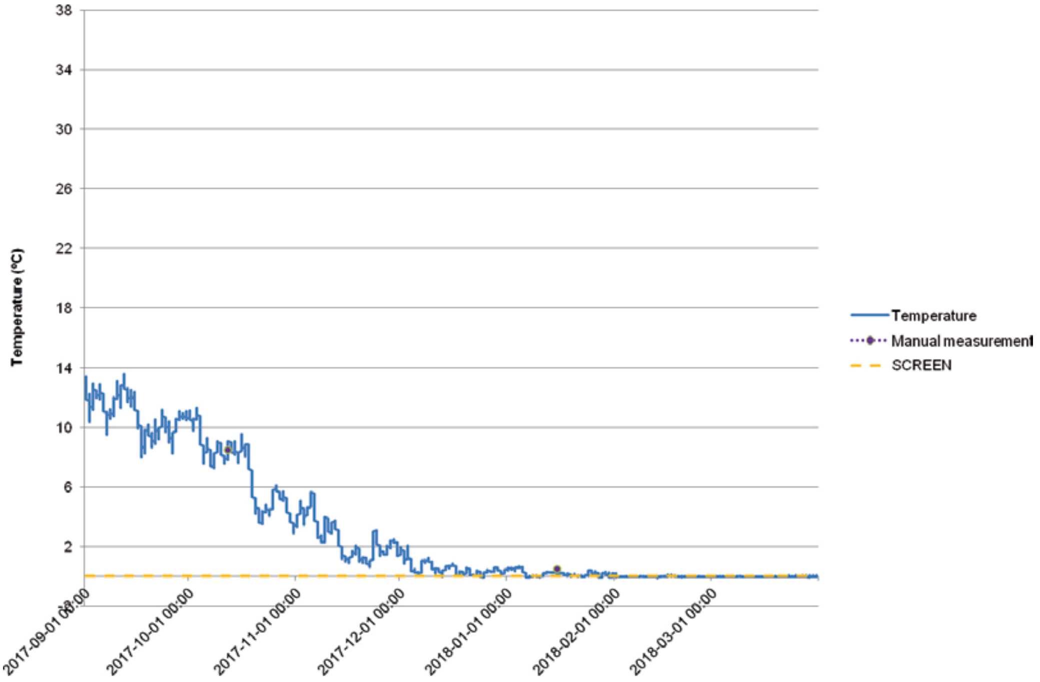


Figure A5-1. Temperature time series for gauging station PFM005764 for the period Sep. 1, 2017 – Mar. 31, 2018.

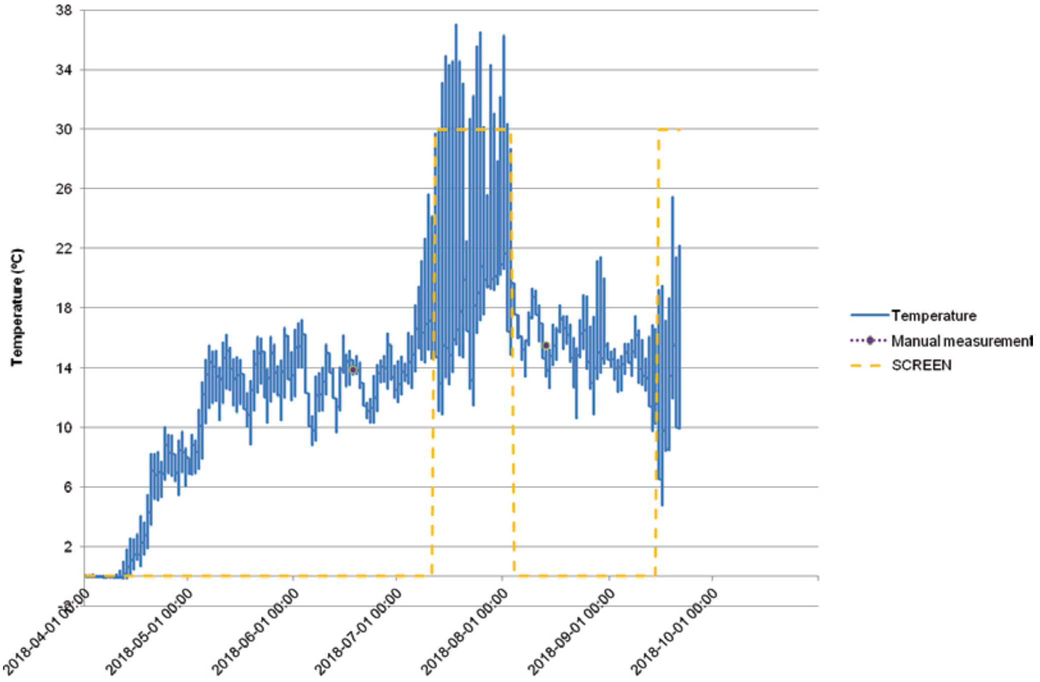


Figure A5-2. Temperature time series for gauging station PFM005764 for the period Apr. 1 – Oct. 31, 2018.

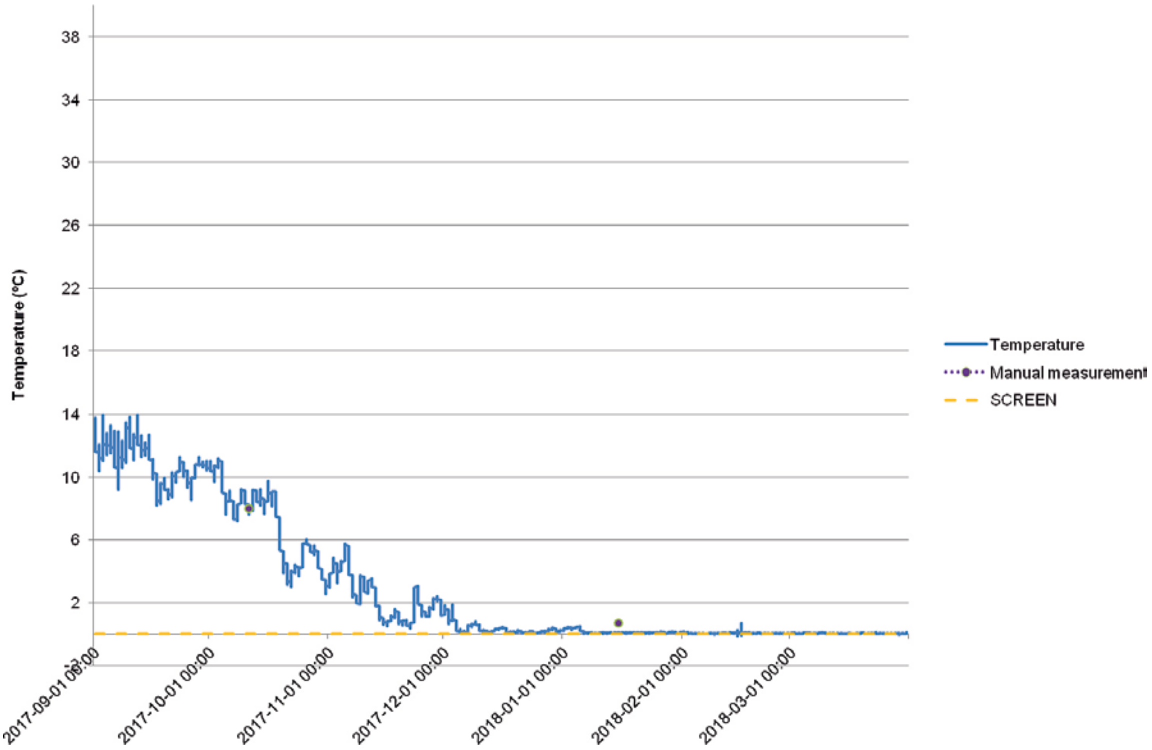


Figure A5-3. *Temperature time series for gauging station PFM002667 for the period Sep. 1, 2017 – Mar. 31, 2018.*

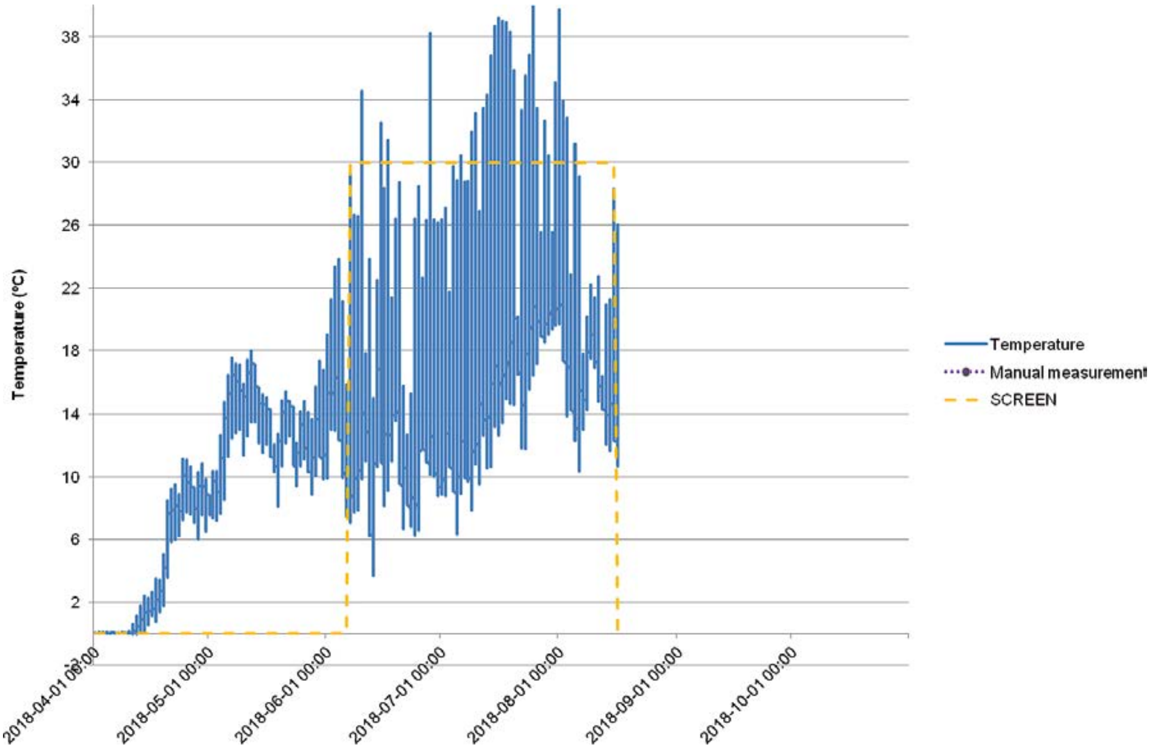


Figure A5-4. *Temperature time series for gauging station PFM002667 for the period Apr. 1 – Oct. 31, 2018.*

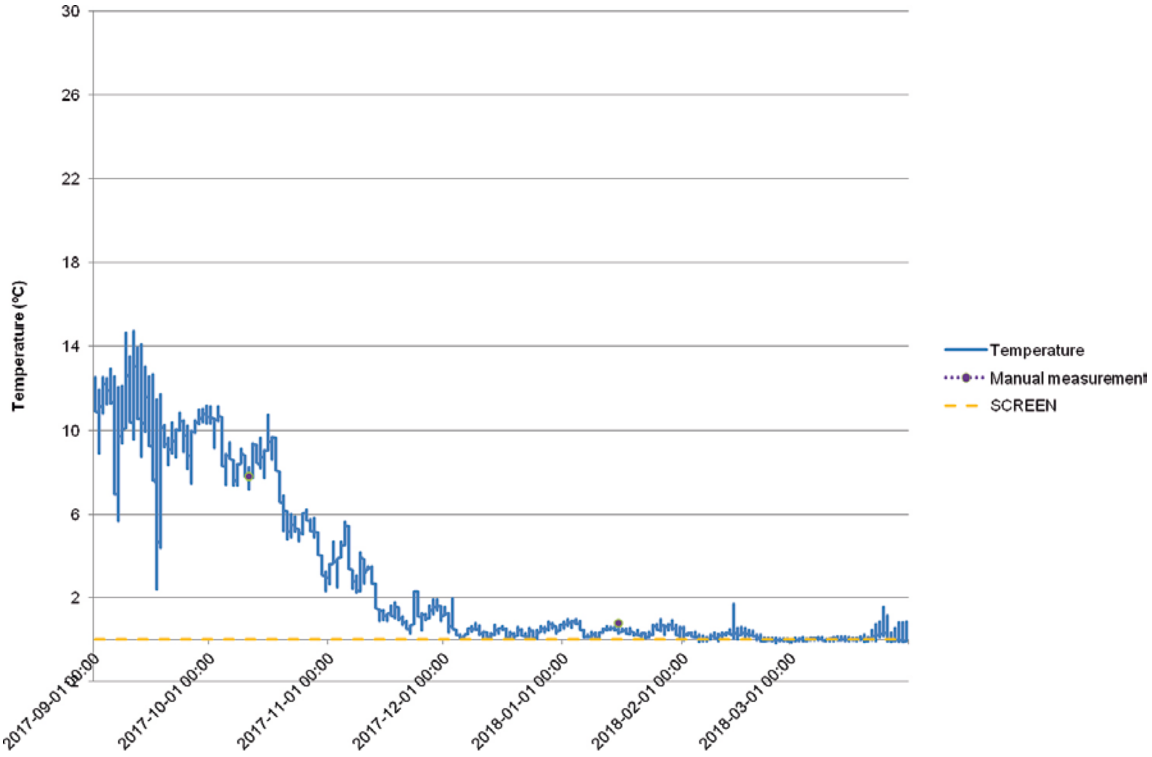


***Figure A5-5.** Temperature time series for gauging station PFM002668 for the period Sep. 1, 2017 – Mar. 31, 2018.*

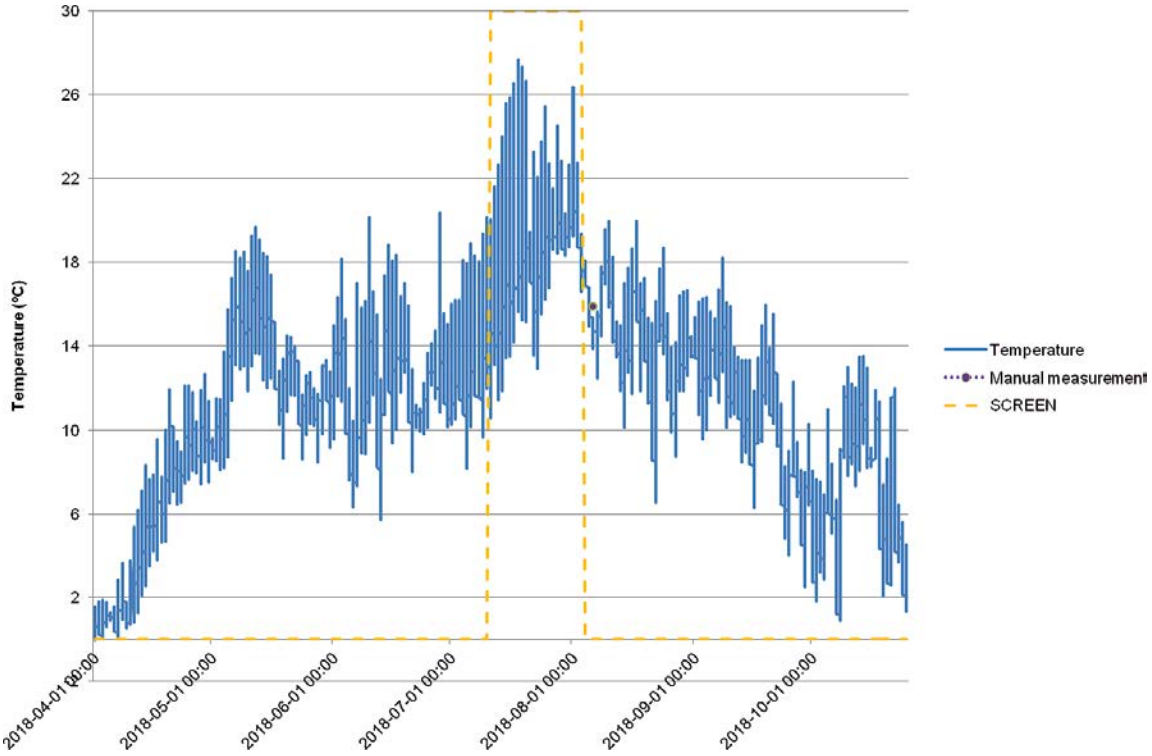


***Figure A5-6.** Temperature time series for gauging station PFM002668 for the period Apr. 1 – Oct. 31, 2018.*

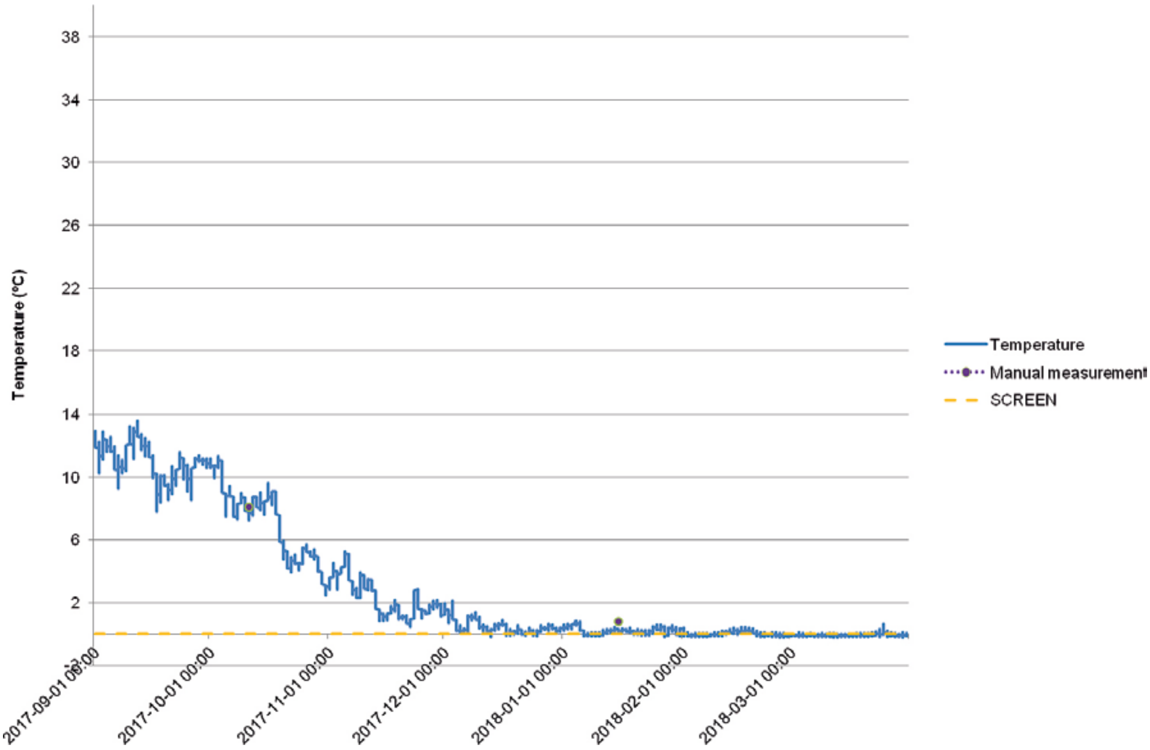


Figure A5-7. *Temperature time series for gauging station PFM002669 for the period Sep. 1, 2017 – Mar. 31, 2018.*

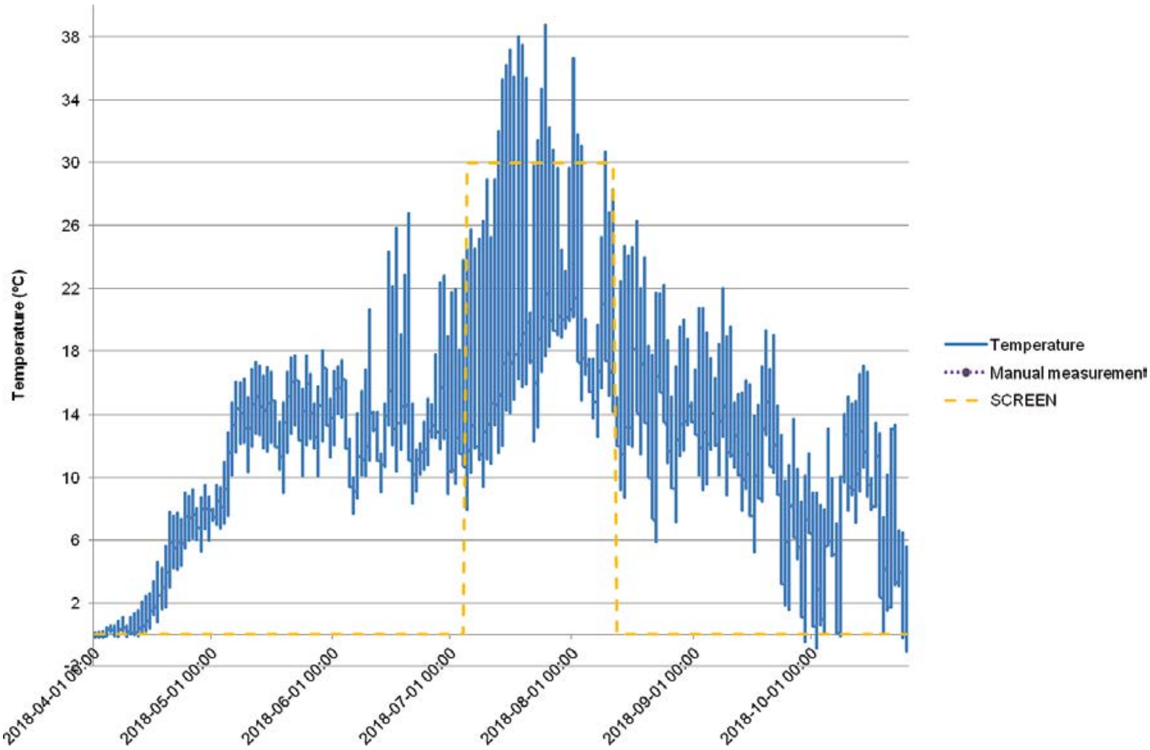
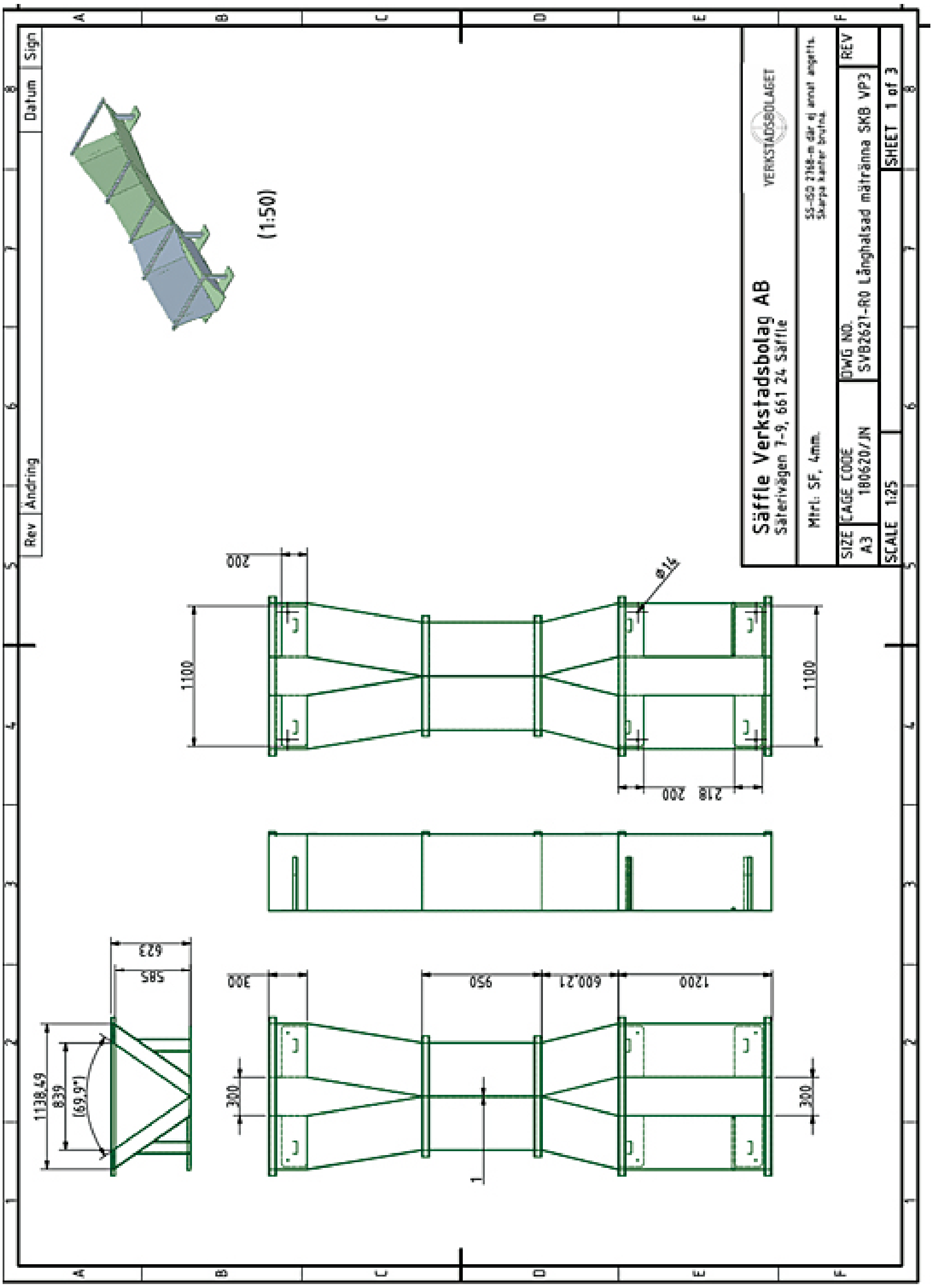
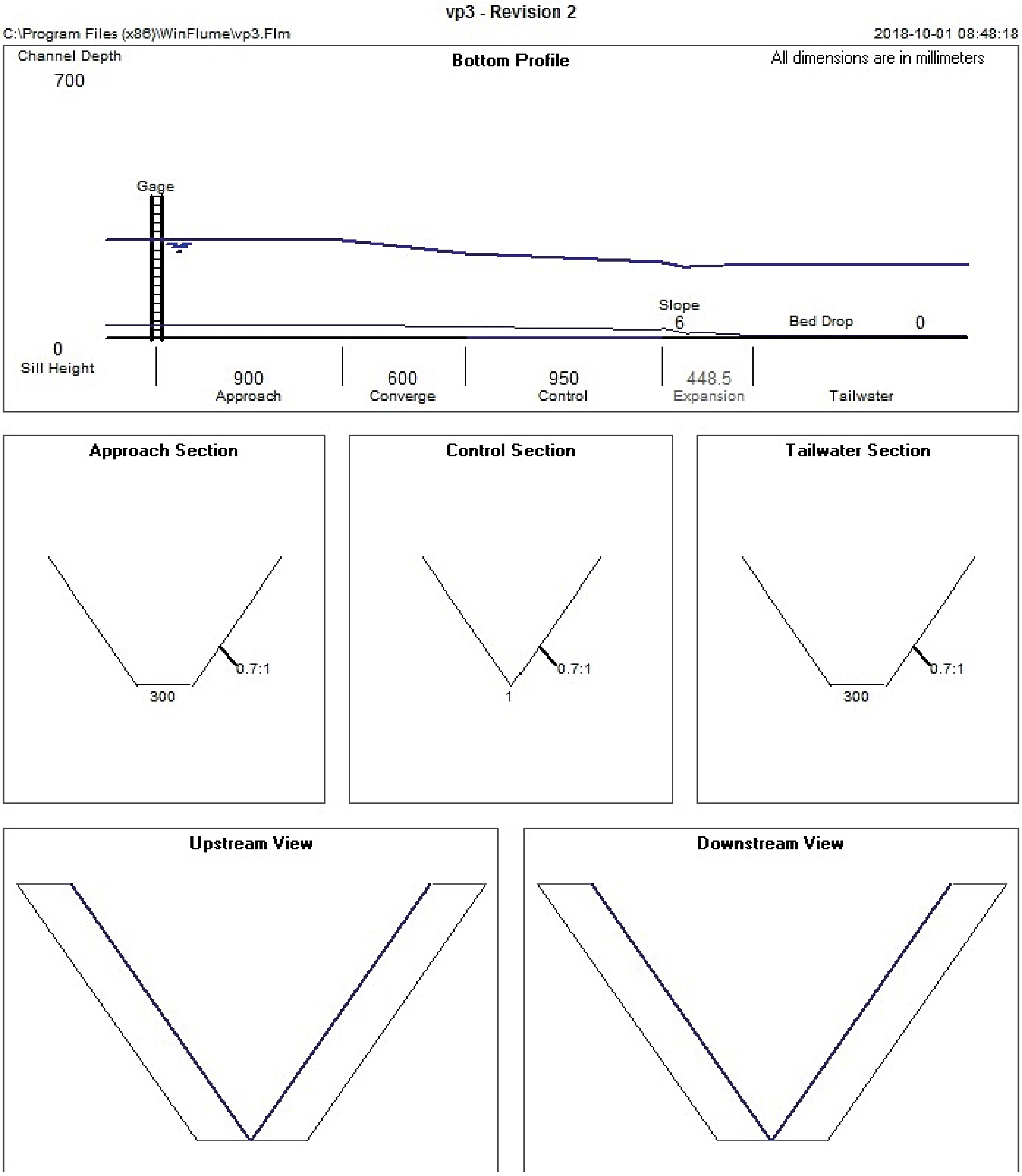


Figure A5-8. *Temperature time series for gauging station PFM002669 for the period Apr. 1 – Oct. 31, 2018.*

PFM002667 CAD and WinFlume drawings




vp3 - Revision 2
C:\Program Files (x86)\WinFlume\vp3.Flm
2018-10-01 08:48:18
Channel Depth
700
Bottom Profile
All dimensions are in millimeters
Gage
Slope
6
Bed Drop
0
0
Sill Height
900
Approach
600
Converge
950
Control
448.5
Expansion
Tailwater
Approach Section
0.7:1
300
Control Section
0.7:1
1
Tailwater Section
0.7:1
300
Upstream View
Downstream View

Appendix 7

Soil temperature and soil moisture

Figures A7-1 to A7-6 show soil-temperature time-series plots and data interpretations for the temperature sensor-stations PFM007822 and PFM007823 (0 °C marked with dashed lines). Figures A7-7 to A7-14 show soil-temperature and soil-moisture time-series plots and data interpretations for the TDR stations PFM007874–7881 (note the coherent data gaps during the period August–November 2017). Data are obtained from the Sicada database.

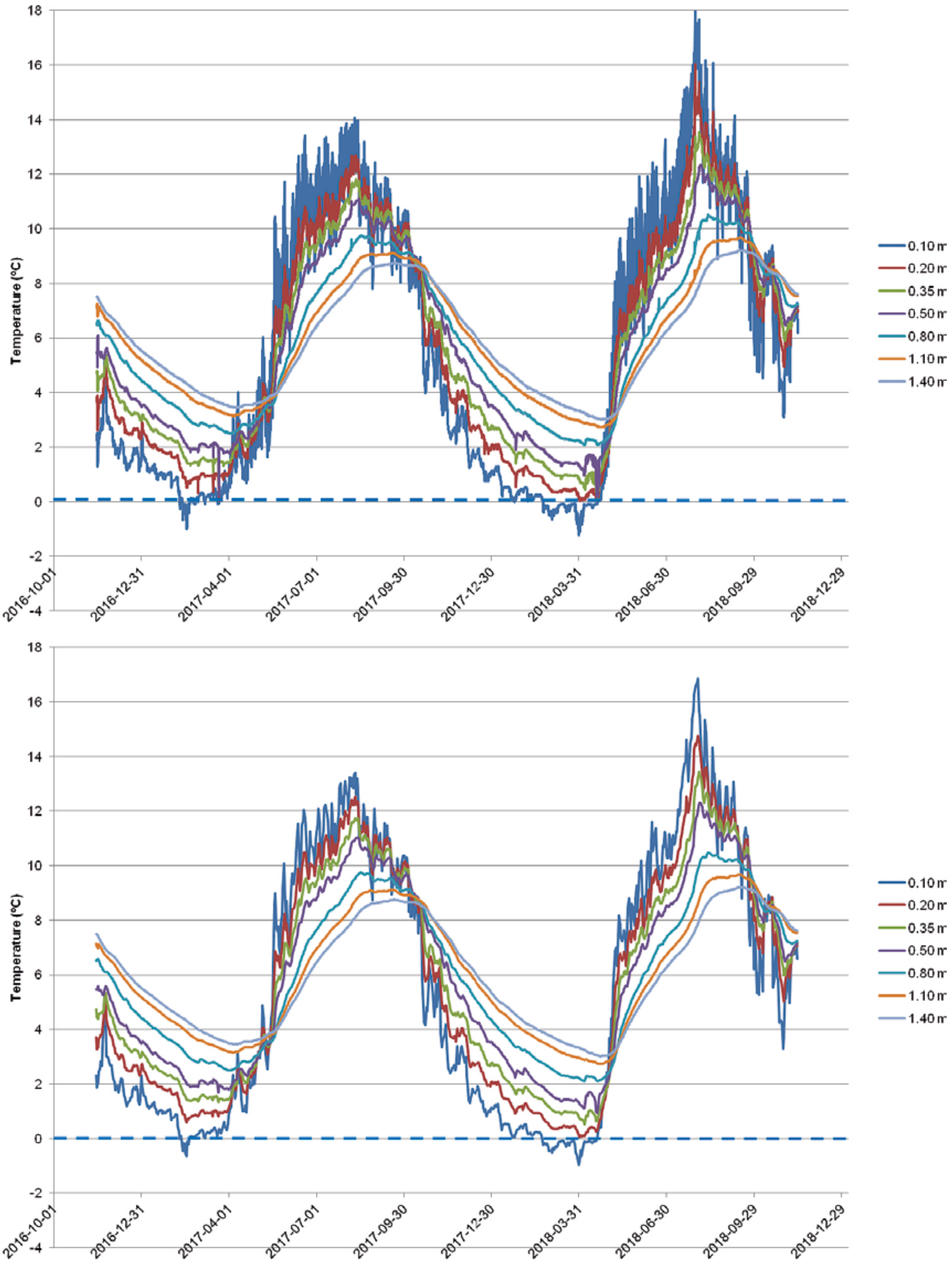


Figure A7-1. *Soil temperature at different depths below ground surface at PFM007822. Upper plot: High-resolved data (measurement interval 3 hours). Lower plot: Daily averages.*

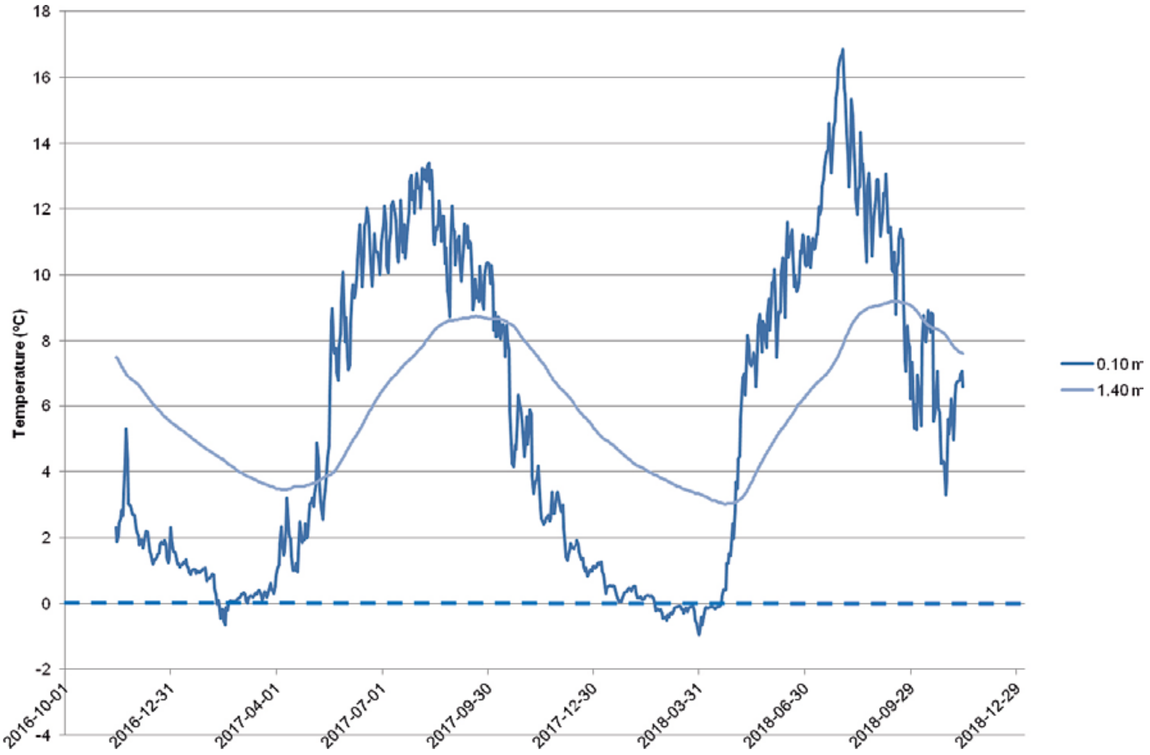


Figure A7-2. *Daily average soil temperatures at the depths 0.10 and 1.40 m below ground surface at PFM007822.*

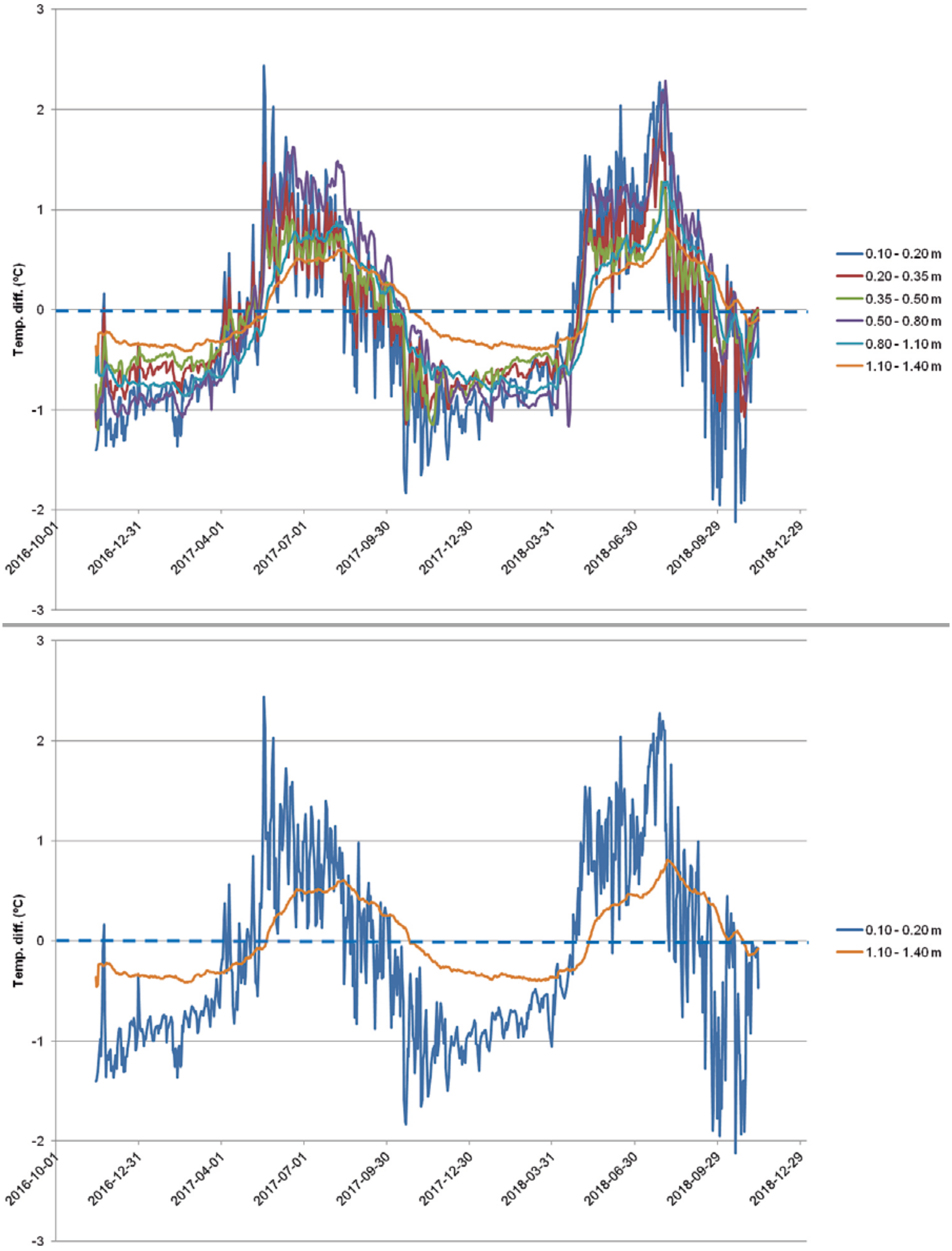


Figure A7-3. *Daily average soil-temperature differences between adjacent measurement depths below ground surface at PFM007822. Upper plot: All depths. Lower plot: Top and bottom measurement depths.*

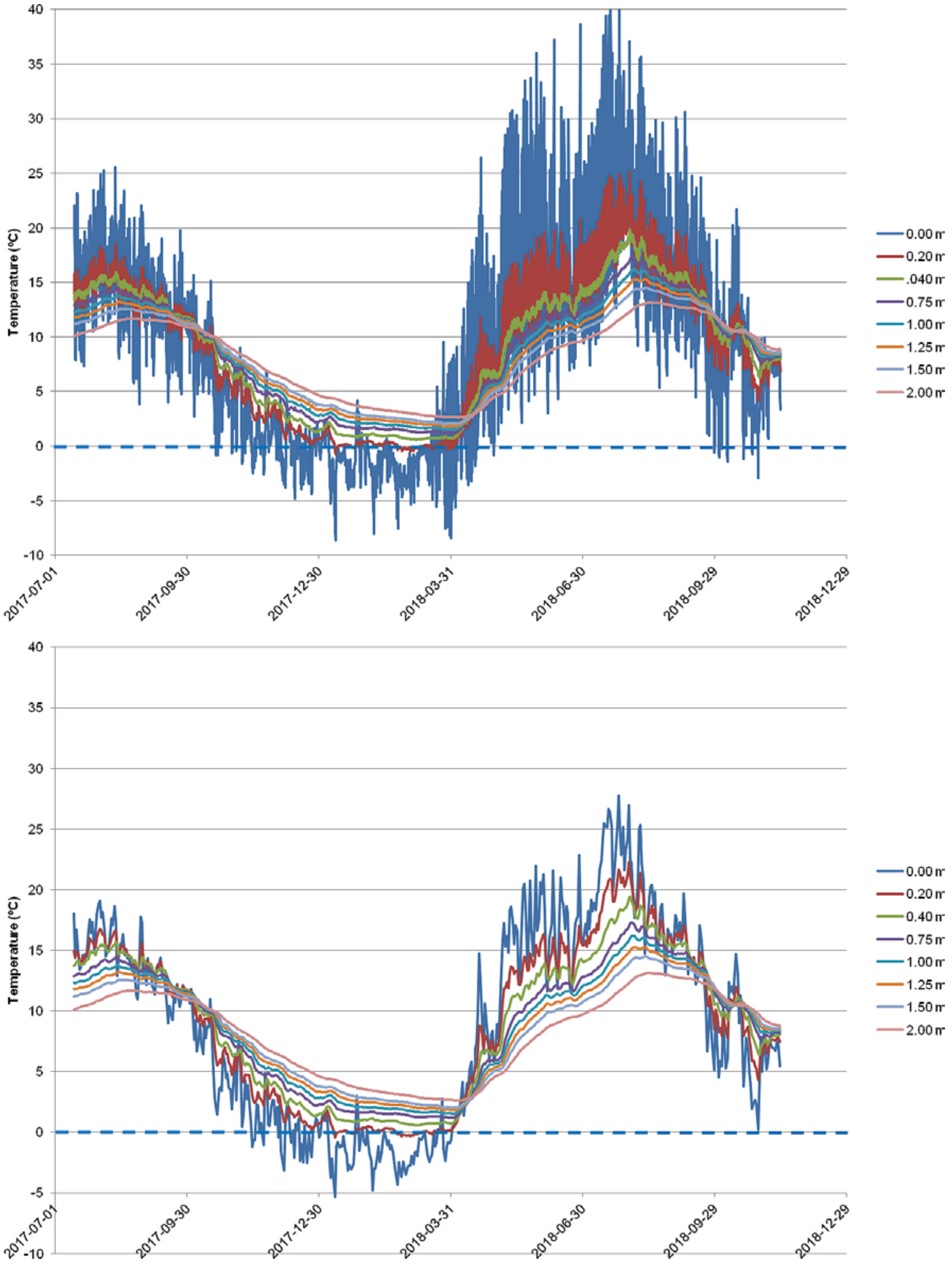


Figure A7-4. *Soil temperature at different depths below ground surface at PFM007823. Upper plot: High-resolved data (measurement interval 3 hours). Lower plot: Daily averages.*

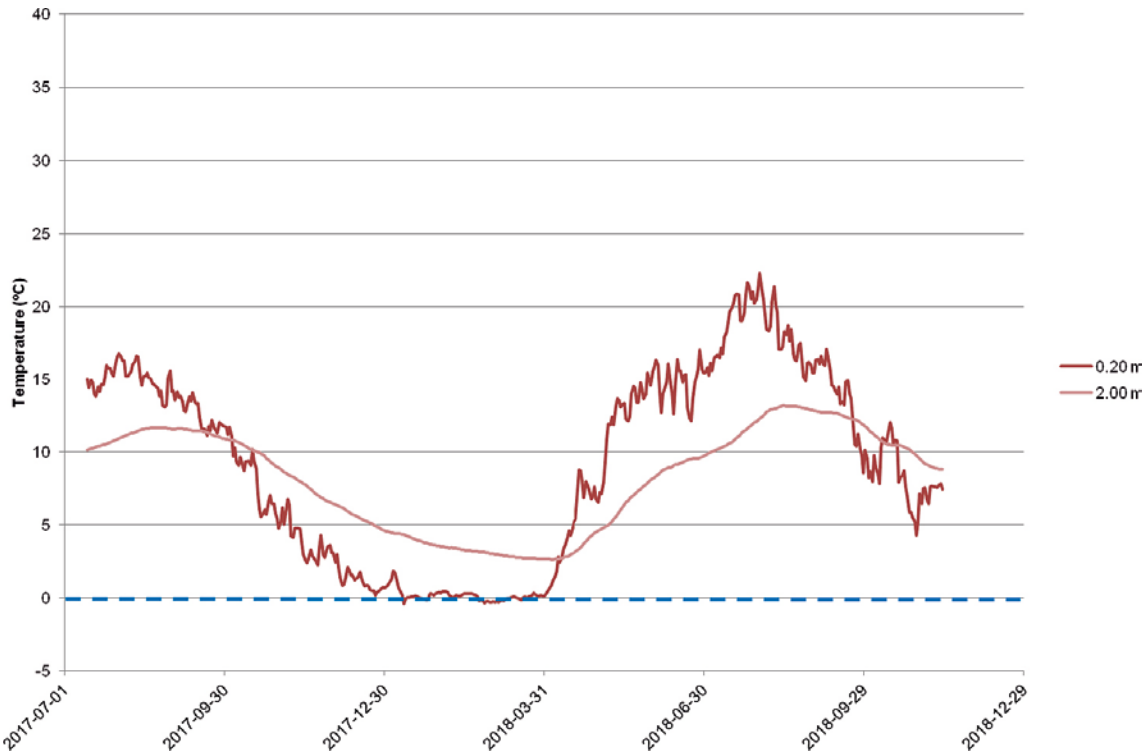


Figure A7-5. *Daily average soil temperatures at the depths 0.20 and 2.00 m below ground surface at PFM007823.*

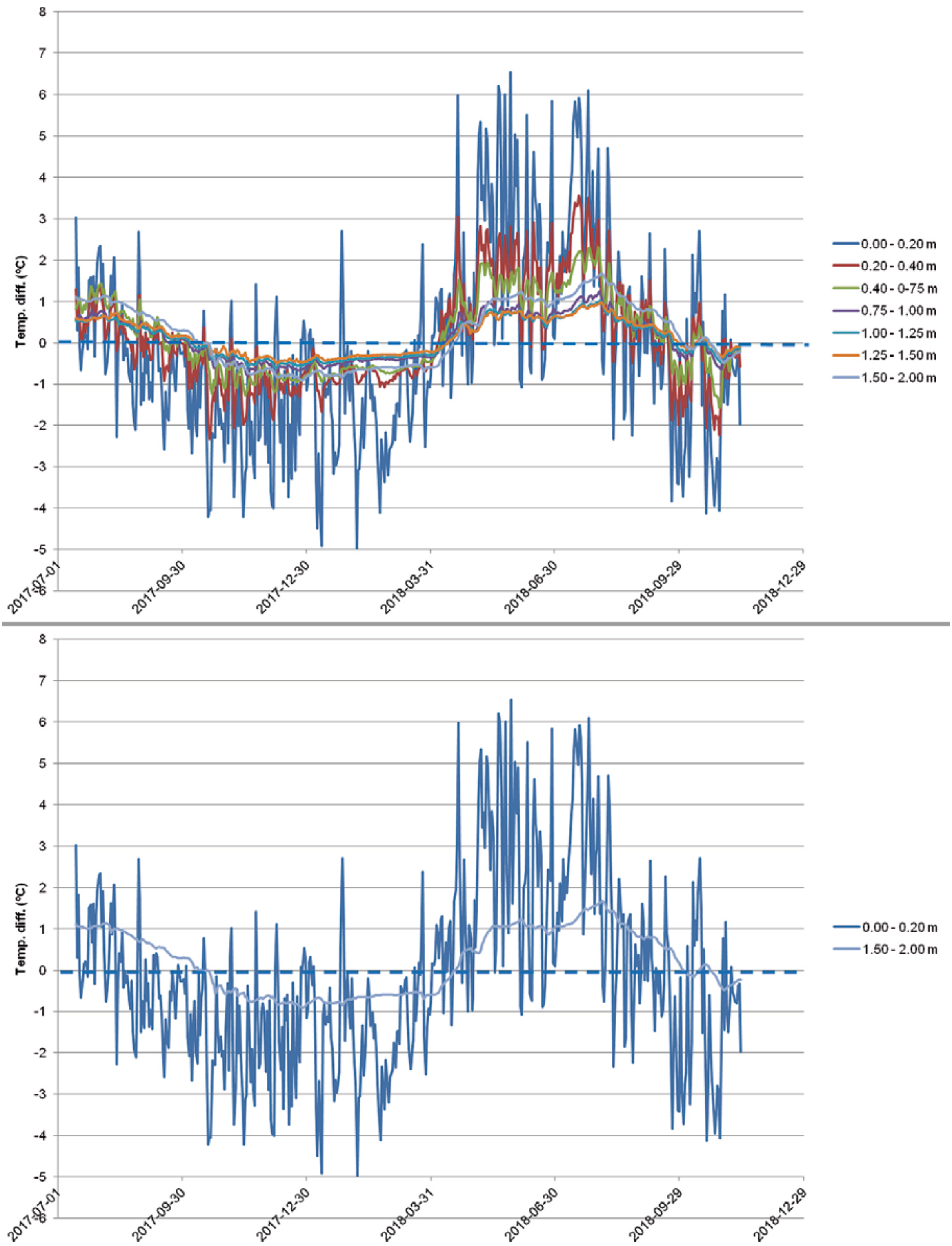


***Figure A7-6.** Daily average soil-temperature differences between adjacent measurement depths below ground surface at PFM007823. Upper plot: All depths. Lower plot: Top and bottom measurement depths.*

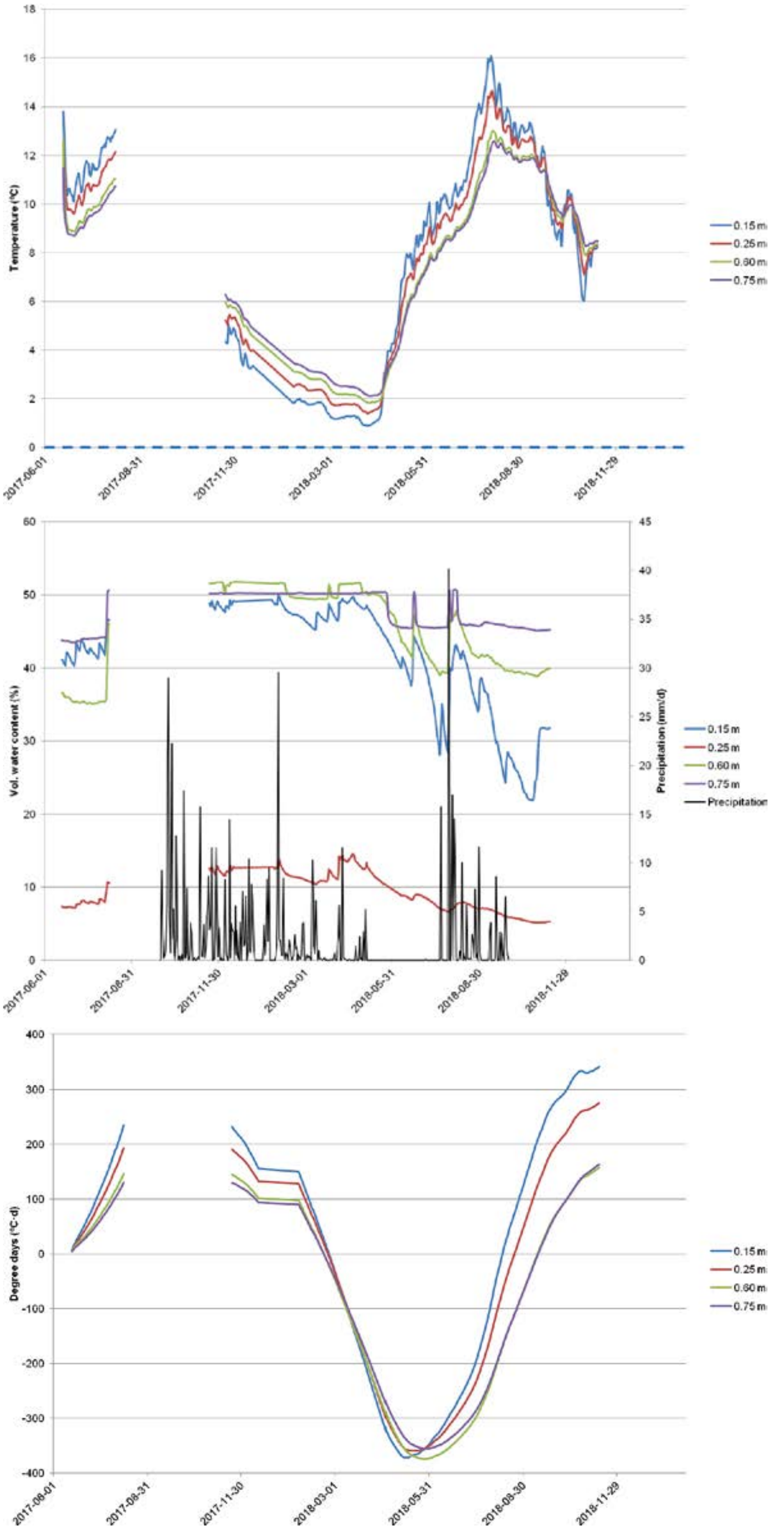


Figure A7-7. *Soil temperature (upper plot) and soil-water content (middle plot) at different depths below ground surface at PFM007874 (note the coherent data gap). The middle plot also shows daily sums of corrected precipitation at the Labbomasten station during the 2017/2018 hydrological year (data are missing for the period May 17 – June 29, 2018). The bottom plot shows cumulative degree days for degrees above 7 °C. The plots show daily averages of high-resolution data.*

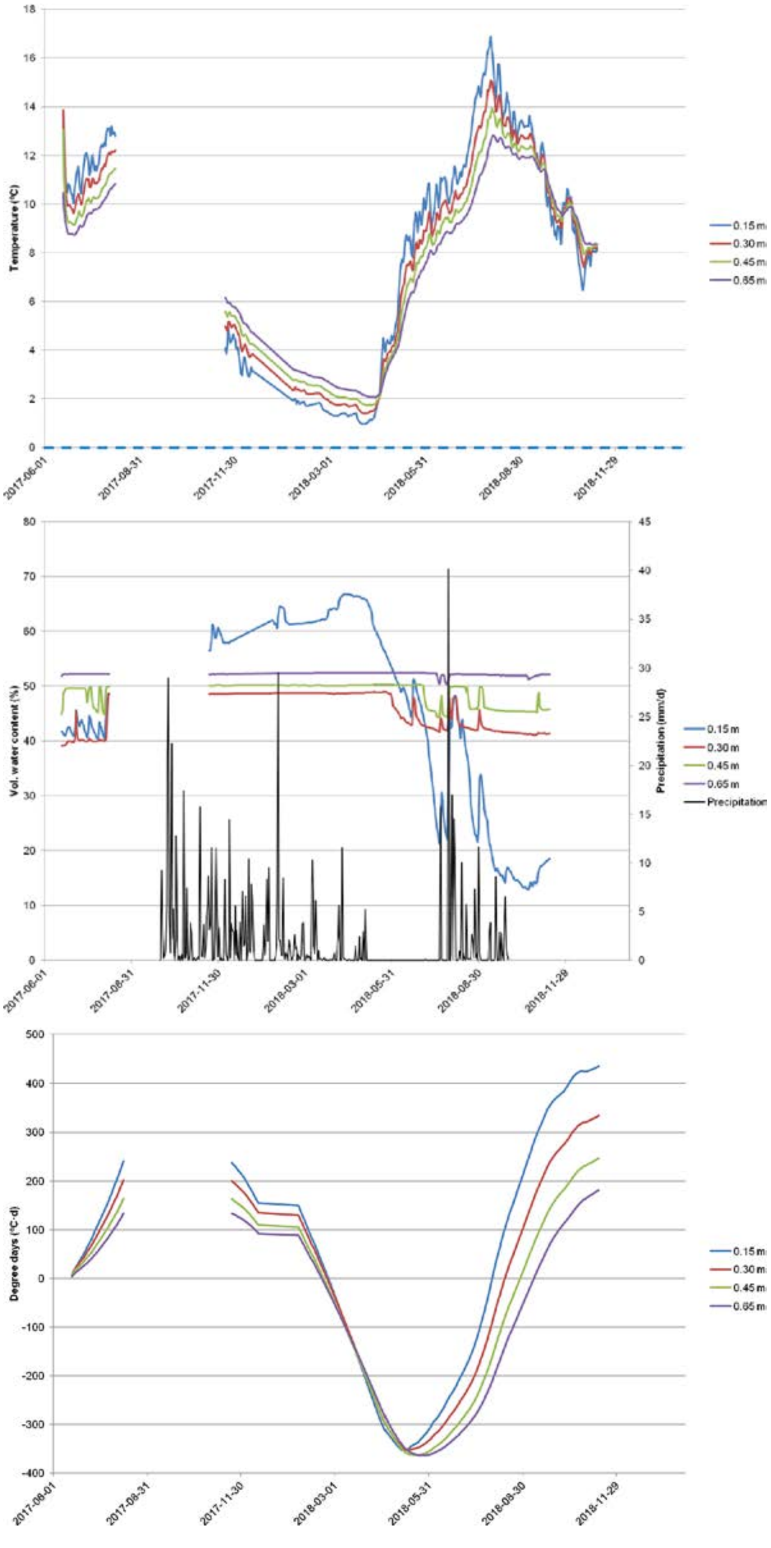


Figure A7-8. *Soil temperature (upper plot) and soil-water content (middle plot) at different depths below ground surface at PFM007875 (note the coherent data gap). The middle plot also shows daily sums of corrected precipitation at the Labbomasten station during the 2017/2018 hydrological year (data are missing for the period May 17 – June 29, 2018). The bottom plot shows cumulative degree days for degrees above 7 °C. The plots show daily averages of high-resolution data.*

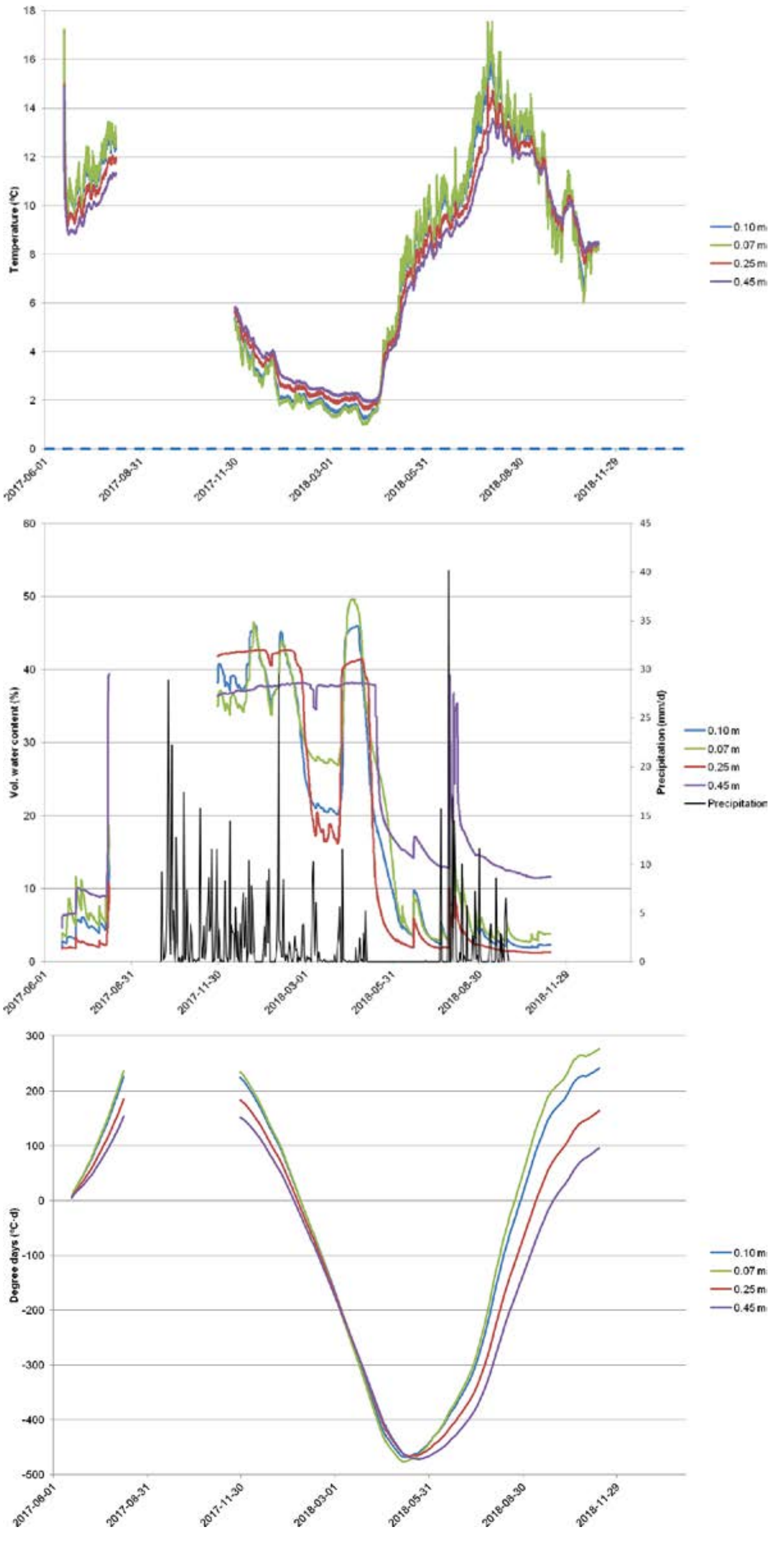


Figure A7-9. *Soil temperature (upper plot) and soil-water content (middle plot) at different depths below ground surface at PFM007876 (note the coherent data gap). The middle plot also shows daily sums of corrected precipitation at the Labbomasten station during the 2017/2018 hydrological year (data are missing for the period May 17 – June 29, 2018). The bottom plot shows cumulative degree days for degrees above 7 °C. The upper and lower plots show high-resolution data.*

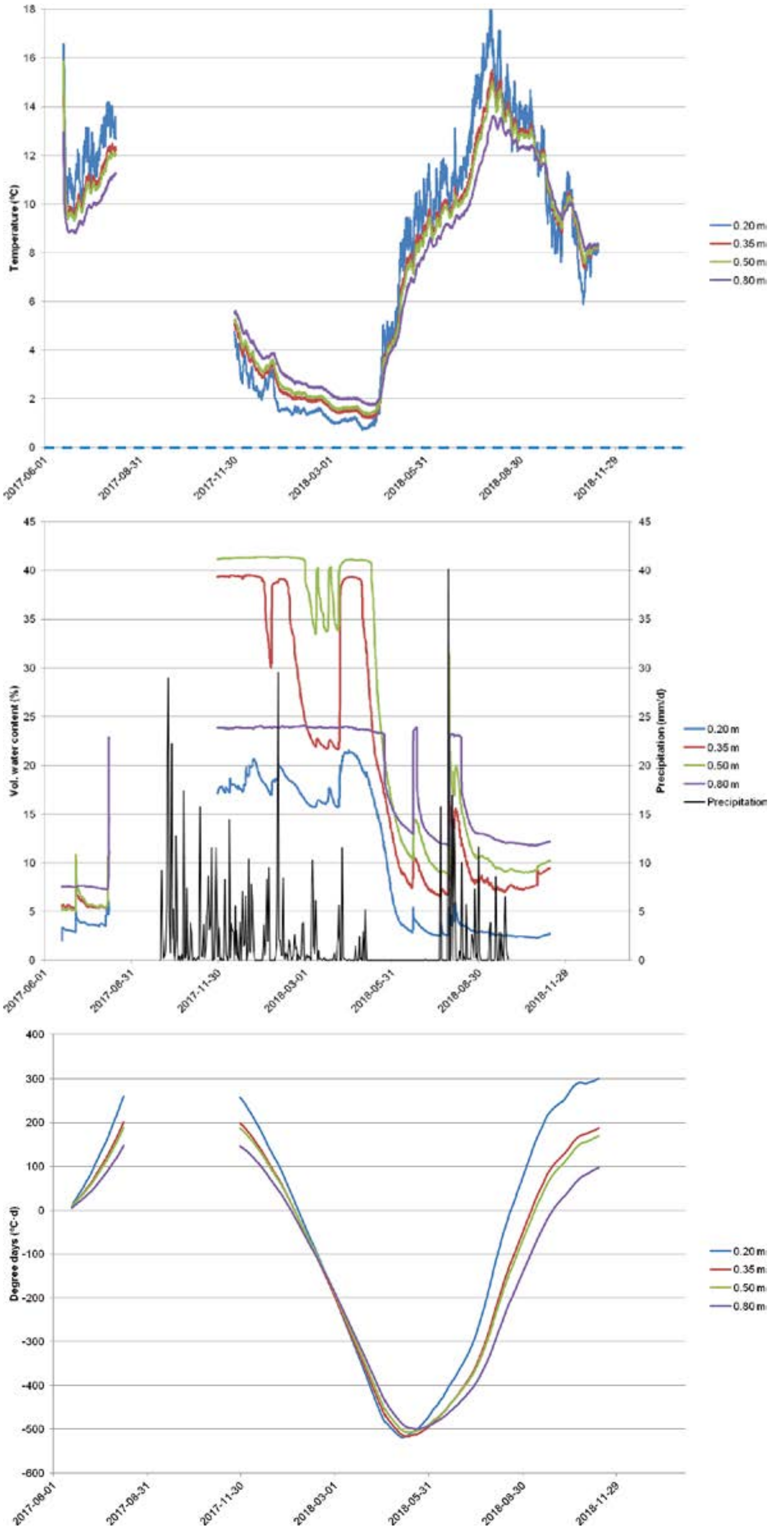


Figure A7-10. *Soil temperature (upper plot) and soil-water content (middle plot) at different depths below ground surface at PFM007877 (note the coherent data gap). The middle plot also shows daily sums of corrected precipitation at the Labbomasten station during the 2017/2018 hydrological year (data are missing for the period May 17 – June 29, 2018). The bottom plot shows cumulative degree days for degrees above 7 °C. The upper and lower plots show high-resolution data.*

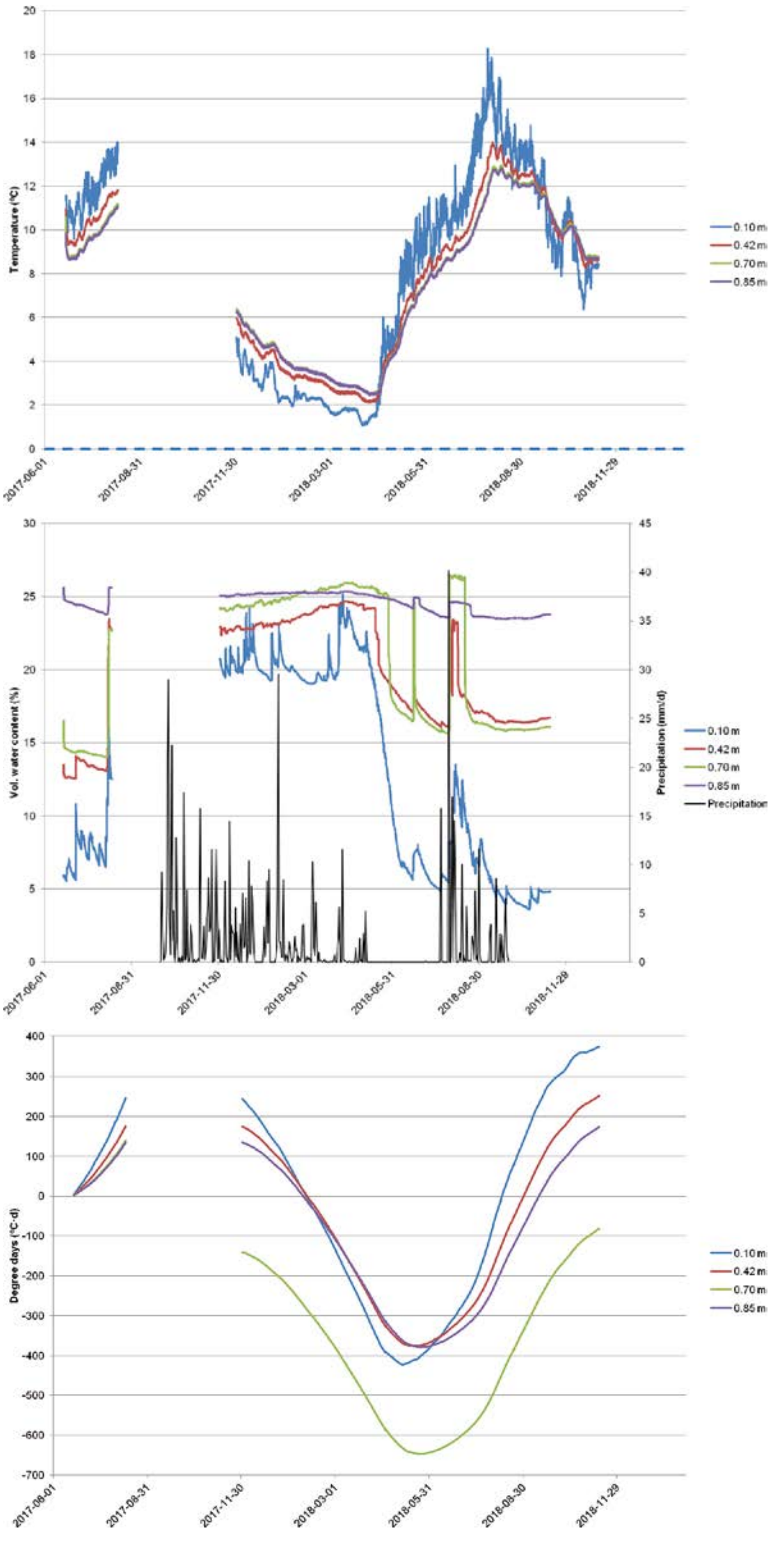


Figure A7-11. *Soil temperature (upper plot) and soil-water content (middle plot) at different depths below ground surface at PFM007878 (note the coherent data gap). The middle plot also shows daily sums of corrected precipitation at the Labbomasten station during the 2017/2018 hydrological year (data are missing for the period May 17 – June 29, 2018). The bottom plot shows cumulative degree days for degrees above 7 °C. The upper and lower plots show high-resolution data.*

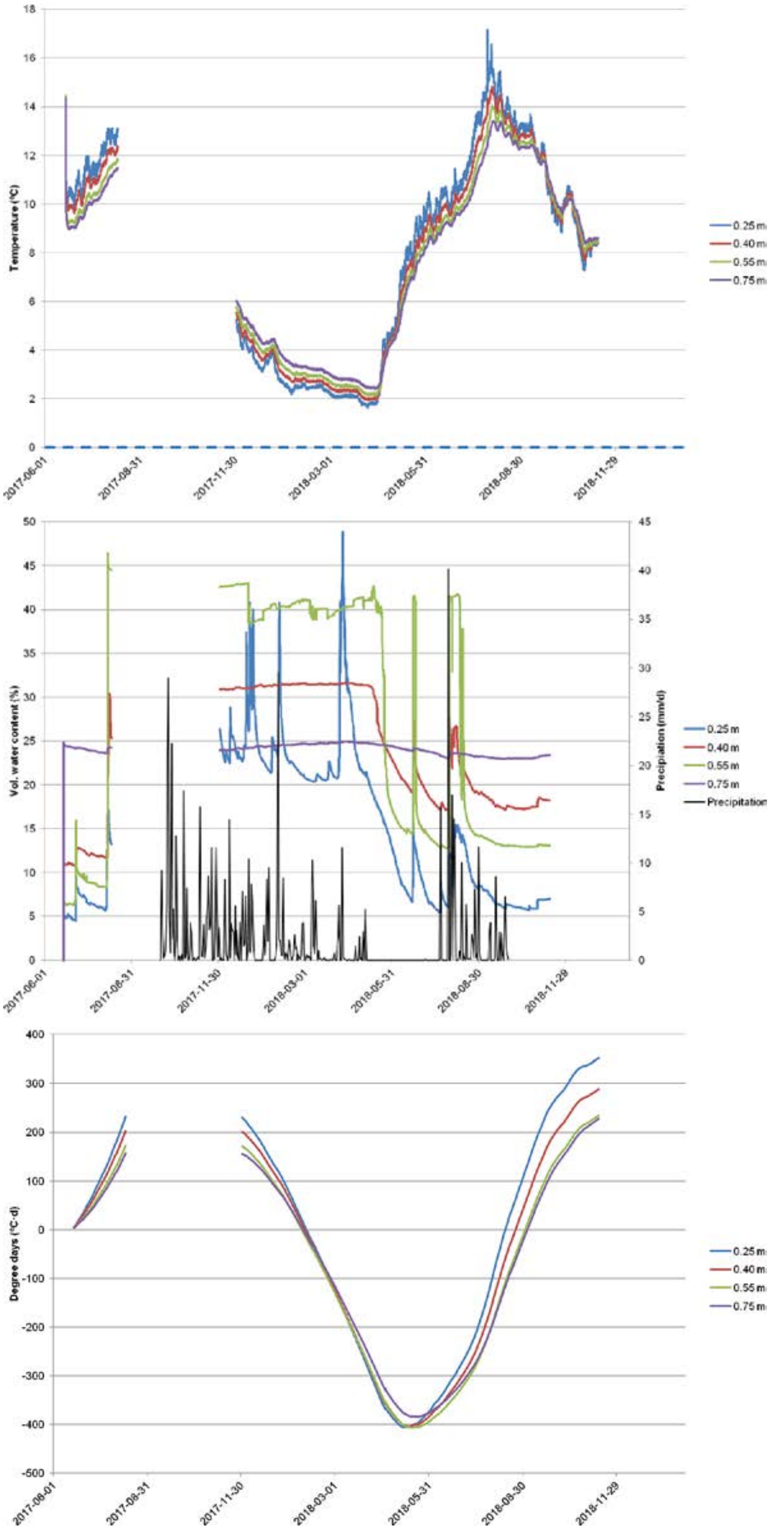


Figure A7-12. Soil temperature (upper plot) and soil-water content (middle plot) at different depths below ground surface at PFM007879 (note the coherent data gap). The middle plot also shows daily sums of corrected precipitation at the Labbomasten station during the 2017/2018 hydrological year (data are missing for the period May 17 – June 29, 2018). The bottom plot shows cumulative degree days for degrees above 7 °C. The upper and lower plots show high-resolution data.

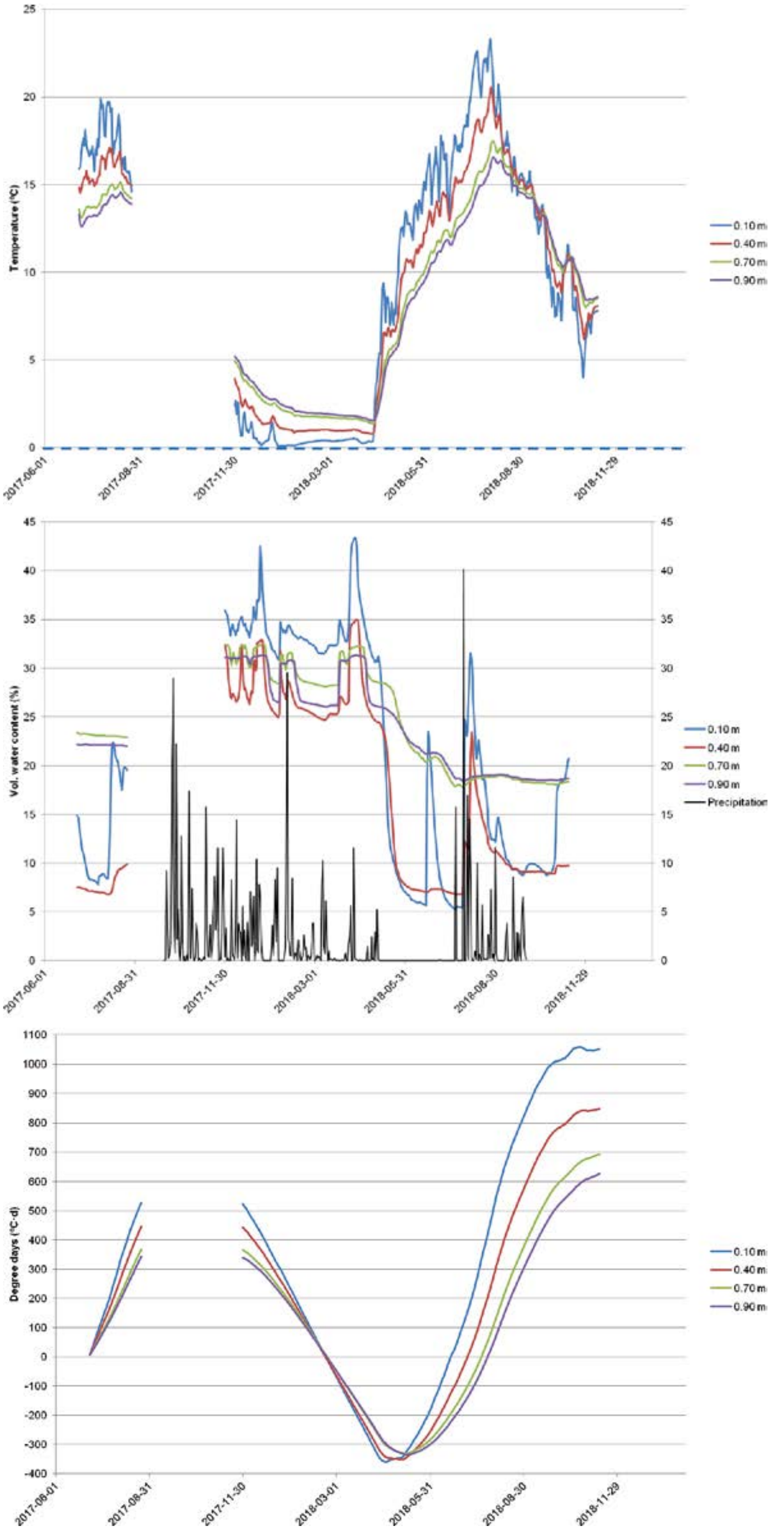


Figure A7-13. *Soil temperature (upper plot) and soil-water content (middle plot) at different depths below ground surface at PFM007880 (note the coherent data gap). The middle plot also shows daily sums of corrected precipitation at the Labbomasten station during the 2017/2018 hydrological year (data are missing for the period May 17 – June 29, 2018). The bottom plot shows cumulative degree days for degrees above 7 °C. The upper and middle plots show daily averages of high-resolution data.*

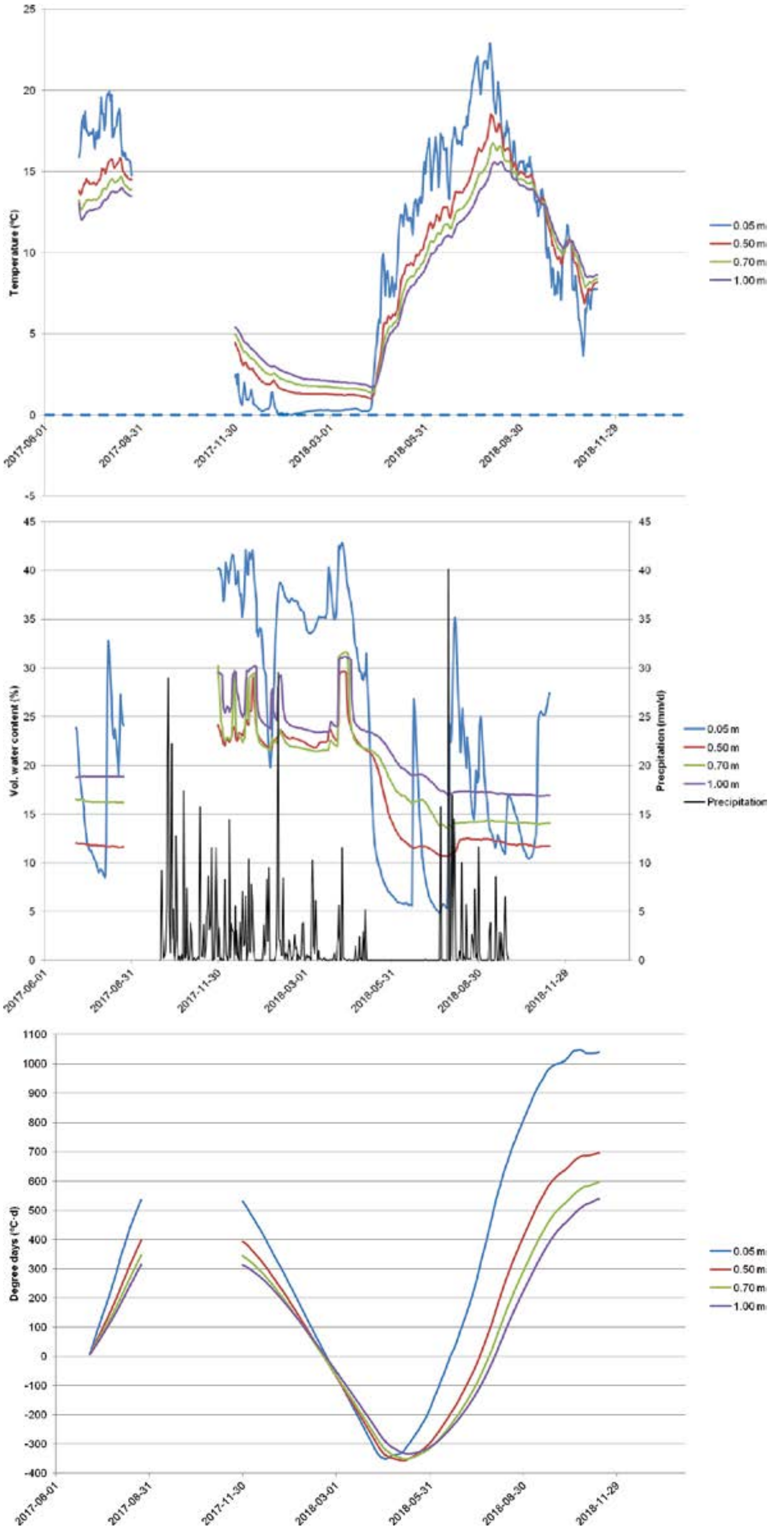


Figure A7-14. *Soil temperature (upper plot) and soil-water content (middle plot) at different depths below ground surface at PFM007881 (note the coherent data gap). The middle plot also shows daily sums of corrected precipitation at the Labbomasten station during the 2017/2018 hydrological year (data are missing for the period May 17 – June 29, 2018). The bottom plot shows cumulative degree days for degrees above 7 °C. The plots show daily averages of high-resolution data.*

Arkitektkopia AB, Bromma, 2019

SKB is responsible for managing spent nuclear fuel and radioactive waste produced by the Swedish nuclear power plants such that man and the environment are protected in the near and distant future.

skb.se

SVENSK KÄRNBRÄNSLEHANTERING