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Hydrological monitoring in Forsmark – surface waters, ground moisture and ground temperature October 1, 2016–September 30, 2017

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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 2016/2017 (October 1, 2016–September 30, 2017). 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 2016/2017 hydrological year, the average discharge was quite low (c 5–10 L/s). The average EC and temperature of the stream water were c 30–40 mS/m and 8–9 °C, respectively. Due to missing data and data excluded as a result of quality control, the hydrological year 2016/2017 is characterised by some long data gaps, in particular water level and hence discharge at the PFM005764 station. It is therefore noted that the statistics for the hydrological year 2016/2017 presented in the report are affected by these data gaps.

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 discharge equations and associated parameters have been checked by independent discharge measurements in 2004–2006, and recently in 2013–2016. Independent discharge measurements need to be performed also in the future. Moreover, it is recommended to make an overview of logger settings, to assure that the stream monitoring produces data with a temporal resolution of at least 1 hour.

The report also provides an overview of and use some results from other hydrology-related monitoring in Forsmark, as illustrative examples on integrated evaluations that may provide insight into near-surface hydrological interactions. Specifically, apart from stream-discharge data, the overview and the integrated evaluations include data from meteorological monitoring and monitoring/observations of "winter parameters" (snow depth and ice coverage), and data from surface-water level and temperature monitoring in lakes and ponds. In addition, the report briefly presents recently installed sensors for monitoring of ground temperature and water content. Data from these installations will be presented and evaluated in forthcoming reports.

Sammanfattning

Denna rapport beskriver mätning 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 2016/2017 (1 oktober 2016–30 september 2017). 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 2016/2017 var den genomsnittliga vattenföringen ganska låg (cirka 5–10 l/s). Bäckvattnets genomsnittliga EC och temperatur var cirka 30–40 mS/m respektive 8–9 °C. Saknade data samt data som baserat på kvalitetskontroll inte överfördes till Sicada innebär att det hydrologiska året 2016/2017 har några långa dataluckor. Detta gäller speciellt vattennivå och vattenföring vid vattenföringsstationen PFM005764. Det ska därför noteras att den statistik för det hydrologiska året 2016/2017 som presenteras i rapporten är påverkad av dessa dataluckor.

Mätrännor och observationsrör har avvägts årligen under perioden 2012–2017, och rekommendationen är årliga avvägningar även i framtiden. Giltigheten för vattenföringsekvationer och tillhörande parametrar har kontrollerats genom oberoende vattenföringsmätningar 2004–2006 och 2013–2016. Oberoende vattenföringsmätningar behöver genomföras även i framtiden. För att säkerställa bäckmätningar med en tidsmässig upplösning på minst 1 timme rekommenderas en översyn av loggerinställningarna.

Rapporten innehåller även en översikt över och använder resultat från andra hydrologirelaterade mätningar i Forsmark, och som illusterar hur integrerade utvärderingar kan ge insikt om hydrologiska processer i ytsystemet. Översikten och de integrerade utvärderingarna inkluderar, förutom vattenföring i bäckarna, meteorologiska mätningar, mätningar/observationer av ”vinterparametrar” (snödjup och istäckning), samt mätningar av ytvattennivå och -temperatur i sjöar och gölar. Rapporten ger även en kortfattad presentation av nyliga installationer av mätsensorer för marktemperatur och vattenhalt. Data från dessa installationer kommer att presenteras och utvärderas i framtida rapporter.

Contents

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, 2016–September 30, 2017. The report also provides an overview of and use 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).

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.*

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, 2016, 2017, 2018) for the period January 1, 2011–September 30, 2016. The monitoring was carried out in accordance with relevant parts of activity plan AP SFK 10-083 (Table 1-2), which is an SKB-internal controlling document. 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 twice during the 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.

Coordinates in this report are given in the coordinate systems RT 90 2.5 gon V/0:15 (X, Y) and RHB 70 (Z), i.e. vertical (Z) coordinates are expressed in terms of elevation (m) above the RHB 70 datum (0 m elevation). Moreover, times are in HMS stored in the time zone GMT+1 (no DST), and this system is used also in this report. SKB is currently making a transition to the coordinate systems SWEREF 99 18 00 (X, Y) and RH 2000 (Z), which will be used in future reports.

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

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

Activity plan	Number	SKBdoc id, version
Hydrologisk och hydrogeologisk monitering 2015–2017	AP SFK 10-083	1464444, ver 2.0
Projekt Kärnbränsleförvaret, quality-control reports		
Monitering Forsmark och SFR – kvalitetskontroll av yt- och grundvattenmonitering Mars–oktober 2016		1579384, ver 1.0
Monitering Forsmark och SFR – kvalitetskontroll av yt- och grundvattenmonitering Oktober 2016–juni 2017		1611609, ver 2.0
Monitering Forsmark och SFR – kvalitetskontroll av yt- och grundvattenmonitering Juni–oktober 2017		1683244, 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 it works under a high degree of submergence (Robinson 1966, Kilpatrick amd 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 (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 in August 2014, including replacement of the small flume (Werner 2016).
- **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.
- **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 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 and PFM002669 refurbishments in 2014 and 2015, 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. 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 2016).

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, is less than ± 2 % for all flumes.

Table 2-1. 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
PFM005764		
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		
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 PFM00574 refurbishment in 2014, the Mitec data logger at that station was switched to a dataTaker DT85 data logger (Werner 2016).

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. Uncompensated water levels, which are available in HMV channels (previously denoted MH) in HMS, 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 (Werner 2016). However, no systematic analysis has yet been performed on the difference in calculated discharge using compensated or uncompensated water levels.

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).

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 2015/2016 hydrological year, the reader is referred to previous data reports (Werner 2014a, b, 2016, 2017, 2018) and reports from independent discharge measurements (Bergqvist 2013, 2014a, b, Werner 2015, 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.

Experiences, inspections and other investigations have led to the conclusion that the gauging stations need to be refurbished 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 of the PFM005764 station (Werner 2016) and the PFM002669 station (Werner 2017) were done during August 2014 and August–September 2015, respectively (Section 2.4.1). Ryman and Strömbeck (2016) 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. Plans for refurbishment of the PFM002667 station are described in Section 2.4.2 and in more detail in Werner (2018).

2.4 Completed and planned station refurbishments

2.4.1 Completed refurbishments

The PFM005764 station was refurbished in August 2014 (Werner 2016), whereas the PFM002669 station was refurbished in August–September 2015 (Werner 2017). Among other improvements, the refurbishments comprised constructions of pools, concrete foundations and cottages above the large flumes. At PFM005764, refurbishements also included replacement of the data logger and installation of an electric heating system (enabled by installation of permament electric supply), and replacement of the small flume.

Werner (2018) provides a continued follow-up (cf Werner 2016, 2017) of the PFM005764 refurbishment, including analysis of water-level and discharge data from the two-year period 2013-08-01–2015-07-31, i.e. one year prior to and one year after the station refurbishment. 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 Drucker pressure sensor. According to current plans, an YSI Waterlog Amazon Bubbler (Smith and Demuzio 2017) will be installed in the observation well at the large flume in early 2018.

2.4.2 Planned refurbishment of the PFM002667 station

As noted in previous monitoring reports (e.g. Werner 2014a, b, 2016, 2017), due to the flat landscape the large flume at PFM002667 generally yields realistic discharge values only up to c 55 L/s. It probably also works satisfactory also at higher discharges in the rising phase of a flow peak, if the downstream wetland is not filled up. 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 leads to erosion damages on the gravel bed that forms its foundation (cf Section 2.3). 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.

Despite the 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. Specifically, a replacement would imply that only one flume needs to be calibrated and maintained, and it would also remove occurences of artificial, short-term discharge fluctuations. Werner (2018) 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. According to current plans, the two flumes at PFM002667 will be replaced by a single flume during 2018.

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 approximately 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. During the hydrological year October 1, 2016–September 30, 2017, manual measurements of the water depth at the upstream edge of each flume were done using a folding rule on 6–8 occasions (the number of occasions varies between gauing stations), and EC and temperature were measured using a hand-held instrument (HACH HQ 14D) on 3–4 occasions. Hence, frequencies of field inspections and measurements were quite low during the hydrological year 2016/2017 (see Appendices 1, 3 and 4).

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 is a factor for conversion from water pressure to water level. This 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 September 30, 2017 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 September 30, 2017. 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
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
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
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)
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 (PFM002667 and -68) or inside (PFM005764 and PFM002669, after refurbishments) of screened tubes, located downstream or upstream of the flumes. 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. No changes of calibration constants have been done during the 2016/2017 period (constants were changed in connection to the PFM005764 refurbishment in August 2014).

3.3.3 Recording interval

Recording intervals were very irregular, generally varying between 1 minute and 2 hours. This implies that hourly values of calculated discharge are missing during periods when the water-level recording interval is longer than 1 hour. It is therefore required to make an overview of logger settings, to assure that the stream monitoring produces data with a temporal resolution of at least 1 hour.

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, 2016–September 30, 2017 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 PFM005764 (2014) and PFM002669 (2015); 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 data gaps were reduced by using the discharge calculated for the large flume, also when the calculated discharge was < 16 or < 20 L/s, in cases when data were missing for the small flume (Figure 3-1). For instance, for PFM005764 the calculated discharge is thereby overestimated by c 0.5–2 L/s when the discharge is less than c 5 L/s, and underestimated by c 0.5–5 L/s in the approximate discharge interval 5–16 L/s.

- PFM005764 and -2667 (cf Figure 3-1):
  - 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.

Gauging station	Bottom elevation (m) of upstream edge	Elevation (m) 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	1.502	1.518
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.

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). The highest 2016/2017 discharge at PFM002667 was only c 20 L/s (Appendix 3), i.e. less than the discharge when the downstream wetland typically is filled up.

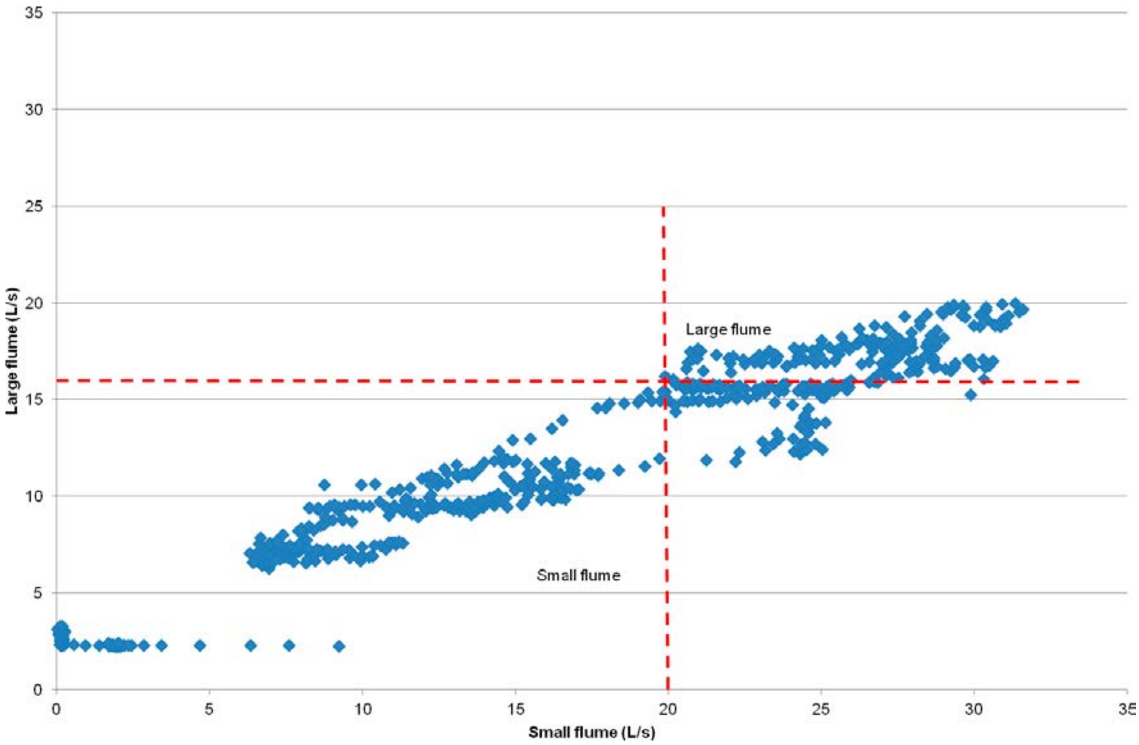


Figure 3-1. Cross plot of calculated small- and large-flume discharges at gauging station PFM005764. Discharge equals the large-flume discharge if the small-flume discharge is above 20 L/s and the large-flume discharge is above 16 L/s (red dashed lines). Typically, no discharge value is reported in this case if the large-flume discharge is less than 16 L/s. However, data gaps due to missing small-flume discharges are here reduced by setting discharge equal to the large-flume discharge, also when the calculated large-flume discharge was less than 16 or 20 L/s. The plot also illustrates artificial discharge fluctuations at transitions between small and large flumes.

3.4 Quality control

3.4.1 Regular quality control

The regular quality control concerns water-level data, neither EC nor temperature data (cf quality-control reports in Table 1-1). Once every week, it was checked that loggers were sending data and that all sensors were in function. Another check was performed twice during the data period of this report. For the 2016/2017 period no water-level data were excluded from the HMS to Sicada data transferral, and at time of this report data have been approved for transferral to Sicada up to April–October 2017 for the different stations and flumes, as part of the regular quality control.

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 November 2, 2016–January 27, 2017, at which time the pressure transducer was replaced. Water-level data are approved to (and including) Apr. 20, 2017.
  - Large flume: Water-level data are approved to (and including) Oct. 11, 2017.
- **PFM002667:**
  - Small flume: Water-level data are approved to (and including) Jun. 11, 2017.
  - Large flume: Water-level data are considered uncertain and have not been approved September 7–November 3, 2016. Water-level data are approved to (and including) Oct. 10, 2017.
- **PFM002668:** Water-level data have not been approved March 10–14, 2017 due to large, unexplained water-level fluctuations. Water-level data are approved to (and including) Oct. 10, 2017.
- **PFM002669:** Water-level data from both flumes are approved to (and including) Oct. 10, 2017.

3.4.2 Quality control of the 2016/2017 dataset

Apart from the regular quality control described above, an additional quality control was done of the whole 2016/2017 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 2016/2017 dataset.

Gauging station (flume)	Dates and times (YYYY-MM-DD hh:mm)	Reason for exclusion (WL = water level)
PFM005764	No data excluded	
PFM002667 (large flume)	2017-05-28 17:00–23:00	WL large flume > WL small flume (likely “frozen” data values for large flume)
PFM002668	No data excluded	
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 2016/2017 dataset.

Gauging station	Dates and times (YYYY-MM-DD hh:mm)	Reason for exclusion (WL = water level)
PFM005764	2016-10-09 14:43–2016-10-10 06:10	Rapidly falling/low EC values
PFM005764	2016-11-07 15:07–15:27	High/low values
PFM005764	2016-11-21 09:30	Single low value
PFM005764	2017-07-31 00:08–2017-08-06 02:40	Low/negative EC values (likely due to dry flume)
PFM002667	2016-11-07 12:40	High EC (likely due to maintenance)
PFM002667	2017-06-22 14:40–2017-06-24 07:10	Fluctuating/negative EC values (likely due to dry flume)
PFM002667	2017-06-28 11:40–2017-07-03 22:20	Negative EC values (likely due to dry flume)
PFM002667	2017-07-06 19:50–2017-08-08 06:20	Negative EC values (likely due to dry flume)
PFM002667	2017-08-29 16:40–2017-08-31 00:30	Negative EC values (likely due to dry flume)
PFM002667	2017-08-31 06:00–2017-09-03 12:50	Negative EC values (likely due to dry flume)
PFM002668	2016-11-21 08:50	High EC (likely due to maintenance)
PFM002668	2017-06-09 13:10–17:40	High EC (likely due to maintenance)
PFM002668	2017-07-02 05:30–2017-07-03 16:10	Negative EC (likely due to dry flume)
PFM002668	2017-07-14 02:10–2017-08-05 12:30	Negative EC (likely due to dry flume)
PFM002668	2017-08-14 10:30–2017-08-19 10:30	Negative EC (likely due to dry flume)
PFM002668	2017-08-20 07:30–2017-08-31 09:40	Negative EC (likely due to dry flume)
PFM002668	2017-09-07 05:40–2017-09-09 23:30	Negative EC (likely due to dry flume)
PFM002668	2017-09-11 13:50–2017-09-12 07:10	Negative EC (likely due to dry flume)
PFM002668	2017-09-13 02:50–2017-09-14 02:40	Negative EC (likely due to dry flume)
PFM002668	2017-09-14 22:50–2017-09-15 03:30	Negative EC (likely due to dry flume)
PFM002668	2017-09-16 04:30–2017-09-19 12:20	Negative EC (likely due to dry flume)
PFM002669	2016-11-01 01:00–2016-11-08 15:00	Negative EC
PFM002669	2016-11-08 17:00–2016-11-09 14:00	Negative EC
PFM002669	2017-07-08 17:40–2017-07-09 13:50	Negative EC
PFM002669	2017-07-12 19:40–2017-07-18 10:50	Negative EC
PFM002669	2017-07-19 16:30–2017-08-05 23:40	Negative EC
PFM002669	2017-08-16 10:20–2017-08-19 15:30	Negative EC
PFM002669	2017-08-23 14:50–2017-08-31 19:40	Negative EC

Table 3-5. Temperature data excluded from the HMS to Sicada data transferral, as a result of the quality control of the 2016/2017 dataset.

Gauging station	Dates and times (YYYY-MM-DD hh:mm)	Reason for exclusion (WL = water level)
PFM005764	2017-07-30 00:09–2017-08-06 23:33	High/fluctuating temperature values (likely due to dry flume)
PFM002667	2017-06-22 00:00–2017-08-04 23:50	High/fluctuating temperature values (likely due to dry flume)
PFM002668	2017-05-27 00:30–2017-05-28 23:50	High/fluctuating temperature values (likely due to dry flume)
PFM002669	2017-07-08 00:00–2017-08-03 23:50	High/fluctuating temperature values (likely due to dry flume)

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 2013), in May and June 2014 (Edvardson 2014), in June 2015 (Edvardson 2015), in May 2016 (Ohrzén 2016), and in May–June 2017 (Hermansson 2017). The results of the levellings 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 measuements 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 Plan (Table 1-2) states that manual water-depth measurements are to be performed at least every second week; the measurement frequency has later been adjusted to once per month. However, such measurements were only done at 6–8 occasions during the period October 1, 2016–September 30, 2017 (Section 3.2). It is recommended that sufficient resources are allocated so that routines stated in the Activity Plan can be followed.

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 stations PFM005764 and -2667:

- **PFM005764:**
  - Small flume: No water-level data are approved after April 20, 2017.
  - Large flume: There is a water-level data gap November 2, 2016–January 27, 2017 (not approved).
- **PFM002667:**
  - Small flume: No water-level data are approved after June 11, 2017.
  - Large flume: There is a water-level data gap (not approved) September 7–November 3, 2016.
- **PFM002668:** There is a water-level data gap March 10–14 (not approved).
- **PFM002669:** There are no water-level data gaps.

Appendix 2 presents high-resolved water-level data from the four gauging stations during the 2016/2017 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. However, PFM002669 flume-bottom levels were levelled in 2016, subsequent to the station refurbishment (Werner 2017). These flume-bottom levels are used for discharge calculation from the refurbishment and onwards, i.e. from September 15, 2015.

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 2016/2017 period, calculated based on the discharge equations of Table 2-1. Missing and excluded data, irregular recording intervals (Section 3.3.3), and flume-specific discharge intervals (Section 3.3.4) imply that hourly average discharge data are missing for 48 % of the time for the PFM005764 station during the period October 1, 2016–September 30, 2017. The corresponding fraction for the other stations is 22–29 %. Average, minimum and maximum discharges, affected by these large data gaps, are shown in Table 4-1. As illustrated in Figure 4-1 (gauging station PFM005764) missing hourly data are rather evenly distributed across the hydrological year. It is therefore required to make an overview of logger settings, to assure that the stream monitoring produces data with a temporal resolution of at least 1 hour.

Table 4-1. Average, minimum and maximum discharges (screened data, rounded to integers) during the hydrological year October 1, 2016–September 30, 2017. The statistics are affected by data gaps (data are missing in HMS), in particular for the PFM005764 and -2667 stations.

	PFM005764	PFM002667	PFM002668	PFM002669
Average discharge (L/s)	10	5	4	6
Min. discharge (L/s)	0	0	0	0
Max. discharge (L/s)	42	21	22	33
Missing hourly values (%)	48	29	22	27

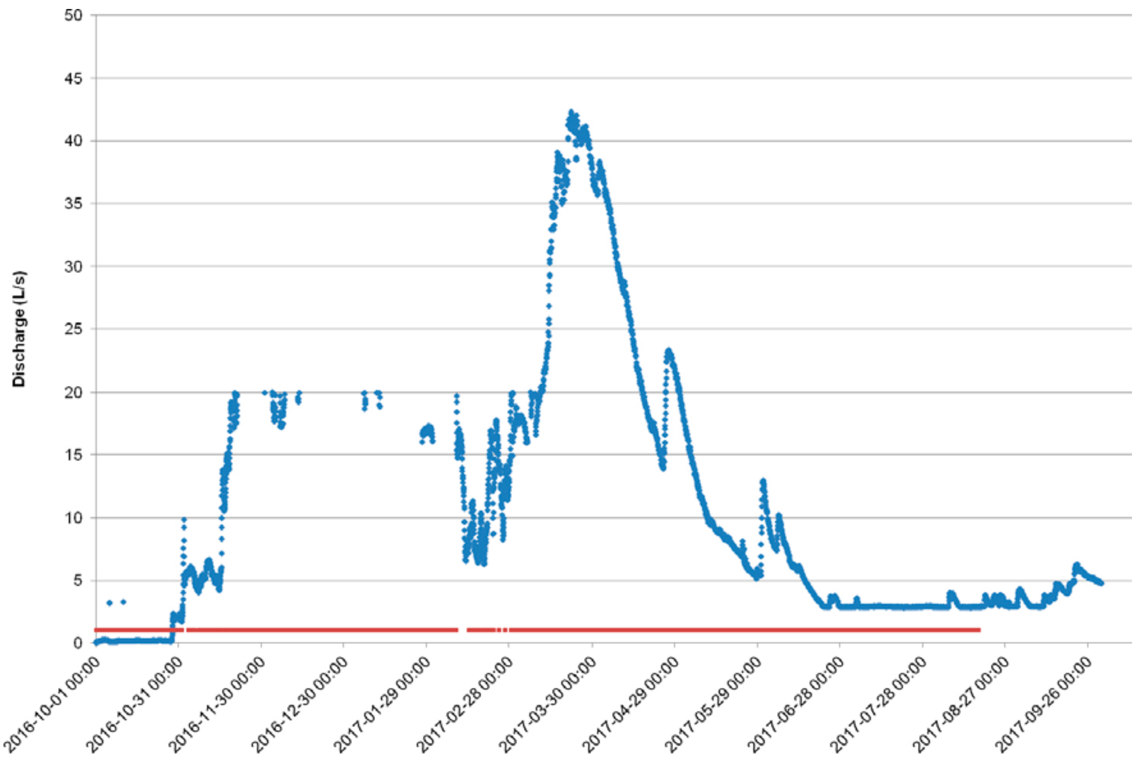


***Figure 4-1.** Hourly average stream discharge at gauging station PFM005764 for the period Oct. 1, 2016–Sep. 30, 2017 (cf Appendix 3). The red dots represent hours with missing discharge data.*

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 2016/2017 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 2016/2017 dataset (Section 3.4.2), EC data were excluded from the HMS to Sicada data transferral in connection to maintenance and 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, 2016–September 30, 2017. The statistics are affected by data gaps.

	PFM005764	PFM002667	PFM002668	PFM002669
Average EC (mS/m)	44	34	33	32
Min. EC (mS/m)	10	8	6	9
Max. EC (mS/m)	66	56	98	46

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 2016/2017 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 2016/2017 dataset (Section 3.4.2), EC data were excluded from the HMS to Sicada data transferral during periods with high or fluctuating temperature values.

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, 2016–September 30, 2017. The statistics are affected by data gaps.

	PFM005764	PFM002667	PFM002668	PFM002669
Average temp. (°C)	9	8	9	8
Min. temp. (°C)	–1	–1	–1	–3
Max. temp. (°C)	24	23	22	22

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 put attention to data gaps, data uncertainties and required/performed changes of monitoring methods or installations. Moreover, recurrent monitoring-data evaluations are important for maintainance 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 on integrated evaluations that may provide insight into near-surface hydrological interactions. Similar integrated evaluations were presented in the 2015 and 2015/2016 monitoring-data reports (Werner 2017, 2018). For instance, these previous evaluations showed that stream discharge and ground- and surface-water levels increase 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 leads to gradually decreasing responses of discharge and ground- and surface-water levels to precipitation events.

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) that was decommissioned in June 2015. The present report uses results of meteorological monitoring reported in Jones and Kindell (2017) and Jones and Björck (2018).

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 (2017).

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 (2018). In addition, automatic water-temperature monitoring was done in natural and constructed ponds during the periods Apr.–Oct. 2016 and Apr.–Oct. 2017. For further details on the water-temperature monitoring, see Section 5.4.

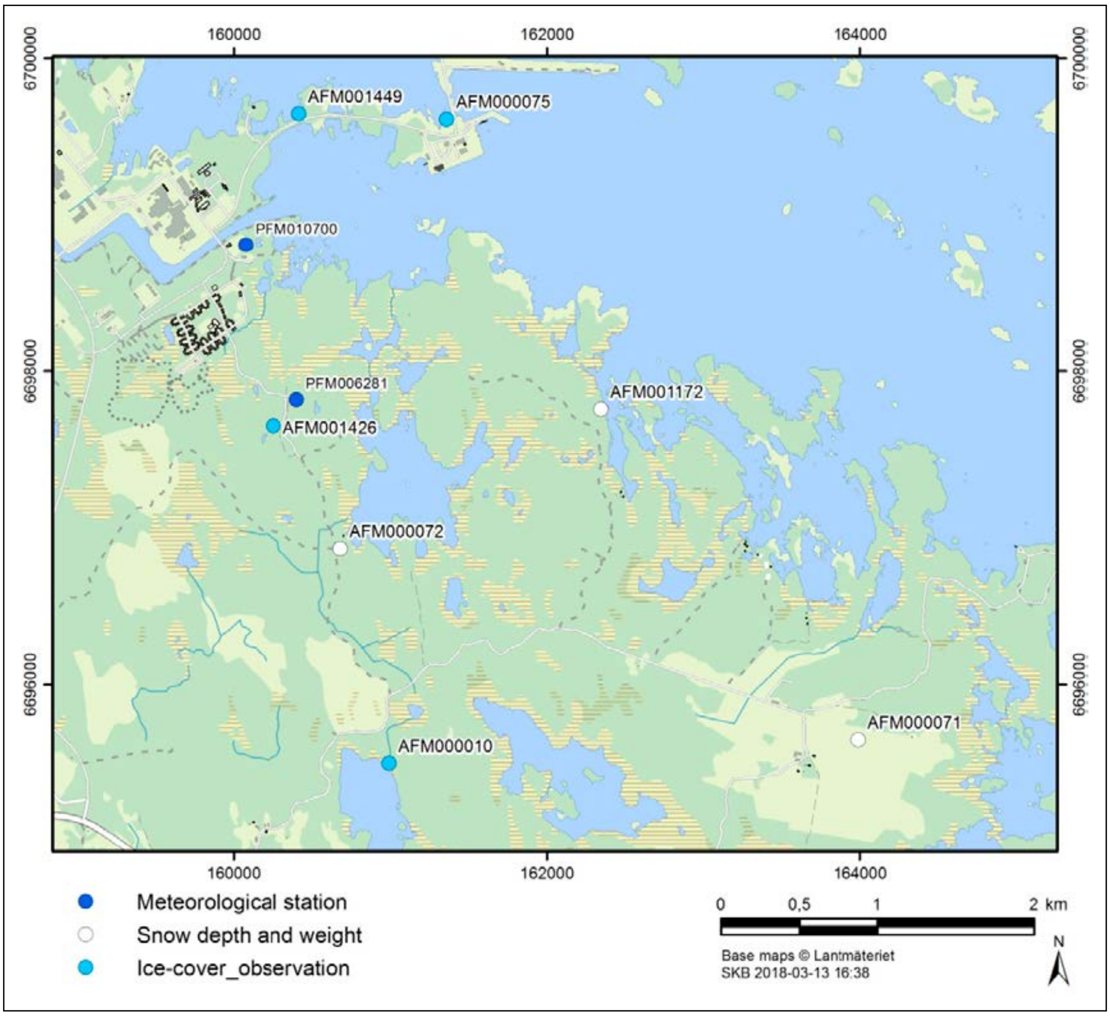


Figure 5-1. *Locations of meteorological stations and winter-time observations of snow depth/weight and ice cover.*

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
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
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)
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
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)

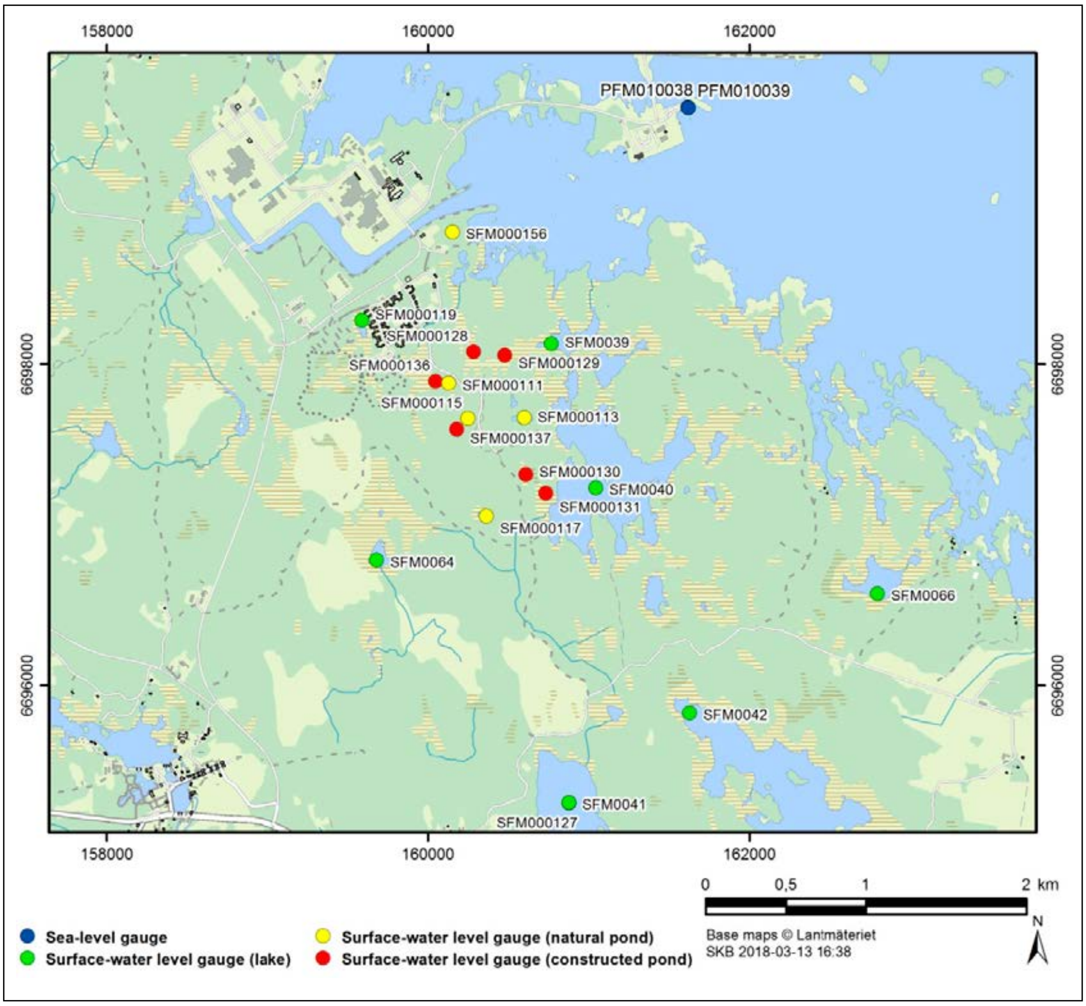


Figure 5-2. *Locations of surface-water level gauges in lakes and natural and constructed ponds, and SKB's (PFM010038) and SMHI's (PFM010039) sea-level gauges.*

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

Figure 5-3 plots daily average surface-water levels for all gauges listed in Table 5-1, including sea level measured at the SKB and SMHI gauging stations. 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 SKB and SMHI sea-level gauges demonstrate identical variations, and that the sea level may rise above threholds and influence surface-water levels of near-coastal lakes and ponds (e.g. SFM0039 in Lake Norra Bassängen and SFM000156 in pond 12).

Figure 5-4 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 5-5. Specifically, the figure shows that surface-water levels and stream discharge rise during periods of increasing cumulative precipitation sums.

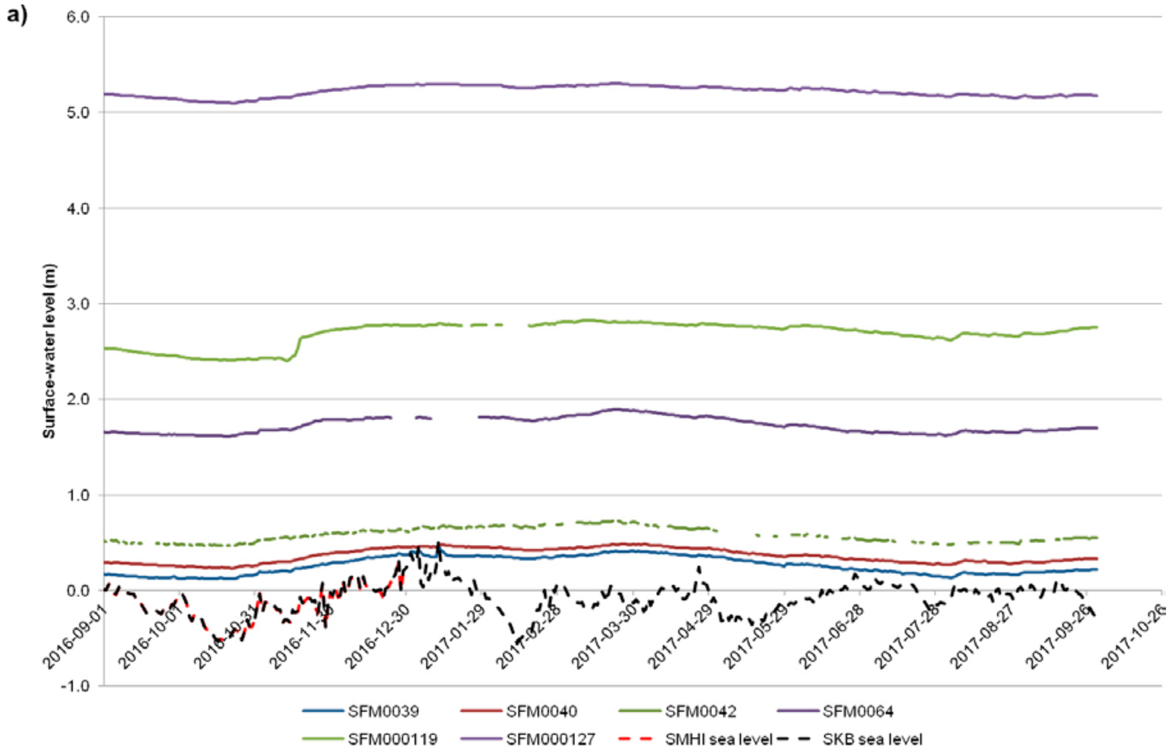


Figure 5-3. *Daily average surface-water levels (m, RHB 70). a) Surface-water levels in lakes and sea level measured at the SKB and SMHI gauging stations (cf Table 5-1). Note that the SKB and SMHI sea-level graphs coincide. b) Surface-water levels in lakes, excluding the SFM000127 gauge (Lake Eckarfjärden) for improved clarity. c) Surface-water levels in natural and constructed ponds.*

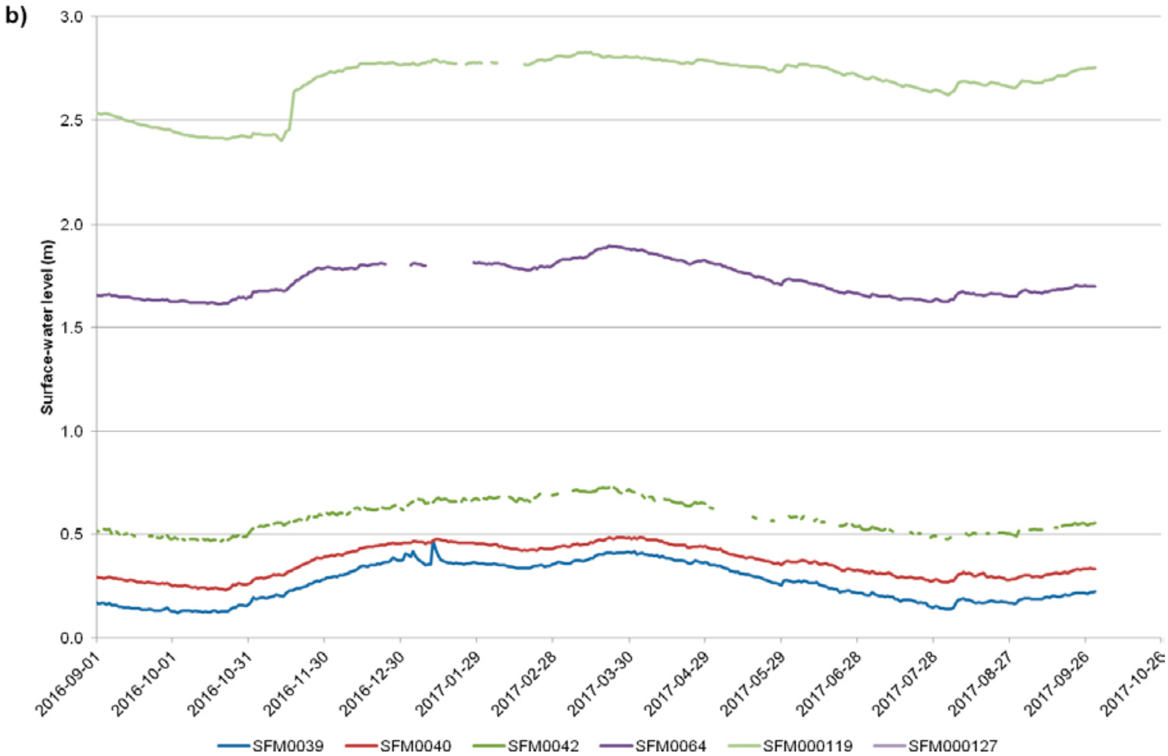


Figure 5-3. *Continued.*

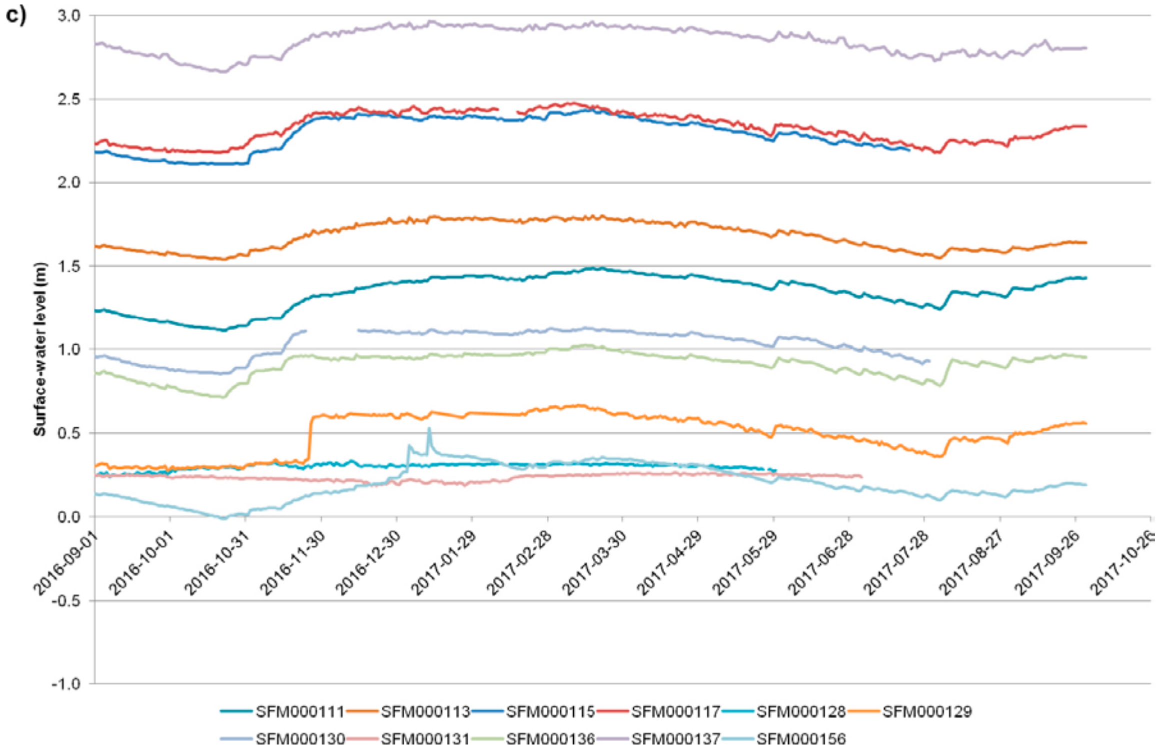


Figure 5-3. *Continued.*

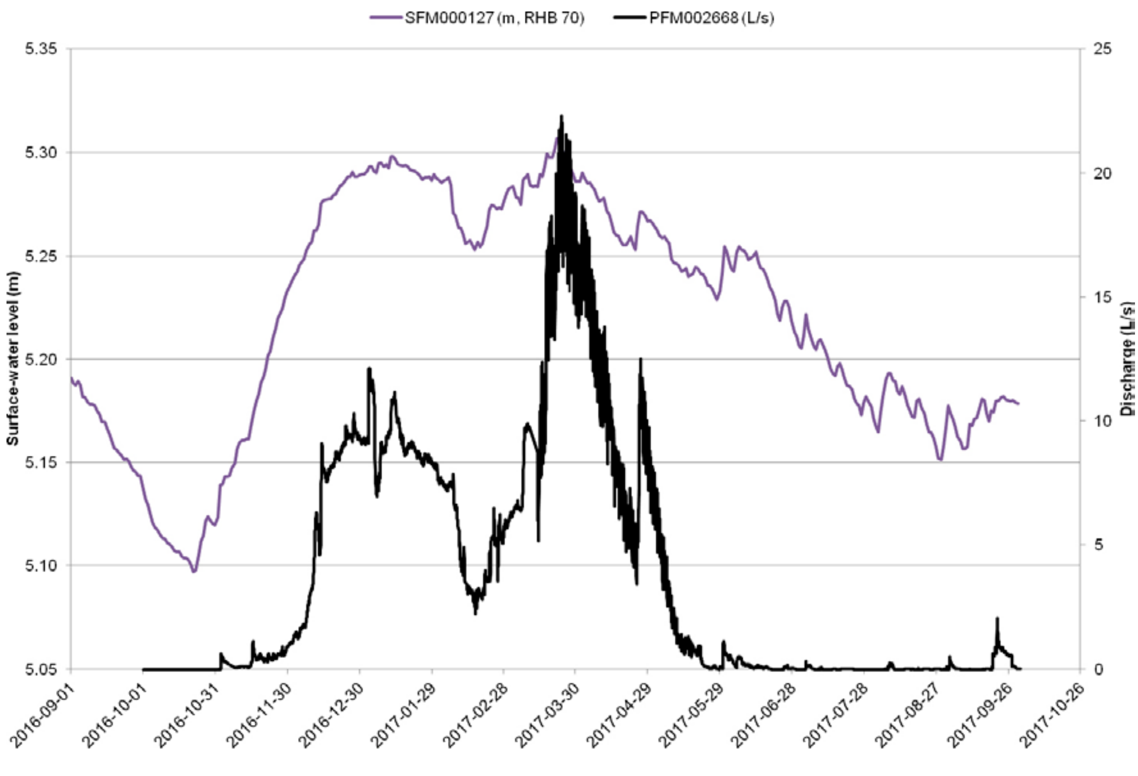


Figure 5-4. *Daily average surface-water level (m, RHB 70) at PFM000127 in Lake Eckarfjärden (upstream from stream-gauging station PFM002668) and discharge at PFM002668.*

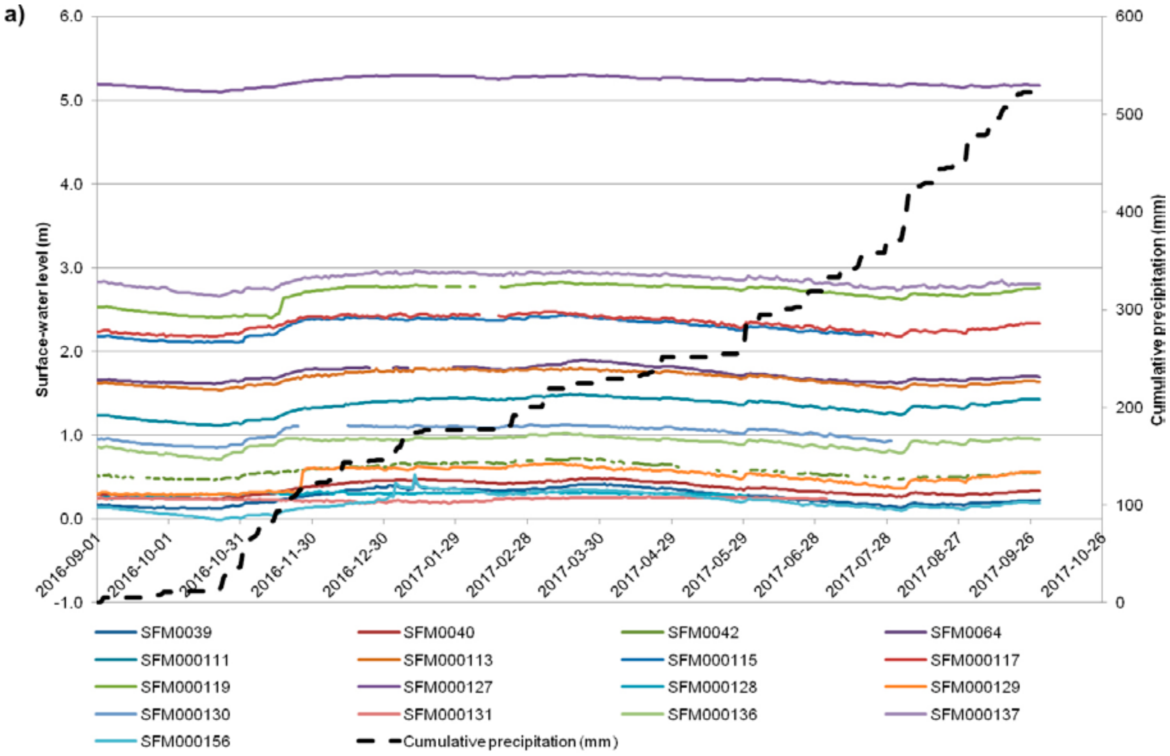


Figure 5-5. *a) Daily average surface-water levels (m, RHB 70) and cumulative sum of corrected precipitation measured at the Labbomasten meteorological station. b) Daily average surface-water level at PFM000127 in Lake Eckarfjärden (upstream from stream-gauging station PFM002668) and cumulative sum of corrected precipitation. c) Daily average stream discharge at gauging station PFM002668 and cumulative sum of corrected precipitation.*

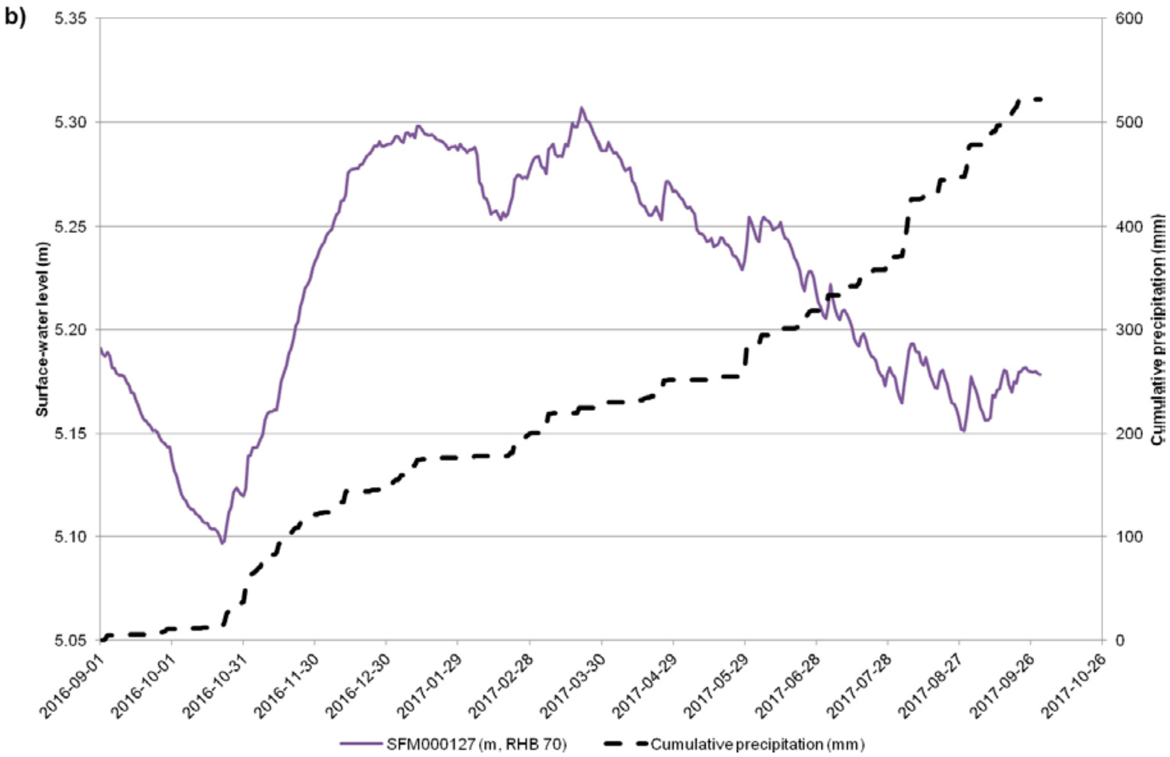


Figure 5-5. *Continued.*

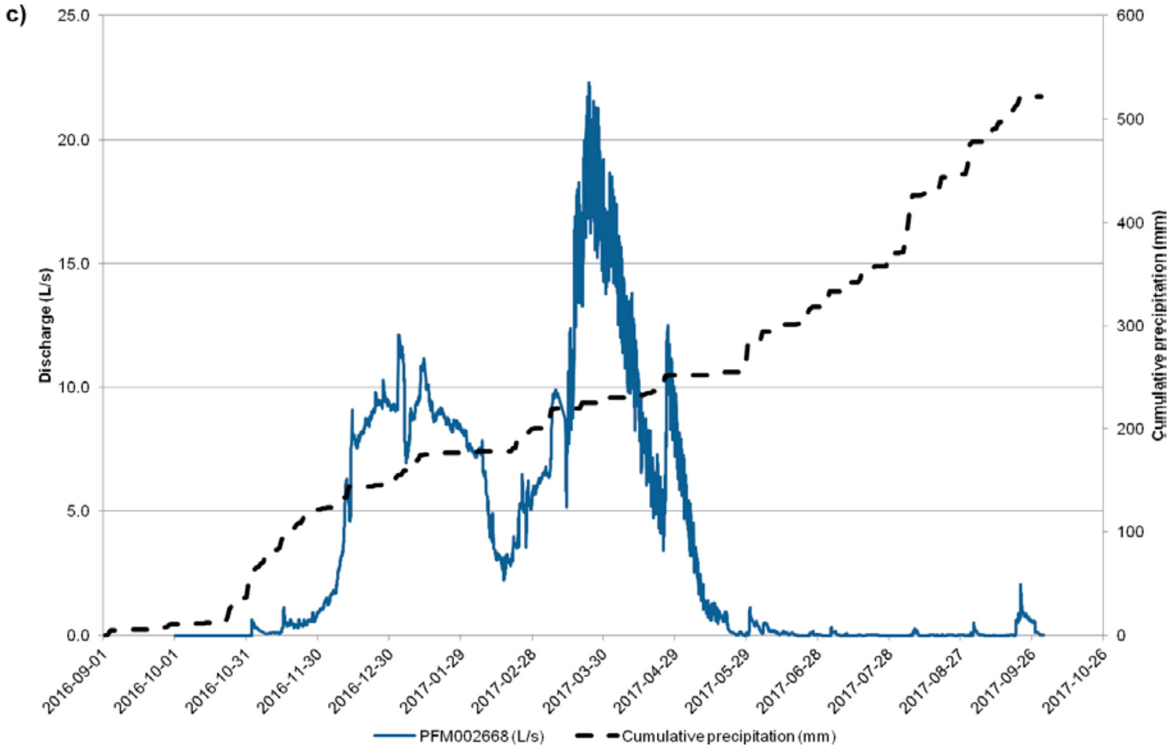


Figure 5-5. *Continued.*

The large influence of ice and snow melt on surface-water levels and stream discharge is shown in Figure 5-6. The figure indicates the ice-covered period in Lake Eckarfjärden (upstream of PFM002668) and the average snow depth (see Section 5.1.1). In particular, the PFM002668 stream discharge (Figure 5-6 b) and the surface-water level in Lake Eckarfjärden (Figure 5-6 c) reaches their annual maxima at the end of the ice- and snow covered period in the end of March/beginning of April, when precipitation is relatively modest (cf Figure 5-5).

As shown in Figure 5-7, surface-water levels and stream discharge decrease during late spring (after the end of the spring-melt period) and during summer. During this period, evapotransporation processes become gradually more active, driven by day temperatures of some 10 °C from April to mid-May, and around 15–20 °C from mid-May to mid-September.

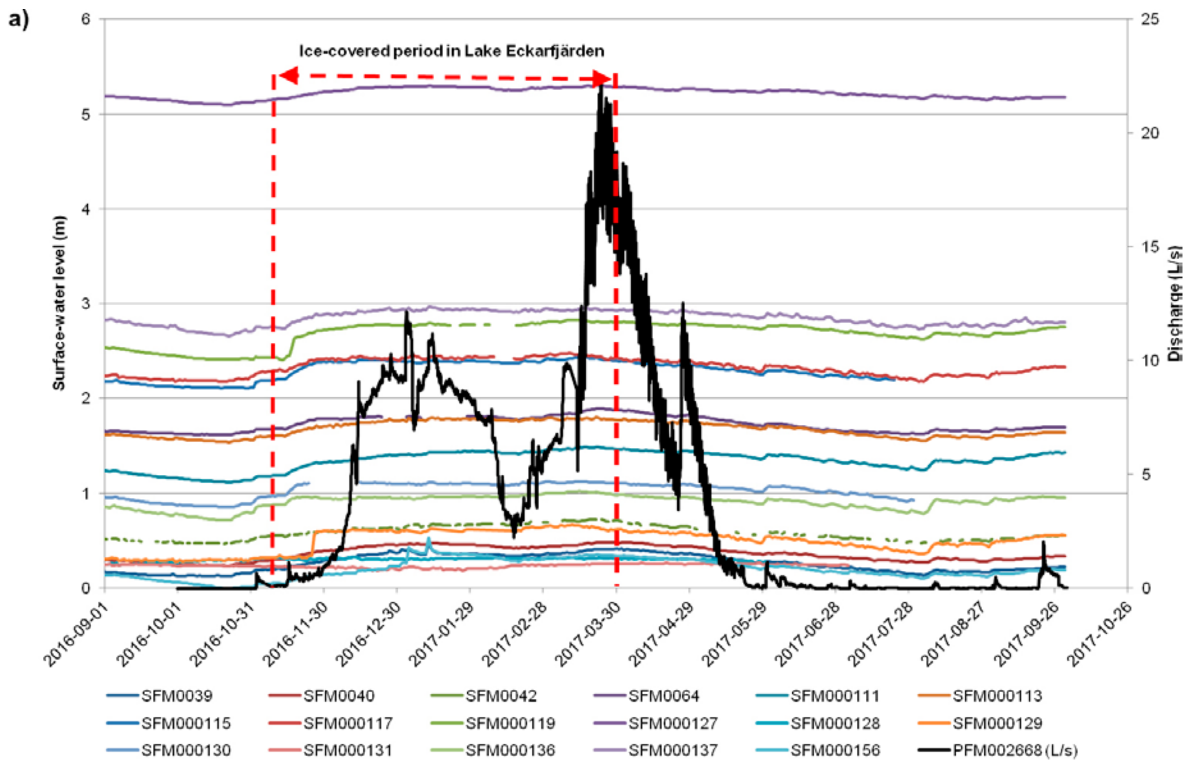


Figure 5-6. *a) Daily average surface-water levels (m, RHB 70) and discharge at stream-gauging station PFM002668. The figure also indicates the ice-covered period in Lake Eckarfjärden (upstream of PFM002668). b) Daily average stream discharge at gauging station PFM002668 (downstream from Lake Eckarfjärden), ice-covered period in Lake Eckarfjärden and average snow cover. c) Daily average surface-water level (m, RHB 70) at PFM000127 in Lake Eckarfjärden and average snow cover.*

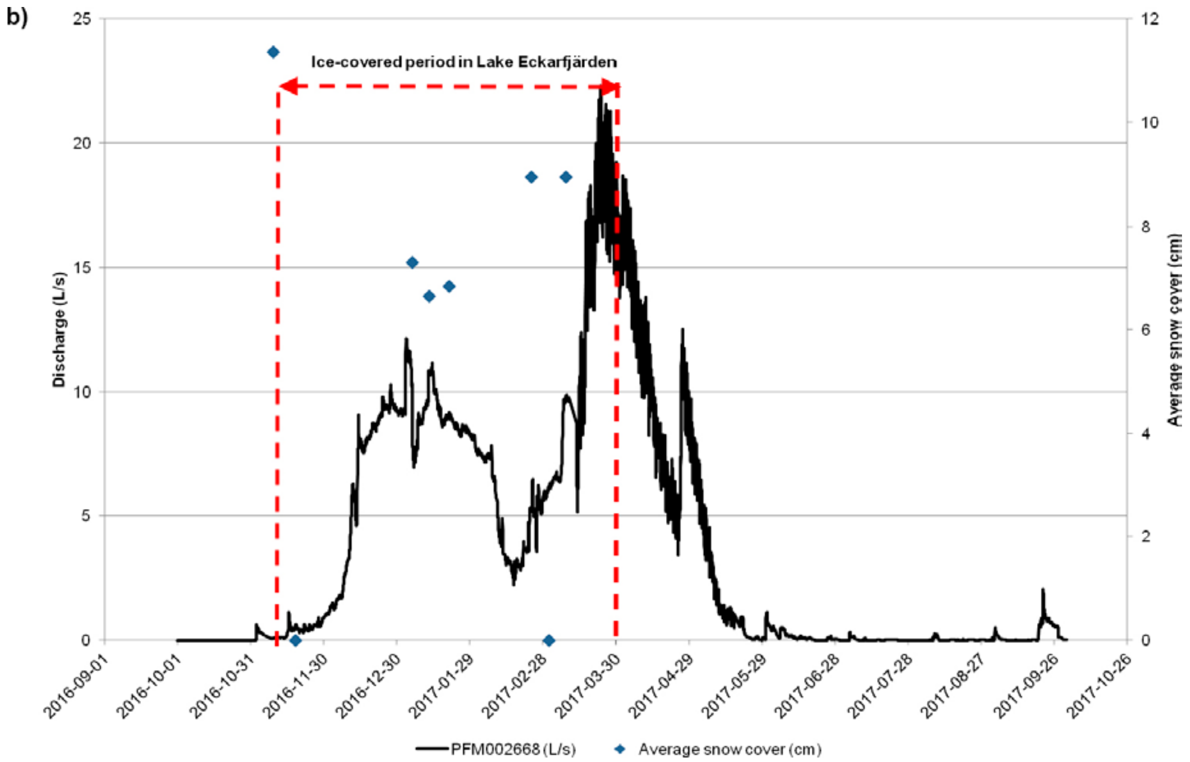


Figure 5-6. *Continued.*

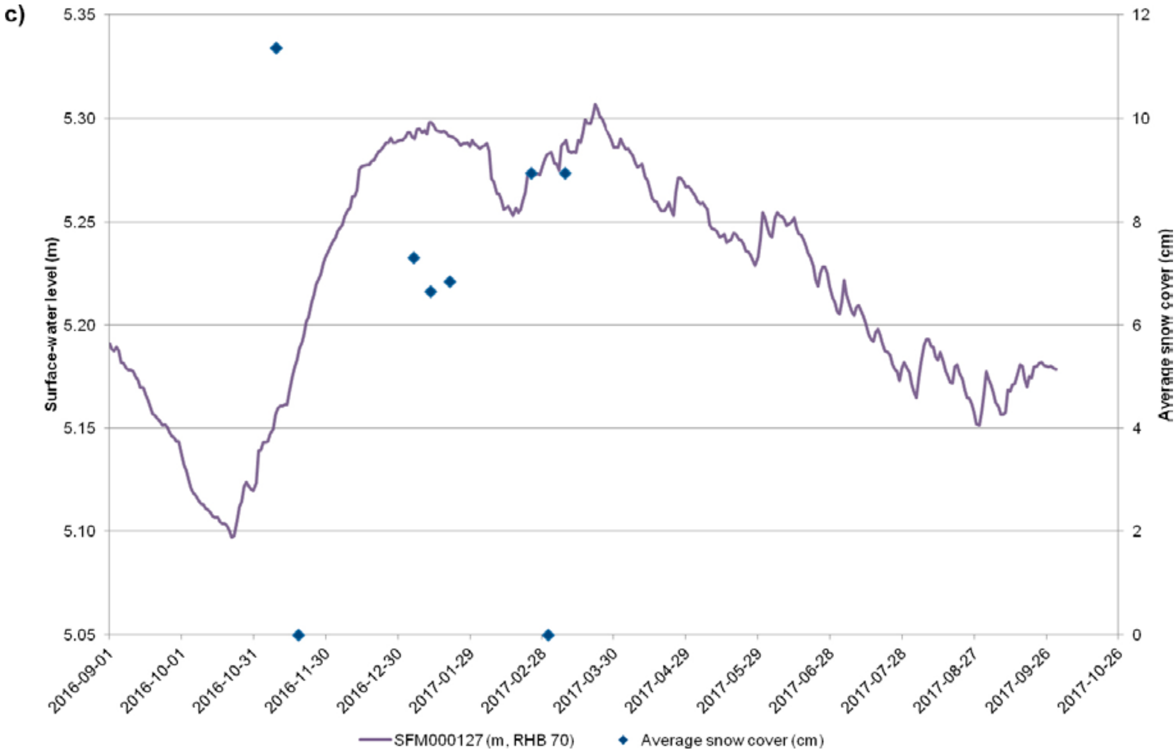
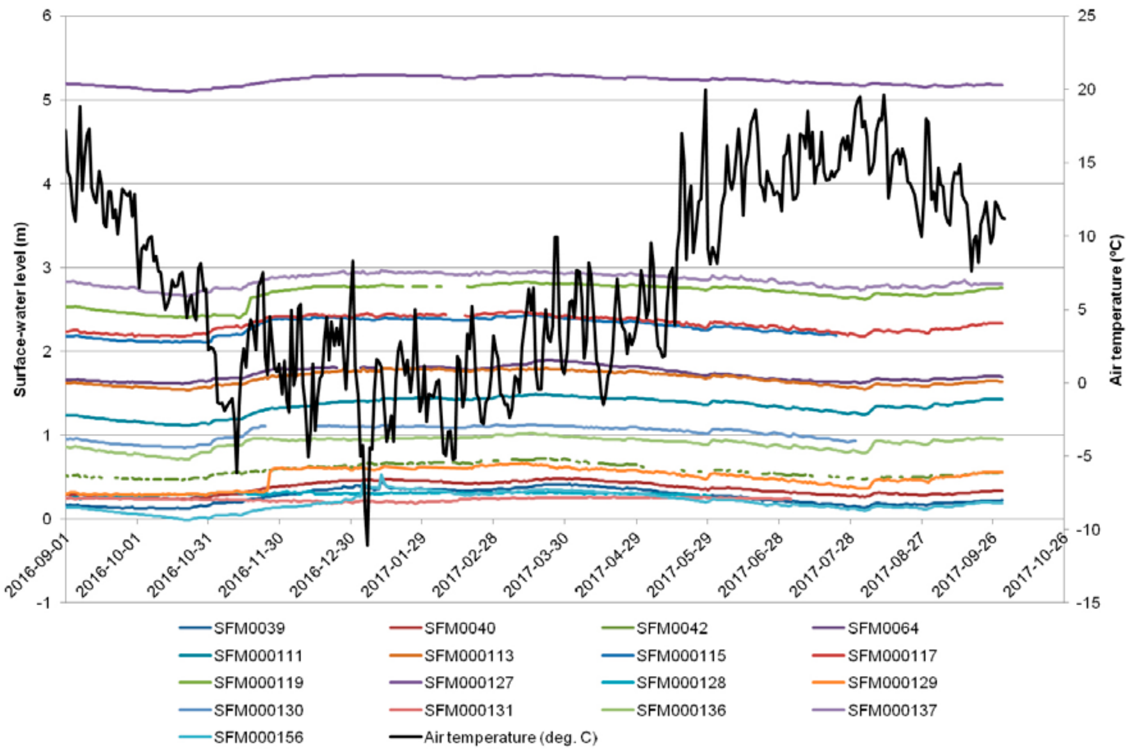


Figure 5-6. *Continued.*

a)



b)

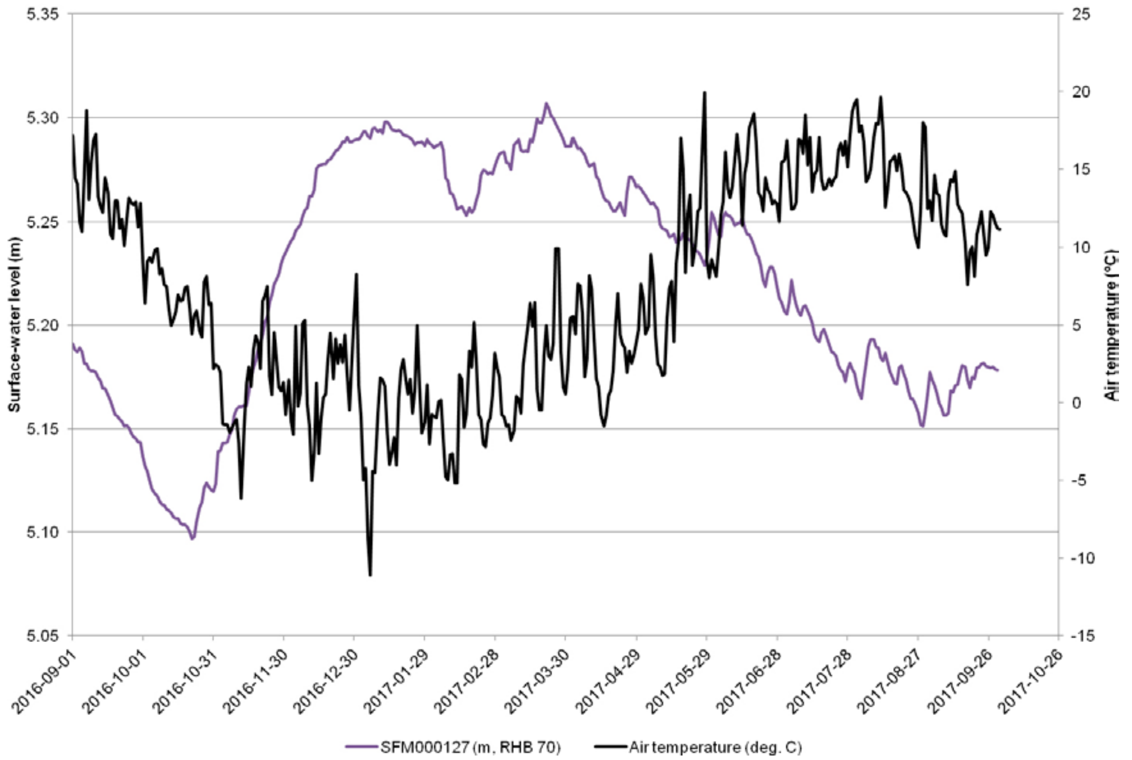


Figure 5-7. *a) Daily average surface-water levels (m, RHB 70) and daily average air temperature measured at the Labbomasten meteorological station. b) Daily average surface-water level at SFM000127 in Lake Eckarfjärden.*

5.4 Evaluation of surface-water temperature monitoring

Automatic water-temperature monitoring was done in natural and constructed ponds during the periods Apr.–Oct. 2016 (Borgiel et al. 2017) and Apr.–Oct. 2017 (Borgiel et al. 2018), see Figure 5-8. This section evaluates data from these measurements, as part of the background information required to evaluate the suitability of the monitored ponds for pool-frog spawning from a water-temperature perspective. Note that the hydrological year of the current report (Oct. 1 2016–Sep. 30, 2017) only covers the very end of the 2016 monitoring campaign, whereas the end of the 2017 campaign is subsequent to the end of the 2016/2017 hydrological year.

During the period Apr.–Oct. 2016, automatic water-temperature measurements (once per hour) were done in 9 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 (Borgiel et al. 2017), see summaries in Table 5-2 and Table 5-3. Moreover, manual water-temperature measurements were done in 5 ponds, in connection to daily pool-frog inventories during the period May–Jun. 2016 (Karlsson et al. 2016). The latter investigation also includes manual air-temperature measurements at the 5 ponds.

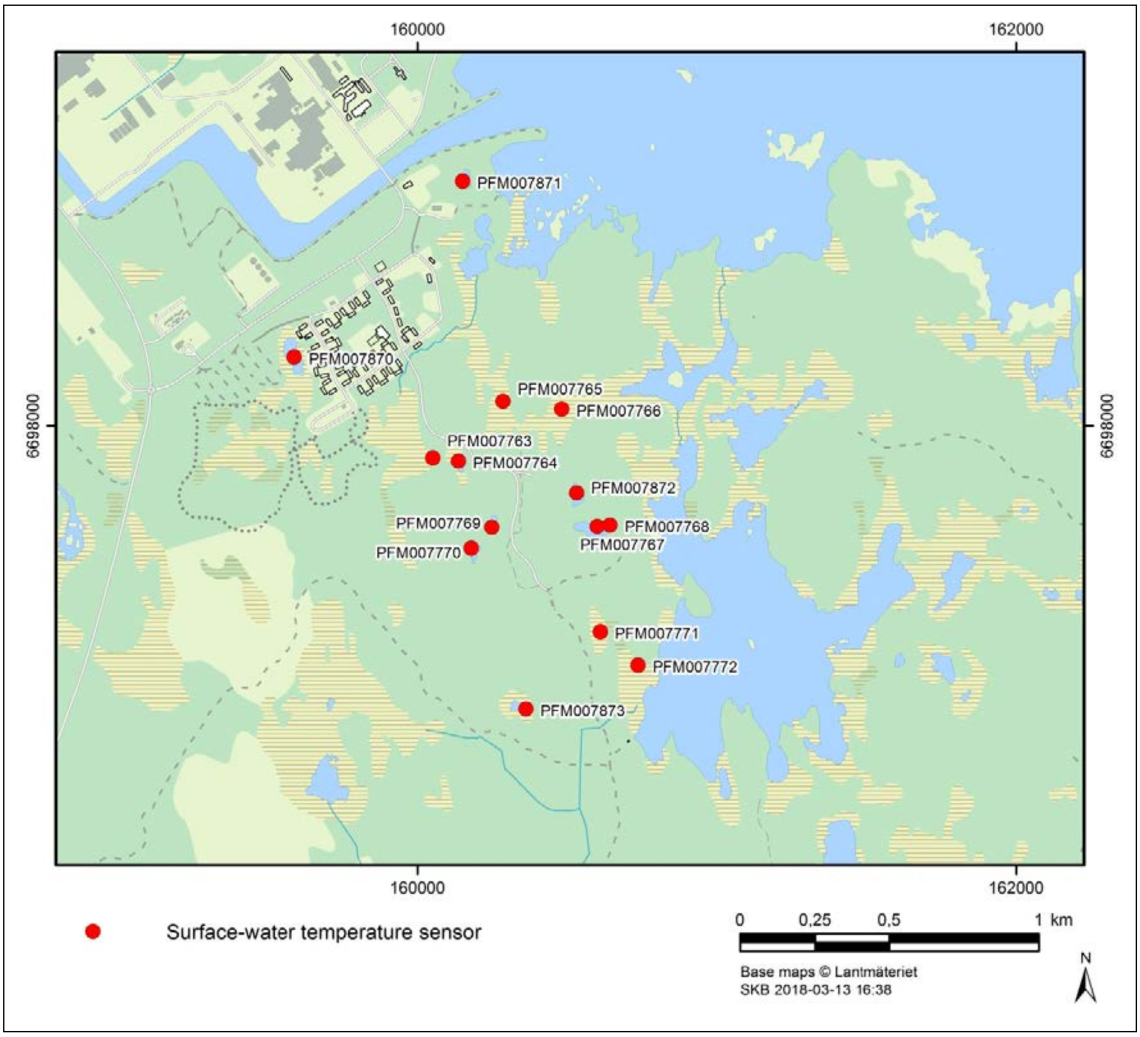


Figure 5-8. Locations of automatic water-temperature measurements during 2016 and 2017. Note that the sensors PFM007767 and –7768 were installed in the same pond.

Table 5-2. Automatic and manual water-temperature measurements in natural and constructed ponds during the period Apr.–Oct. 2016 (Borgiel et al. 2017, Karlsson et al. 2016).

Location id (automatic water-temp. meas.)	Pond id (alias)	Comments
PFM007763	AFM001442 (6b), pond constructed in 2014	
PFM007764	AFM001428 (7), natural pond	Also manual water- and air-temperature measurements
PFM007765	AFM001419 (11f), pond constructed in 2012	
PFM007766	AFM001420 (11g), pond constructed in 2012	
PFM007767	AFM001444 (14), natural pond	Also manual water- and air-temperature measurements
PFM007768	As above	As above
PFM007769	AFM001426 (16), natural pond	As above
PFM007770	AFM001443 (17a), pond constructed in 2014	
PFM007771	AFM001421 (19a), pond constructed in 2012	Also manual water- and air-temperature measurements
PFM007772	AFM001422 (66a), pond constructed in 2012	

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		Correl. r (PFM006281)	
		Av.	Max	Min	Std. dev.	Time frac., full data period	Deg. hrs. (°C × h), May 15–Sep. 30	Air temp.	Glob. rad.
7763 (6b*)	2016-04-21–2016-10-08	16.97	29.21	6.52	4.50	0.36	3801	0.79	0.42
7764 (7)	2016-04-21–2016-10-08	16.88	32.26	5.48	5.17	0.35	4933	0.83	0.52
7765 (11f*)	2016-04-21–2016-10-09	16.78	29.80	5.00	4.70	0.34	3845	0.82	0.43
7766 (11g*)	2016-04-21–2016-10-09	17.04	29.25	6.14	4.68	0.37	4156	0.82	0.49
7767 (14)	2016-04-21–2016-10-08	17.77	30.42	5.23	4.92	0.44	5675	0.76	0.37
7768 (14)	2016-04-21–2016-10-08	17.41	31.78	4.80	5.09	0.38	5391	0.78	0.43
7769 (16)	2016-04-21–2016-10-08	16.05	29.57	4.53	4.77	0.29	3115	0.84	0.44
7770 (17a*)	2016-04-21–2016-10-08	17.33	29.57	6.59	4.71	0.39	4651	0.78	0.45
7771 (19a*)	2016-04-21–2016-10-08	17.02	28.96	5.65	4.68	0.37	4201	0.81	0.40
7772 (66a*)	2016-04-21–2016-10-08	17.15	29.43	5.85	4.63	0.37	4237	0.80	0.41

As can be seen Table 5-3 the ponds demonstrate rather similar temperature characteristics in terms of overall average (c 16–18 °C), maximum (c 29–32 °C), minimum (c 5–7 °C), and standard deviation (c 4.5–5.2 °C). It is noted that the average water temperature was highest in the natural pond AFM001444 (pond 14) and lowest in the natural pond AFM001426 (pond 16). It is also 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 5-23) demonstrate some inter-pond variations (c 30–40 % and c 3 100–5 700 °C·h , respectively); some variations can also be observed within the same pond (PFM007767 and -7768). The correlation (expressed as the correlation coefficient, r) between automatic and manual water-temperature measurements is r ≈ 0.80 for PFM007769 and -7771, r ≈ 0.88 for PFM007764, and r ≈ 0.96–0.97 for PFM007767–7768.

The correlation between automatic water-temperature measurements and automatic air-temperature measurements (PFM006281, Labbomasten meteorological station) is c 0.75–0.85. The automatically measured water temperature is most of the time above the air temperature measured at Labbomasten, with an average difference of c 2.5–4.3 °C (see examples in Figure 5-14 and Figure 5-15). The correlation between automatic water-temperature measurements and global radiation (Labbomasten) is r ≈ 0.4–0.5. The highest water temperatures (>32 °C) are noted for PFM007764 during the period Jul. 24–26, 2016, and they are associated with peaks of global radiation (c 750 W/m^2), see Figure 5-22.

The overall correlation between same-time automatic (Labbomasten) and manual air-temperature measurements is r ≈ 0.78. The average difference between automatic and manual air-temperature measurements is −3.41 °C (interval −12.76–3.11 °C), and the manually measured air temperature is above the automatically measured air temperature more than 90 % of the time. Moreover, the average difference between manually measured water and air temperatures is c 0.3 °C, hence lower than the difference between automatically measured water and air temperatures (2.5–4.3 °C).

Water-temperature characteristics are rather similar at the two locations in pond AFM001444, PFM007767 and -7768, where the latter location is shaded by trees in the eastern part of the pond. The average temperature difference (PFM007767 minus PFM007768) is 0.36 °C, varying between 3.78 °C and −3.12 °C (Figure 5-17). Specifically, there is a regular pattern with higher water temperature at PFM007767 during nights (peak difference at approximately 6 AM), and higher temperatures at PFM007768 during daytime (peak difference at noon).

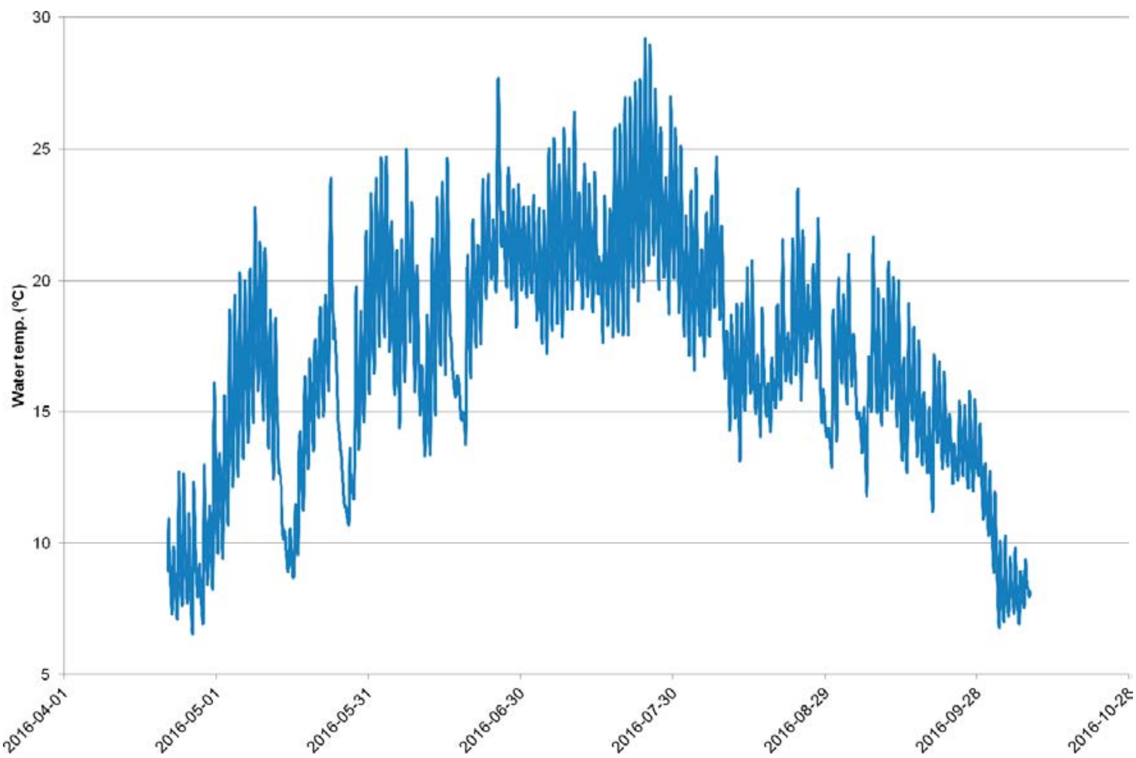


***Figure 5-9.** Automatically measured water temperature at PFM007763 (pond AFM001442/6b).*

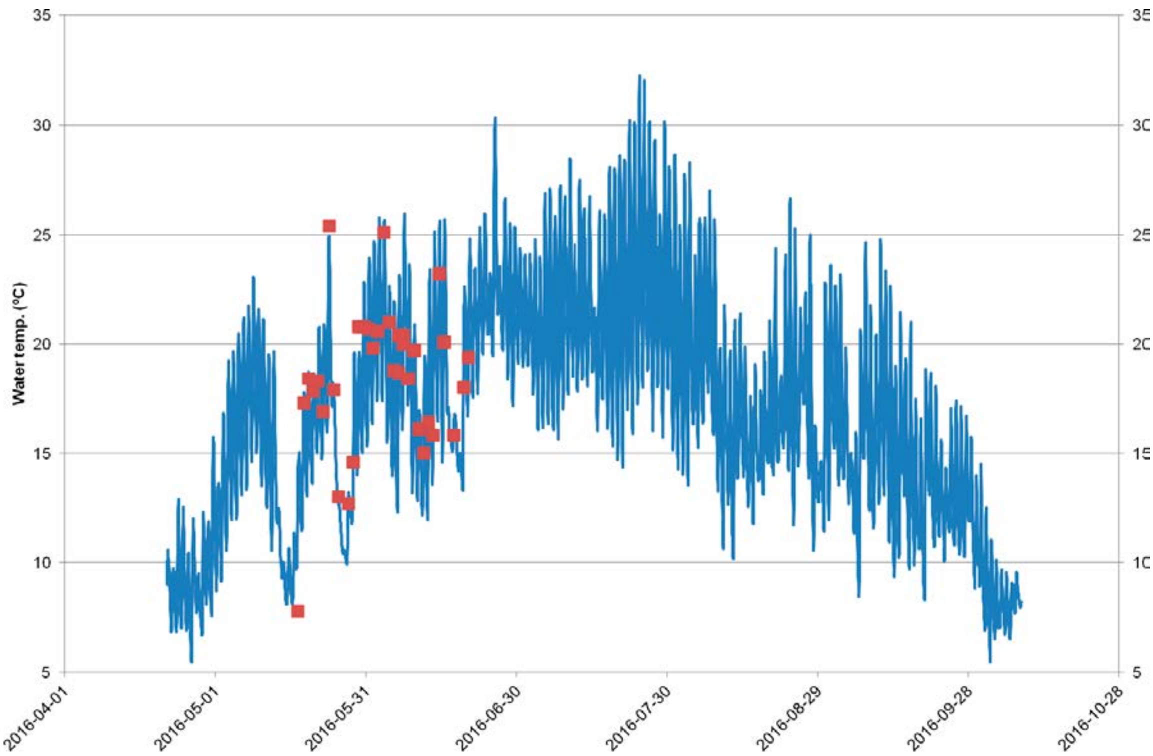


Figure 5-10. *Automatically measured water temperature at PFM007764 (pond AFM001428/7). Red dots symbolize manual water-temperature measurements.*

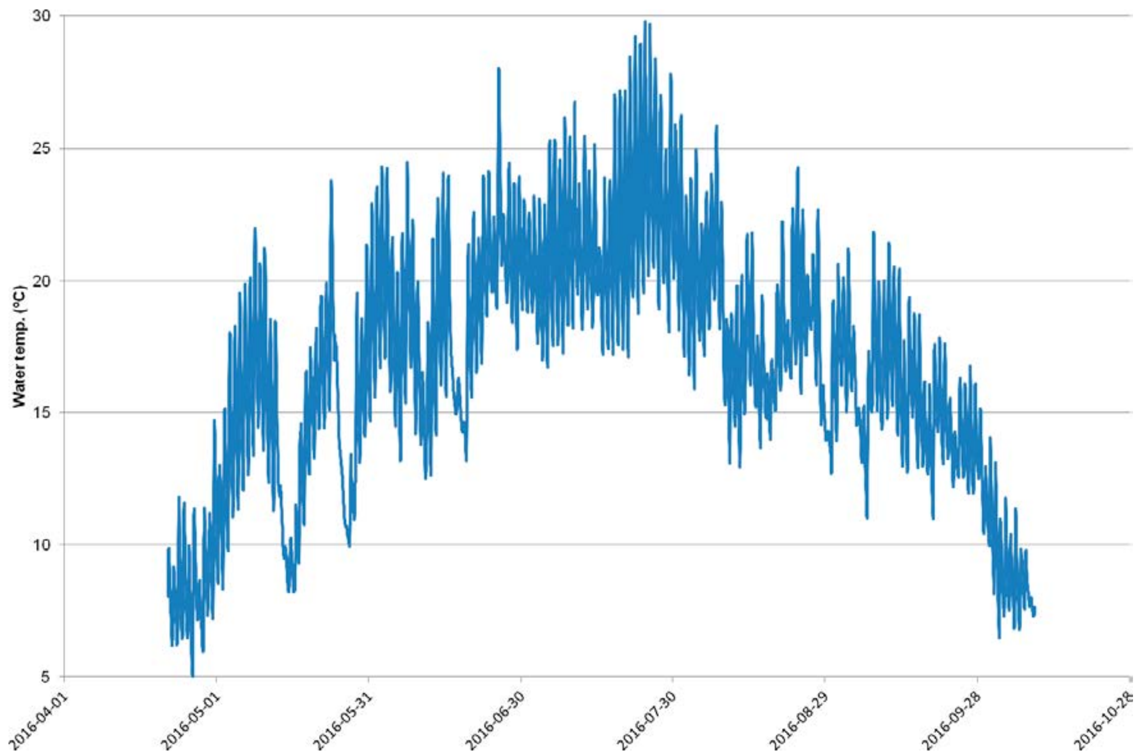


Figure 5-11. *Automatically measured water temperature at PFM007765 (pond AFM001419/11f).*

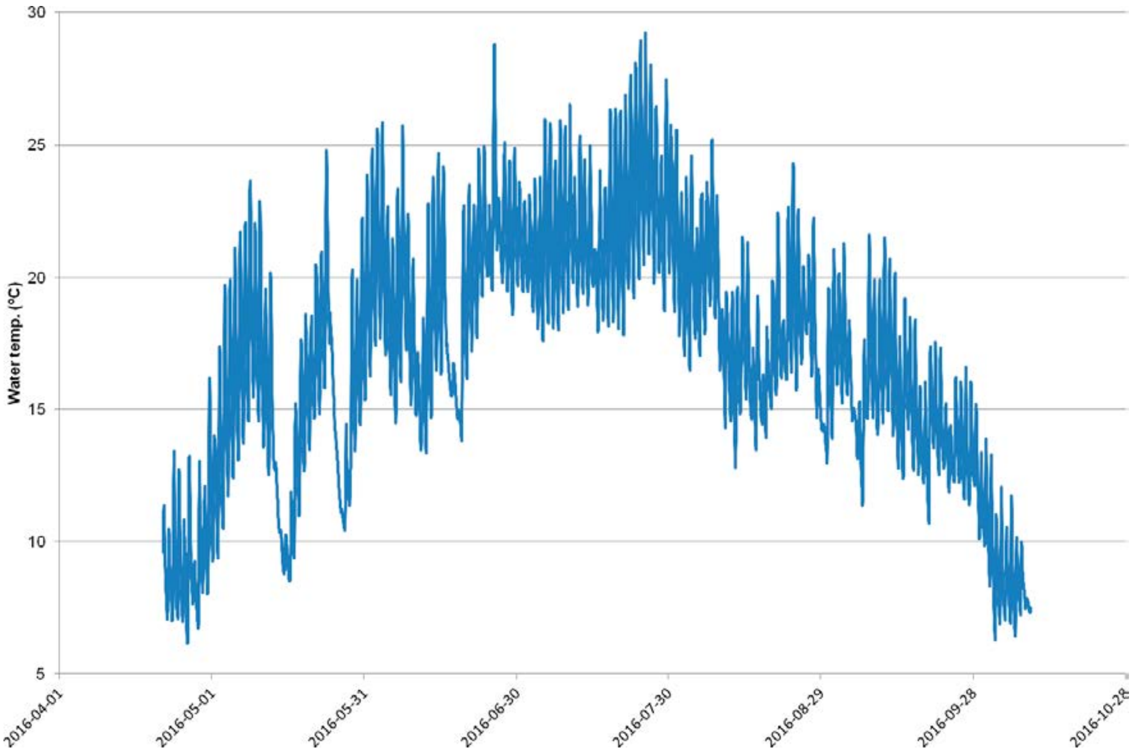


Figure 5-12. *Automatically measured water temperature at PFM007766 (pond AFM001420/11g).*

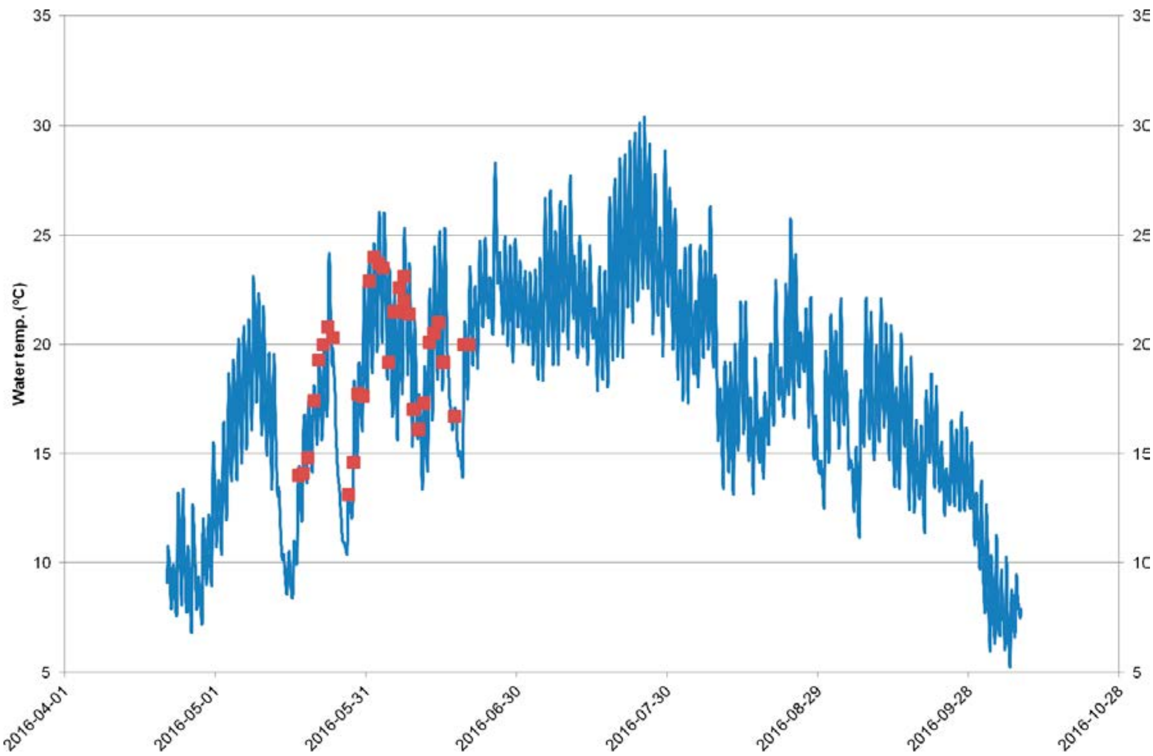


Figure 5-13. *Automatically measured water temperature at PFM007767 (pond AFM001444/14). Red dots symbolize manual water-temperature measurements.*

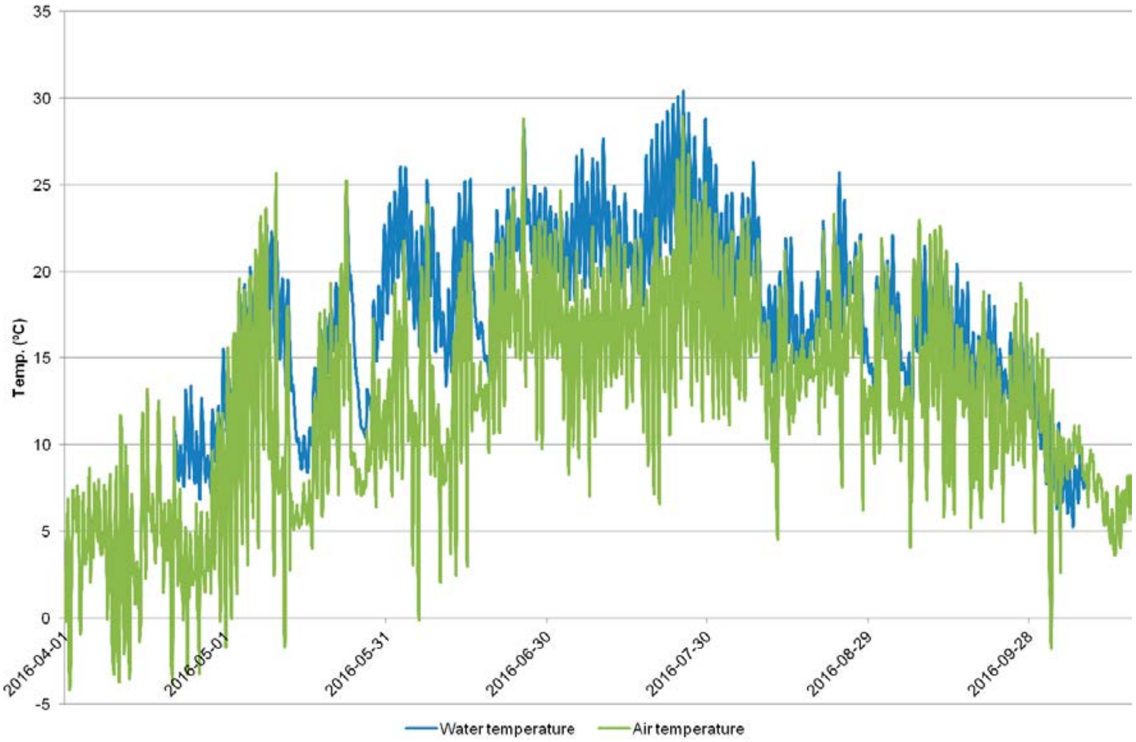


Figure 5-14. *Automatically measured water temperature at PFM007767 (AFM001444/pond 14) and air temperature at PFM006281 (Labbomasten).*

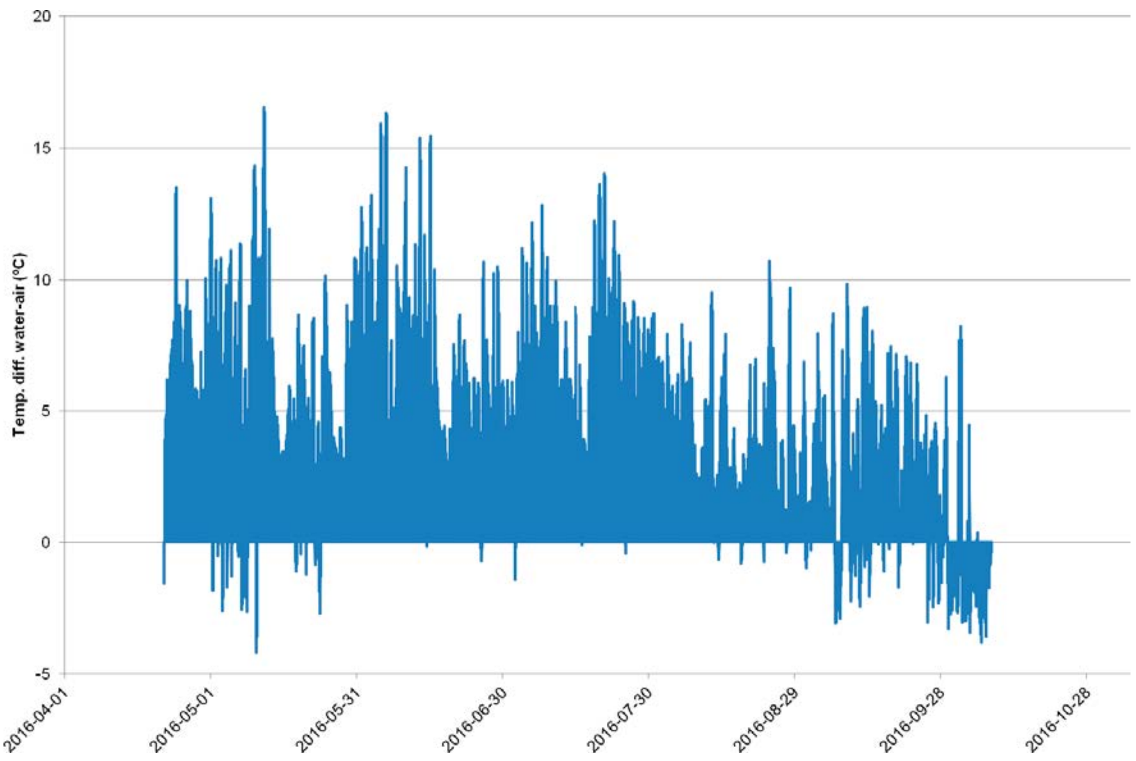


Figure 5-15. *Difference in automatically measured temperatures; water temperature at PFM007767 (AFM001444/pond 14) minus air temperature at Labbomasten.*

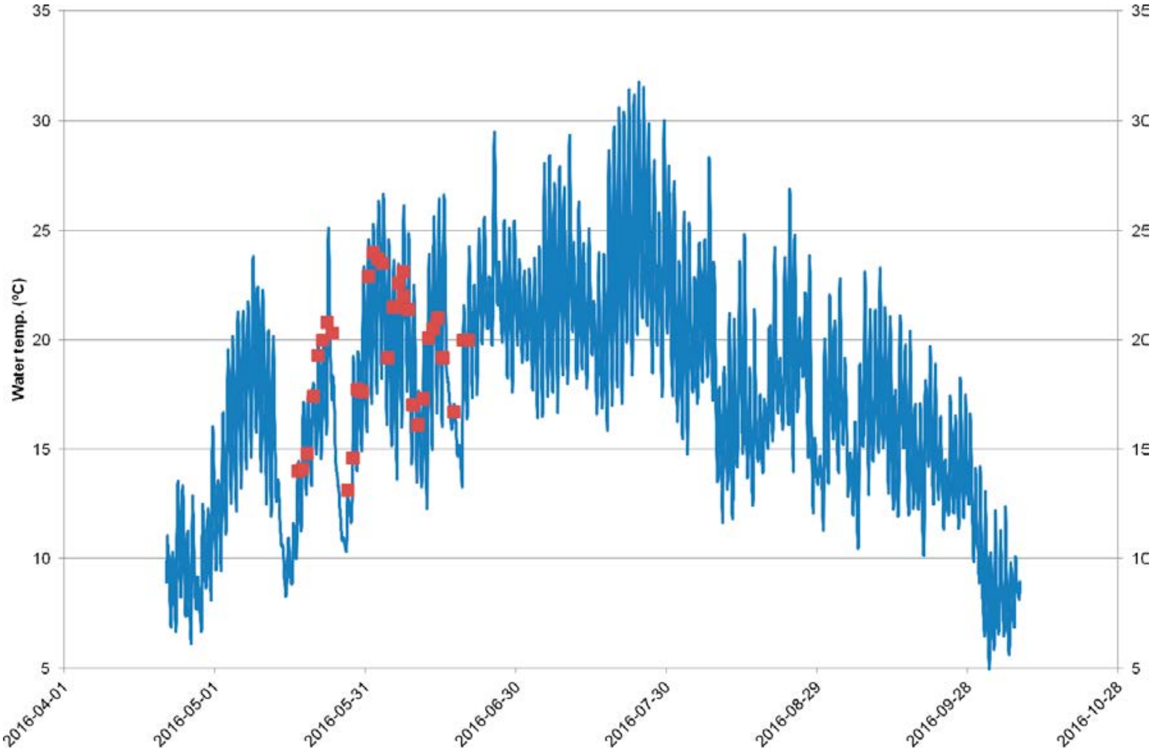


Figure 5-16. *Automatically measured water temperature at PFM007768 (AFM001444/pond 14). Red dots symbolize manual water-temperature measurements.*

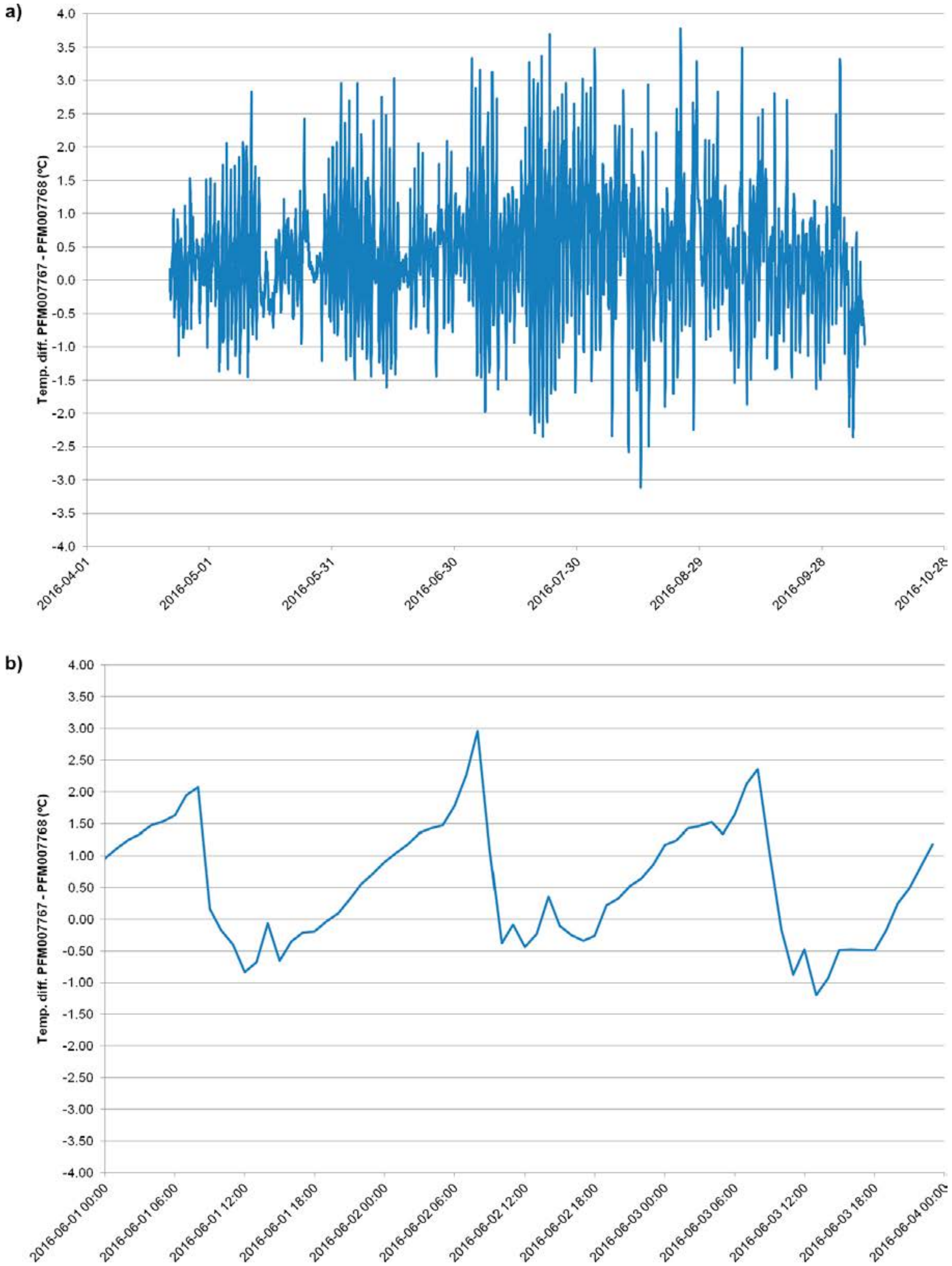


Figure 5-17. *Difference in automatically measured water temperatures; PFM007767 minus PFM007768 in pond AFM001444/14). a) Temperature difference during the whole 2016 measurement period. b) Temperature difference during the period Jun. 1–3, 2016.*

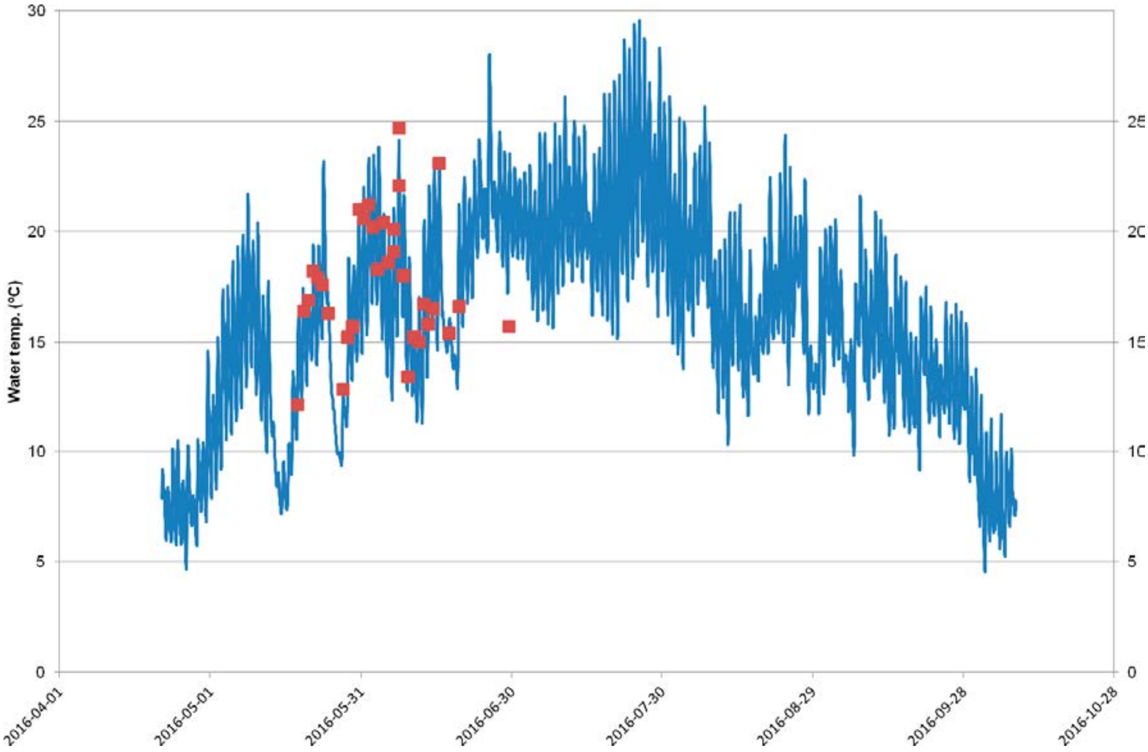


***Figure 5-18.** Automatically measured water temperature at PFM007769 (pond AFM001426/pond 16). Red dots symbolize manual water-temperature measurements.*

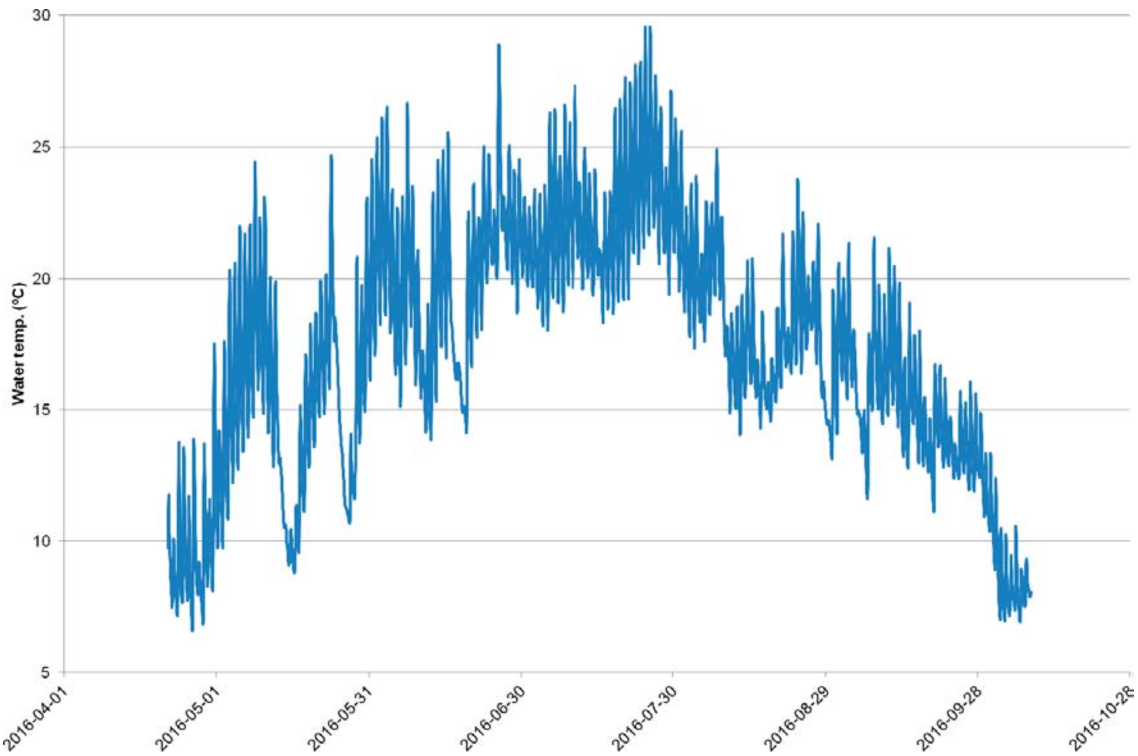


***Figure 5-19.** Automatically measured water temperature at PFM007770 (pond AFM001443/17a).*

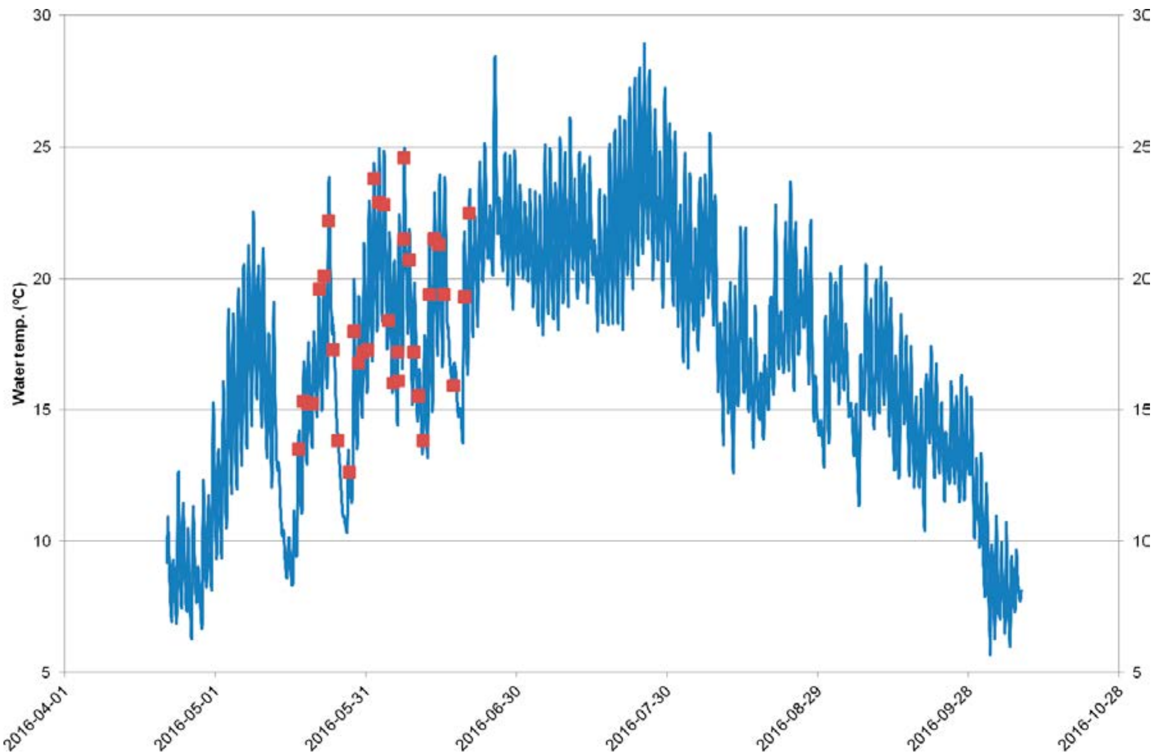


Figure 5-20. *Automatically measured water temperature at PFM007771 (pond AFM001421/19a). Red dots symbolize manual temperature measurements.*

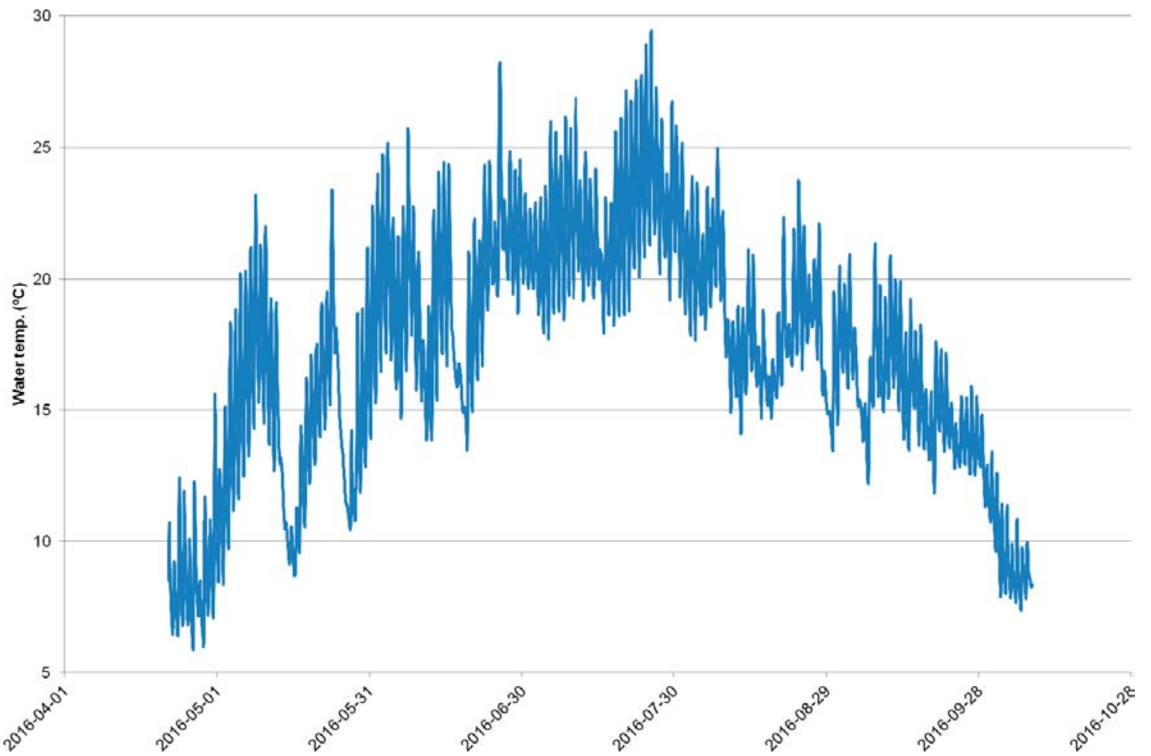


Figure 5-21. *Automatically measured water temperature at PFM007772 (pond AFM001422/66a).*

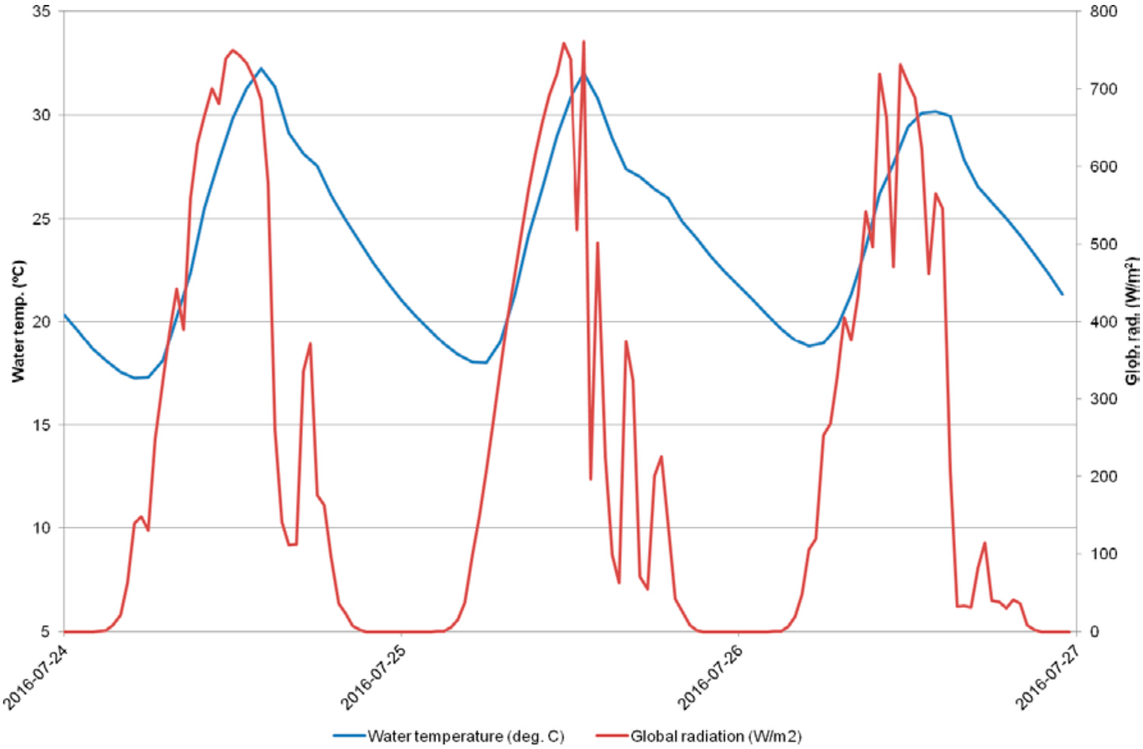


Figure 5-22. *Automatically measured water temperature at PFM007764 (pond AFM001428/7) and global radiation at Labbomasten during the period Jul. 24–26, 2016.*

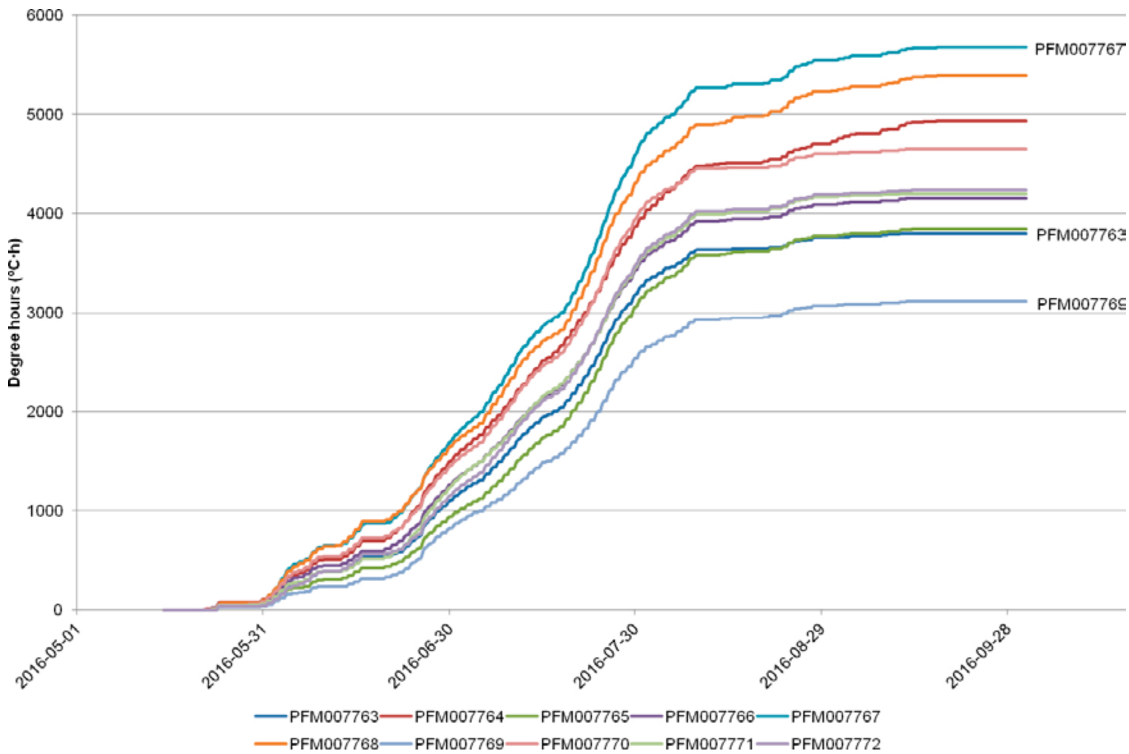


Figure 5-23. *Cumulative degree-hours sum (degrees above 19 °C times time in hours) for automatically measured water temperatures during the period May 15–Sep. 30, 2016.*

Automatic water-temperature measurements were continued, in a partly different set of ponds, during the period Apr.–Oct. 2017 (Borgiel et al. 2018). The 11 natural and constructed ponds monitored during 2017 are listed in Table 5-4, and the results are summarised in Table 5-5. In Table 5-5, it is noted that PFM007870–73 (Lake Tjärnpussen, and ponds 12, 15 and 18) were added in the 2017 monitoring, whereas PFM007764 (pond 7), PFM007768 (one location in pond 14) and PFM007769 (pond 16) were not included in the 2017 monitoring.

Table 5-4. Automatic water-temperature monitoring in natural and constructed ponds during the period Apr.–Oct. 2017 (Borgiel et al. 2018).

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

Table 5-5. 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		Correl. r (air temp. PFM006281)
		Av.	Max	Min	Std. dev.	Time frac., full data period	Deg. hrs. (°C·h), May 15–Sep. 30	
7763 (6b*)	2017-04-28–2017-10-07	16.86	26.46	7.45	3.89	0.32	2762	0.77
7765 (11f*)	2017-04-28–2017-10-07	16.84	27.82	6.88	4.17	0.31	3189	0.78
7766 (11g*)	2017-04-28–2017-10-07	17.11	26.77	7.19	4.06	0.35	3302	0.79
7767 (14)	2017-04-28–2017-10-07	17.78	28.67	7.56	4.24	0.40	4673	0.73
7770 (17a*)	2017-04-28–2017-10-07	17.27	27.63	7.66	4.05	0.36	3578	0.76
7771 (19a*)	2017-04-28–2017-10-07	16.98	26.45	6.84	4.09	0.34	3210	0.78
7772 (66a*)	2017-04-28–2017-10-07	17.26	27.50	7.28	3.97	0.36	3389	0.76
7870 (8)	2017-04-28–2017-10-07	17.08	25.27	7.80	3.66	0.37	2601	0.75
7871 (12)	2017-04-28–2017-10-07	16.66	25.38	6.82	3.57	0.27	2006	0.78
7872 (15)	2017-04-28–2017-10-07	16.61	29.25	5.83	4.49	0.30	3463	0.80
7873 (18)	2017-04-28–2017-10-07	17.44	28.66	6.64	4.30	0.37	4250	0.74

As was also observed in the 2016 monitoring (Table 5-3), the ponds demonstrate rather similar temperature characteristics in terms of overall average (c 16.5–17.8 °C), maximum (c 25.4–29.3 °C), minimum (c 5.8–7.8 °C), and standard deviation (c 3.6–4.5 °C). However, the fraction of time with water temperatures above 19 °C (threshold for pool-frog spawning) and the cumulative degree-hours sum (degrees above 19 °C times time in hours, specifically for the period May 15–Sep. 30) demonstrate some inter-pond variations (27–40 % and c 2000–4600 °C·h , respectively), see Figure 5-24.

The correlation (expressed as the correlation coefficient, r) between automatic water-temperature measurements and automatic air-temperature measurements (PFM006281, Labbomasten) is 0.73–0.80. The automatically measured water temperature is most of the time above the air temperature measured at Labbomasten, with an average difference of c 4.0–5.2 °C. The highest water temperatures (>29 °C) are noted for PFM007872 during Jul. 10 and Aug. 3, 2017, and they are associated with high air temperatures (c 23–24 °C). Note that global radiation is omitted from the 2017 data evaluation, as Labbomasten global-radiation data were not available for the whole 2016/2017 hydrological year at the time of the current report.

In summary, water temperatures were higher during the 2016 measurement period than during the 2017 measurement period. 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, 2016 was almost 5700 °C·h in the warmest pond (pond AFM001444/14). During the corresponding period in 2017, the cumulative degree-hours sum was only c. 4700 °C·h in that pond.

Among the ponds in which measurements took place in both 2016 and 2017, one natural pond (AFM001444/14) and one constructed pond (AFM001143/17a) were the warmest both years. The other constructed ponds do not demonstrate any marked water-temperature deviations from those of the natural ponds. In both 2016 and 2017, the smallest cumulative degree-hours sums are noted for natural ponds; AFM001426 (pond 16) in 2016 and AFM001453 (pond 12) in 2017.

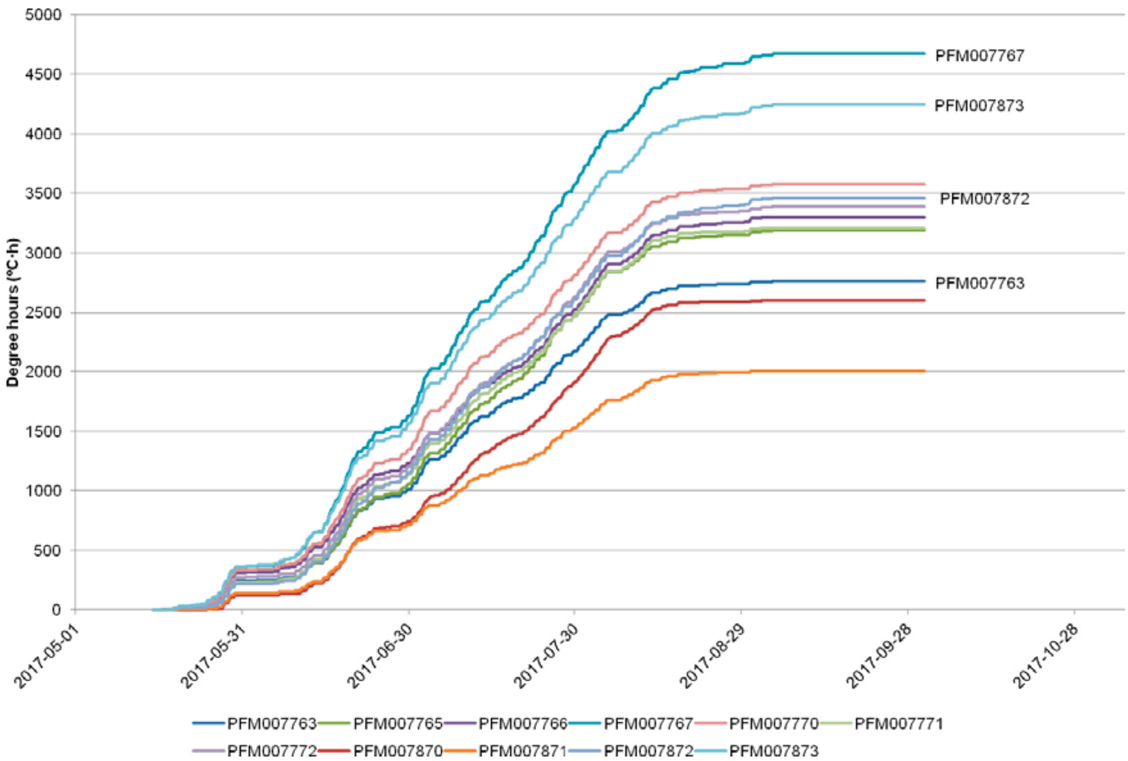


Figure 5-24. *Cumulative degree-hours sum (degrees above 19 °C times time in hours) for automatically measured water temperatures during the period May 15–Sep. 30, 2017.*

5.5 Installations for monitoring of soil moisture and temperature

During the summer of 2017 sensors for soil-moisture monitoring were installed in regolith at different depths below the ground surface at four locations (see Table 5-6 and Figure 5-25), representing different regolith and evapotranspiration conditions (Hargelius et al. 2018): (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 based on TDR (time domain reflectrometry) technique. The sensors also measure EC and temperature, and they are connected to CR300 data loggers (Campbell Scientific Inc.).

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 5-25: (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.).

For the soil-moisture sensors, it is planned to transfer logger data to HMS for quality control and transferral to Sicada (activity type HY008 Soil moisture content (TDR)) two times per year, in May and October (Hargelius et al. 2018). So far, soil-moisture data were retrieved in November 2017 and February 2018, whereas soil-temperature data were retrieved in February 2018. These data sets represent an initial test period, and data from the moisture and temperature sensors will be presented and analysed in the forthcoming data report for the 2017/2018 hydrological year.

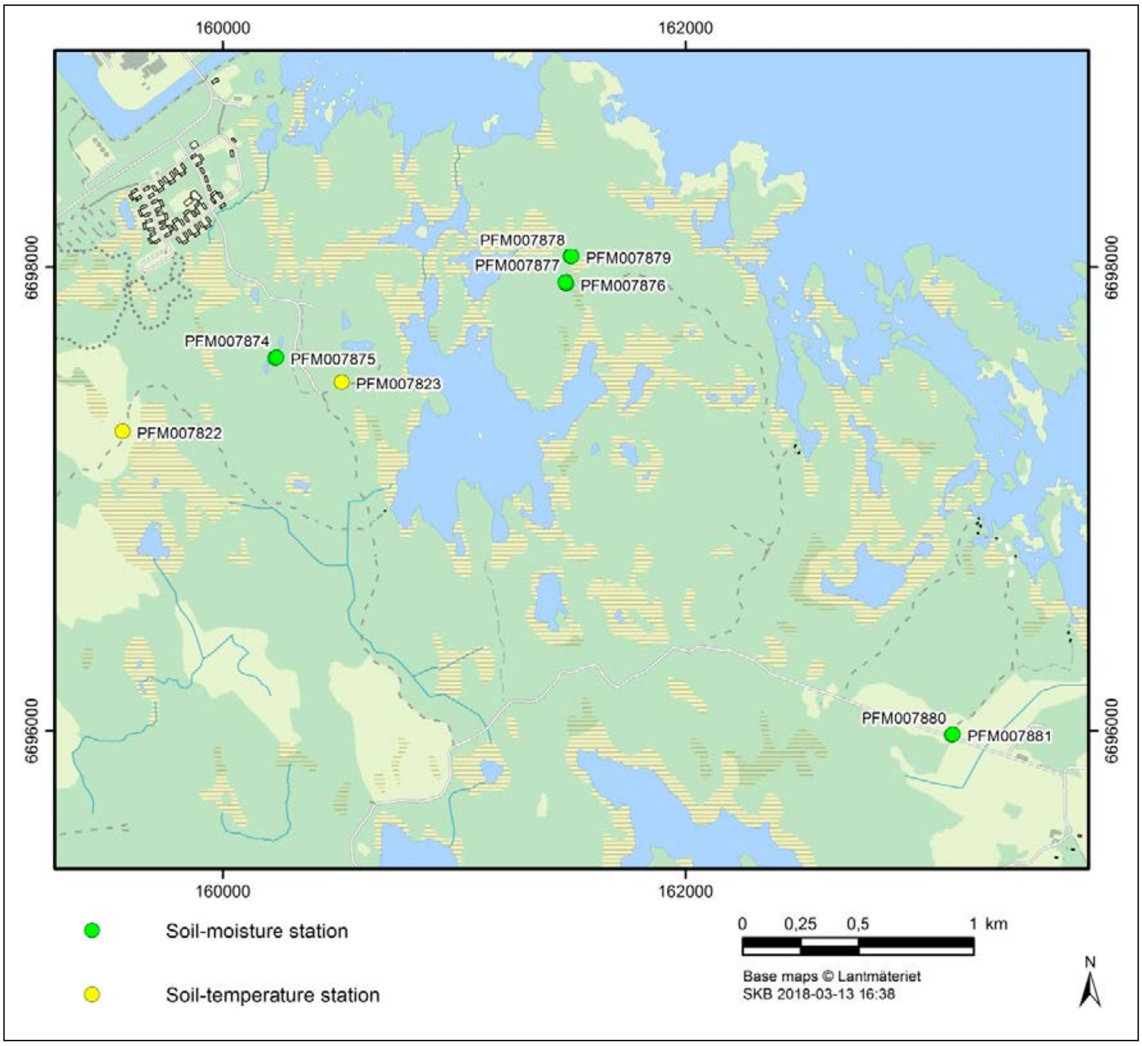


Figure 5-25. *Locations of sensors for soil-moisture and soil-temperature monitoring.*

Table 5-6. Installed soil-moisture probes (Hargelius et al. 2018).

Location/ station id	Regolith stratigraphy	Installation depth (m bgs)	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 4415)			
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

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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).

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			
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
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. The flumes at PFM002669 were reinstalled in 2007, and the PFM005764 and PFM002669 stations were refurbished in Aug. 2014 and Aug.–Sep. 2015, 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)
Levelling after refurbishment (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 refurbish-ment)
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)

Gauging station and flume)	Point B (RHB 70)	Point C (RHB 70)	Average (RHB 70)	Level change (m)
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	1.570	1.573	1.572	+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)
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		Dito	
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. The wells at PFM002669 were reinstalled in 2007, and the PFM005764 and PFM002669 stations were refurbished i Aug. 2014 and Aug.–Sep. 2015, 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 Point I (RHB 70)	Comment on original levelling 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
Leveling 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	–
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)

Gauging station and well	Original levelling Point I (RHB 70)	Comment on original levelling Level change since original levelling (m)
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)
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, 2016–October 31, 2017. 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 2016/2017 water-level dataset. Note that water levels for September 2016 and October 2017 are shown for reference only.

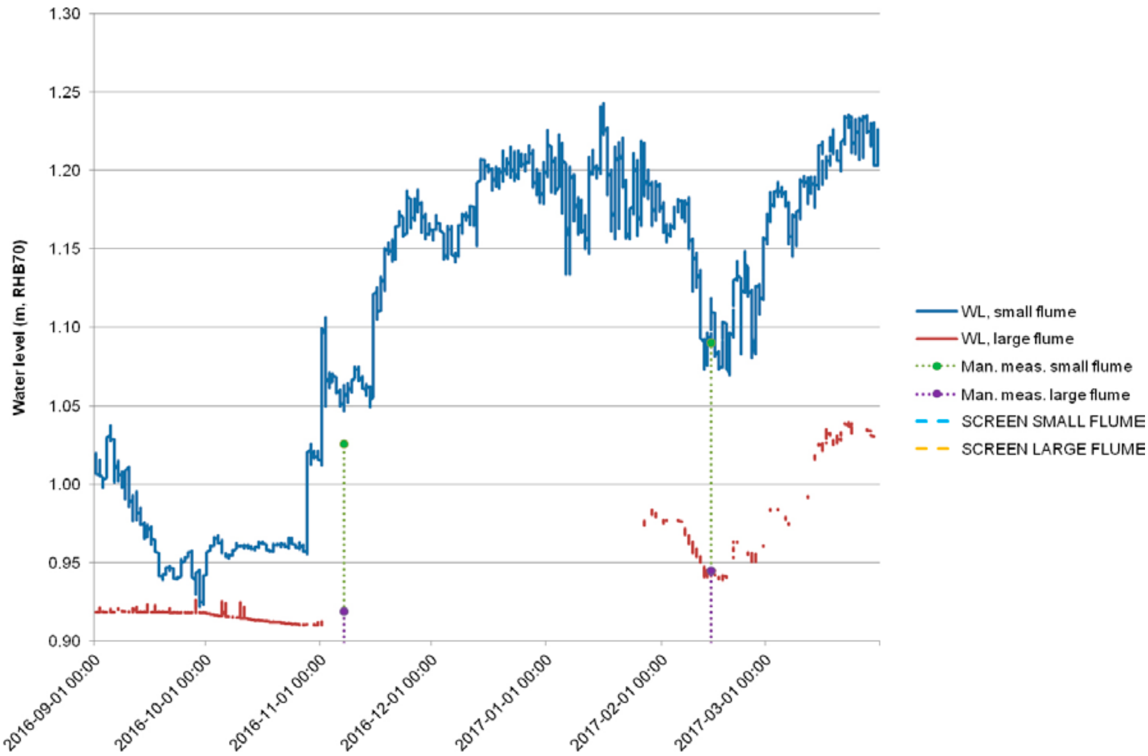

Figure A2-1. *Water-level time series for the flumes at gauging station PFM005764 for the period Sep. 1, 2016–Mar. 31, 2017.*

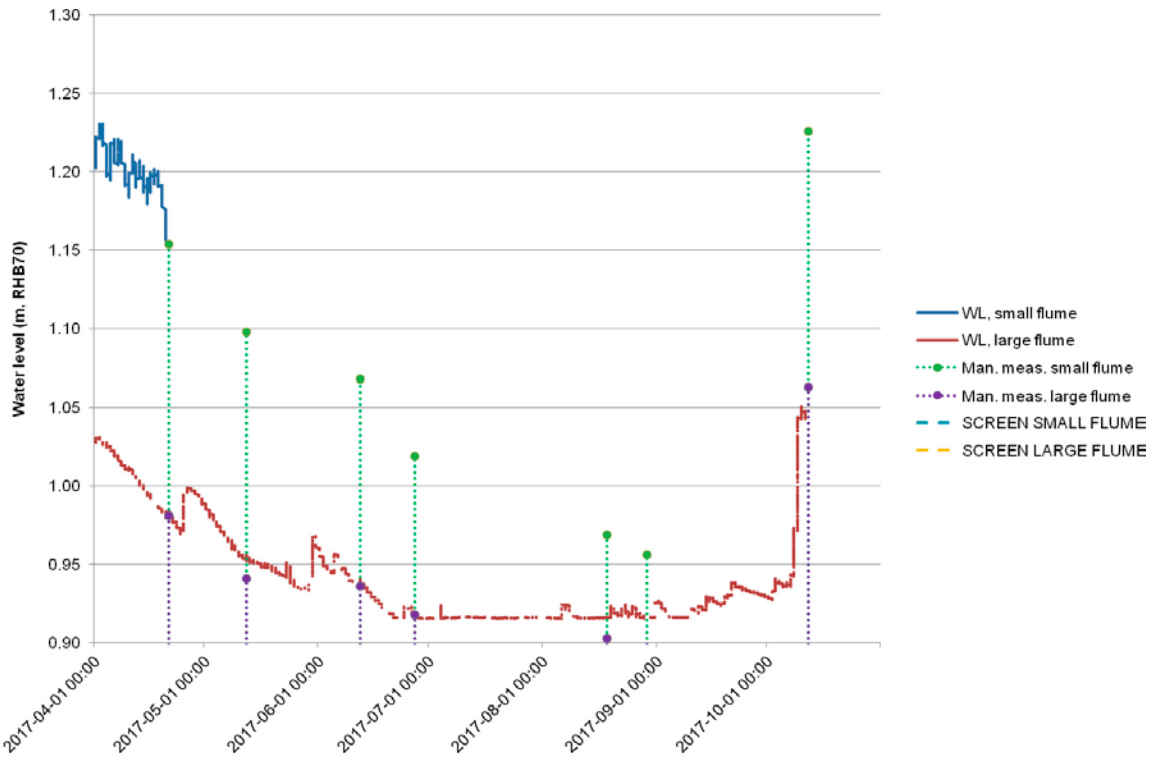

Figure A2-2. *Water-level time series for the flumes at gauging station PFM005764 for the period Apr. 1–Oct. 31, 2017.*

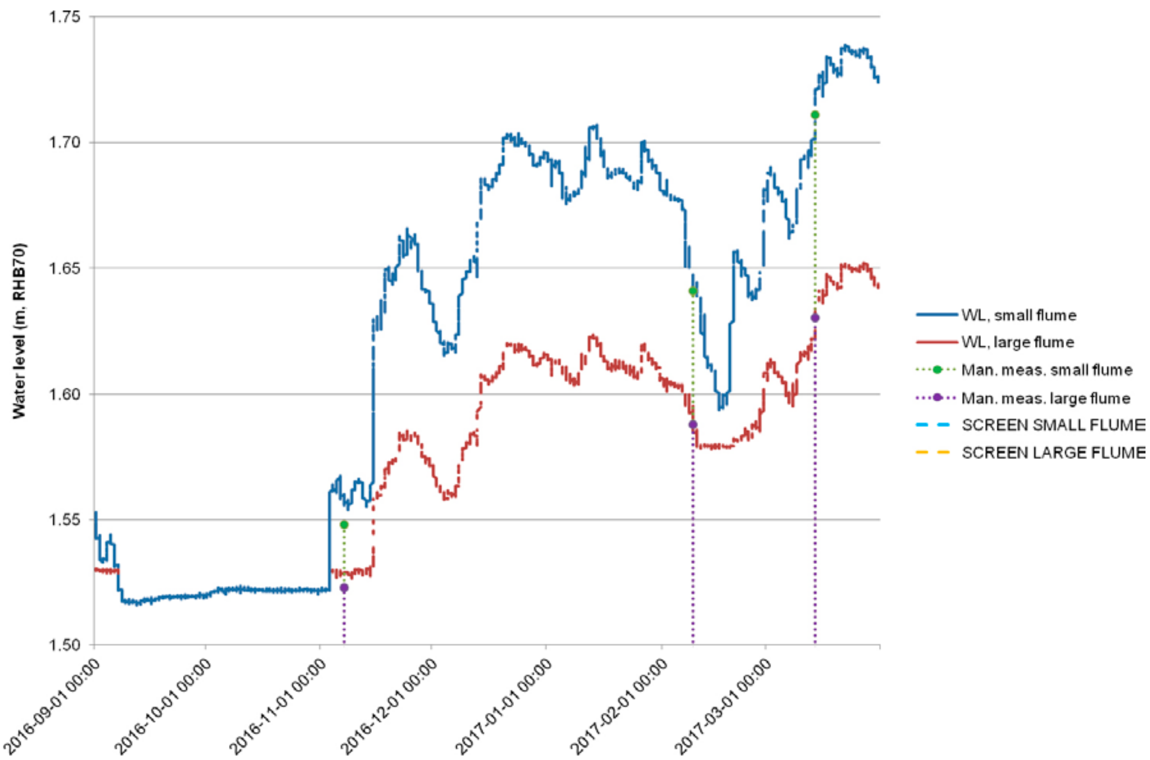

Figure A2-3. *Water-level time series for the flumes at gauging station PFM002667 for the period Sep. 1, 2016–Mar. 31, 2017.*

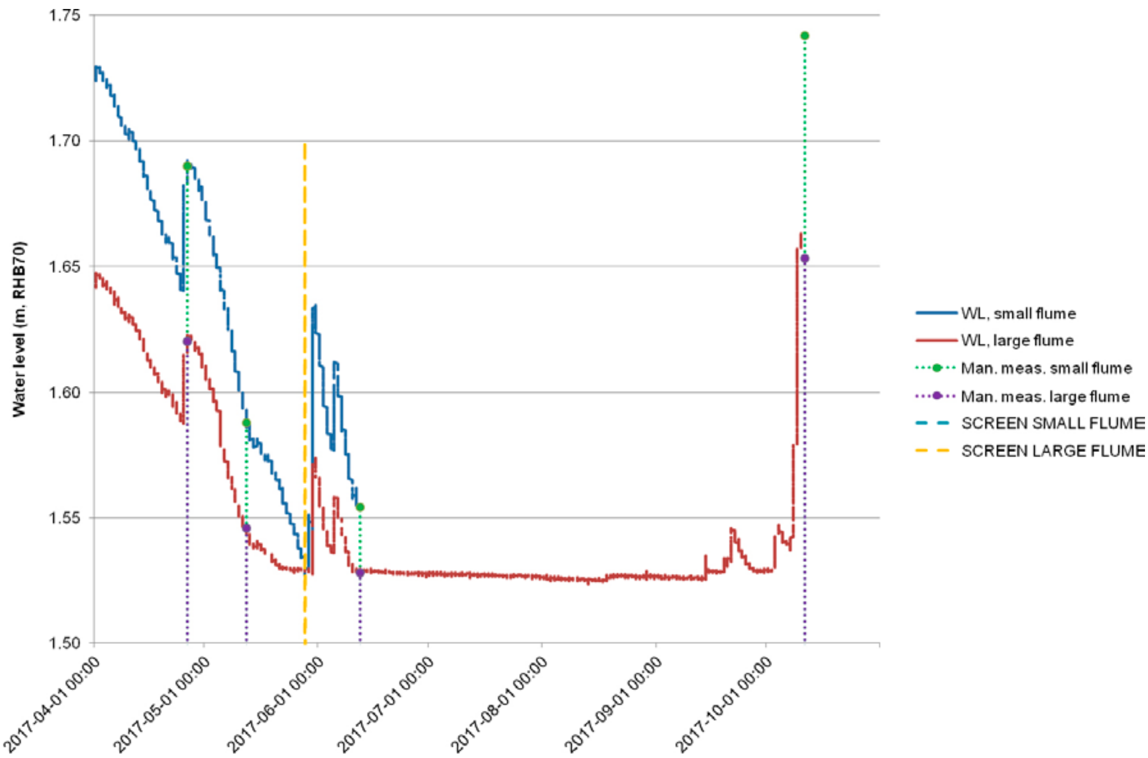

Figure A2-4. *Water-level time series for the flumes at gauging station PFM002667 for the period Apr. 1–Oct. 31, 2017.*

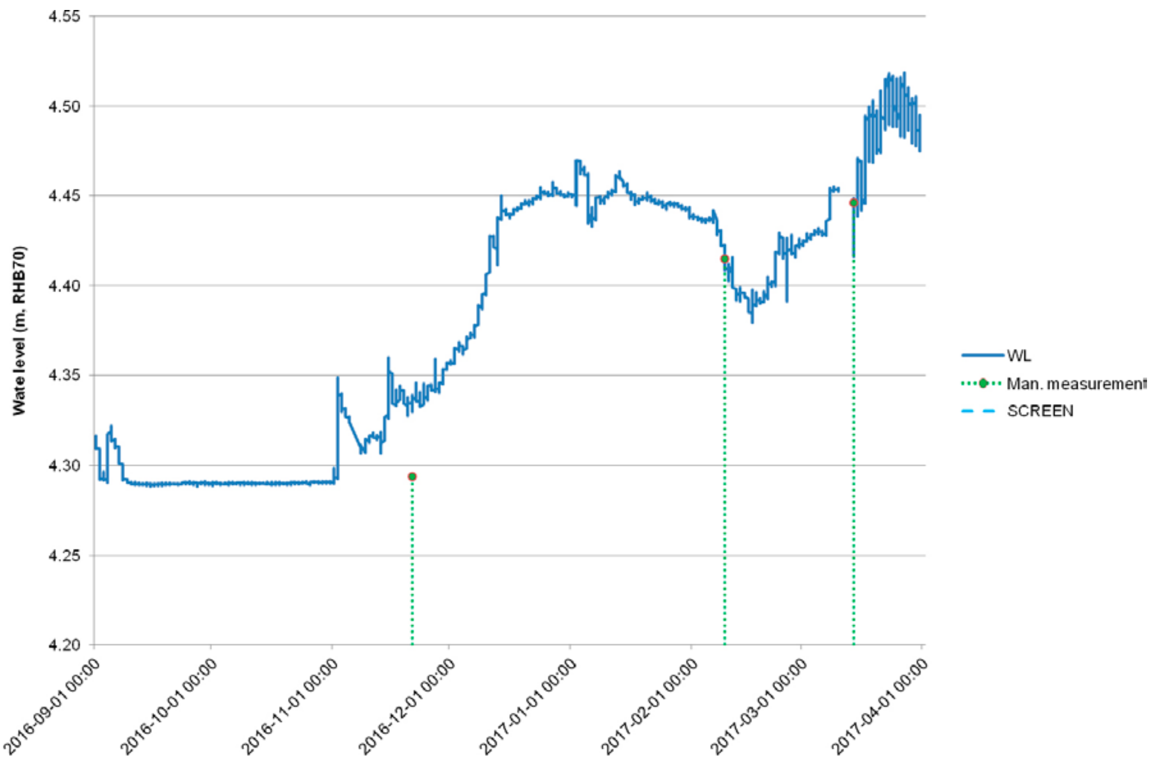

Figure A2-5. *Water-level time series for the flume at gauging station PFM002668 for the period Sep. 1, 2016–Mar. 31, 2017.*

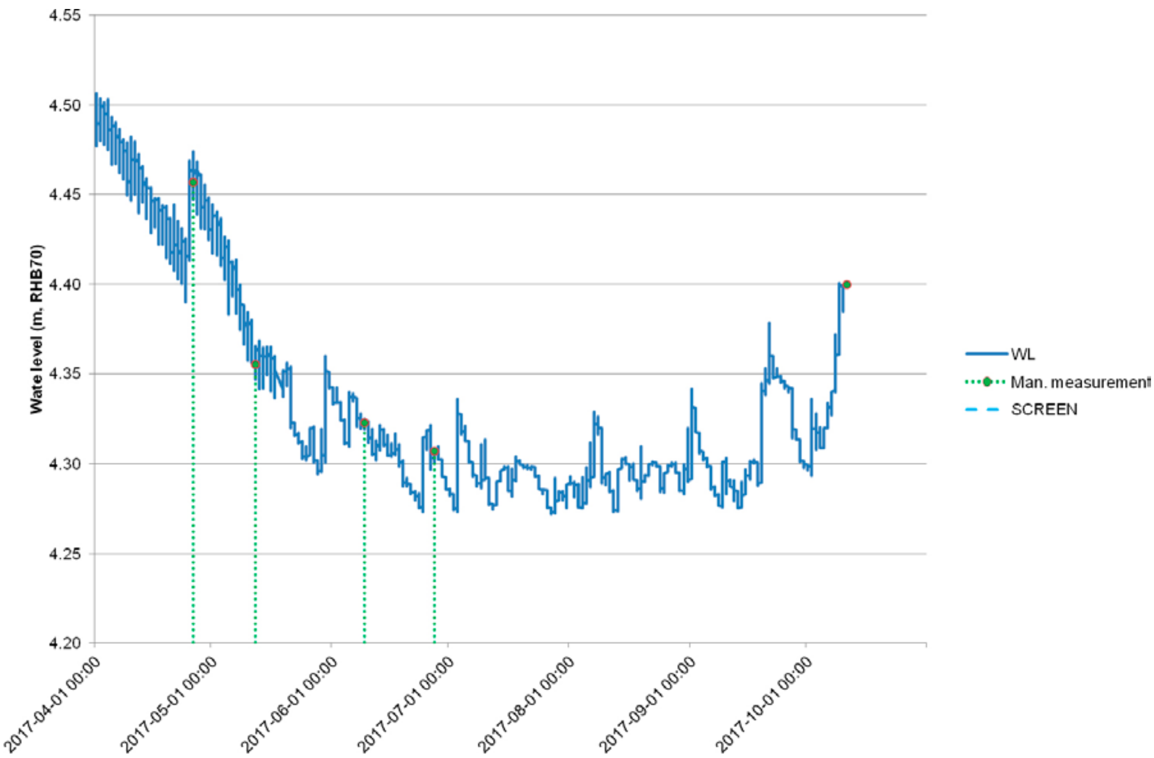

***Figure A2-6.** Water-level time series for the flume at gauging station PFM002668 for the period Apr. 1–Oct. 31, 2017.*

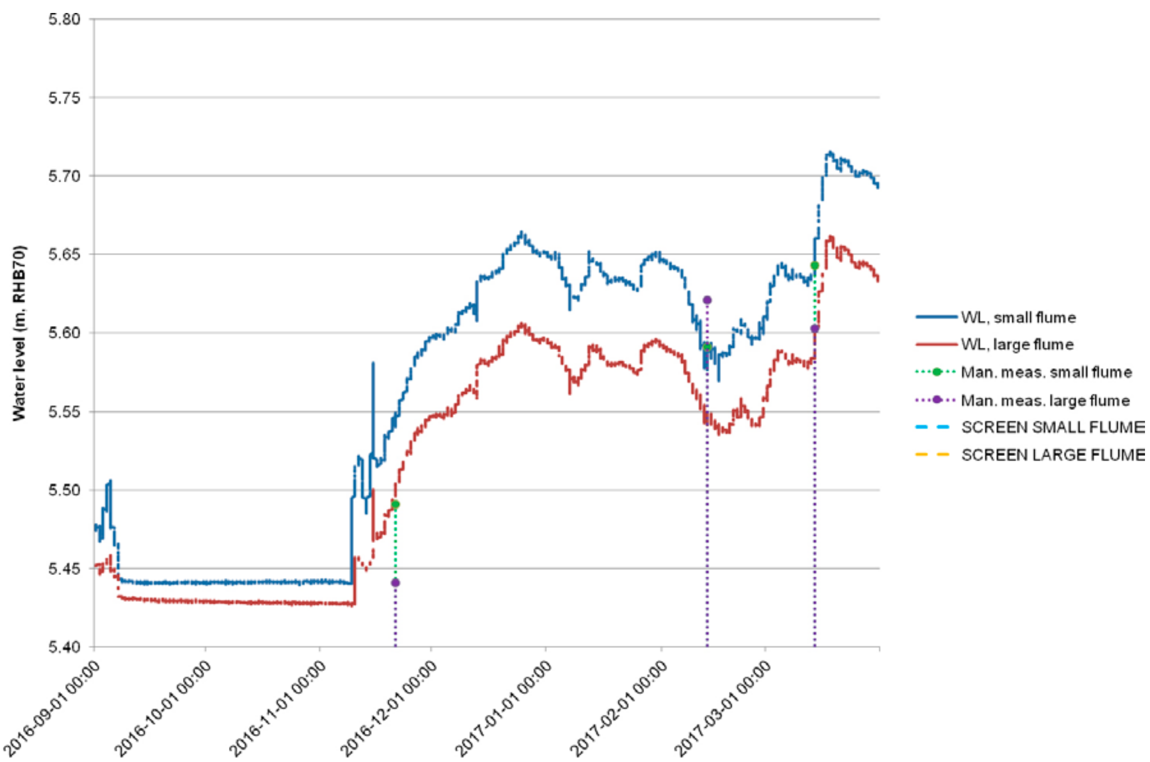

***Figure A2-7.** Water-level time series for the flumes at gauging station PFM002669 for the period Sep 1, 2016–Mar. 31, 2017.*

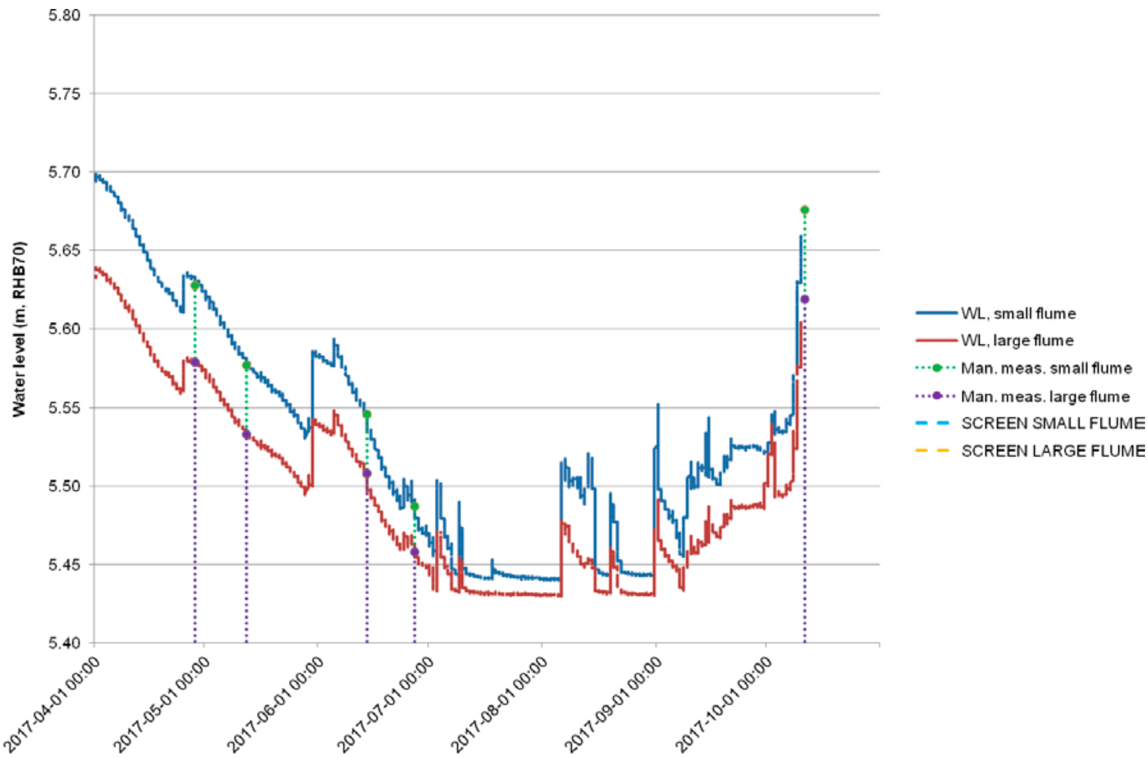

Figure A2-8. *Water-level time series for the flumes at gauging station PFM002669 for the period Apr. 1–Oct. 31, 2017.*

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, 2016–September 30, 2017. Hourly averages are calculated without the data periods excluded as a result of the regular quality control and the quality control of the 2016/2017 water-level dataset (Appendix 2).

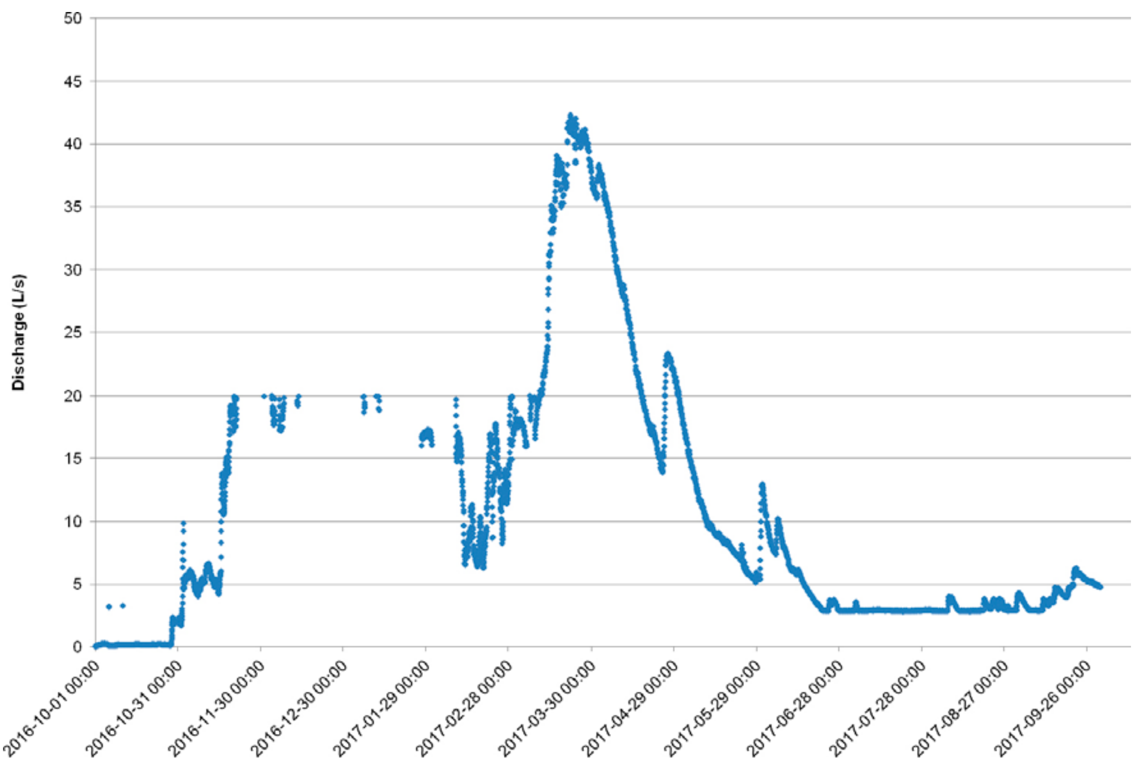

Figure A3-1. *Hourly average stream discharge at gauging station PFM005764 for the period Oct. 1, 2016–Sep. 30, 2017.*

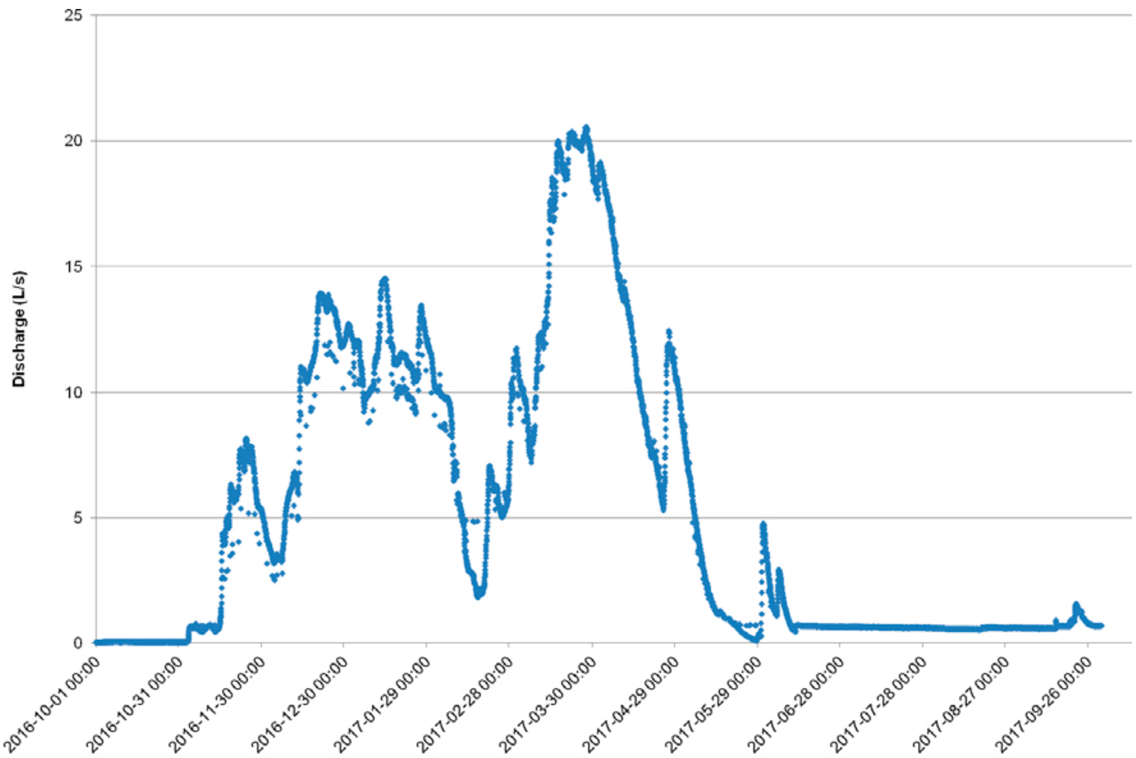

Figure A3-2. *Hourly average stream discharge at gauging station PFM002667 for the period Oct. 1, 2016–Sep. 30, 2017.*

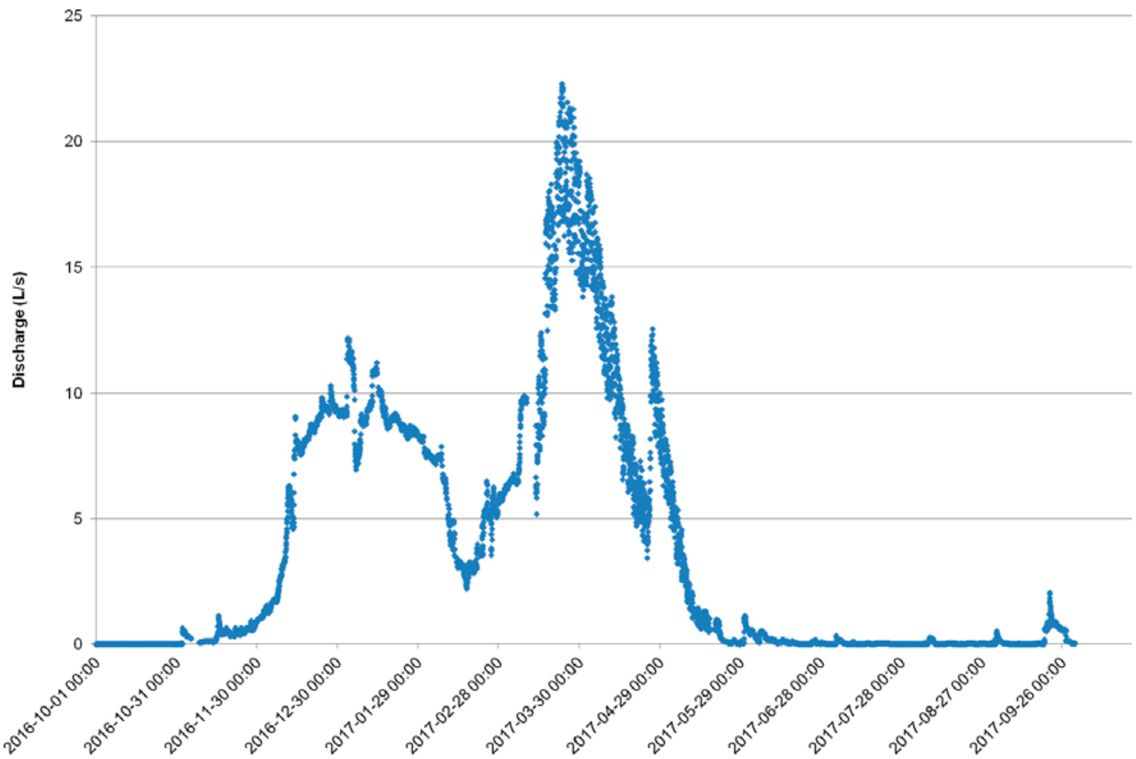

Figure A3-3. *Hourly average stream discharge at gauging station PFM002668 for the period Oct. 1, 2016–Sep. 30, 2017.*

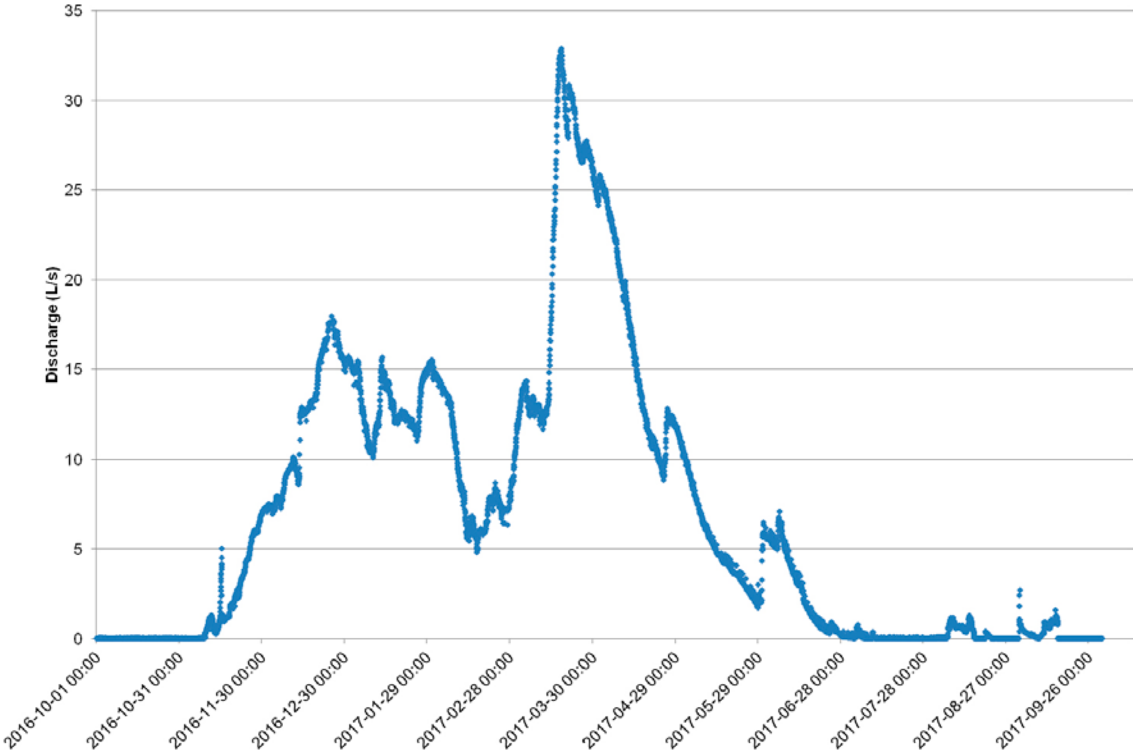

Figure A3-4. *Hourly average stream discharge at gauging station PFM002669 for the period Oct. 1, 2016–Sep. 30, 2017.*

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, 2016–October 31, 2017. The plots also show manually measured EC values and data periods excluded (SCREEN) as a result of the quality control of the 2016/2017 EC dataset. Note that EC values for September 2016 and October 2017 are shown for reference only.

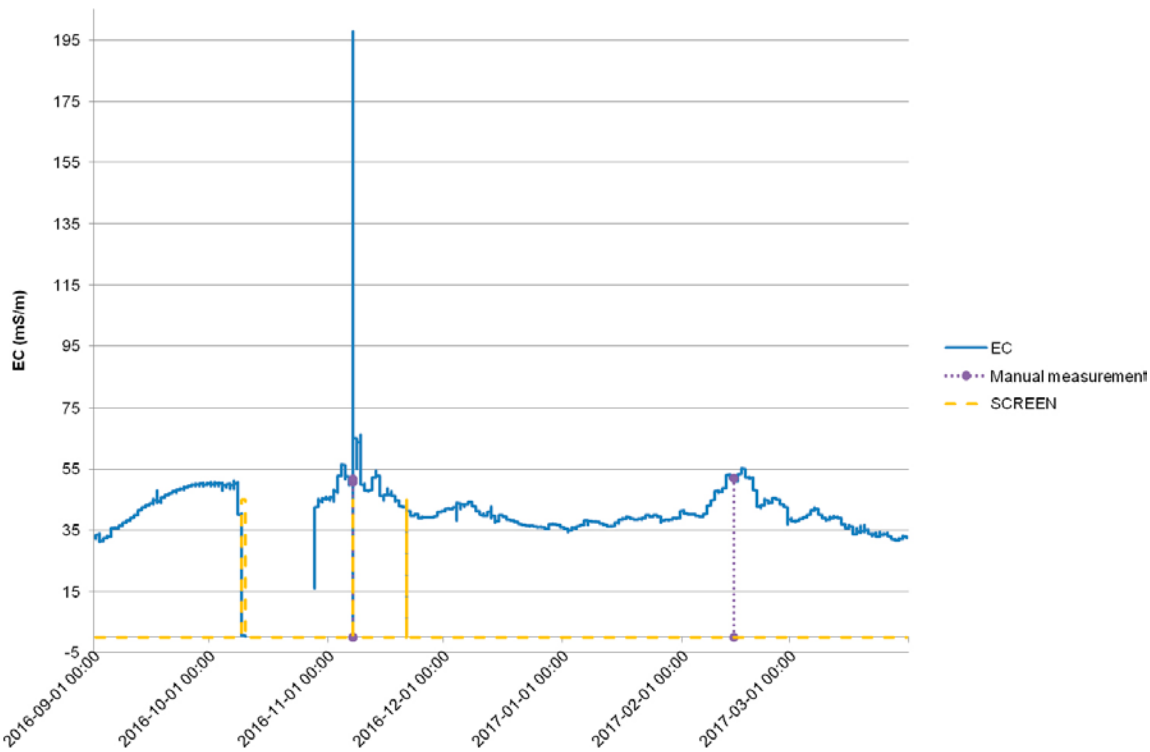

Figure A4-1. *EC time series for gauging station PFM005764 for the period Sep. 1, 2016–Mar. 31, 2017.*

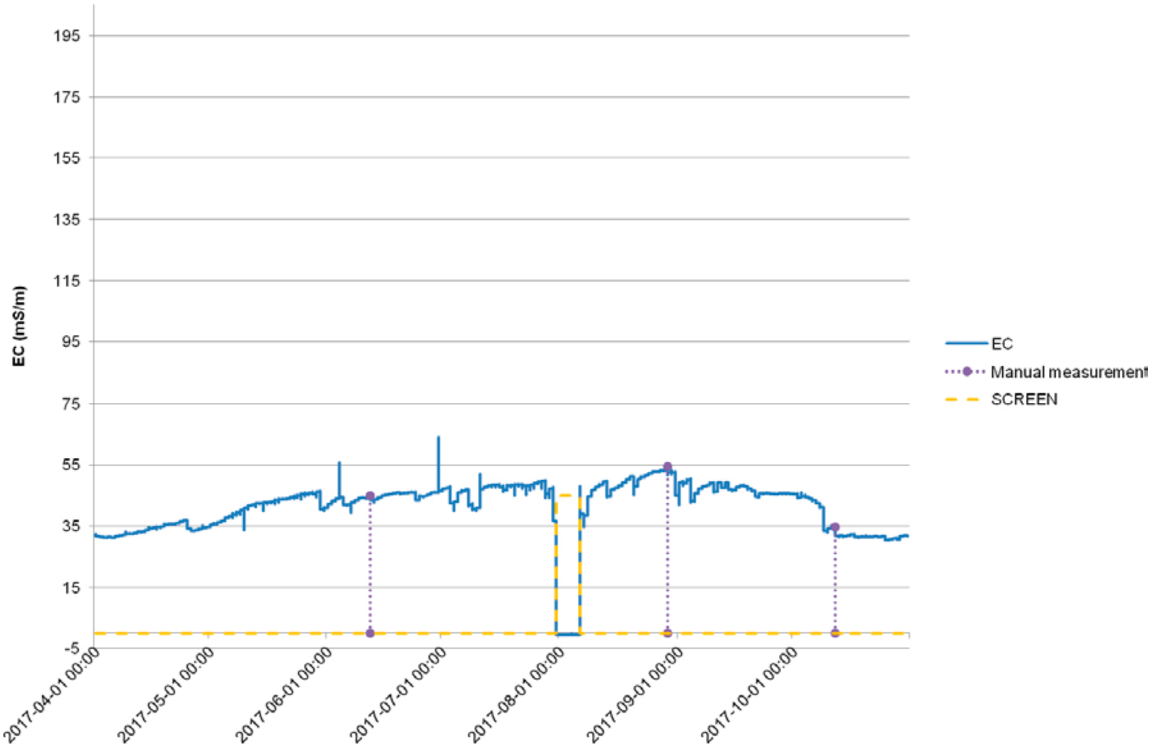

***Figure A4-2.** EC time series for gauging station PFM005764 for the period Apr. 1–Oct. 31, 2017.*

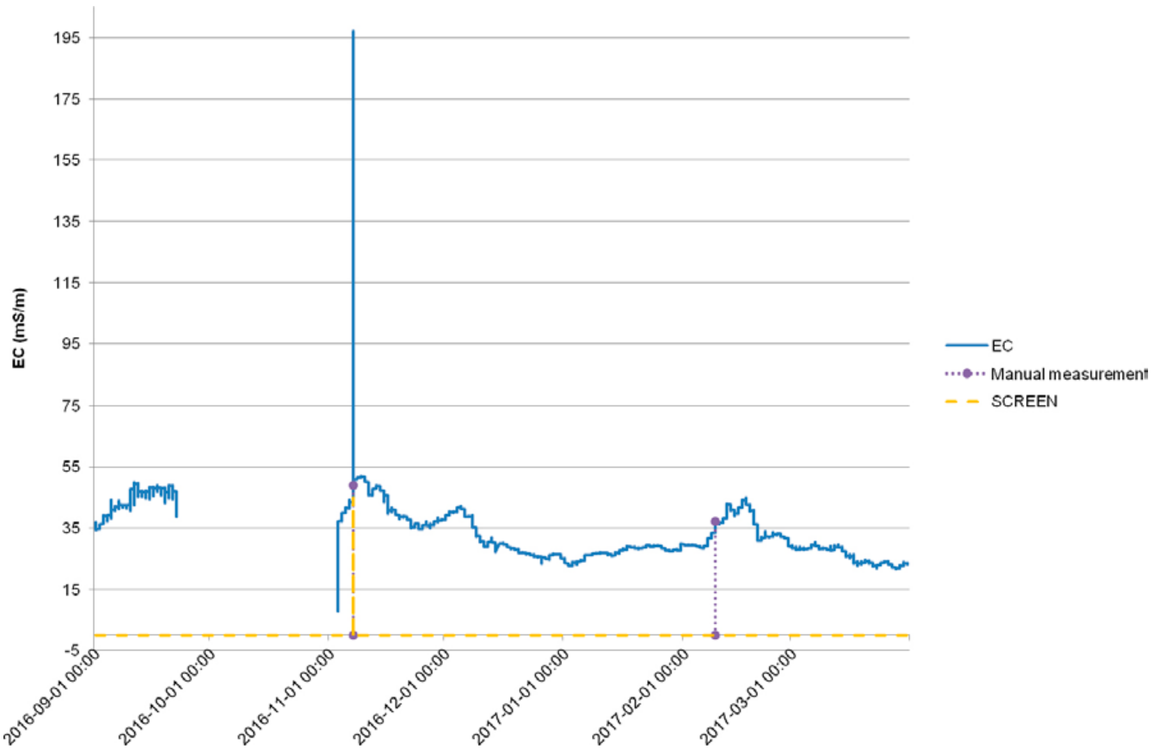

***Figure A4-3.** EC time series for gauging station PFM002667 for the period Sep. 1, 2016–Mar. 31, 2017.*

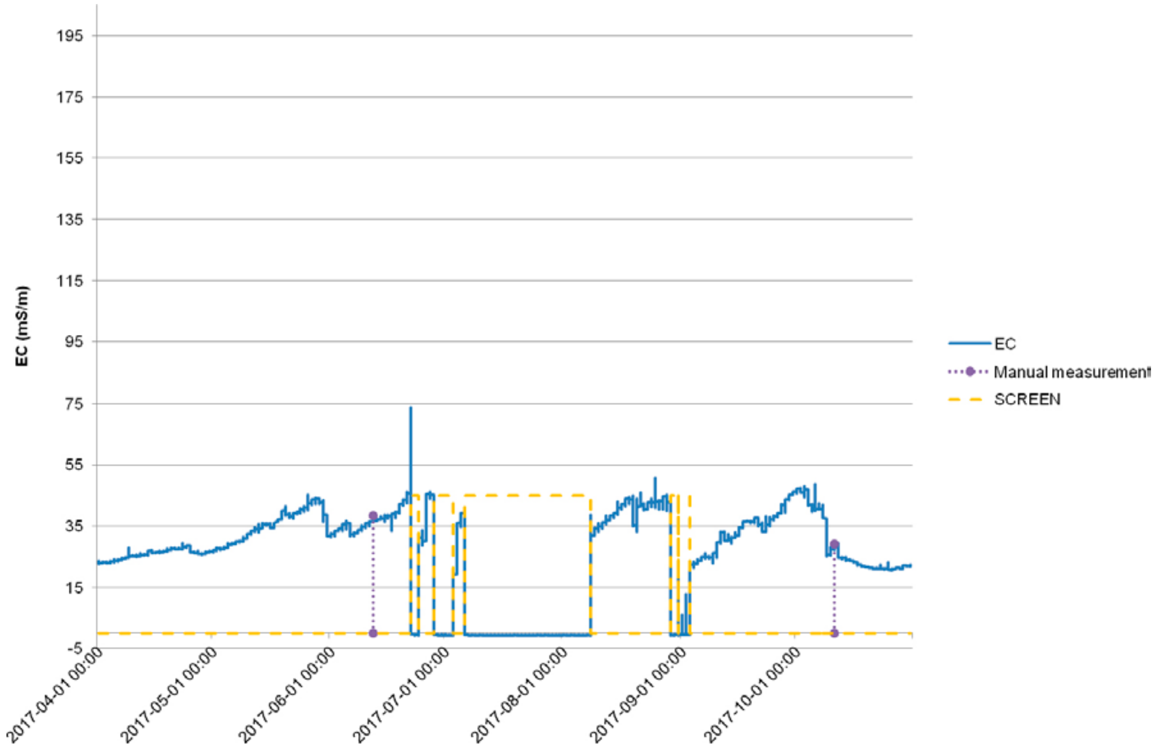

Figure A4-4. *EC time series for gauging station PFM002667 for the period Apr. 1–Oct. 31, 2017.*

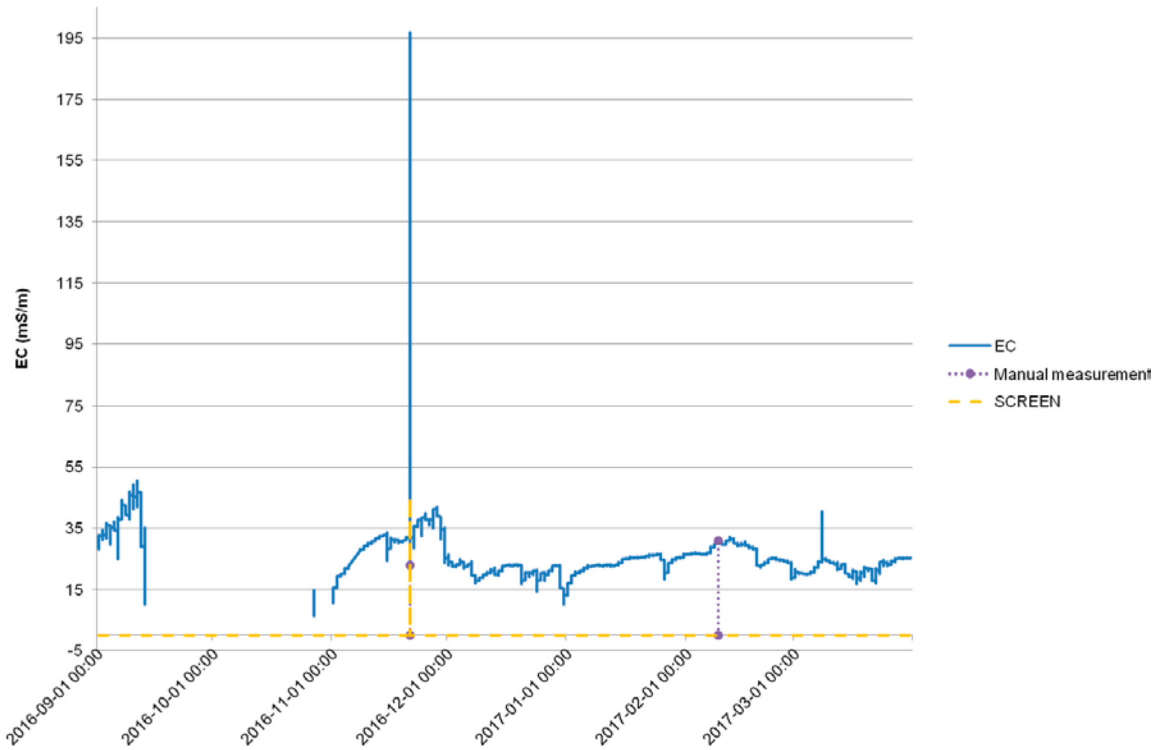

Figure A4-5. *EC time series for gauging station PFM002668 for the period Sep. 1, 2016–Mar. 31, 2017.*

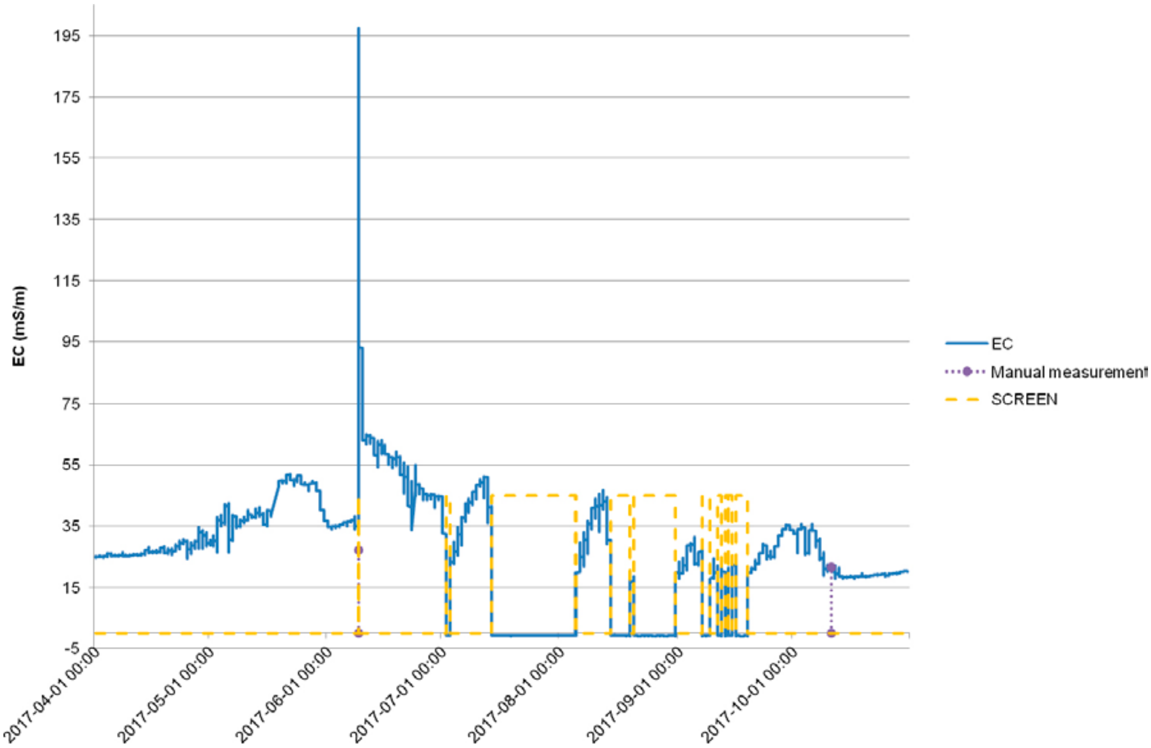

Figure A4-6. *EC time series for gauging station PFM002668 for the period Apr. 1–Oct. 31, 2017.*

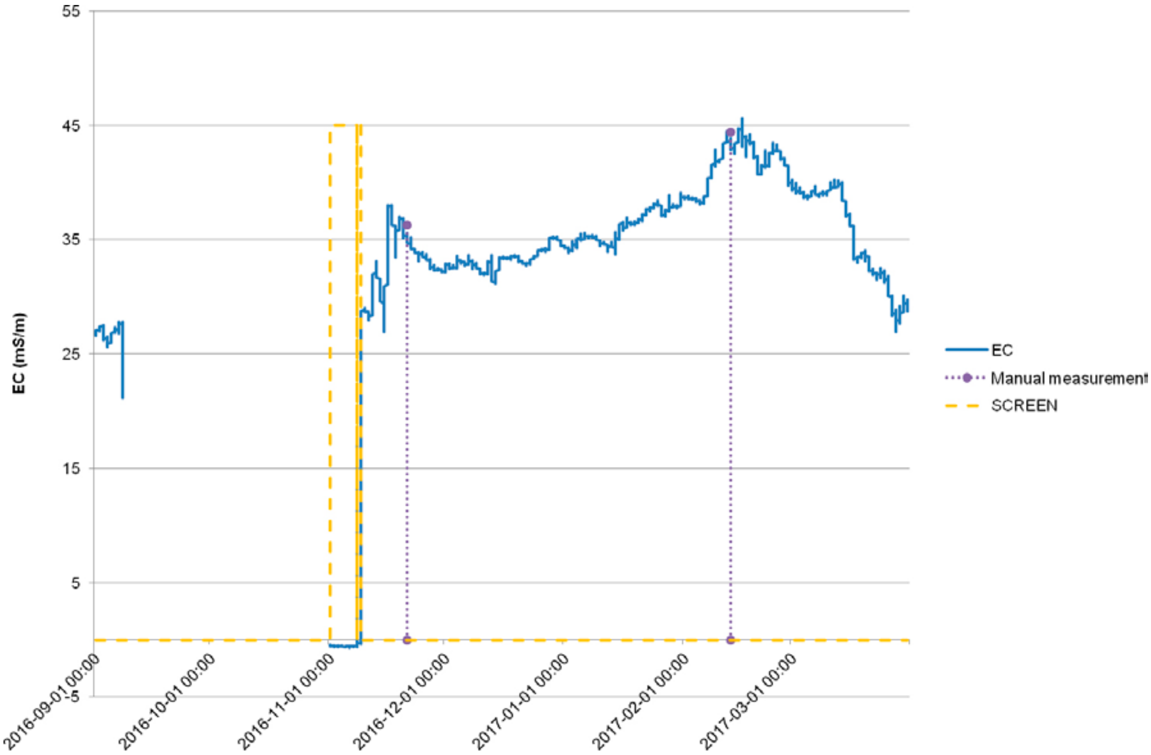

Figure A4-7. *EC time series for gauging station PFM002669 for the period Sep. 1, 2016–Mar. 31, 2017.*

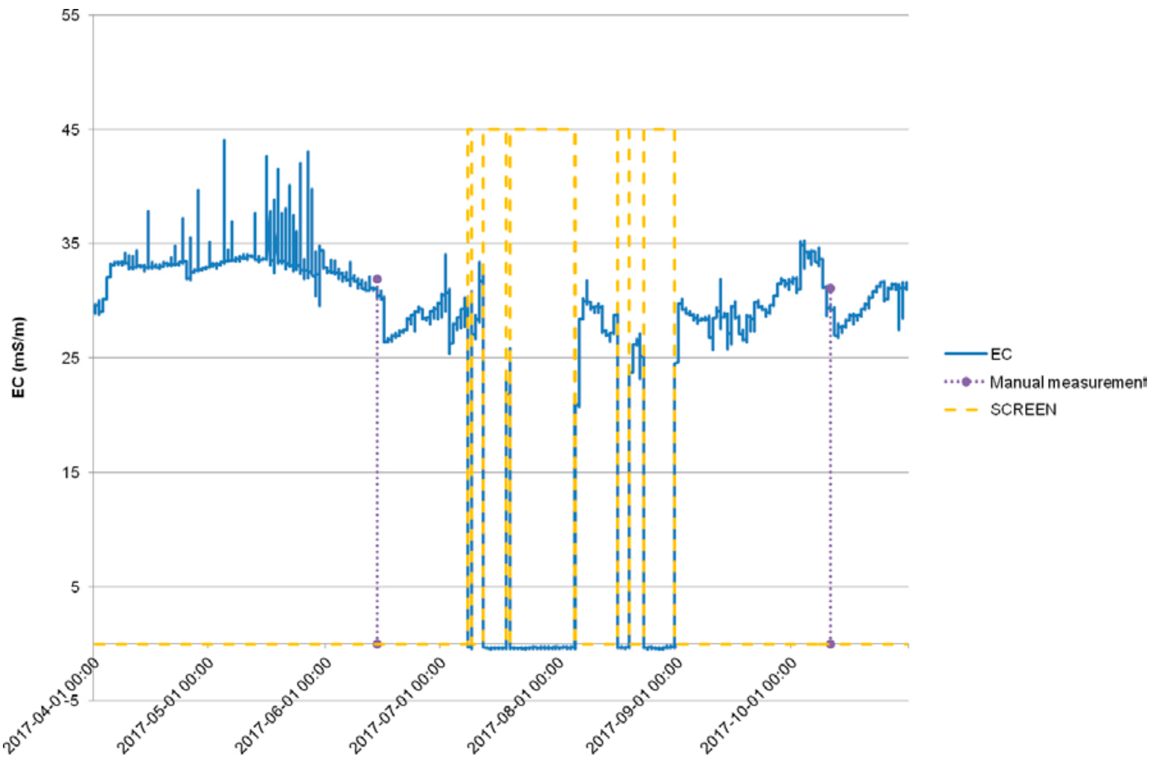

Figure A4-8. *EC time series for gauging station PFM002669 for the period Apr. 1–Oct. 31, 2017.*

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, 2016–October 31, 2017. The plots also show manually measured temperature values and data periods excluded (SCREEN) as a result of the quality control of the 2016/2017 temperature dataset. Note that temperature values for September 2016 and October 2017 are shown for reference only.

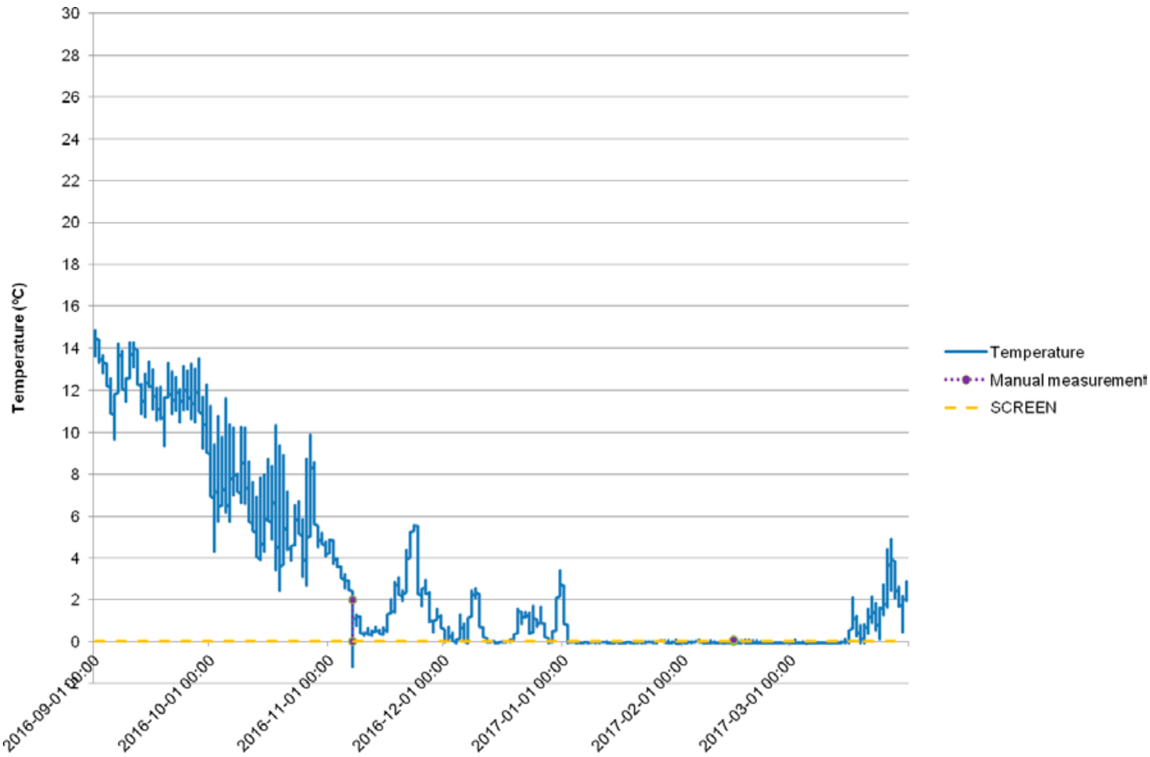

Figure A5-1. *Temperature time series for gauging station PFM005764 for the period Sep. 1, 2016–Mar. 31, 2017.*

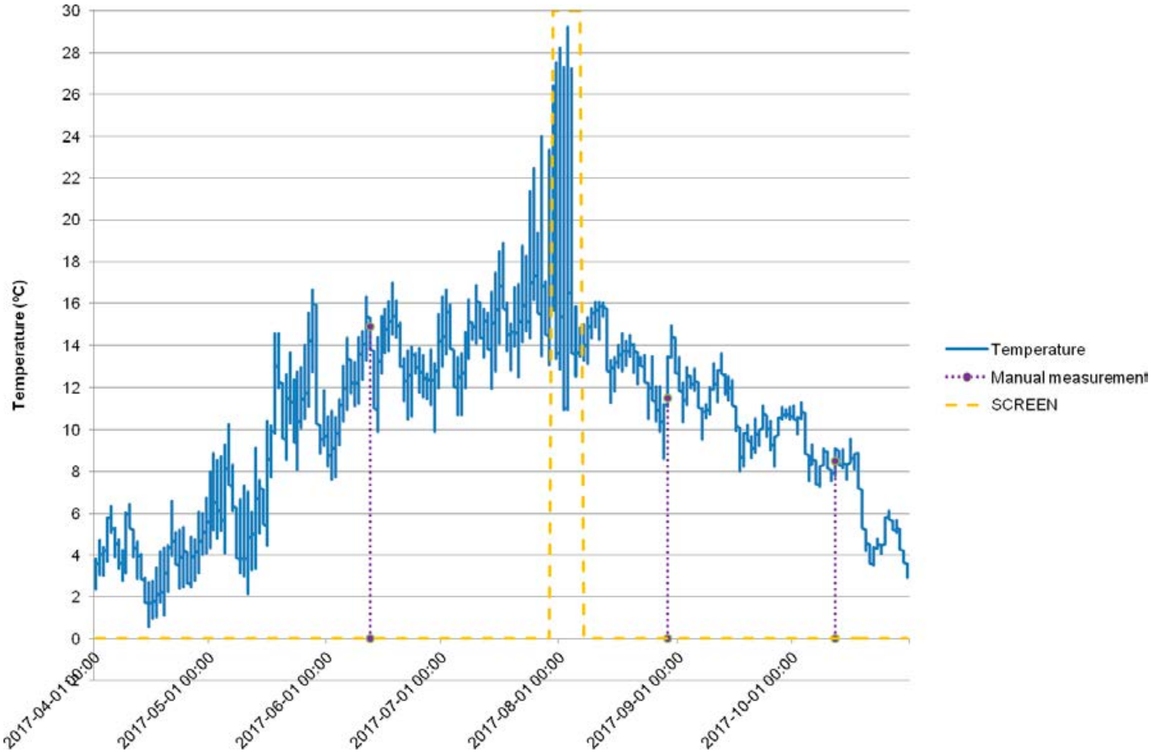

Figure A5-2. *Temperature time series for gauging station PFM005764 for the period Apr. 1–Oct. 31, 2017.*

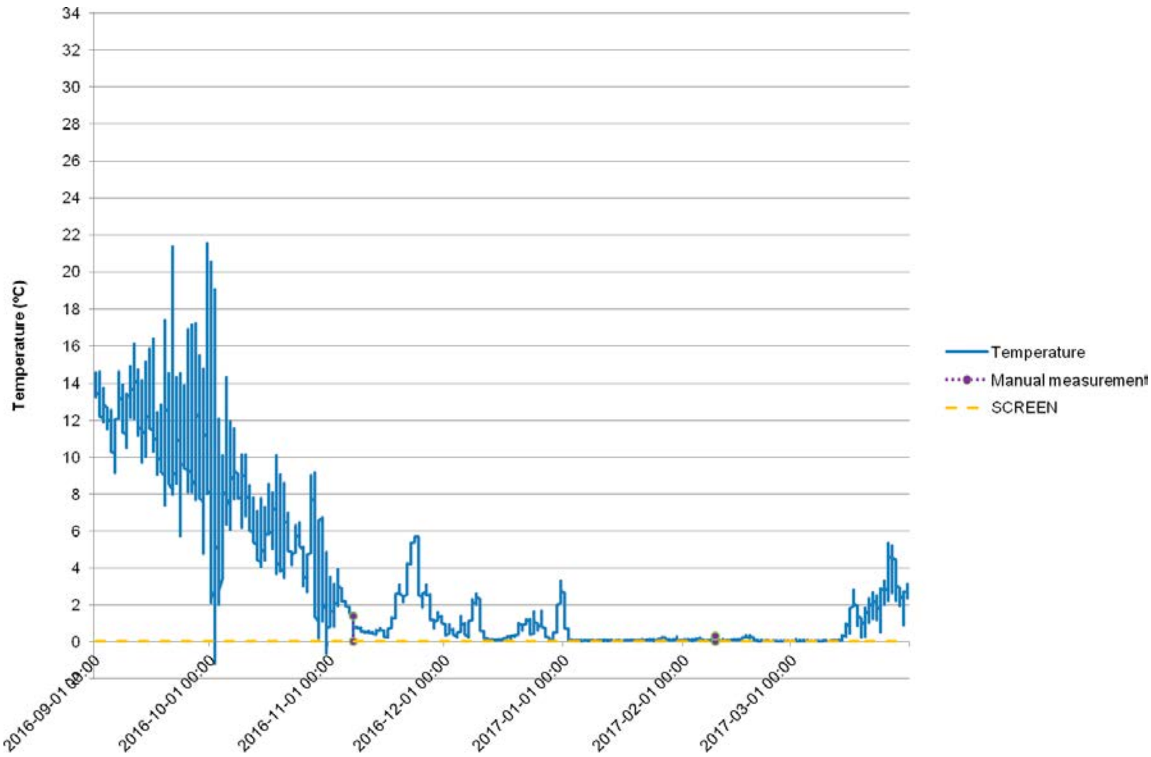

Figure A5-3. *Temperature time series for gauging station PFM002667 for the period Sep. 1, 2016–Mar. 31, 2017.*

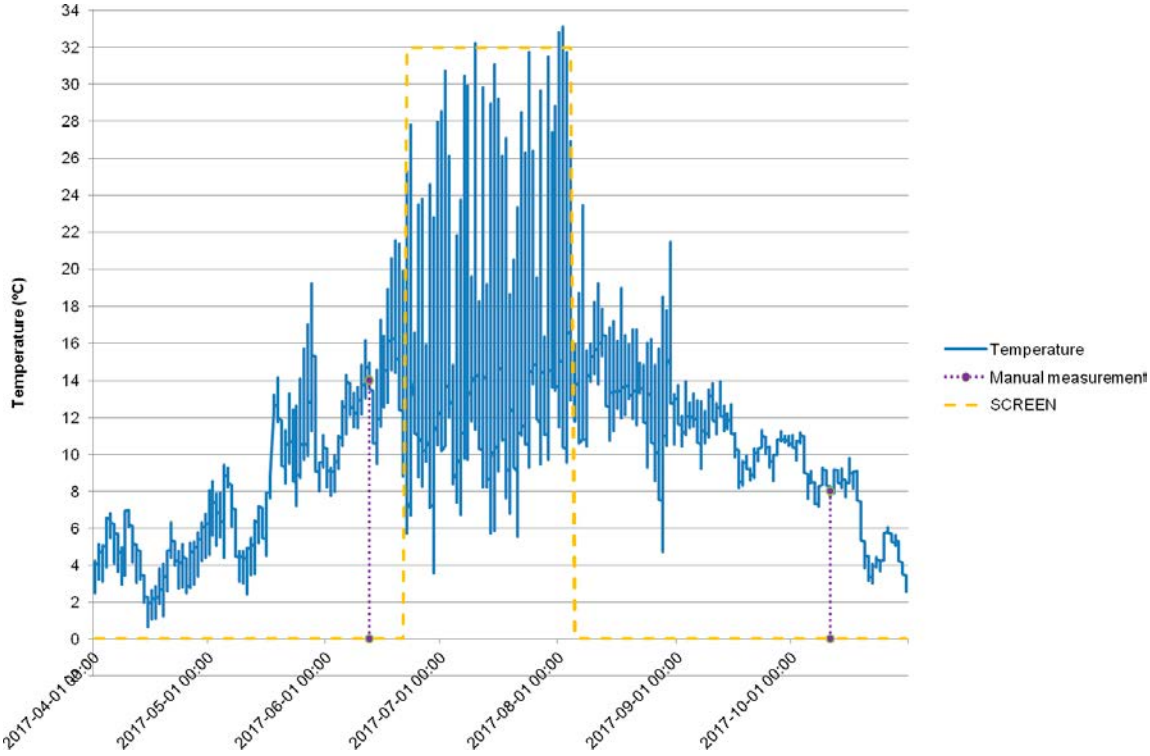

Figure A5-4. *Temperature time series for gauging station PFM002667 for the period Apr. 1–Oct. 31, 2017.*

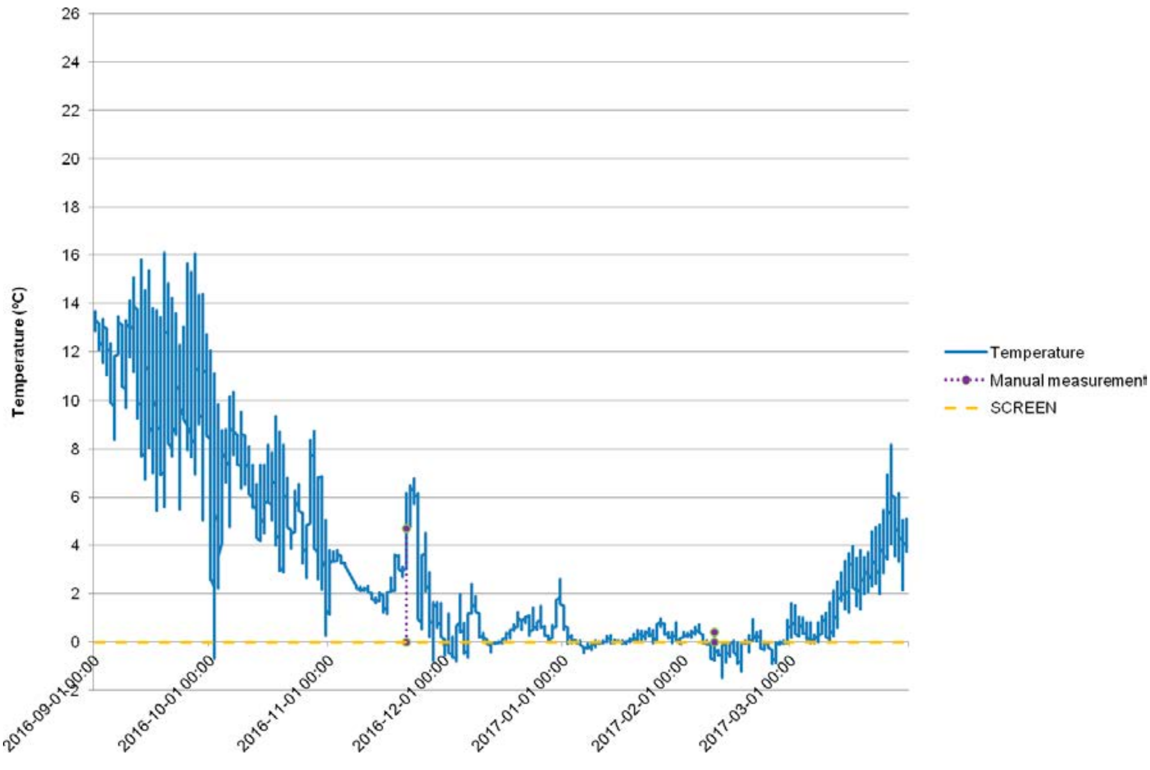

Figure A5-5. *Temperature time series for gauging station PFM002668 for the period Sep. 1, 2016–Mar. 31, 2017.*

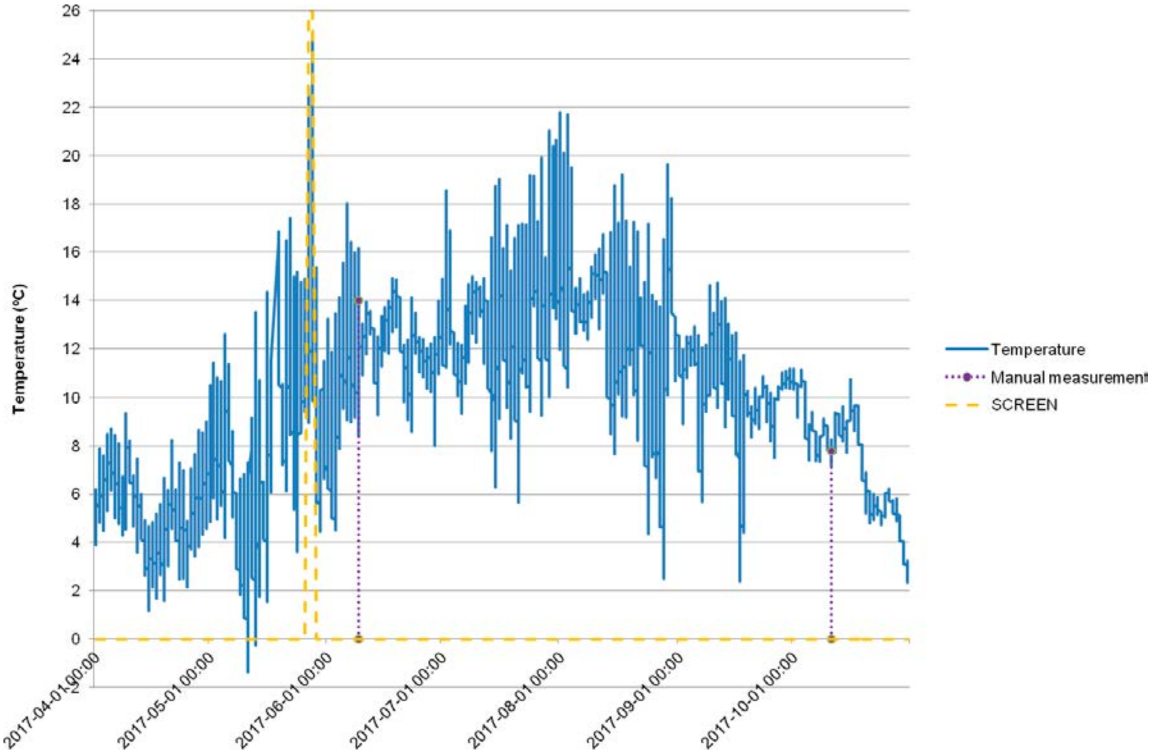

Figure A5-6. Temperature time series for gauging station PFM002668 for the period Apr. 1–Oct. 31, 2017.

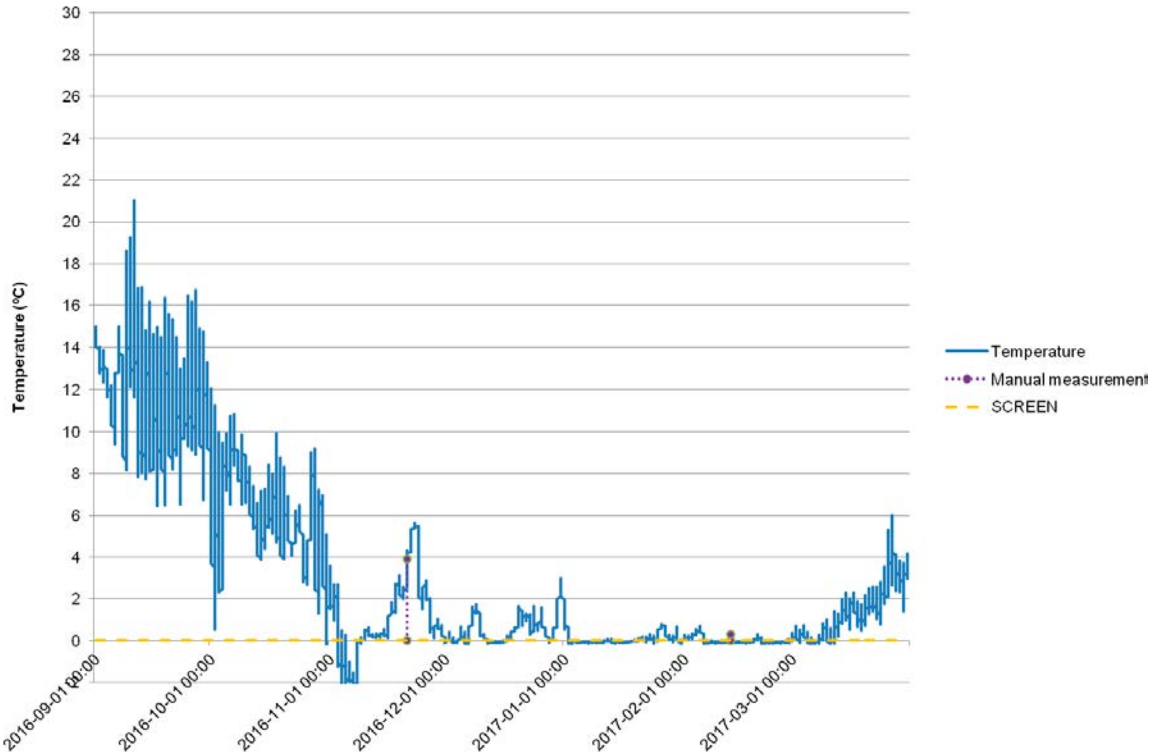

Figure A5-7. Temperature time series for gauging station PFM002669 for the period Sep. 1, 2016–Mar. 31, 2017.

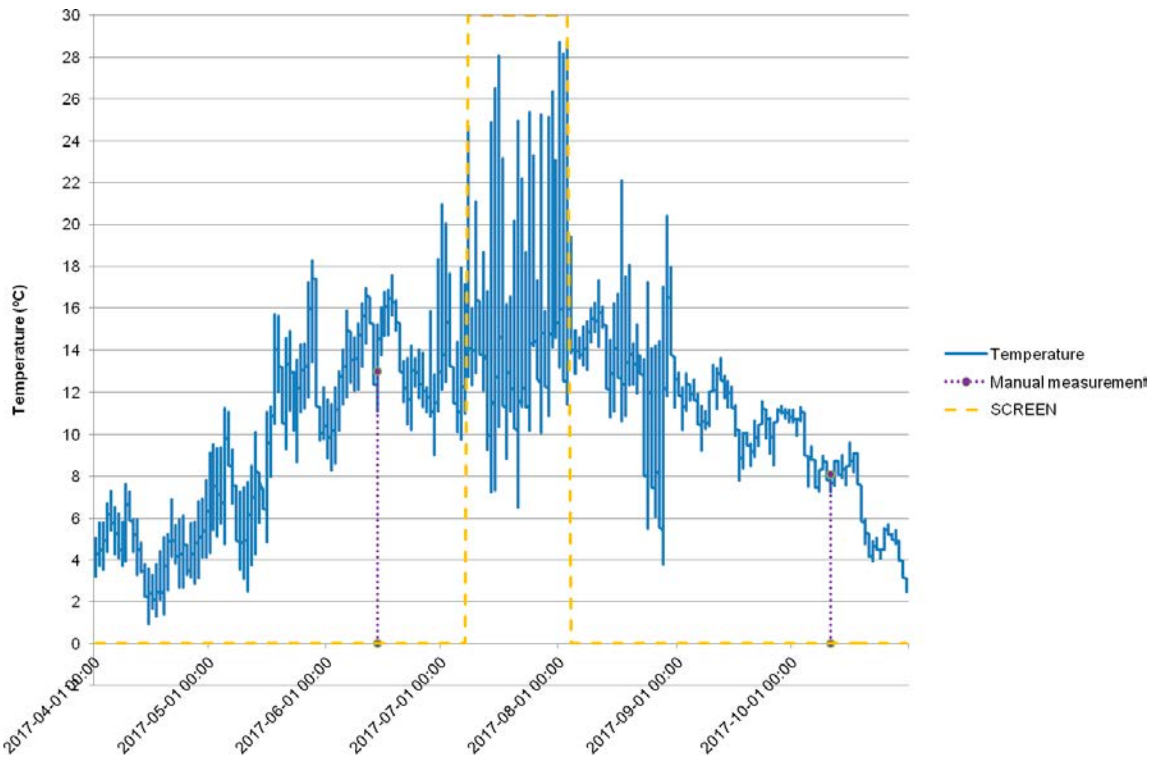

Figure A5-8. *Temperature time series for gauging station PFM002669 for the period Apr. 1–Oct. 31, 2017.*

Arkitektkopia AB, Bromma, 2018

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