

Report

P-17-27

November 2017



Monitoring hydrology in Forsmark 2015

**Monitoring of streams: Water level, discharge,
electrical conductivity and temperature**

Kent Werner

SVENSK KÄRNBRÄNSLEHANTERING AB

SWEDISH NUCLEAR FUEL
AND WASTE MANAGEMENT CO

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

SVENSK KÄRNBRÄNSLEHANTERING

ISSN 1651-4416

SKB P-17-27

ID 1571610

November 2017

Monitoring hydrology in Forsmark 2015

Monitoring of streams: Water level, discharge, electrical conductivity and temperature

Kent Werner, EmpTec

Keywords: Gauging station, Flume, Water level, Discharge, Electrical conductivity, Temperature, AP SFK 10-083.

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

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

A pdf version of this document can be downloaded from www.skb.se.

© 2017 Svensk Kärnbränslehantering AB

Summary

This document reports the monitoring of water level, EC (electrical conductivity), temperature, and water-level based calculations of discharge at four gauging stations in four streams in Forsmark for the year 2015. 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.

Discharge was calculated based on water levels measured by pressure sensors, installed in observation wells located alongside long-throated flumes, whereas EC and temperature sensors are mounted on the outside or inside of screened tubes located in the streams. For calibration of the measured water level, water depths in the flumes were regularly measured using a folding rule, and automatically measured water levels were adjusted in case of poor fit to the manually measured water level, i.e. flume-bottom level plus water depth.

2012–2015 levelling campaigns indicate that the flumes have moved vertically since they were installed in 2004, including movements during the period 2012–2015. However, actual vertical movements since 2004 are uncertain as the original levelling had less accuracy, and it is recommended that evaluations of levelling methods and associated accuracies are integrated parts of continued levelling campaigns. Vertical flume movements likely have only small effects on the validity of the calculated discharge, provided that manual water-depth measurements in the flumes are done regularly and with high accuracy. This reduces potential errors due to vertical flume movements, whereas the validity of discharge equations and associated parameters can be checked by independent discharge measurements. Doppler measurements done in 2004–2006, and recently in 2013, indicate that discharge equations and their parameters likely are applicable. However, due to various types of measurement uncertainties the knowledge is yet incomplete. An alternative method, so-called salt-dilution measurements, was applied in December 2014. Dilution and/or other types of independent discharge measurements need to be performed also in the future.

Practical experiences, inspections and 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. The PFM002669 station was refurbished during August–September 2015. Among other things, the refurbishment comprises construction of concrete foundations for the flumes and construction of a pool between them. Moreover, in December 2014–January 2015 the PFM002668 temperature sensor was relocated due to observed discrepancies between manually and automatically measured temperatures.

As part of the quality control of the whole 2015 dataset, water-level data were only excluded from the HMS to Sicada transferral for short periods with low water levels. However, the year 2015 is characterised by unusually long data gaps, mainly due to malfunctioning radio communication with data loggers, few manual control measurements and long periods with non-approved data. It is therefore noted that the statistics for year 2015 presented in the report are affected by long data gaps.

Sammanfattning

Detta dokument beskriver monitorering av vattennivå, EC (elektrisk konduktivitet), temperatur samt vattennivåbaserade beräkningar av vattenföring vid fyra vattenföringsstationer i fyra bäckar i Forsmark under år 2015. 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.

Vattenföring beräknades utifrån vattennivåer som är mätta med trycksensorer i observationsrör vid sidan om mättrännor av typen ”long-throated flumes”, medan EC- och temperatursensorerna är installerade på ut- eller insidan av slitsade rör i bäckarna. För kalibrering av uppmätt vattennivå mättes regelbundet vattendjup i rännor med tumstock, och automatiskt mätta vattennivåer justerades vid dålig passning mot den manuellt mätta nivån, d.v.s. rännbotten plus vattendjup.

Avvägning som genomfördes under 2012–2015 indikerar att rännorna har rört sig i höjdlid sedan de installerades 2004, inklusive perioden 2012–2015. De verkliga vertikala rörelserna är dock osäkra eftersom den ursprungliga avvägningen från 2004 hade lägre noggrannhet, och det rekommenderas att utvärdering av avvägningsmetoder och tillhörande osäkerheter är en integrerad del av fortsatta avvägningsskampanjer. Vertikala rännrörelser har sannolikt endast liten inverkan på giltigheten för den beräknade vattenföringen, givet att manuella vattendjupsmätningar görs regelbundet och med hög noggrannhet. Detta minskar potentiella fel till följd av vertikala rännrörelser, medan giltigheten för vattenföringsekvationer och tillhörande parametrar kan kontrolleras genom oberoende vattenföringsmätningar. Dopplermätningar 2004–2006, och nyligen under 2013, indikerar att vattenföringsekvationerna och deras parametrar sannolikt är tillämpbara. På grund av diverse mätosäkerheter är kunskapen dock inte komplett. En alternativ metod, så kallade saltutspädningsmätningar, genomfördes i december 2014. Det finns behov av utspädnings- och/eller andra typer av oberoende vattenföringsmätningar även i framtiden.

Praktiska erfarenheter, inspektioner och utredningar har lett till slutsatsen att vattenföringsstationerna måste renoveras för att förbättra deras funktion, mätnoggrannhet och för att göra dem stabilare och därmed lämpade för långtidsmonitorering. Stationen PFM002669 renoverades under augusti–september 2015. Renoveringen omfattade bland annat uppförande av betongfundament för rännorna och en damm mellan dem. I december 2014–januari 2015 flyttades temperaturgivaren vid PFM002668 till följd av observerade diskrepanser mellan manuella och automatiska temperaturmätningar.

Som del av kvalitetskontrollen av hela datasetet för år 2015 undantogs vattennivådata för överföring från HMS till Sicada främst under perioder med låga vattennivåer. År 2015 karaktäriseras dock av ovanligt långa dataluckor, huvudsakligen till följd av brister i radiokommunikation med dataloggrar, få manuella kontrollmätningar samt långa perioder med icke godkända data. Det noteras därför att den statistik för år 2015 som presenteras i rapporten är påverkad av långa dataluckor.

Contents

1	Introduction and objectives	7
2	Equipment	9
2.1	Gauging stations	9
2.2	Data-collection systems	11
2.3	Practical experiences, field inspections and independent discharge measurements	12
2.4	Refurbishment of the PFM002669 station	12
2.5	Follow-up of the 2014 refurbishment of the PFM005764 station	15
3	Execution	17
3.1	General	17
3.2	Field work	17
3.3	Data handling and post processing	17
	3.3.1 Water-level calibration	17
	3.3.2 Controls of EC and temperature	18
	3.3.3 Recording interval	19
	3.3.4 Calculation of discharge	19
3.4	Quality control	20
	3.4.1 Regular quality control	20
	3.4.2 Quality control of the 2015 dataset	21
	3.4.3 Flume and well levelling: Results and influence on discharge calculations	22
3.5	Nonconformities	26
4	Results	27
4.1	General	27
4.2	Water level	27
4.3	Calculated discharge	27
4.4	Electrical conductivity	28
4.5	Temperature	28
4.6	Integrated monitoring-data evaluations: Illustrative examples	29
	References	33
	Appendix 1 Water level	35
	Appendix 2 Calculated discharge	41
	Appendix 3 Electrical conductivity	45
	Appendix 4 Temperature	51

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 year 2015. 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.

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) for the period 2011–2014. 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). It is noted that quality control was performed only twice during the period of this report. Specifically, in autumn 2015 quality control was done of water-level data gathered during a rather long period, as there was an ongoing switch to a new HMS (see below) user interface the spring of 2015.

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.

Automatic monitoring of water electrical conductivity (station id PFM002292) was initiated at the outlet from Lake Bolundsfjärden in December 2004, primarily to identify occasions of sea-water intrusion. In the quality control of the 2010 dataset, no electrical-conductivity data from PFM002292 were approved due poor fit to manual measurements (Johansson and Juston 2011b). As mentioned in Werner (2014a), the automatic monitoring at PFM002292 was terminated in the spring of 2012 and replaced by regular (10–12 times per year) manual EC measurements. The EC data from this station were not discussed further in the corresponding 2011–2014 dataset reports, and neither in the present report.

Note that 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.

In connection to Figure 1-1, it should be 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). The 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.

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

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

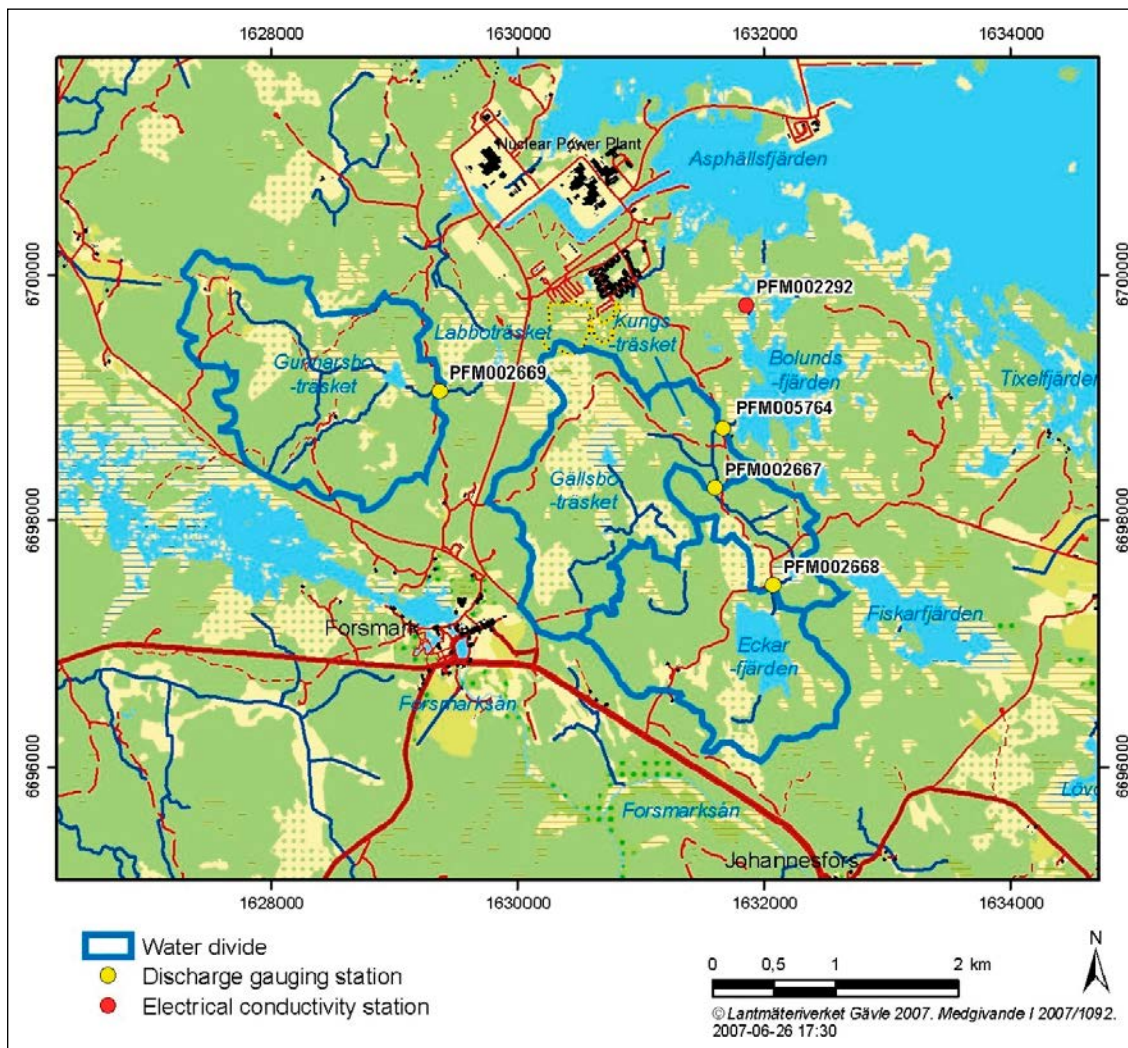


Figure 1-1. Locations of the four gauging stations. Automatic EC measurements at PFM002292 were terminated in spring 2012. It is noted that the catchment-area boundaries (SDEADM.POS_FM_VTN_5441) for PFM002667 and PFM002668 were updated in December 2006, and therefore do not match the boundaries shown in the original installation report (Johansson 2005). The 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.

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

Activity plan	SKBdoc id, version	Reference
AP SFK 10-083 Hydrologisk och hydrogeologisk monitoring 2015–2017	1464444, ver 2.0*	
Projekt Kärnbränsleförvaret, quality-control reports		
Monitoring Forsmark och SFR – kvalitetskontroll av yt- och grundvattenmonitoring Januari–september 2015	1523231, ver 2.0	Geosigma 2015
Monitoring Forsmark och SFR – kvalitetskontroll av yt- och grundvattenmonitoring September 2015–februari 2016	1540762, ver 1.0	Geosigma 2016

* Internal document (in Swedish).

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.

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 (see Section 2.4).

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 and the sensors were again installed inside the tubes. 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 2-1 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 calculation of stream discharges (Johansson and Juston 2011b). As described in Section 3.4.3, 2012–2015 levelling campaigns indicate that all flumes may have moved vertically since they were installed, including movements during the period 2012–2015. However, the levelling performed at time of the original flume installations had less accuracy compared to the 2012–2015 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. 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 (November 27, 2003–October 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 (October 5, 2004–August 25, 2014)			
Small flume			
Top of obs. well	6698745.4	1631660.9	2.190 (orig. levelling; lowered to 2.050 in September 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 (August 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 (November 10, 2003–September 14, 2015)			
Small flume			
Top of obs. well	6699047.4	1629371.7	6.994 (orig. levelling; reinstalled in November 2007, handled by cal.-const. adjustment; Table 3-1)
Flume bottom, upstream edge	6699046.6	1629371.2	5.852 (orig. levelling; reinstalled in November 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 November 2007, handled by cal.-const. adjustment; Table 3-1)
Flume bottom, upstream edge	6699043.9	1629379.1	5.843 (orig. levelling; reinstalled in November 2007, handled by cal.-const. adjustment; Table 3-1)
PFM002669 (September 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 2-2 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) discharge-equation errors are less than $\pm 2\%$ for all flumes.

Table 2-2. 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		
November 27, 2003–October 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		
October 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 number of data sources. 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 HVM 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 2014, the reader is referred to the corresponding 2011–2014 dataset reports (Werner 2014a, b, 2016) and reports from independent discharge measurements (Bergqvist 2013, 2014, SKBdoc 1467666¹). No independent discharge measurements were performed during 2015. However, planning has been undertaken to continue such measurements during 2016, including Doppler based area-velocity measurements and the salt-dilution method (cf. Werner 2016).

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 (Section 2.4) were done during August 2014 and August–September 2015, respectively.

2.4 Refurbishment of the PFM002669 station

A refurbishment of the PFM002669 station was done during the period August 25–September 15, 2015. Prior to the refurbishment a pre study was performed on different flume options, including replacement of the two flumes with a single so called H flume (SKBdoc 1488216²). Based on the pre study it was decided to keep the existing flume setup, i.e. a small and a large flume. The main motivation was to reduce the risk of flooding in the surroundings of the station and in the upstream flat landscape during high-discharge periods (SKBdoc 1488217³). The refurbishment comprises the following:

- Construction of concrete foundations for the flumes (Figure 2-3), at larger inter-flume distances compared to the previous flume setup.
- Adjustment of the LPG heating system, also with specific heating of the pipe connecting the large flume to its observation well (Figure 2-2).
- Construction of a pool between the two flumes to reduce the approach flow velocity to the large flume (Figures 2-1 and 2-3). Moreover, parts of concrete pipes were installed at upright positions in the pool to further reduce the approach velocity.
- The tube hosting the EC and temperature sensors was moved to the grating (Figure 2-3), which was relocated some distance further upstream of the small flume. The tube was previously installed in the stream bottom downstream of the small flume, periodically disturbing the inflow to the large flume. The EC and temperature sensors were installed inside (and not outside of) the tube, which in its new position communicates hydraulically with the stream water not only through the tube screen but also via the open tube bottom.
- During 2016, it is planned to construct a cottage above the large flume (cf. Section 2.5).

As the PFM002669 monitoring was interrupted during the refurbishment works, there are no data from August 25 (last registrations: water level 1 PM, EC 2 PM, temperature 1:40 PM) to September 15 (first registrations after refurbishment: 3 PM). The original flume-bottom elevations have been used in discharge calculations since the flumes were installed in 2004. The reinstallation in 2007 was handled by adjustments of calibration constants (see Table 2-1), whereas levellings of the flumes during the period 2012–2014 show that the flumes were actually lowered c. 0.4 m in 2007. The flumes were levelled in 2016, i.e. subsequent to the refurbishment (see Table 3-6). These flume-bottom levels are used for discharge calculation from the refurbishment and onwards, i.e. from September 15, 2015.

¹ Internal document (in Swedish).

² Internal document (in Swedish).

³ Internal document (in Swedish).



Figure 2-1. Excavation of the pool between the two flumes at PFM002669.



Figure 2-2. Installation of the heater system at PFM002669.



Figure 2-3. The refurbished PFM002669 station, with a pool and parts of concrete pipes between the two flumes, reducing the approach flow velocity towards the large flume. The picture also shows the grating and the attached tube hosting the EC and temperature sensors, some distance upstream of the small flume. During 2016, it is planned to construct a cottage above the large flume.

2.5 Follow-up of the 2014 refurbishment of the PFM005764 station

As reported in Werner (2016), the PFM005764 station was refurbished in August 2014. Among other improvements, the refurbishment comprised construction of a pool and concrete foundations, replacement of the data logger, installation of an electric heating system (enabled by installation of permanent electric supply), and replacement of the small flume. During autumn 2015, a cottage was constructed above the large flume (Figure 2-4). Loggers and other equipment were installed inside the cottage, and infra heaters were installed above the flume (Figure 2-5). The objectives of the cottage and its installations are to reduce maintenance needs during both winter (removal of snow and ice) and summer (ongrowth due to direct sunlight), to provide physical protection for equipment, and to improve working conditions at field inspections.



Figure 2-4. Ongoing construction of the cottage above the large flume at PFM005764 during autumn 2015.



Figure 2-5. Interior view of the cottage, showing one of the infra heaters and the walking platform that improves working conditions at field inspections.

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 2-1) and also transferred to Sicada.

3.2 Field work

The gauging stations were inspected approximately once a week. If needed, the stations and the stream reaches immediately upstream and downstream of the stations were cleaned from debris, vegetation, snow and ice. During the year 2015, manual measurements of the water depth at the upstream edge of each flume were done using a folding rule on 15–18 occasions (the number of occasions varies between gauging stations), and EC and temperature were measured using a hand-held instrument (HACH HQ 14D) on 12–15 occasions. However, the measurement frequency was very unevenly distributed, with only 2–3 occasions during the period August–December (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 2-1). 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 2-1) 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 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 to the end of 2015 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 noted in Table 2-1, 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 to the end of 2015. 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
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)
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
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
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
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 refurbishment) 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 regularly measured outside of tubes using a hand-held instrument. No changes of calibration constants have been done during 2015 (constants were changed in connection to the PFM005764 refurbishment in August 2014).

3.3.3 Recording interval

Recording interval were very irregular, generally varying between 10 minutes (1 minute at PFM005764) 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 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.

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 2015 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 2-2 and the bottom level at the upstream edge of each flume shown in Table 2-1.

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 2-2). For these gauging stations, a single discharge time series for each station was obtained as follows:

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

Table 3-2. Levelled small-flume bottom elevations and elevations to signify zero discharge.

Gauging station	Bottom elevation (m) of upstream edge	Elevation (m) signifying zero discharge
PFM005764 (up to August 25, 2014)	0.903	0.903 (0.990 prior to September 13, 2006, when the observation well was lowered)
PFM005764 (from August 26, 2014)	0.924	0.924 (station refurbished)
PFM002667	1.502	1.518
PFM002668 (single flume)	4.287	4.296
PFM002669 (up to September 14, 2015)	5.852	5.872
PFM002669 (from September 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 2015 discharge at PFM002667 was c. 62 L/s, and it occurred during a short period in response to precipitation and/or snow and ice melt during early spring (Appendix 2). However, as part of the regular quality control (Section 3.4.1) water-level data for this station have only been approved up to August 3, 2015.

3.4 Quality control

3.4.1 Regular quality control

The regular quality control concerns water-level data, and does hence not concern EC or 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. Despite these regular checks, during 2015 there are some rather long data gaps for PFM005764 and PFM002667 (see Section 4.2). Another check was performed twice during 2015, when obviously erroneous data were excluded from the HMS to Sicada data transferral. Specifically, in autumn 2015 quality control was done of water-level data gathered during a rather long period, as there was an ongoing switch to a new HMS (see below) user interface the spring of 2015.

Moreover, calibration constants were corrected 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.

During 2015, two single water-level data outliers (October 2, 2015 at 1:30 and 1:31 PM; large flume at PFM005764) were excluded from the HMS to Sicada data transferral as part of the regular quality control. Moreover, at time of this report only part of the water-level dataset has been approved for transferral to Sicada for the following reasons (Geosigma 2016):

- **PFM005764:**
 - Small flume: For the period of this report, data have only been approved up to October 2 00:00. There was an approved fit to the manual water-depth measurement on October 2, whereas the flume was flooded during the measurement on December 21.
 - Large flume: For the period of this report, data have only been approved up to July 21 00:00. There was an approved fit to the manual water-depth measurement on July 21, whereas there were poor fits to the measurements on October 2 and December 21.
- **PFM002667:** For the period of this report, data are only approved up to August 4 00:00. There were approved fits to the manual water-depth measurements on August 4. The manual measurement on October 2 occurs some hours after data recording is resumed after a long data gap, whereas there is a poor fit to the manual measurement on December 21.
- **PFM002668:** Data are approved for the whole period of this report, except for data labelled as uncertain during the period September 3–October 2 (these uncertain water-level data are not used to calculate discharge in this report).
- **PFM002669:** Data are approved for the whole period of this report.

The results of the subsequent quality control of the whole 2015 dataset are presented in Section 3.4.2.

3.4.2 Quality control of the 2015 dataset

Apart from the regular quality control described above, an additional quality control was done of the whole 2015 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 2015 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)	2015-07-04 05:00–2015-07-05 02:40, 2015-07-06 10:00–11:00, 2015-07-24 13:30–2015-07-25 22:50	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 2015 dataset (WL = water level).

Gauging station	Dates and times (YYYY-MM-DD hh:mm)	Reason for exclusion
PFM005764	2015-03-24 12:20–12:22	Low/negative EC values (likely due to maintenance)
PFM005764	2015-06-26 11:44–11:47	Low/negative EC values (likely due to low WL or maintenance)
PFM005764	2015-07-21 13:18–13:19	Low EC values (likely due to low WL or maintenance)
PFM005764	2015-07-05 00:39–2015-07-05 00:43, 2015-07-13 09:43, 2015-07-21 22:20	Single outliers (likely due to low WL)
PFM005764	2015-09-29 13:22–2015-10-01 12:17	Negative EC values (likely due to low WL or malfunctioning radio communication with the data logger)
PFM002667	2015-05-08 21:40, 2015-06-18 00:30, 2015-08-01 00:00	Single outliers
PFM002668	2015-01-08 14:00–2015-01-08 20:20	Low/fluctuating EC values (likely due to ice)
PFM002668	2015-07-06 13:20	Single outlier (likely due to maintenance)
PFM002668	2015-07-06 14:40–2015-07-16 11:30	High/fluctuating EC values (reason unknown)
PFM002668	2015-07-28 01:00–2015-07-28 07:00	Negative EC values (likely due to low WL)
PFM002668	2015-07-31 00:00–2015-08-04 09:00	Low/negative EC values (likely due to low WL)
PFM002668	2015-08-23 20:40–2015-09-02 14:20	Negative EC values (likely due to low WL)
PFM002668	2015-12-29 04:30, 10:00, 10:10	Single outliers
PFM002669	2015-07-21 13:40	Negative EC value (likely due to maintenance)

Table 3-5. Temperature data excluded from the HMS to Sicada data transferral, as a result of the quality control of the 2015 dataset (WL = water level).

Gauging station	Dates and times (YYYY-MM-DD hh:mm)	Reason for exclusion
PFM005764	2015-06-26 11:46–2015-06-26 11:50	Single outliers (likely due to low WL)
PFM005764	2015-09-29 13:22–2015-10-01 11:00	Negative temp. values (likely due to low WL, or malfunctioning radio communication with the data logger)
PFM002667	2015-08-20 00:10–2015-08-21 14:20	Fluctuating/high temp. values (likely due to low WL)
PFM002668	2015-08-23 00:00–2015-09-02 23:00	Fluctuating/high temp. values (likely due to low WL)
PFM002669	2015-07-21 13:40	Single outlier (likely due to maintenance)

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), and in June 2015 (Edvardson 2015). The results of the levellings at time of flume and well installations and the 2012–2015 levelling campaigns, which have a stated level accuracy of ± 2 mm, are shown in Table 3-6 and Table 3-7. In addition, the tables also show results of levelling of the station PFM002669 in May 2016, i.e. subsequent to the refurbishment of the station. As mentioned in Section 2.1, the levelling performed at time of installations had less accuracy compared to the recent levelling campaigns, which implies that actual vertical movements since the flume and well installations are uncertain.

Table 3-6. Results of the levelling of bottom levels (m) of upstream edges of flumes at time of flume installations (2004) and in 2012–2015; the table also shows the results of the 2016 levelling after refurbishment of PFM002669 (Ohrzén 2016). Using the notation of the levelling reports, points B and C refer to each flume-bottom corner. Level changes since the original levelling are uncertain due to less accuracy of the original levelling. The flumes at PFM002669 were reinstalled in 2007. The results of the 2013 levelling are somewhat dubious. Note that the data in the table are not stored in the Sicada database. Dates are given as YYYY-MM-DD.

Gauging station and flume	Original levelling (RHB 70)	Comment on original levelling		
	Point B (RHB 70)	Point C (RHB 70)	Average (RHB 70)	Level change since original levelling (m)
PFM005764				
Original levelling (2004-04-30):				
Small flume	0.577	Used for discharge calc. 2003-11-27 to 2004-10-01		
Large flume	0.551	As above		
Levelling after reconstruction (2004-11-09):				
Small flume	0.903	Station reconstructed in October 2004 Used for discharge calc. 2004-10-05 to 2014-08-25 and as ref. level for man. meas. in HMS 2004-11-03 to 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	+0.007
Large flume	0.889	0.896	0.893	-0.002
2013:				
Small flume	0.894	0.892	0.893	-0.01
Large flume	0.885	0.890	0.888	+0.003
2014:				
Small flume	0.909	0.908	0.909	+0.006
Large flume	0.891	0.898	0.895	0
Levelling after refurbishment (2015):				
Small flume	0.924	0.923	0.924	Refurbished in August 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

Gauging station and flume	Original levelling (RHB 70)	Comment on original levelling		
	Point B (RHB 70)	Point C (RHB 70)	Average (RHB 70)	Level change since original levelling (m)
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	+0.063
Large flume	1.566	1.569	1.568	+0.057
2013:				
Small flume	1.570	1.570	1.570	+0.068
Large flume	1.572	1.576	1.574	+0.063
2014:				
Small flume	1.568	1.568	1.568	+0.066
Large flume	1.570	1.573	1.572	+0.061
2015:				
Small flume	1.566	1.566	1.566	+0.064
Large flume	1.567	1.570	1.569	+0.058
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	-0.007
2013:				
	4.286	4.282	4.284	-0.003
2014:				
	4.283	4.279	4.281	-0.006
2015:				
	4.282	4.278	4.280	-0.007
PFM002669				
Original levelling (2004-11-10):				
Small flume	5.852		Used for discharge calc. 2004-12-08 to 2015-09-14 and as reference point in HMS 2004-11-03 to 2015-09-14 (obs. well before that)	
Large flume	5.843		As above	
2012:				
Small flume	5.438	5.439	5.439	-0.413
Large flume	5.425	5.431	5.428	-0.415
2013:				
Small flume	5.443	5.444	5.444	-0.408
Large flume	5.433	5.440	5.437	-0.406

Gauging station and flume	Original levelling (RHB 70)	Comment on original levelling		
	Point B (RHB 70)	Point C (RHB 70)	Average (RHB 70)	Level change since original levelling (m)
2014:				
Small flume	5.440	5.441	5.441	-0.411
Large flume	5.427	5.435	5.431	-0.412
Levelling after refurbishment (2016)				
Small flume	5.441	5.441	5.441	Refurbished in August–September 2015 Used for discharge calc. and as ref. level for man. meas. in HMS 2015-09-15
Large flume	5.428	5.433	5.431	

Table 3-7. Results of the levelling of top of casing of observation wells (m) at flumes in 2012–2015; the table also shows the results of the 2016 levelling after refurbishment of PFM002669 (Ohrzén 2016). Using the notation of the levelling reports, point I refer to the well ToC. Note that level changes since the original levelling are uncertain due to less accuracy of the original levelling. The wells at PFM002669 were reinstalled in 2007. The results of the 2013 levelling and the 2012 levelling of PFM002668 (likely measurement error) are somewhat dubious. Unless stated otherwise, data are not stored in Sicada. Dates are given as YYYY-MM-DD.

Gauging station and well	Original levelling	Comment on original levelling
	Point I (RHB 70)	Level change since original levelling (m)
PFM005764		
Original levelling (2004-04-30):		
Small flume	1.701 (stored in Sicada)	Used as ref. level for man. meas. in HMS 2003-03-01 to 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 October 2004 Used as ref. level for man. meas. in HMS 2004-10-05 to 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	+0.009
Large flume	2.141	+0.024
2013:		
Small flume	2.064	+0.014
Large flume	2.147	+0.03
2014:		
Small flume	2.058	+0.008
Large flume	2.144	+0.027
Levelling after refurbishment (2015):		
Small flume	2.085 (stored in Sicada)	Station refurbished in August 2014
Large flume	2.131	

Gauging station and well	Original levelling	Comment on original levelling
	Point I (RHB 70)	Level change since original levelling (m)
PFM002667		
Original levelling (2004-11-09):		
Small flume	2.679 (stored in Sicada)	Used as ref. level for man. meas. in HMS 200410-01 to 2004-11-02 (flume-bottom level is used after 2004-11-02)
Large flume	2.721	As above
2012:		
Small flume	2.769	+0.09
Large flume	2.804	+0.083
2013:		
Small flume	2.787	+0.108
Large flume	2.823	+0.102
2015:		
Small flume	2.770 (stored in Sicada)	+0.091
Large flume	2.804	+0.083
PFM002668		
2004-11-10:		
	5.482 (stored in Sicada)	Used as ref. level for man. meas. in HMS 2004-10-01 to 2004-11-02 (flume-bottom level is used after 2004-11-02)
2012:		
	5.128	-0.354 (likely measurement error)
2013:		
	5.497	+0.015
2015:		
	5.479 (stored in Sicada)	-0.003
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 to 2004-11-02 (flume-bottom level is used after 2004-11-02)
Large flume	6.901	As above
2012:		
Small flume	6.605	-0.389 (well reinstalled in 2007)
Large flume	6.509	-0.392 (as above)
2013:		
Small flume	6.631	-0.363
Large flume	6.532	-0.369
2014:		
Small flume	6.609	-0.385
Large flume	6.510	-0.391
Levelling after refurbishment (2016):		
Small flume	6.607	Refurbished in August–September 2015
Large flume	6.501	

As can be seen in Table 3-6 and Table 3-7, flume and well movements since the original levelling seem to be particularly large for gauging station PFM002667 (both flumes have raised c 0.06–0.07 m and both wells c. 0.08–0.09 m). The large vertical movements at PFM002669 are due to that both flumes and wells were reinstalled in 2007. For some flumes (e.g. PFM005754 and -2669) the 2012–2015 levelling results indicate back-and-forth movements. This is primarily due to somewhat dubious results of the 2013 levelling campaign, an issue which is related to the actual inaccuracies of the levelling. It is therefore recommended that evaluations of levelling methods and associated accuracies are integrated parts of continued levelling campaigns.

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

3.5 Nonconformities

The Activity Plan (Table 1-2) states that manual water-depth measurements are to be performed at least every second week, whereas such measurements were only done at 2–3 occasions during the period August–December (Section 3.2). Despite the regular checks that were done according to the Activity plan, during 2015 there are some rather long data gaps, in particular for stations PFM005764 and PFM002667 (Section 4.2).

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

During the period of this report, there are some rather long water-level data gaps, in particular for stations PFM005764 and PFM002667:

- **PFM005764:** Data are missing during the periods June 5–23, July 22 to August 10, and August 13 to September 29. The data gaps are likely due to malfunctioning radio communication with the data logger (Geosigma 2015). As mentioned in Section 3.4.1, water-level data have only been approved up to October 2 00:00 (small flume) and July 21 00:00 (large flume), which implies that several further months of water-level data are missing for this report due to missing and non-approved data.
- **PFM002667:** Data are missing during the period August 21 to October 2, likely due to malfunctioning radio communication with the data logger (Geosigma 2015). As mentioned in Section 3.4.1, water-level data have only been approved up to August 4 2 00:00, which implies that almost five months of water-level data are missing for this report due to non-approved data.
- **PFM002668:** As mentioned in Section 3.4.1, water-level data are marked as uncertain during the period September 3 to October 2, which implies that one month of water-level data is missing for this report due to non-approved data.
- **PFM002669:** Data are missing during the refurbishment of the station, August 25 (2 PM) to September 15 (3 PM). Hence, some three weeks of water-level data are missing for this report.

Appendix 1 presents high-resolved water-level data from the four gauging stations during 2015. 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 (Table 3-6). These flume-bottom levels are used for discharge calculation from the refurbishment and onwards, i.e. from September 15, 2015.

As a result of the quality control of the 2015 dataset (Section 3.4.2), PFM002667 water-level data were excluded from the HMS to Sicada data transferral during a periods when the large-flume water level is “frozen” and higher than the small-flume water level. Missing and non-approved data, refurbishment, irregular recording intervals (Section 3.3.3) and flume-specific discharge intervals (Section 3.3.4) imply that hourly average water-level data are missing for almost 60 % of the time for the PFM005764 and PFM002667 stations during 2015. The corresponding fraction for the PFM002668 and -2669 stations is 34 %.

4.3 Calculated discharge

Appendix 2 presents hourly average (screened) discharge data from the four gauging stations during 2015, calculated based on the discharge equations of Table 2-2. Average, minimum and maximum discharges, affected by large data gaps, are shown in Table 4-1.

Table 4-1. Average, minimum and maximum discharges (screened data, rounded to integers) during 2015. The statistics are affected by long data gaps.

	PFM005764	PFM002667	PFM002668	PFM002669
Average discharge (L/s)	45	18	11	20
Min. discharge (L/s)	3	0	0	1
Max. discharge (L/s)	123	63	48	87

4.4 Electrical conductivity

Appendix 3 presents high-resolved EC data from the four gauging stations during the year 2015, whereas average, minimum and maximum EC values (based on screened data) are shown in Table 4-2. Note that there are some rather long EC data gaps for stations PFM005764 (June 5–23, July 22–August 10, August 13–September 29) and PFM002667 (August 21 to October 2), likely due to malfunctioning radio communication with the data logger (cf. Section 4.2). Moreover, the PFM002668 EC sensor was relocated and out of operation during the period November 11, 2014 to January 7, 2015 (Werner 2016), and there is a data gap during the PFM002669 refurbishment August 25 to September 15 (cf. Section 2.4).

Table 4-2. Average, minimum and maximum EC (screened data, rounded to integers) during 2015. The statistics are affected by long data gaps.

	PFM005764	PFM002667	PFM002668	PFM002669
Average EC (mS/m)	36	32	28	34
Min. EC (mS/m)	23	14	10	23
Max. EC (mS/m)	47	57	46	46

4.5 Temperature

Appendix 4 presents high-resolved water-temperature data from the four gauging stations during 2015, whereas average, minimum and maximum temperature values (based on screened data) are shown in Table 4-3. Note that there are some rather long temperature data gaps for stations PFM005764 and PFM002667, likely due to malfunctioning radio communication with the data logger (cf. Section 4.2 and Section 4.4). Moreover, the PFM002668 temperature sensor was relocated and out of operation in the beginning of 2015 (Werner 2016), and there is a data gap during the PFM002669 refurbishment August 25–September 15 (cf. Section 2.4).

It was previously noted that manually measured water temperatures at PFM002668 generally were some 1–3 °C lower than automatically measured temperatures (Werner 2014 a, b). This phenomenon was likely due to that water formed a rapid and was mixed with air on the downstream side of the flume, at the location of the well that hosts the sensor. In December 2014–January 2015, the PFM002668 temperature sensor was relocated to avoid this discrepancy; specifically, it was out of operation during the period November 11, 2014–January 7, 2015 (first data record January 7, 2 PM).

Table 4-3. Average, minimum and maximum temperature (screened data, rounded to integers) measured at the gauging stations PFM005764, -2667, -2668 and -2669 during 2015. The statistics are affected by long data gaps.

	PFM005764	PFM002667	PFM002668	PFM002669
Average temp. (°C)	7	7	8	8
Min. temp. (°C)	0	0	0	0
Max. temp. (°C)	19	21	19	21

After the sensor relocation, manually measured temperatures are always within $\pm 1^\circ\text{C}$ (in most cases within $\pm 0.1\text{--}0.5^\circ\text{C}$) of automatically measured temperatures (Appendix 4). This indicates that the move of the PFM002668 temperature sensor was successful, as it seems to provide more reliable temperature data after the relocation.

4.6 Integrated monitoring-data evaluations: Illustrative examples

The stream monitoring described in this report 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. It is part of the extensive programme for monitoring of the rock and the surface system in Forsmark (SKB 2007), a programme that also includes e.g. meteorological monitoring, monitoring of the near-coastal sea, lakes and ponds, and monitoring of near-surface groundwater.

The present and also 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 on data gaps, data uncertainties and required/performed changes of monitoring methods or installations. Moreover, recurrent monitoring-data evaluations are important for maintenance of the site understanding, and as a basis for identification of potential anthropogenic disturbances (Berglund and Lindborg 2017).

This section uses results from other types of surface-system monitoring in Forsmark (for details, see Berglund and Lindborg 2017) as illustrative examples on integrated evaluations that may provide insight into near-surface hydrological interactions. The examples presented below focus on interactions with the calculated stream discharge at gauging station PFM002668, as this station (along with PFM002669) has least data gaps during 2015 (Appendix 2).

Figure 4-1 shows a co-plot of hourly average stream discharge at the PFM002668 gauging station and daily sums of corrected precipitation measured at the Labbomasten meteorological station (Jones and Kindell 2016) during 2015. The figure also indicates the snow-covered period in Forsmark and the ice-free period in Lake Eckarfjärden (Wass 2015, 2016), which is located upstream from PFM002668.

As shown in the figure, the discharge increases in response to precipitation and/or minor snow-melt events during January and the beginning of February. During 2015, there was a snow cover from mid-January to the end of February/beginning of March, whereas Lake Eckarfjärden was totally free from ice in the end of March. Hence, the increasing discharge during the rest of February is likely a response to snow and ice melt. The discharge decreases during March, subsequent to the snow-melt period and when most of the ice in the lake has melted.

Loss of water by evapotranspiration increases from the beginning of April and onwards, which increases the thickness and the associated storage capacity of the unsaturated zone. Hence, the response of the discharge to precipitation events decreases gradually during spring, whereas there is little or no response to precipitation events during the summer. Evapotranspiration decreases during late summer and autumn, gradually decreasing the storage capacity of the unsaturated zone and increasing the response of the discharge to precipitation events.

These concepts are further illustrated in Figure 4-2, which shows a co-plot of hourly average stream discharge at PFM002668, daily average groundwater levels in two monitoring wells (SFM0014 and SFM000126) located within the catchment area of the station, and daily average surface-water level in the upstream Lake Eckarfjärden (SFM000127) (Geosigma 2015, 2016). It is noted that there is no ongoing monitoring in three groundwater-monitoring wells (SFM0016–18) that are also located within the station catchment. Moreover, it is noted that approved SFM000126 and -127 monitoring data were only available for the first half of 2015 at the time of this report. For purposes of integrated data evaluations, there is hence a need to coordinate different parts of the monitoring programme, in terms of e.g. logger dumping and quality control.

According to Figure 4-2, available data on ground- and surface-water levels demonstrate a similar temporal variability pattern as the stream discharge, with increasing levels during January and February in response to precipitation and/or snow and ice melt. There are decreasing levels during March, subsequent to the snow-melt period and when most of the ice in the lake has melted. Gradually increasing evapotranspiration from the beginning of April and onwards lowers ground- and surface-water levels within the PFM002668 catchment. This increases the storage capacity of the unsaturated zone, causing gradually decreasing responses of discharge to precipitation events (cf. Figure 4-1).

In Figure 4-2, it is also noted that the hydraulic gradient between SFM000126, which is installed below the bottom of Lake Eckarfjärden, and surface-water level gauge SFM000127 in the lake changes direction from the beginning of May and onwards. Specifically, the groundwater level in SFM000126 is above the surface-water level in SFM000126 (indicating groundwater discharge to the lake) up to the beginning of May, whereas the gradient has the opposite direction during the rest of the data period available for this report.

Comparison between stream discharge (Appendix 2) and EC (Appendix 3) indicates that there are important discharge-hydrochemistry relationships. Specifically, EC decreases during the high-discharge period in late winter and early spring, likely due to dilution with low-EC melt water, and the opposite during low-discharge periods. The current hydrochemical monitoring programme includes sampling of near-surface groundwater and surface water (once per season) in lakes and a shallow sea bay (Wallin et al. 2016). Moreover, the programme includes sampling (once per month, except July) in four streams. Three of the stream-sampling locations coincide with locations of stream-gauging stations (PFM002667 is located further upstream from the Lake Gällsboträsk tributary). A potential development of the format for annual reporting would therefore be to report stream discharge and stream hydrochemistry in the same report, as support for integrated data evaluations.

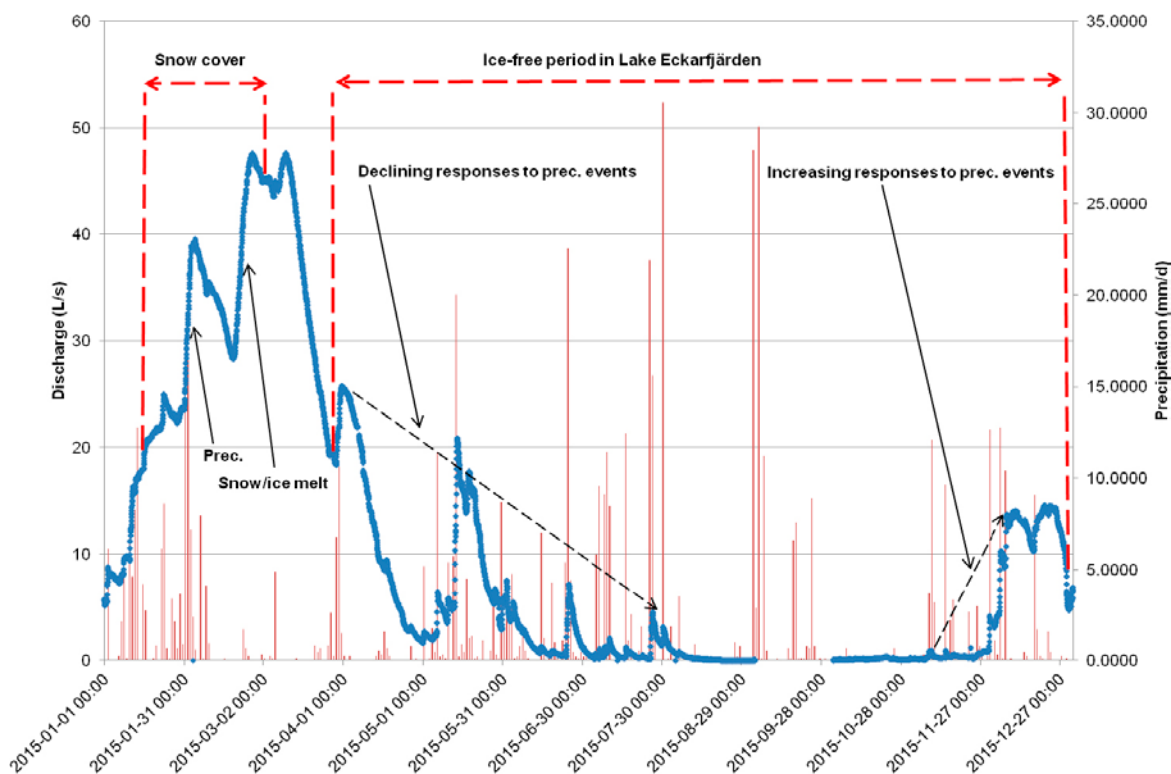


Figure 4-1. Hourly average stream discharge at gauging station PFM002668 (blue dots) and daily sums of corrected precipitation measured at the Labbomasten meteorological station (PFM006281, red bars) during 2015. The figure also indicates the snow-covered period in Forsmark and the ice-free period in Lake Eckarfjärden, located upstream from PFM002668.

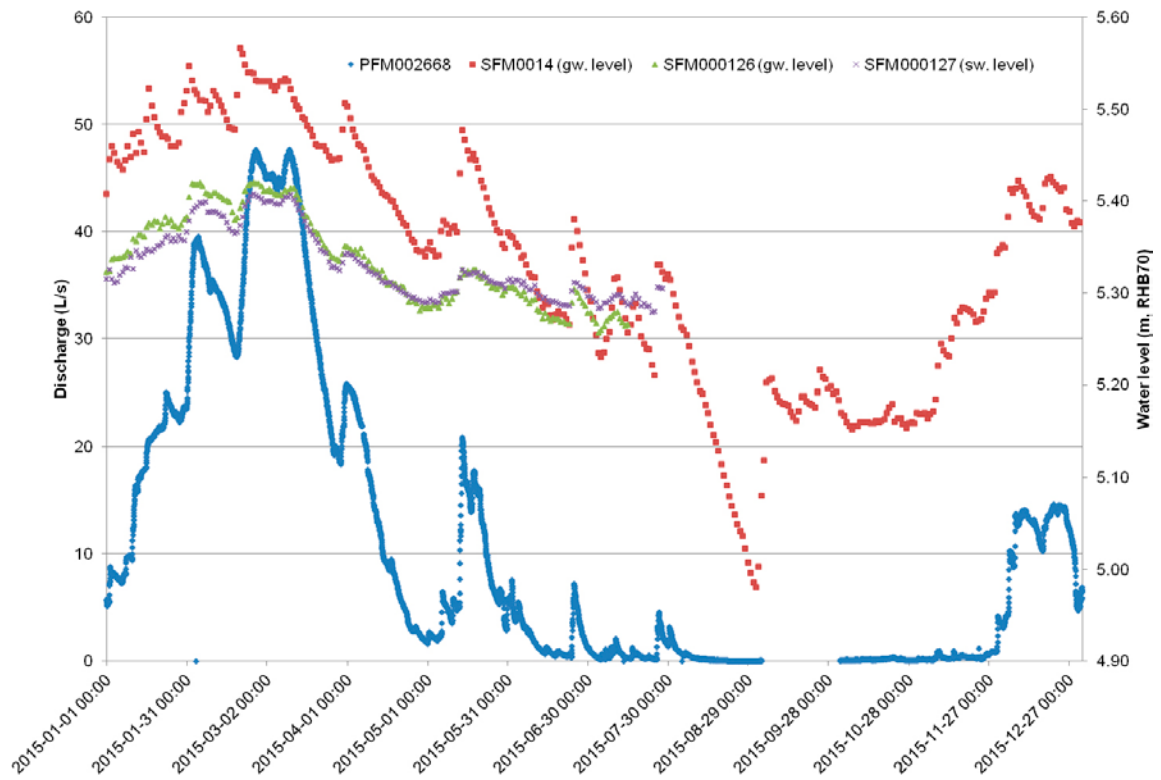


Figure 4-2. Hourly average stream discharge at gauging station PFM002668 (blue dots), daily average groundwater levels (gw. level) in monitoring wells SFM0014 and SFM000126 (the latter installed below the bottom of Lake Eckarfjärden) and daily average surface-water level (sw. level) in the lake (SFM000127) during 2015. Note that approved SFM000126 and -127 monitoring data were only available for the first half of 2015 at the time of this report.

References

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

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

Bergqvist N, 2013. Kontrollmätning Forsmark VP 3 2013-12-16. SKBdoc 1445903 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

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

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

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

Edvardson K, 2014. SKB höjdkontroll GV-rör, bäckrännor. Uppföljande höjdbestämmning av 28 jordrör och sju bäckrännor, nybestämning av sju jordrör samt inmätning av strandlinjen i två nya gölar. SWECO Civil AB. SKBdoc 1444516 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Edvardson K, 2015. Uppföljande höjdbestämmning av 30 jordrör och fem bäckrännor. SWECO Civil AB. SKBdoc 1593195 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Geosigma, 2015. Monitoring Forsmark och SFR. Kvalitetskontroll av yt- och grundvattenmonitoring. Period: januari–september 2015. SKBdoc 1523231 ver 2.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Geosigma, 2016. Monitoring Forsmark och SFR – kvalitetskontroll av yt- och grundvattenmonitoring. Period: september 2015 – februari 2016. SKBdoc 1540762 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

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

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

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

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

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

Jones J, Kindell S, 2016. Meteorological monitoring at the Högmasten and Labbomasten stations in Forsmark during January–December 2015. SMHI 2015/560/9.5. SKBdoc 1540483 ver 1.0, Svensk Kärnbränslehantering AB.

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

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

SWECO, 2013. SKB avvägning jordrör/bäckrännor – uppföljande mätning av 29 jordrör, lägen på sju bäckrännor samt sju strandlinjer. SWECO Infrastructure AB. SKBdoc 1417299 ver 2.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Wahl T L, Clemmens A J, Replogle J A, Bos M G, 2000. WinFlume – Windows-based software for the design of long-throated measuring flumes. In National irrigation symposium. Proceedings of the 4th Decennial Symposium, Phoenix, Arizona, 14–16 November 2000, 606–611.

Wallin A, Qvarfordt S, Borgiel M, 2016. Hydrochemical monitoring of near surface groundwater and surface waters in Forsmark. Results from the sampling period January to December 2014. SKBdoc 1459924 ver 1.0, Svensk Kärnbränslehantering AB.

Wass E, 2015. Snow depth and ice cover during the winter 2014/2015. SKBdoc 1483084 ver 1.0, Svensk Kärnbränslehantering AB.

Wass E, 2016. Snow depth and ice cover during the winter 2015/2016. SKBdoc 1549190 ver 1.0, Svensk Kärnbränslehantering AB.

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

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

Werner K, 2016. Monitoring hydrology in Forsmark 2014. Monitoring of streams: Water level, discharge, electrical conductivity and temperature 2014. SKBdoc 1520285 ver 1.0, Svensk Kärnbränslehantering AB.

Water level

Figures A1-1 to A1-9 show water level time-series plots for the flumes at gauging stations PFM005764, -2667, -2668 and -2669 for the period December 1, 2014–January 31, 2016. 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 whole 2015 dataset. Note that water levels for December 2014 and January 2016 are shown for reference only.

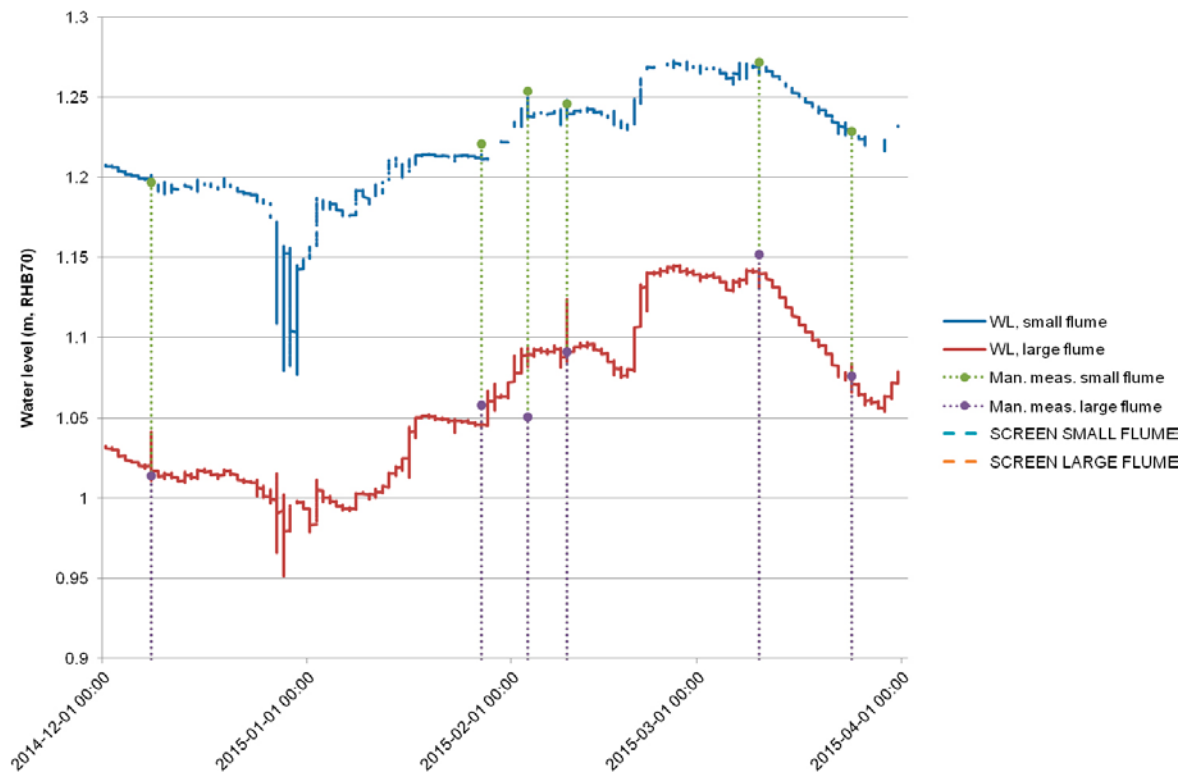


Figure A1-1. Water-level time series for the flumes at gauging station PFM005764 for the period December 1, 2014–March 31, 2015.

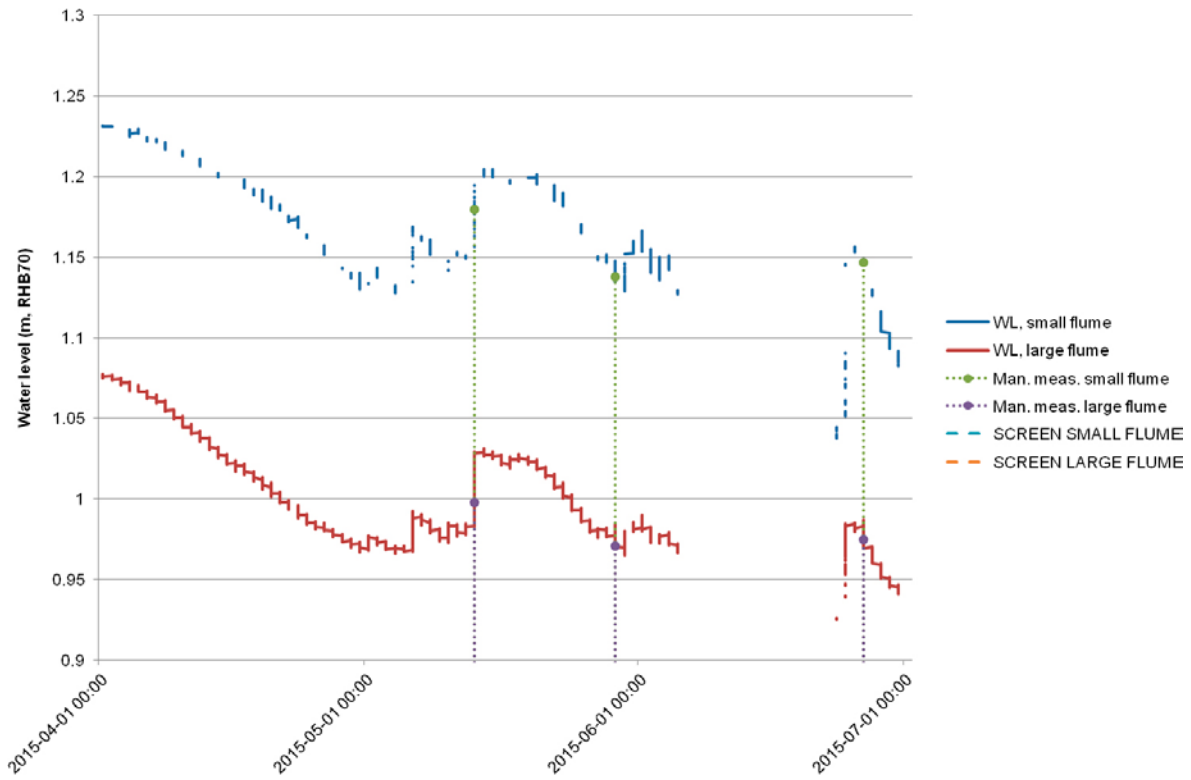


Figure A1-2. Water-level time series for the flumes at gauging station PFM005764 for the period April 1–June 30, 2015.

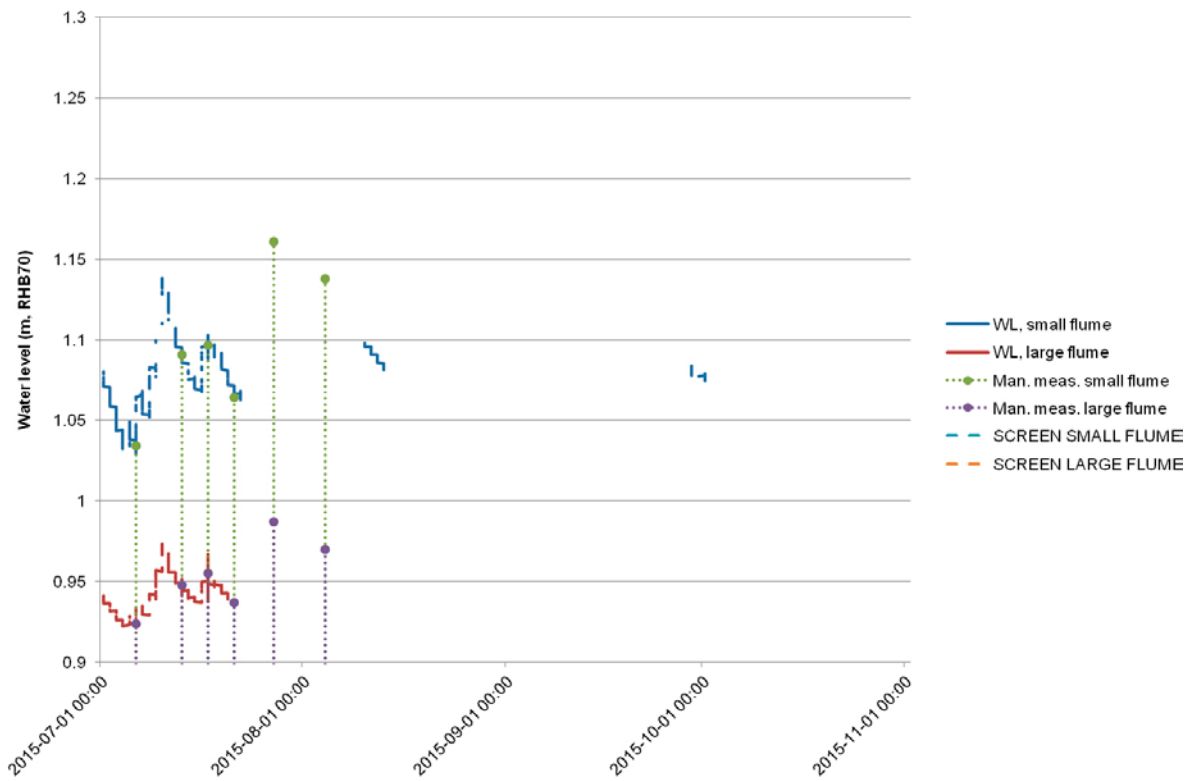


Figure A1-3. Water-level time series for the flumes at gauging station PFM005764 for the period July 1–October 31, 2015.

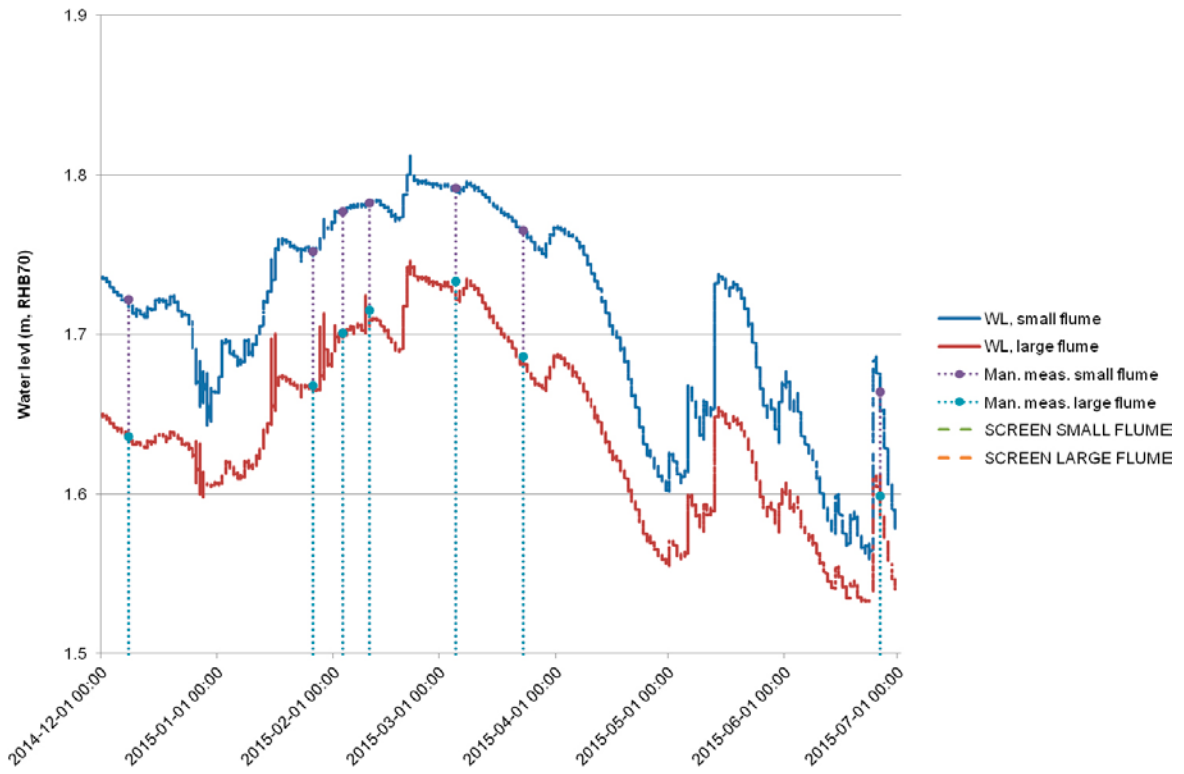


Figure A1-4. Water-level time series for the flumes at gauging station PFM002667 for the period December 1, 2014–June 30, 2015.

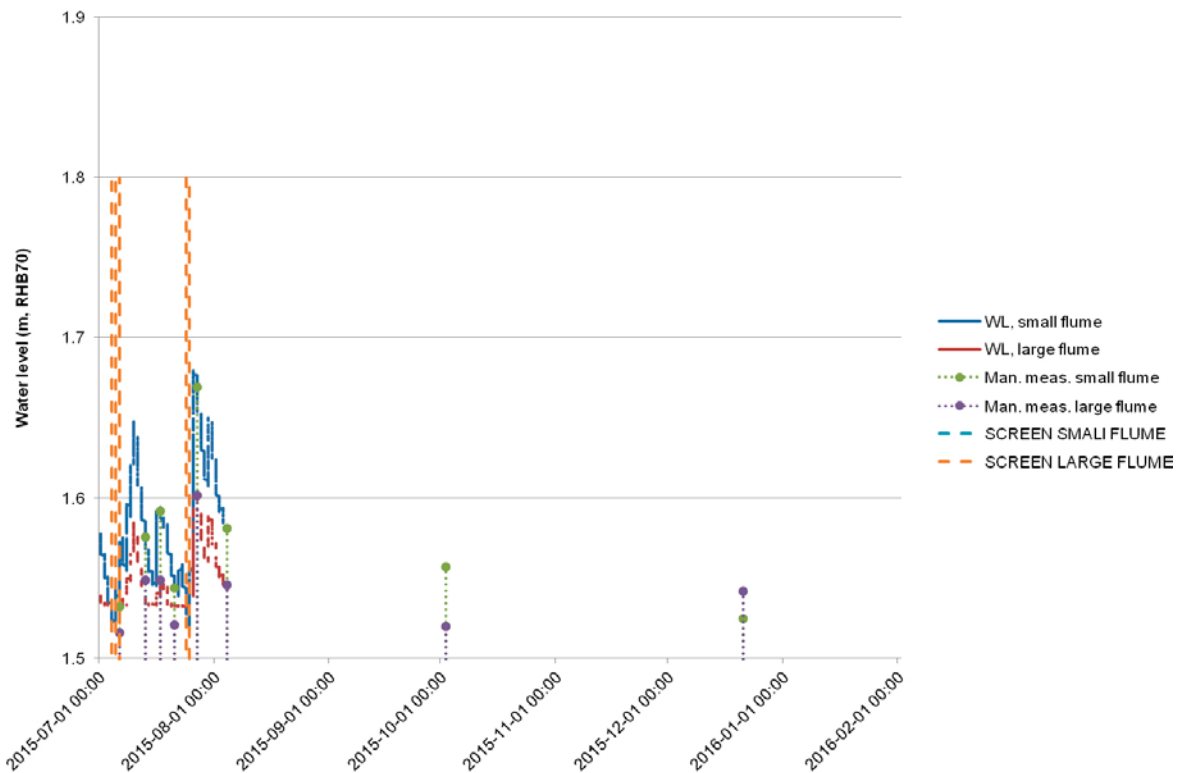


Figure A1-5. Water-level time series for the flumes at gauging station PFM002667 for the period July 1, 2015–January 31, 2016.

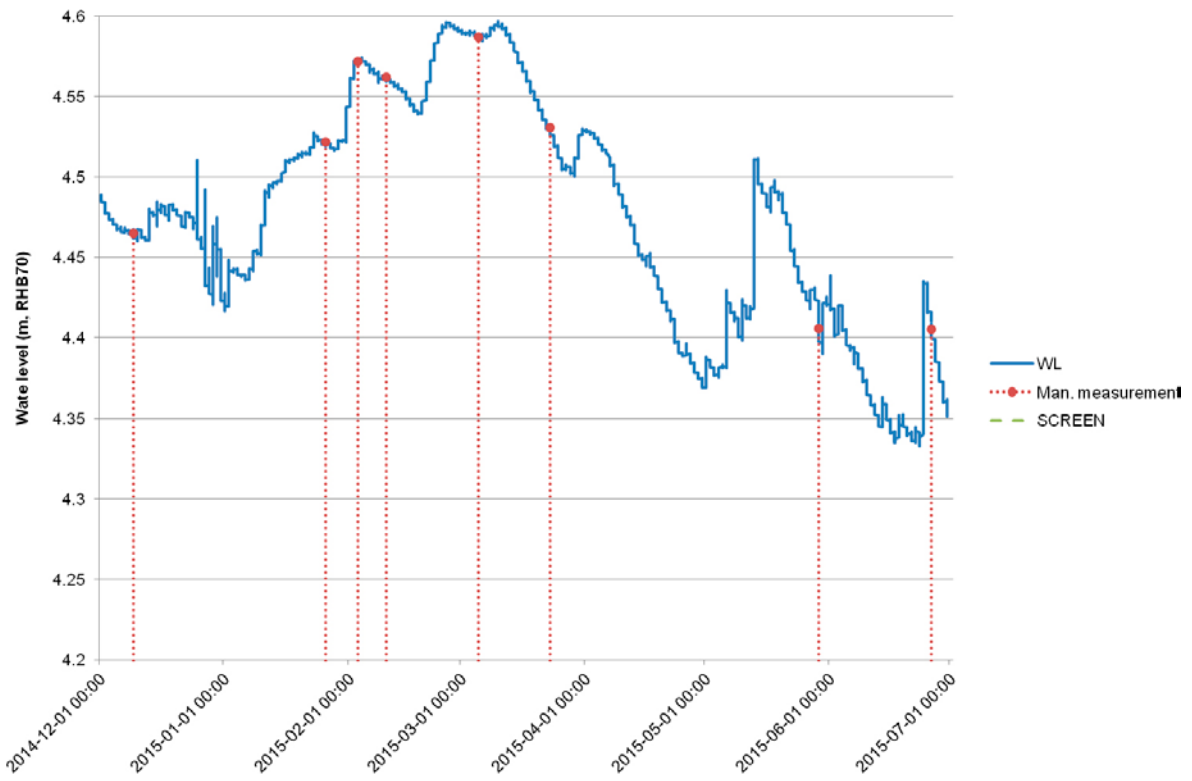


Figure A1-6. Water-level time series for the flume at gauging station PFM002668 for the period December 1, 2014–June 30, 2015.

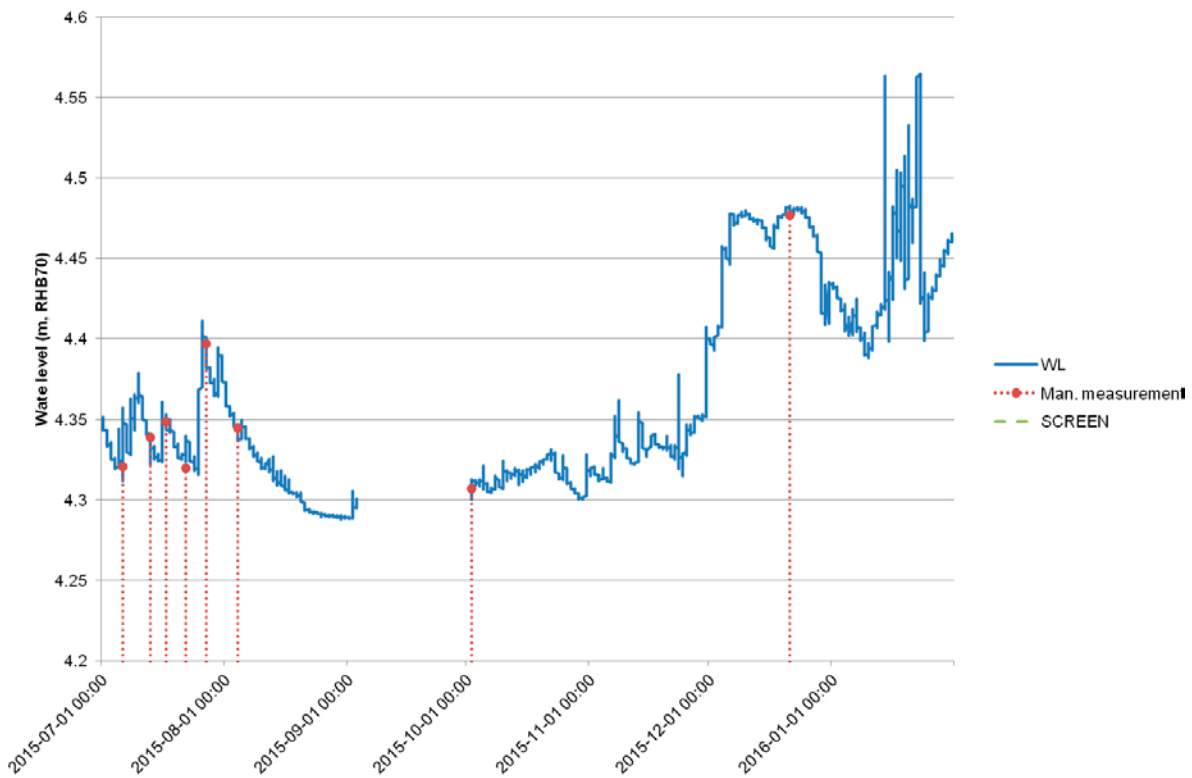


Figure A1-7. Water-level time series for the flume at gauging station PFM002668 for the period July 1, 2015–January 31, 2016.

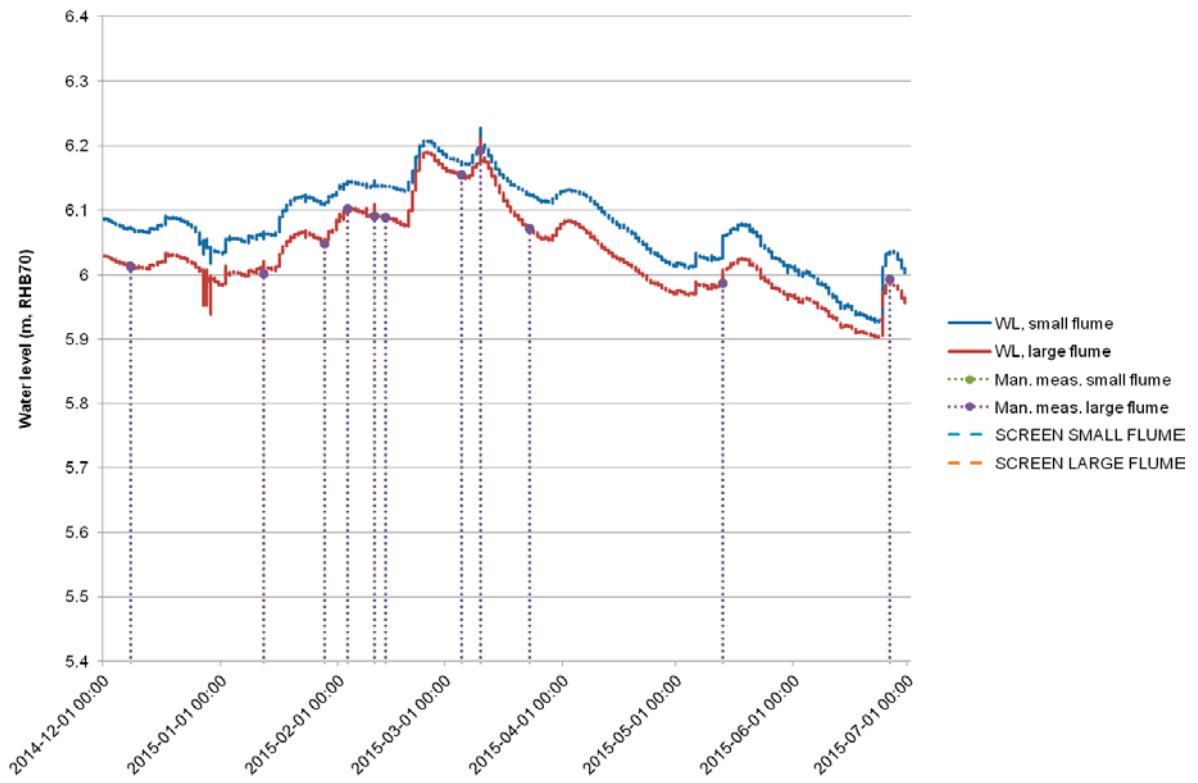


Figure A1-8. Water-level time series for the flumes at gauging station PFM002669 for the period December 1, 2014–June 30, 2015.

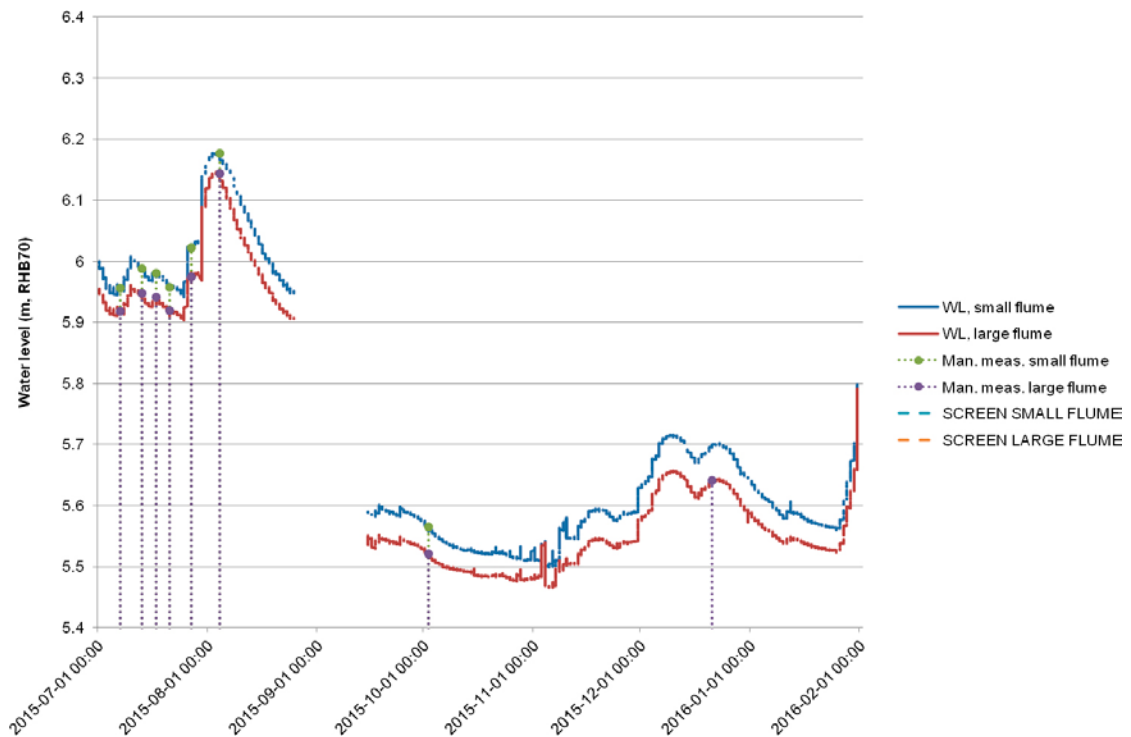


Figure A1-9. Water-level time series for the flumes at gauging station PFM002669 for the period July 1, 2015–January 31, 2016.

Calculated discharge

Figures A2-1 to A2-4 show time-series plots of calculated hourly average stream discharges at gauging stations PFM005764, -2667, -2668 and -2669 for the year 2015. Hourly averages are calculated without the data periods excluded as a result of the regular quality control and the quality control of the whole 2015 water-level dataset.

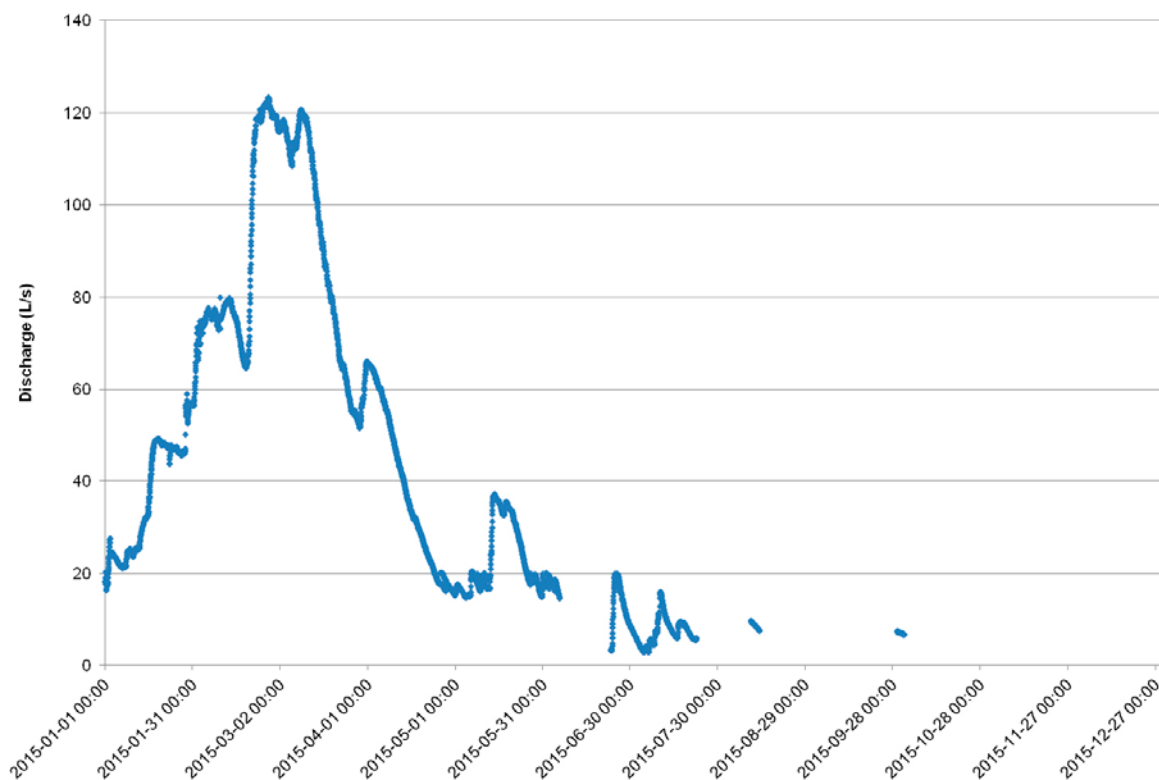


Figure A2-1. Hourly average stream discharge at gauging station PFM005764 for the period January 1–October 1, 2015.

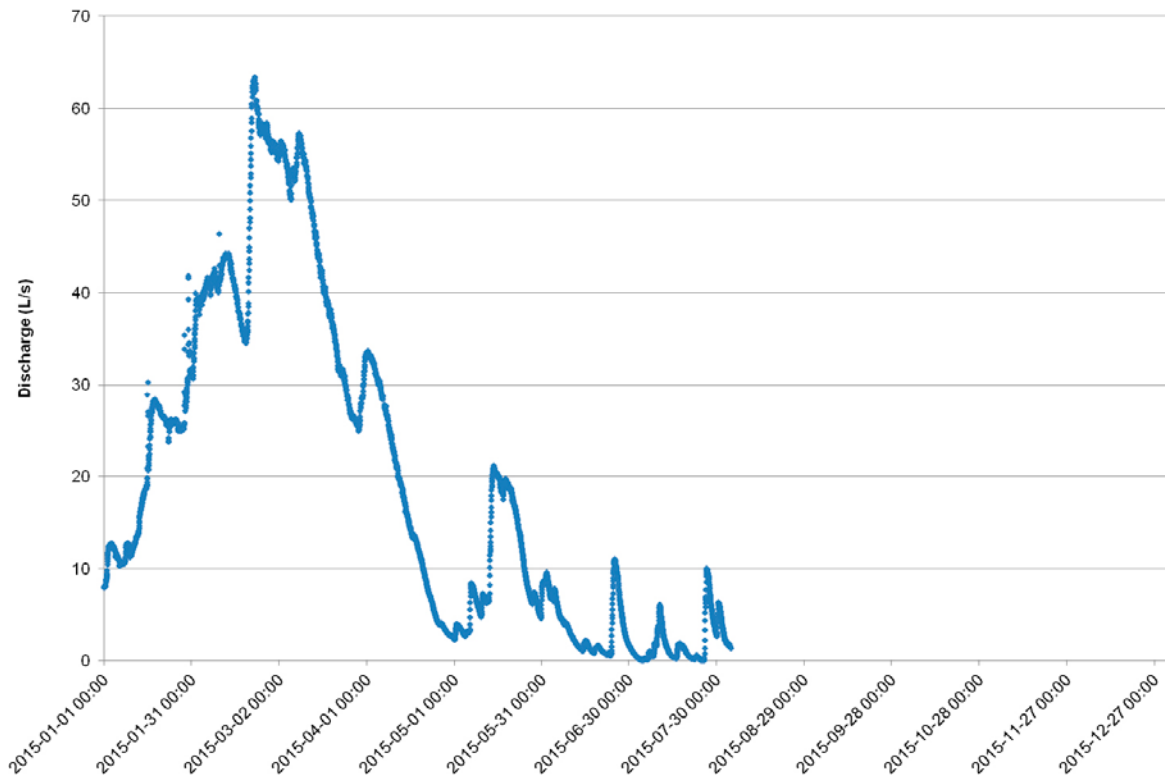


Figure A2-2. Hourly average stream discharge at gauging station PFM002667 for the period January 1–August 3, 2015.

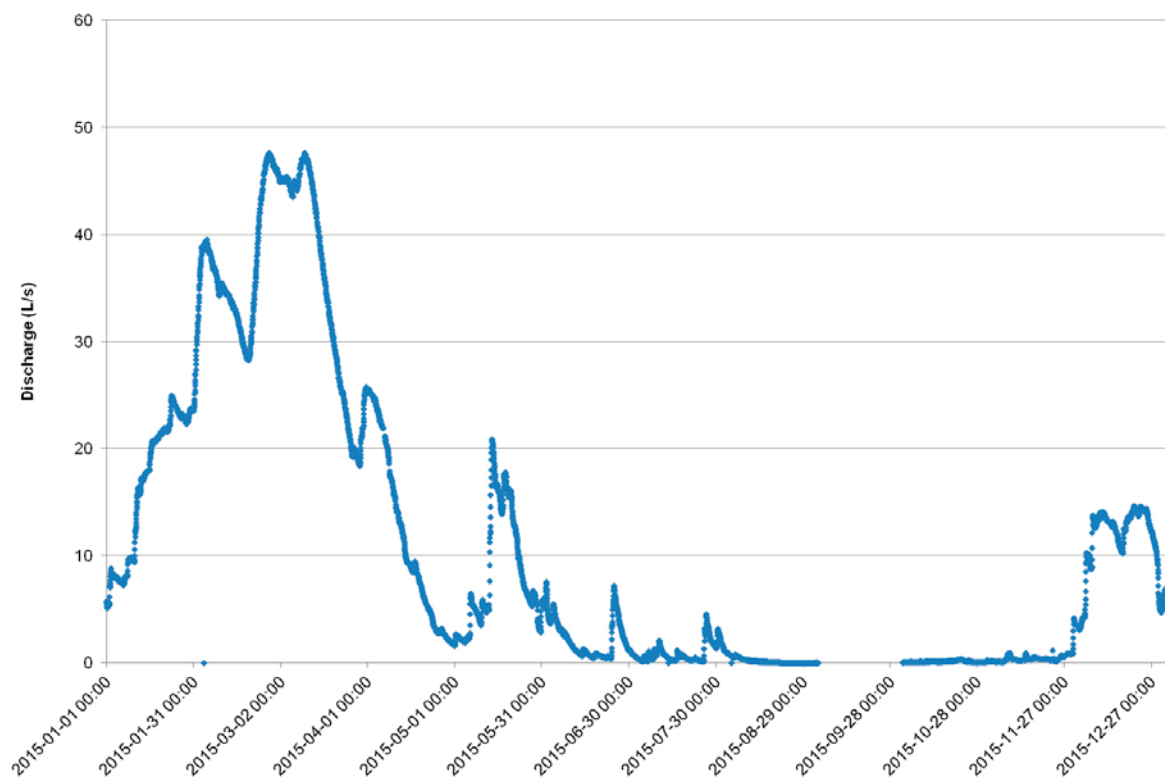


Figure A2-3. Hourly average stream discharge at gauging station PFM002668 for the period January 1–December 31, 2015.

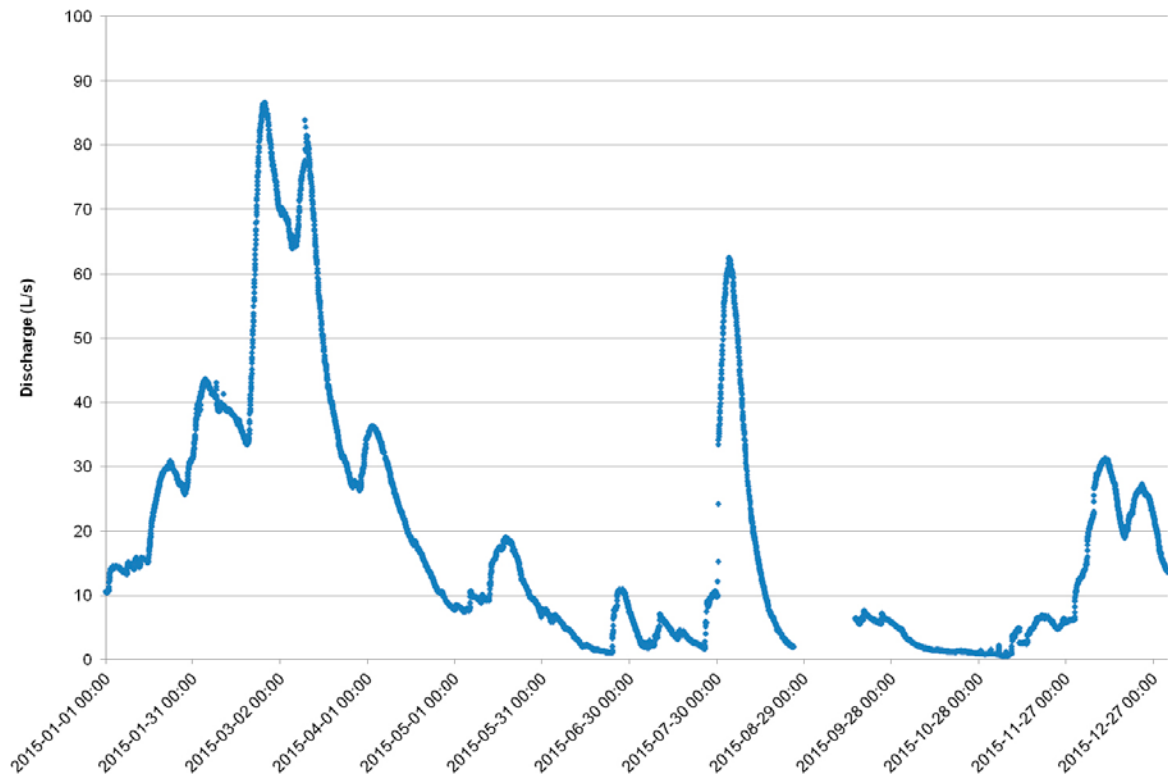


Figure A2-4. Hourly average stream discharge at gauging station PFM002669 for the period January 1–December 31, 2015.

Electrical conductivity

Figures A3-1 to A3-8 show EC time-series plots for gauging stations PFM005764, -2667, -2668 and -2669 for the period December 1, 2014–January 31, 2016. The plots also show manually measured EC values and data periods excluded (SCREEN) as a result of the quality control of the whole 2015 dataset. Note that EC values for December 2014 and January 2016 are shown for reference only.

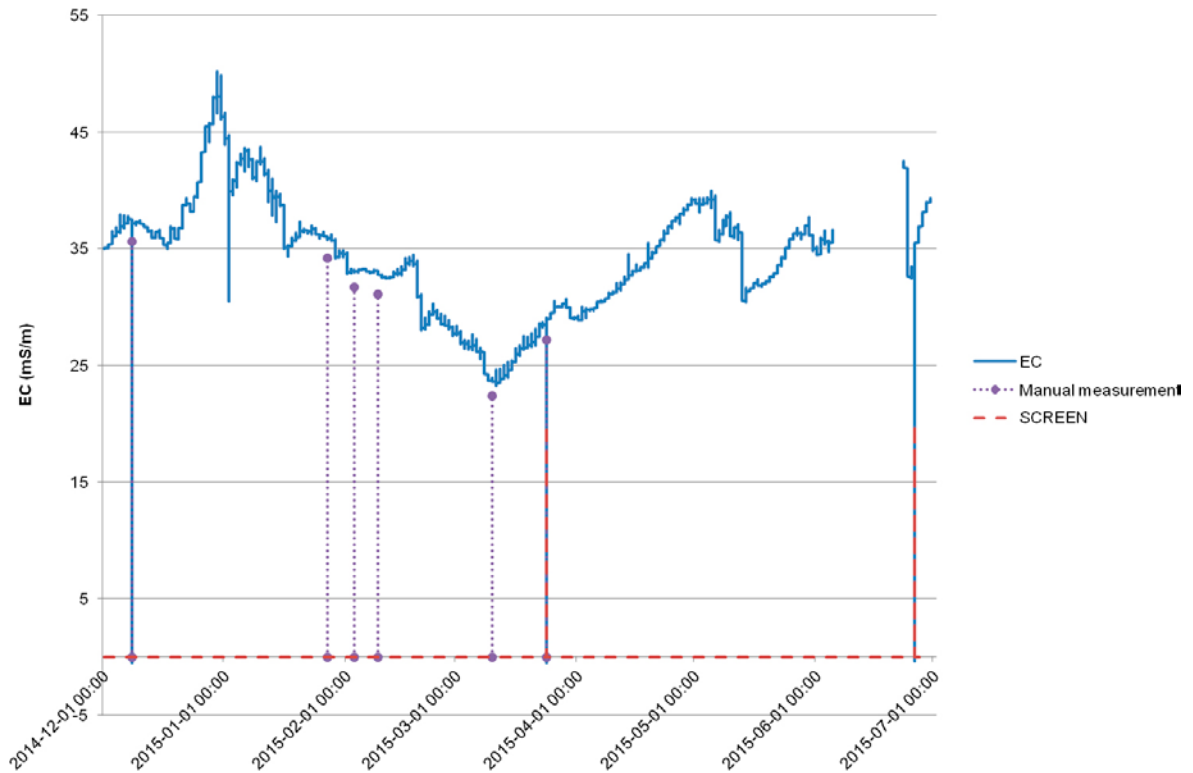


Figure A3-1. EC time series for gauging station PFM005764 for the period December 1, 2014–June 30, 2015.

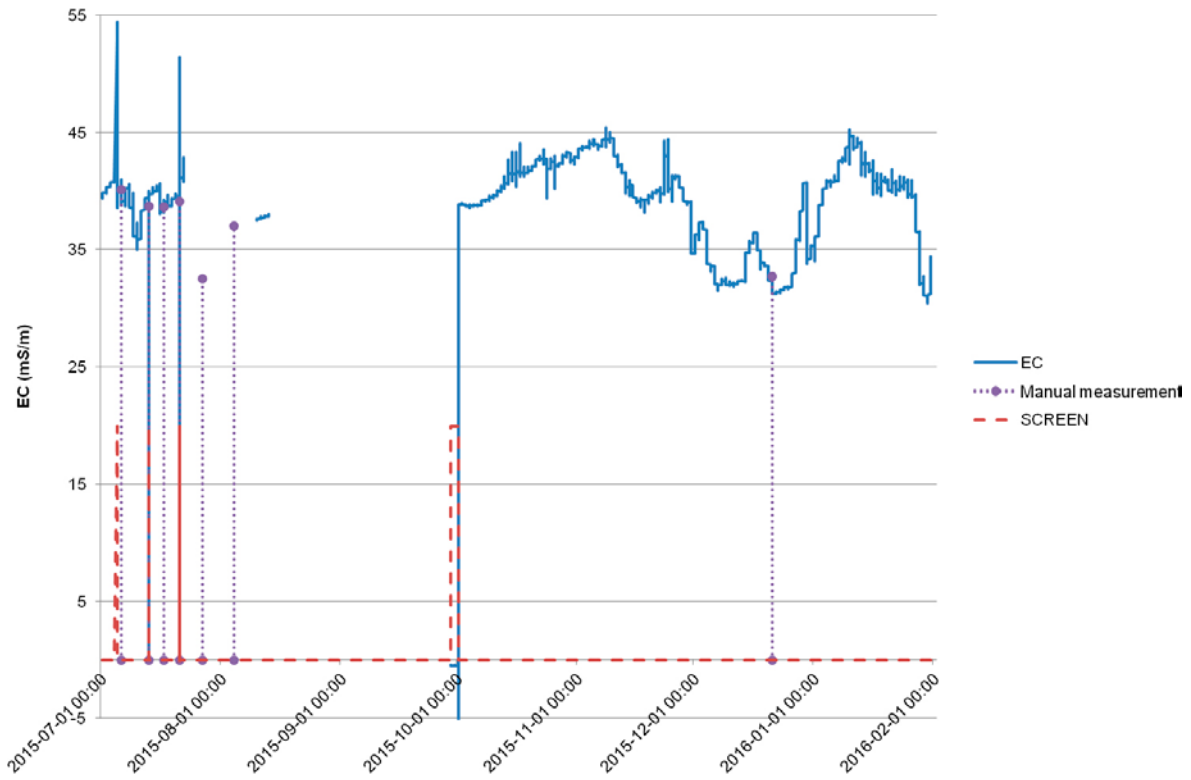


Figure A3-2. EC time series for gauging station PFM005764 for the period July 1, 2014–January 31, 2015.

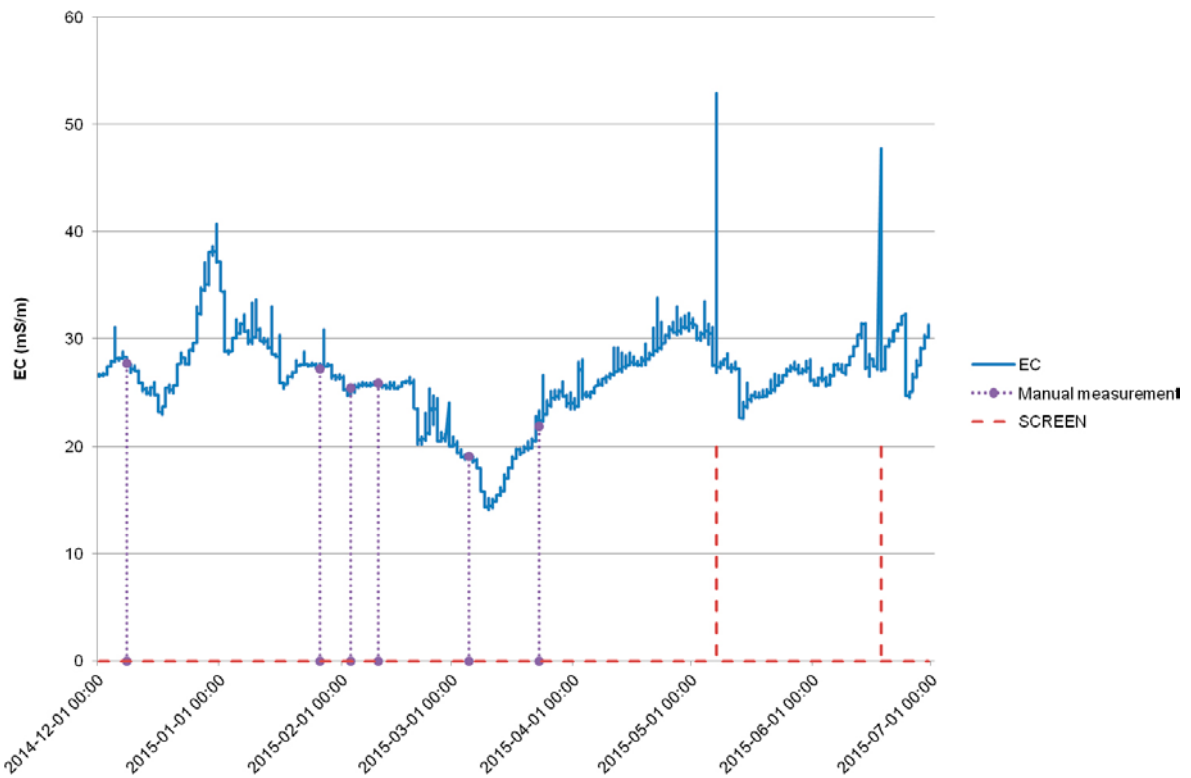


Figure A3-3. EC time series for gauging station PFM002667 for the period December 1, 2014–June 30, 2015.

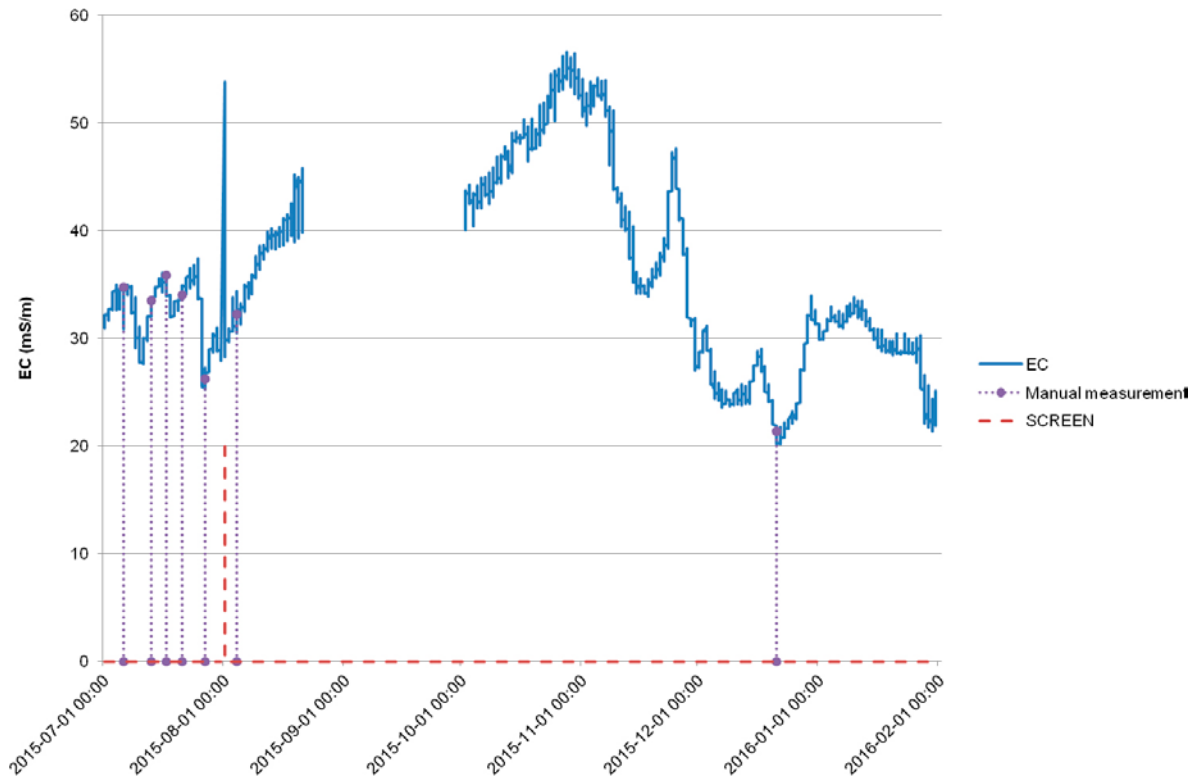


Figure A3-4. EC time series for gauging station PFM002667 for the period July 1, 2015–January 31, 2016.

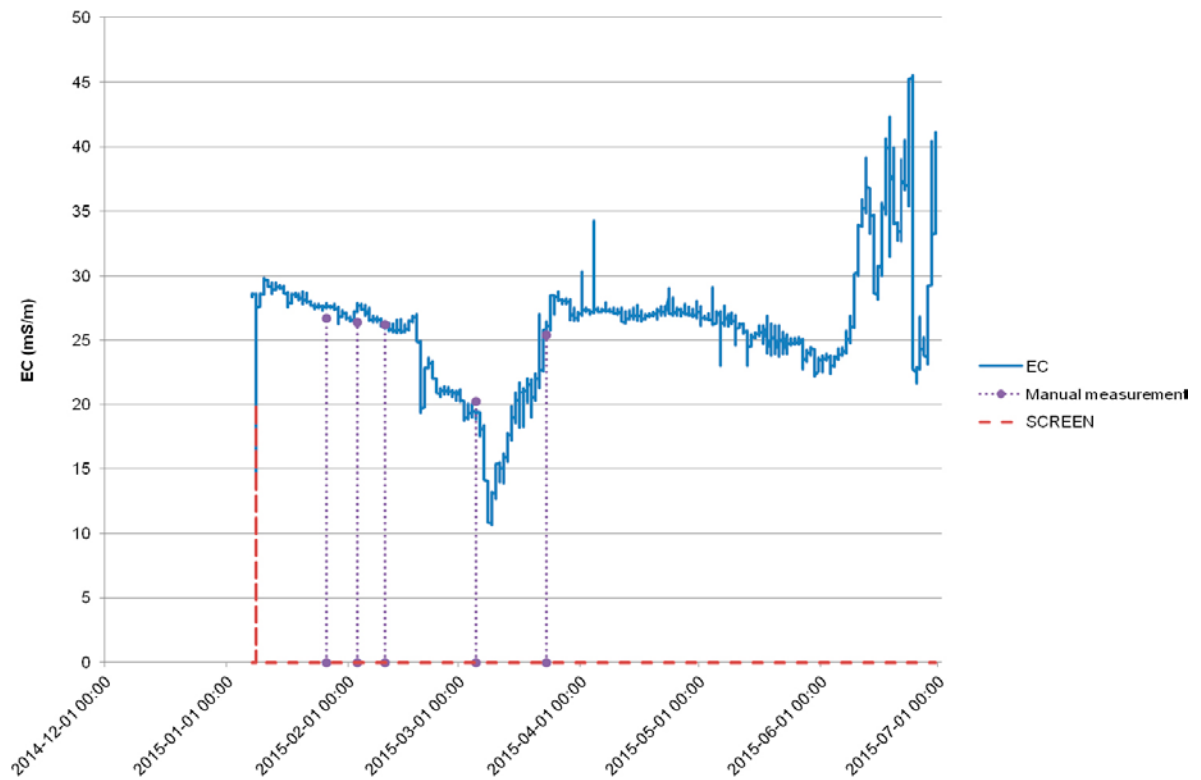


Figure A3-5. EC time series for gauging station PFM002668 for the period January 7–June 30, 2015 (the EC sensor was relocated prior to January 7, 2015).

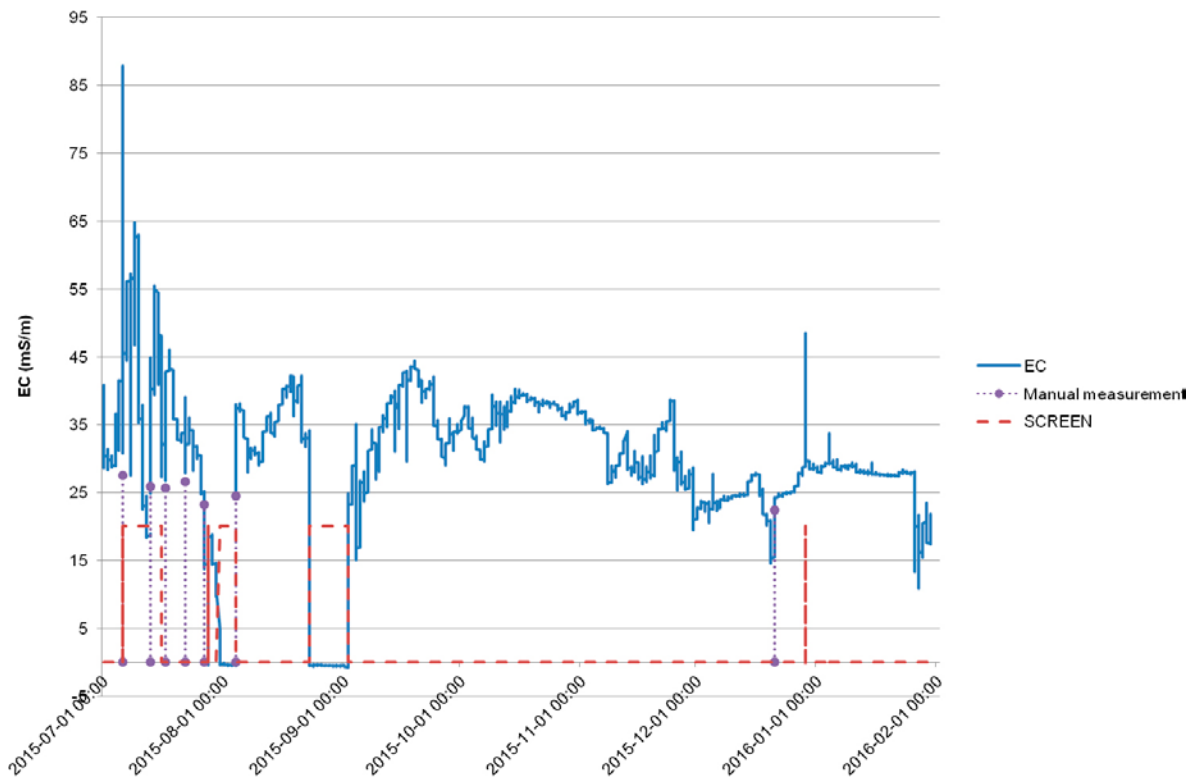


Figure A3-6. EC time series for gauging station PFM002668 for the period July 1, 2015–January 31, 2016.

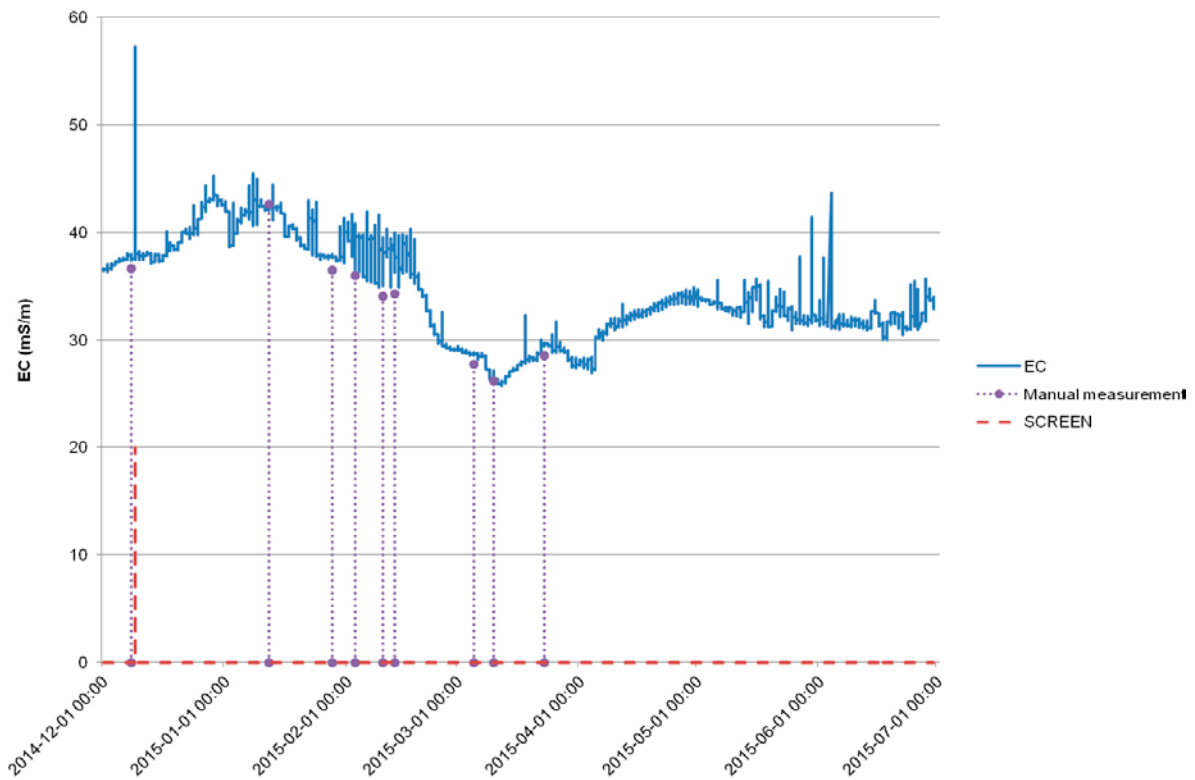


Figure A3-7. EC time series for gauging station PFM002669 for the period December 1, 2014–June 30, 2015.

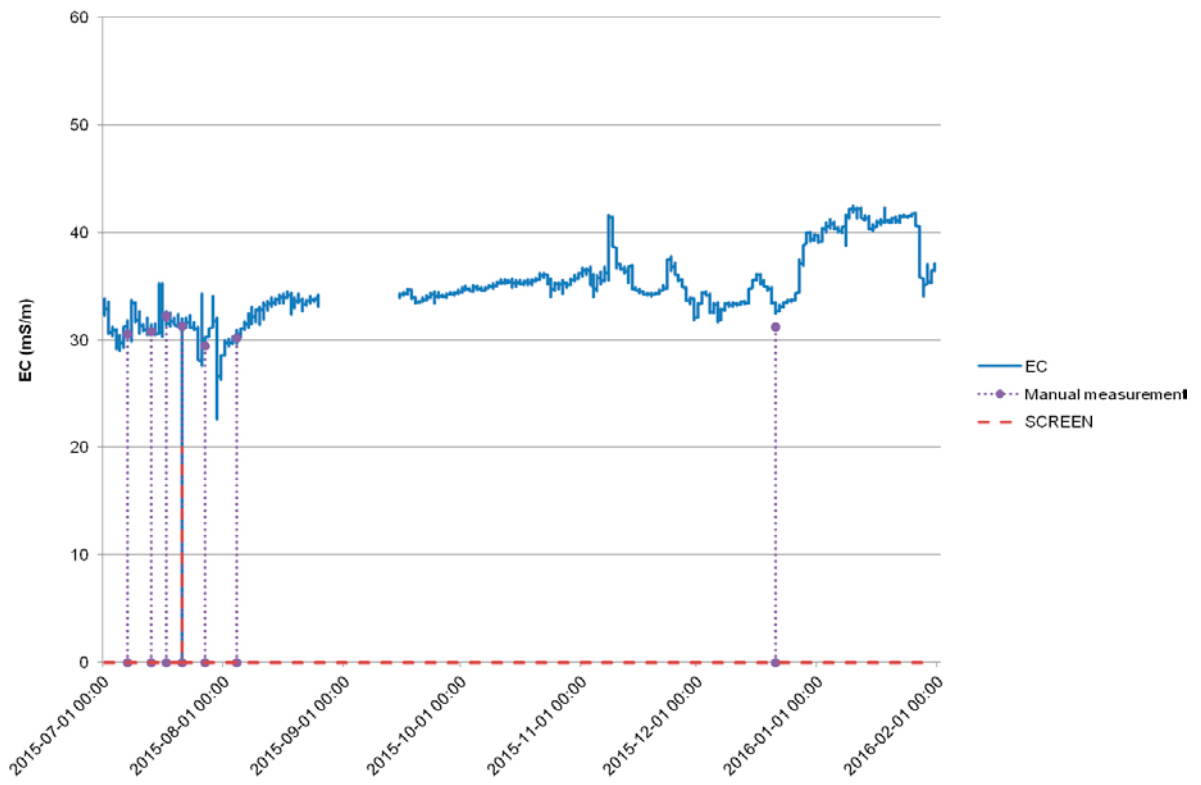


Figure A3-8. EC time series for gauging station PFM002669 for the period July 1, 2014–January 31, 2015.

Temperature

Figures A4-1 to A4-8 show temperature time-series plots for gauging stations PFM005764, -2667, -2668 and -2669 for the period December 1, 2014–January 31, 2016. The plots also show manually measured temperature values and data periods excluded (SCREEN) as a result of the quality control of the whole 2015 dataset. Note that temperature values for December 2014 and January 2016 are shown for reference only.

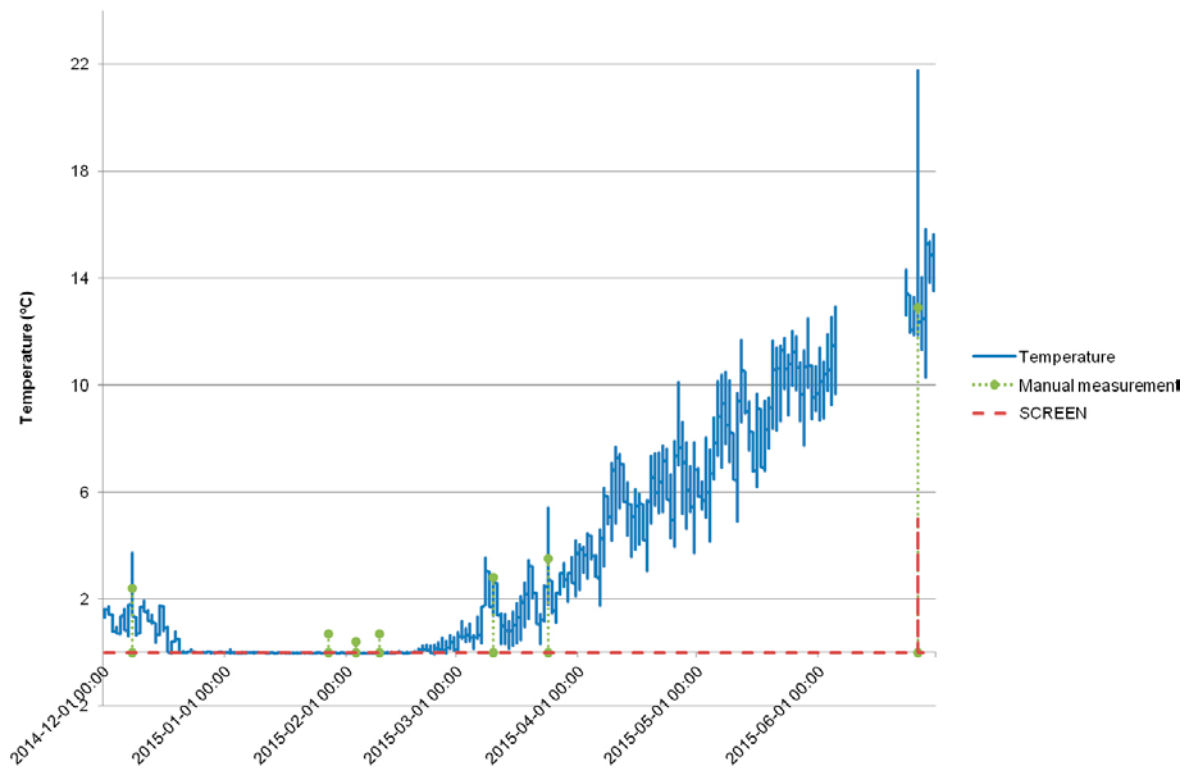


Figure A4-1. Temperature time series for gauging station PFM005764 for the period December 1, 2014–June 30, 2015.

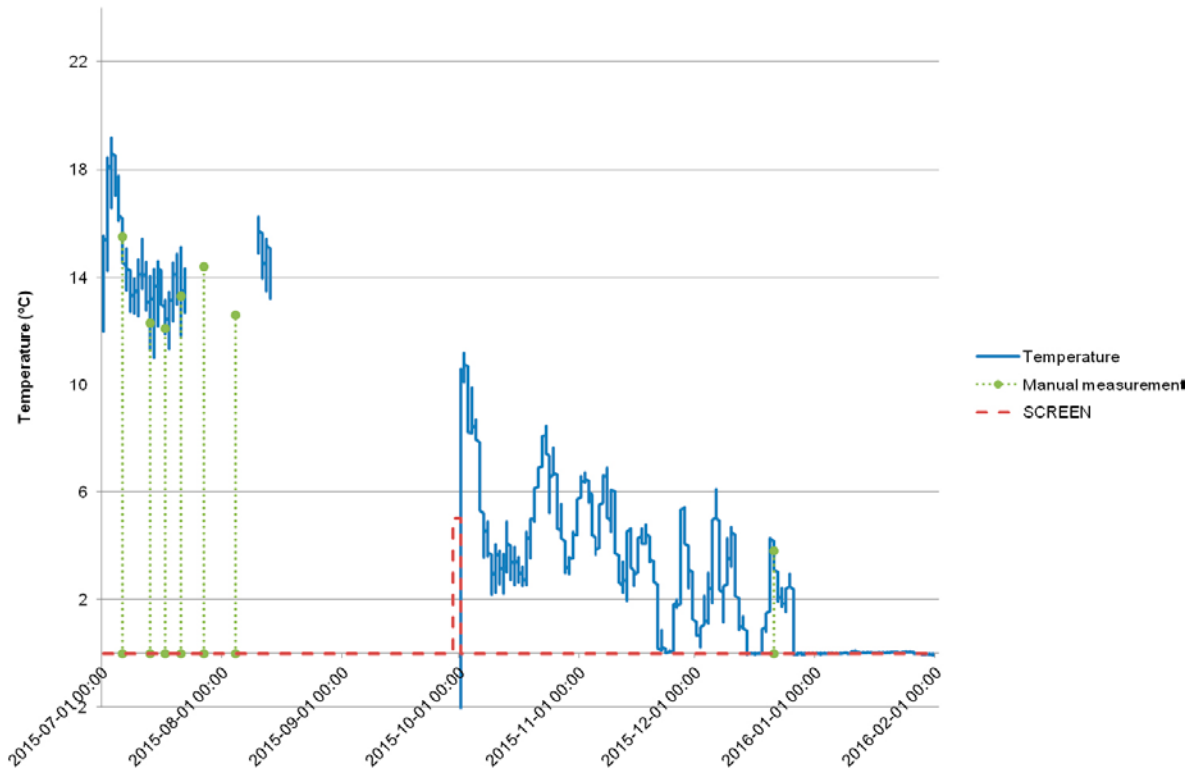


Figure A4-2. Temperature time series for gauging station PFM005764 for the period July 1, 2015–January 31, 2016.

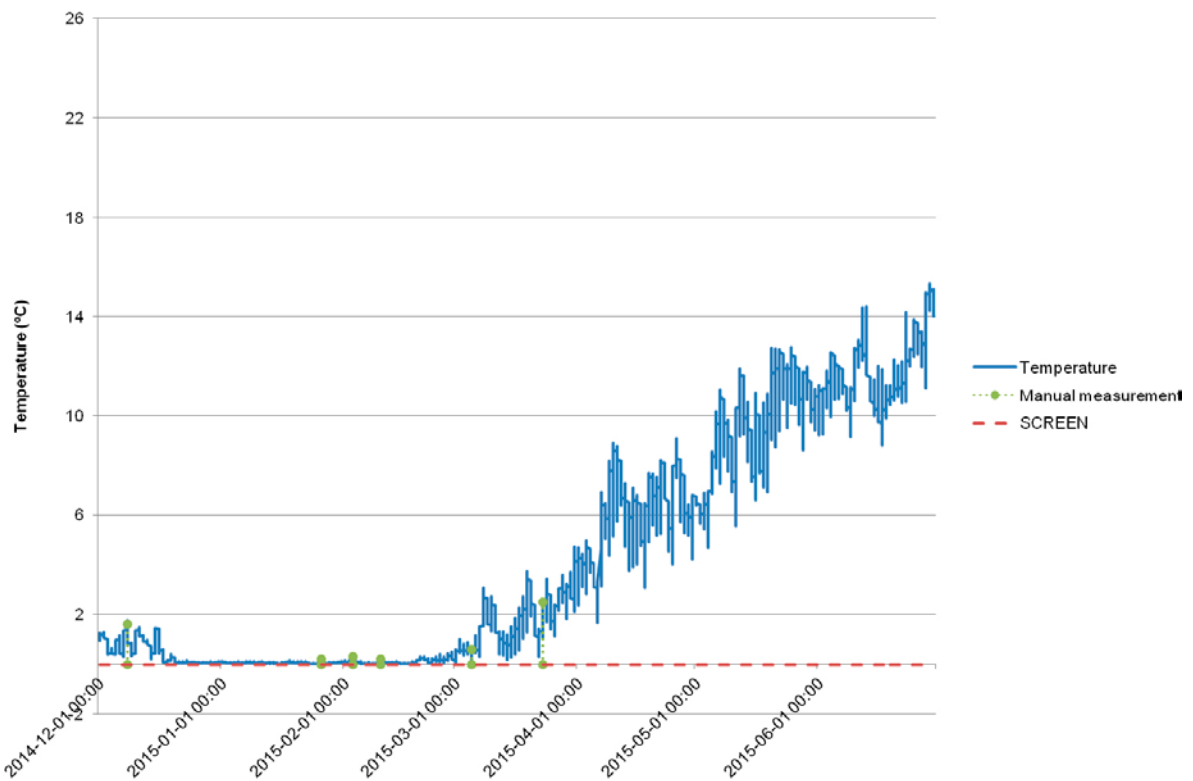


Figure A4-3. Temperature time series for gauging station PFM002667 for the period December 1, 2014–June 30, 2015.

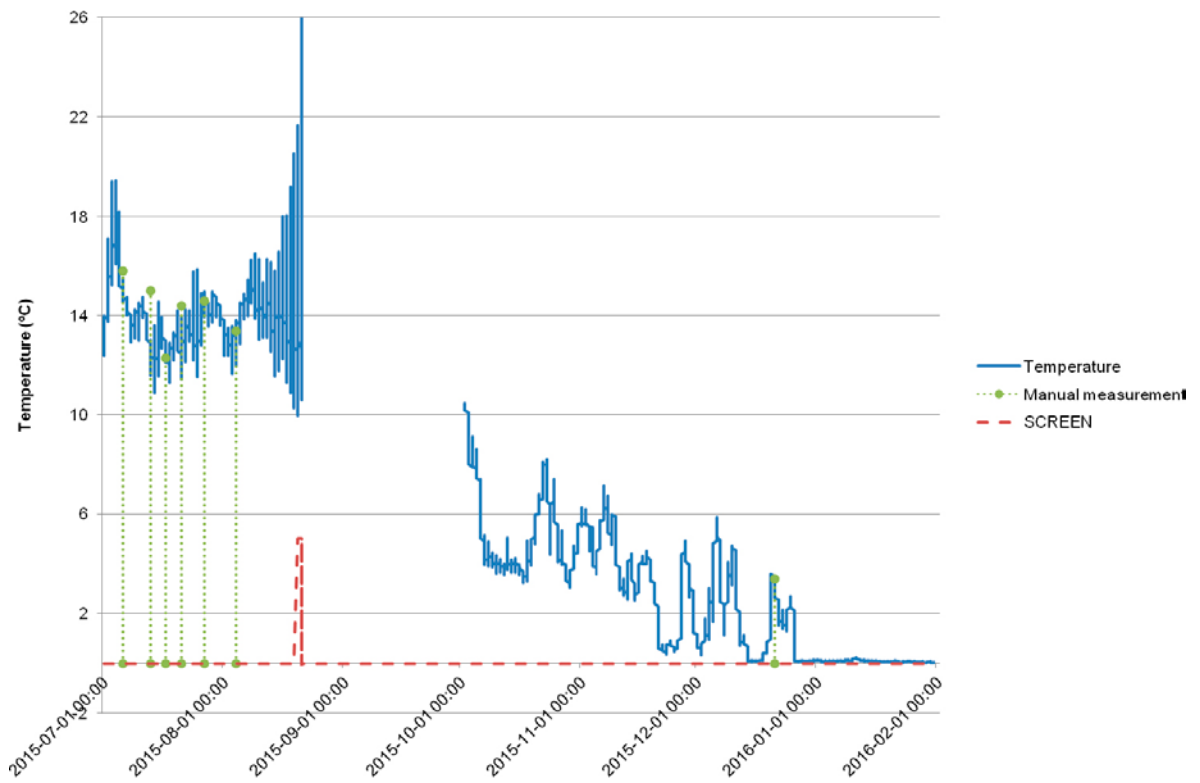


Figure A4-4. Temperature time series for gauging station PFM002667 for the period July 1, 2015–January 31, 2016.

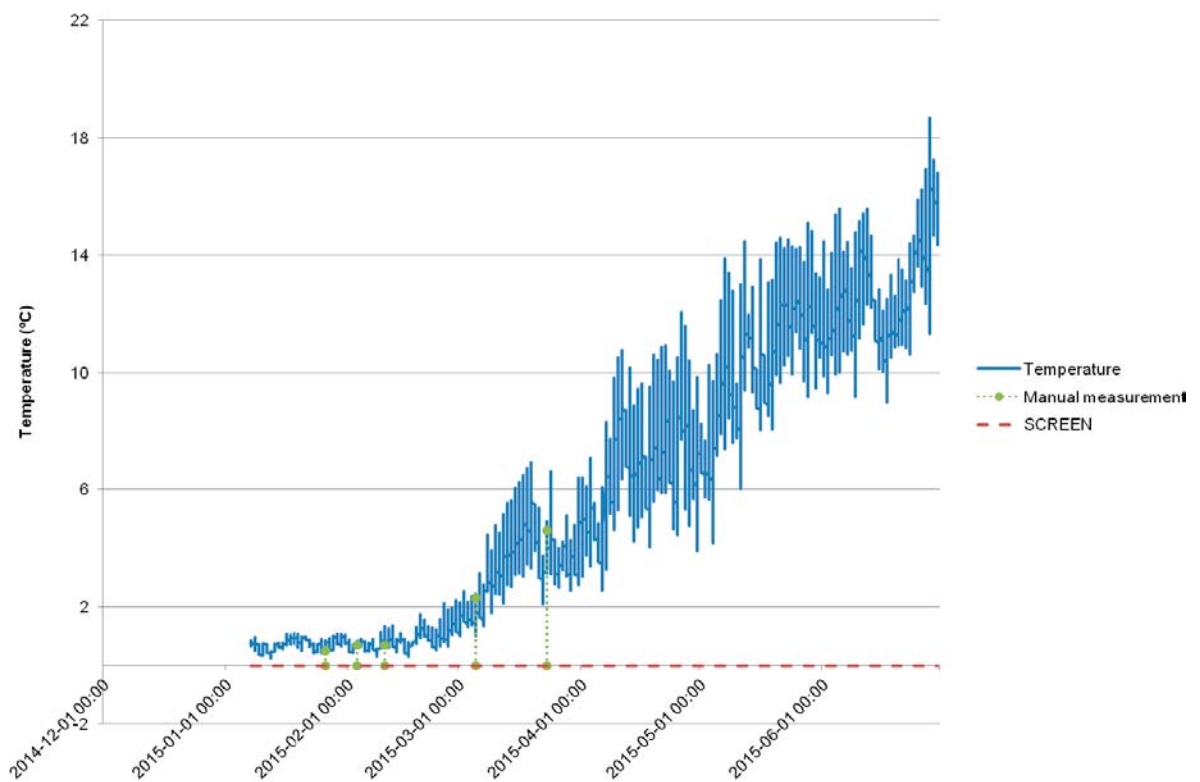


Figure A4-5. Temperature time series for gauging station PFM002668 for the period January 7–June 30, 2015 (the temperature sensor was relocated prior to January 7, 2015).

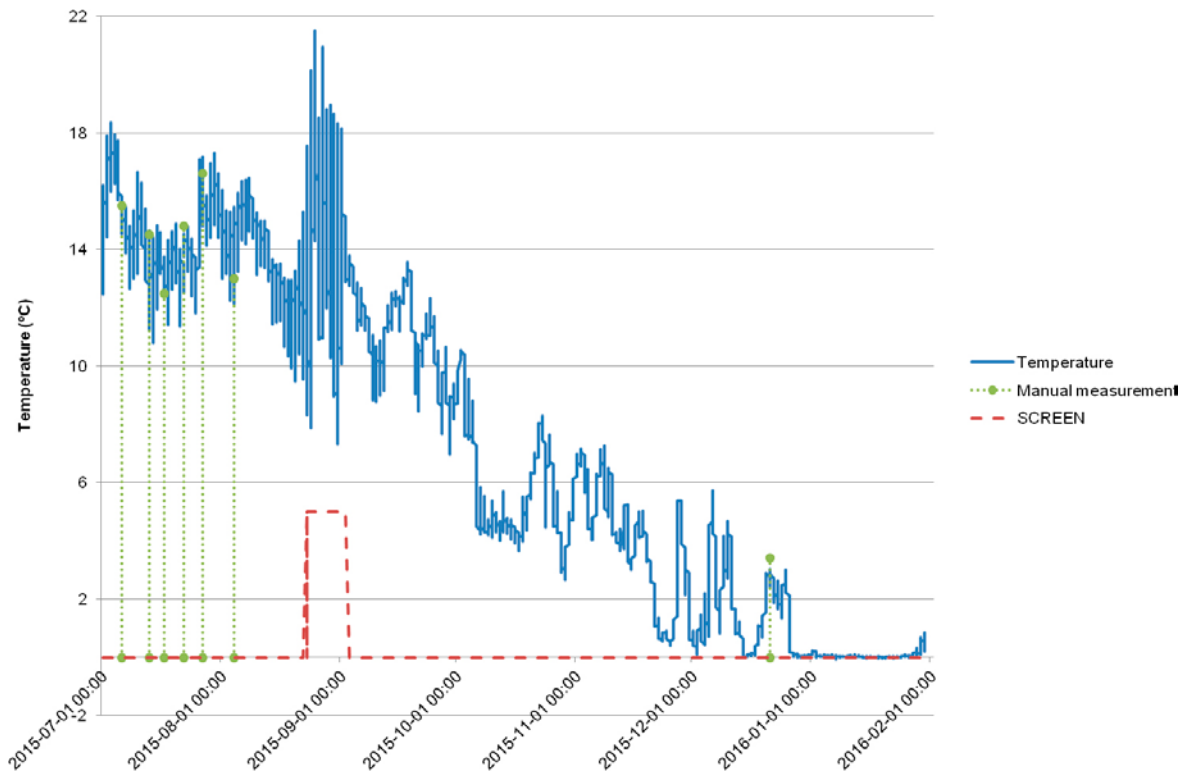


Figure A4-6. Temperature time series for gauging station PFM002668 for the period July 1, 2015–January 31, 2016.

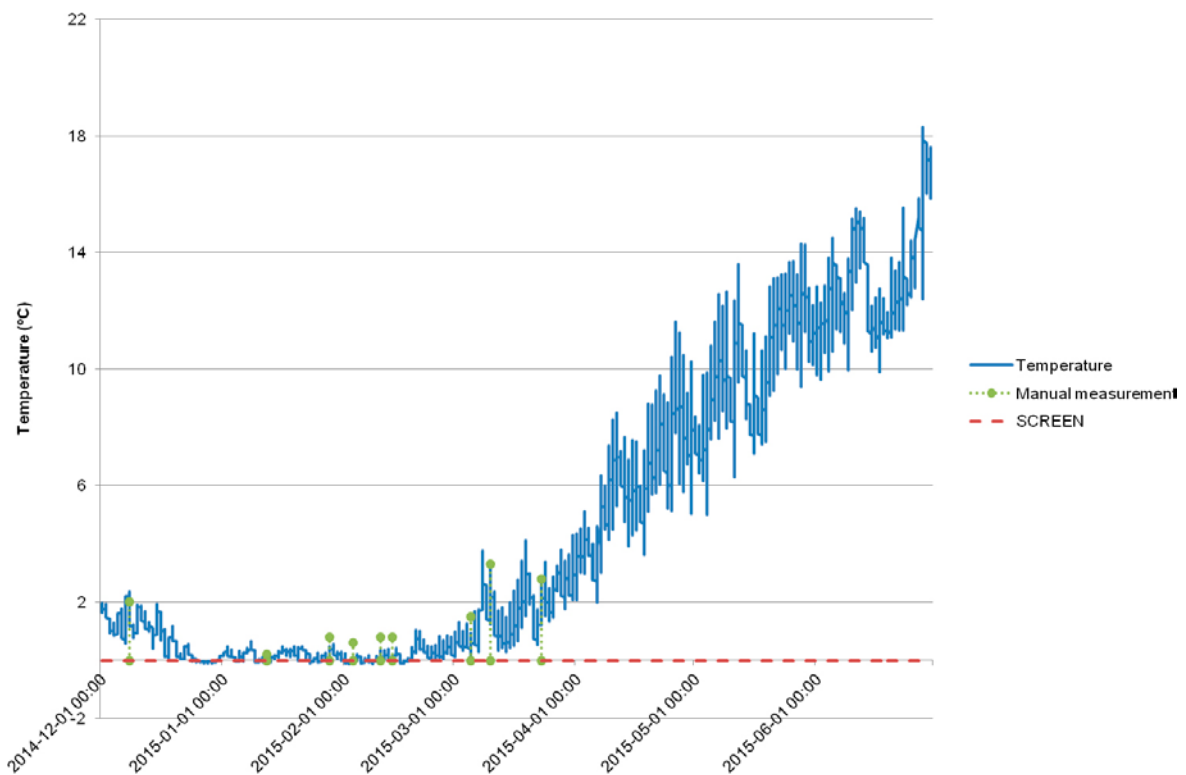


Figure A4-7. Temperature time series for gauging station PFM002669 for the period December 1, 2014–June 30, 2015.

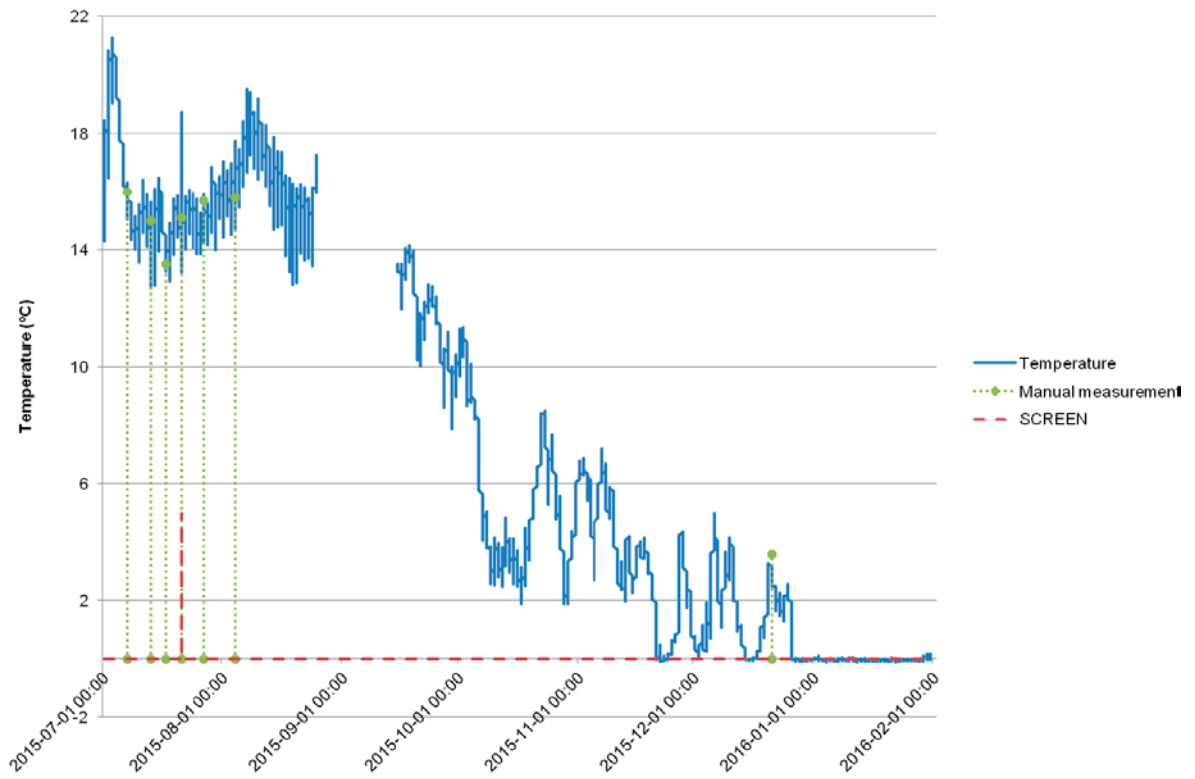


Figure A4-8. Temperature time series for gauging station PFM002669 for the period July 1, 2015–January 31, 2016.

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

skb.se