Report

P-17-29

March 2018

Monitoring hydrology in Forsmark Hydrological year October 1, 2015 – September 30, 2016

Monitoring of streams: Water level, discharge, electrical conductivity and temperature 2015–2016 AP SFK 10-083

SVENSK KÄRNBRÄNSLEHANTERING AB

SWEDISH NUCLEAR FUEL
AND WASTE MANAGEMENT CO

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

Kent Werner

SVENSK KÄRNBRÄNSLEHANTERING

ISSN 1651-4416
SKB P-17-29
ID 1607160

March 2018

Monitoring hydrology in Forsmark Hydrological year October 1, 2015 – September 30, 2016

Monitoring of streams: Water level, discharge, electrical conductivity and temperature 2015–2016 AP SFK 10-083

Kent Werner, EmpTec

Keywords: Gauging station, Flume, Water level, Discharge, Electrical conductivity, Temperature.

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

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

Summary

This document reports the monitoring of water level, which is used to calculate water depth, EC (electrical conductivity), temperature, and water-depth based calculations of discharge at four gauging stations in four streams in Forsmark for the hydrological year 2015/2016 (October 1, 2015–September 30, 2016). 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 and 2016, 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 2014 and also in 2016. 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 stations PFM005764 and PFM002669 were refurbished in 2014 and 2015, respectively, and houses have subsequently been constructed on top of the stations. 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 dataset for the hydrological year 2015/2016, water-level data were only excluded from the HMS to Sicada transferral for short periods with low water levels. The hydrological year 2015/2016 is characterised by long data gaps (data are missing in HMS), in particular for the PFM005764 station. It is therefore noted that the statistics for hydrological year 2015/2016 presented in the report are affected by these data gaps.

Sammanfattning

Detta dokument beskriver monitering av vattennivå, som används för ett beräkna vattendjup, EC (elektrisk konduktivitet), temperatur samt vattendjupsbaserade beräkningar av vattenföring vid fyra vattenföringsstationer i fyra bäckar i Forsmark under år det hydrologiska året 2015/2016 (1 oktober 2015–30 september 2016). 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 mätrännor 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 höjdled 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 avvägningskampanjer. 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 och 2016, 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 under 2014 och även under 2016. Det finns behov av utspädnings- och/eller andra typer av oberoende vattenföringsmätningar även i framtiden.

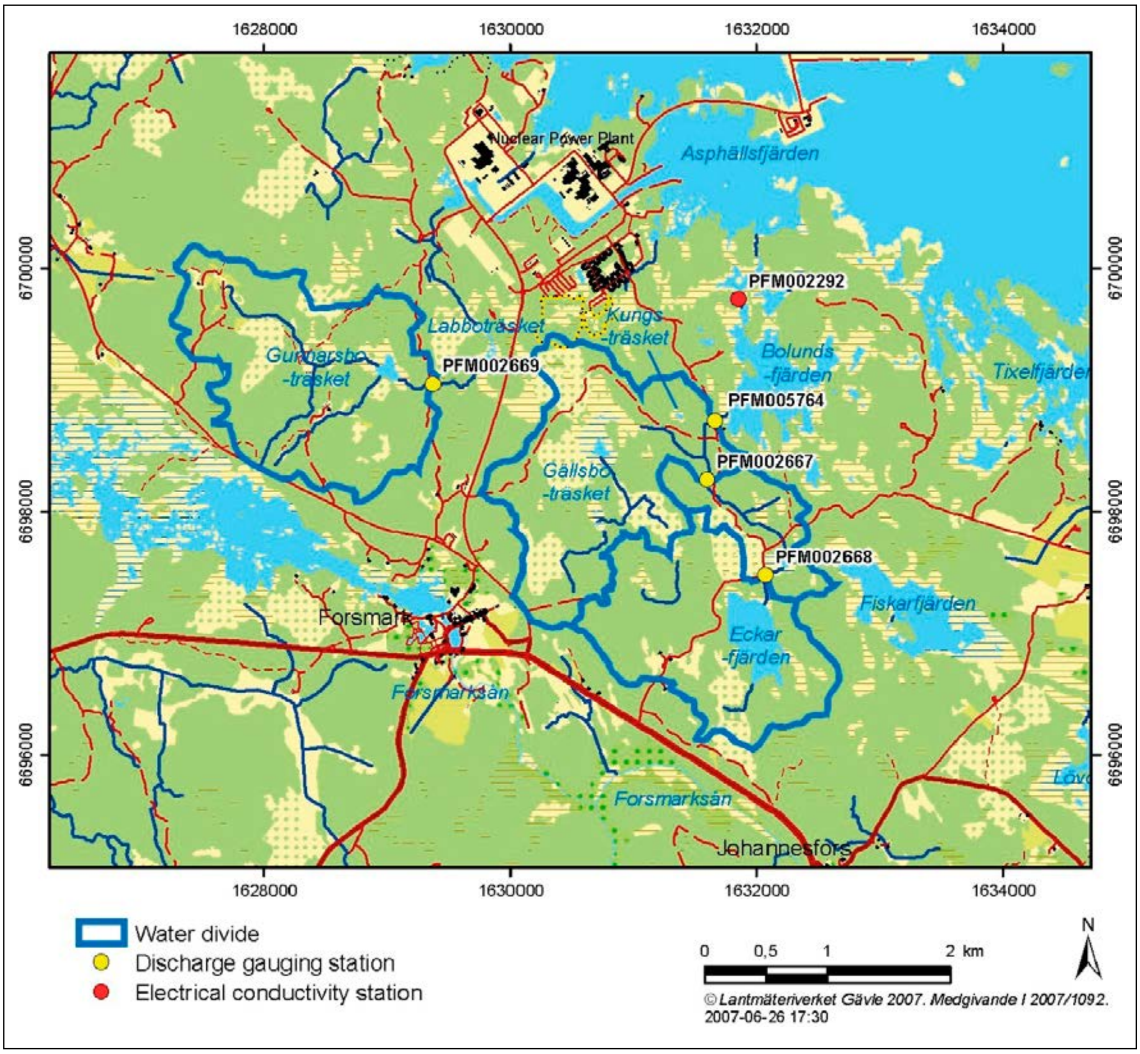
Praktiska erfarenheter, inspektioner och utredningar har lett till slutsatsen att vattenföringsstationerna måste renoveras för att förbättra deras funktion, mätnoggrannhet och för att göra dem stabilare och därmed lämpade för långtidsmonitering. Stationerna PFM005764 och PFM002669 renoverades under 2014 respektive 2015 och har sedermera försetts med hus. 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 det hydrologiska året 2015/2016 undantogs vattennivådata för överföring från HMS till Sicada främst under perioder med låga vattennivåer. Det hydrologiska året 2015/2016 karaktäriseras vidare av långa dataluckor (data saknas i HMS), i synnerhet för stationen PFM005764. Det ska därför noteras därför att den statistik för det hydrologiska året 2015/2016 som presenteras i rapporten är påverkad av dessa dataluckor.

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, 2015–September 30, 2016. 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. It is noted that 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).



©Lantmäteriverket Gävle 2007. Medgivande I 2007/1092.
2007-06-26 17:30

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, possibly combined with checks of road culverts.*

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) for the period 2011–2015. Hence, there is a temporal overlap between the current report and the report for 2015 (Werner 2017). 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 only 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.

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 2011–2015 dataset reports, and neither in the present report.

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, possibly combined with checks of road culverts.

Table 1-1. Catchment areas of the four gauging stations (Johansson and Juston 2011b). Catchment-area sizes are stored in Sicada.

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 documents and quality-control documents for the activity.

Activity plan	SKBdoc id, version	Reference
AP SFK 10-083 Hydrologisk och hydrogeologisk monitering 2015–2017	1464444, ver 2.0	
Projekt Kärnbränsleförvaret, quality-control reports		
Monitering Forsmark och SFR – kvalitetskontroll av yt- och grundvattenmonitering September 2015–februari 2016	1540762, ver 1.0	Geosigma 2016
Monitering Forsmark och SFR – kvalitetskontroll av yt- och grundvattenmonitering Mars–oktober 2016	1579384 ver 1.0	Geosigma 2017

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 and Schneider 1983, Clemmens et al. 2001).

At three of the gauging stations, two different types of flumes were installed to obtain good accuracy over a wide range of discharge (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 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 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, 2012–2016 levelling campaigns indicate that all flumes may have moved vertically since they were installed, including movements during the period 2012–2016. However, the levelling performed at time of the original flume installations had less accuracy compared to the 2012–2016 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) discharge-equation errors are 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 2014, the reader is referred to the corresponding 2011–2014 dataset reports (Werner 2014a, b, 2016) and reports from independent discharge measurements (Bergqvist 2013, 2014a, b, Werner 2015). With few exceptions, independent discharge measurements have only been performed when the prevailing discharge is above the discharge interval for the small flumes. Independent discharge measurements were again performed on March 17, 2016 (Ryman and Strömbeck 2016), including the salt-dilution method (cf. Werner 2015) and Doppler based area-velocity measurements (e.g. Rehmel 2007) using a SonTec FlowTracker®. A single measurement using any of these two methods has an uncertainty of ± 10–15 %, whereas the weighted average of repeated measurements at a single occasion has an uncertainty of ± 5 % (Ryman and Strömbeck 2016).

Based on the measurements, it is judged that the salt-dilution method works reasonably well for the conditions at all gauging stations. The Doppler method seems to work well at PFM005764 and PFM002668, but is regarded to be less suitable at the other two stations (Ryman and Strömbeck 2016). The results of the independent discharge measurements are summarised in the bullet list below, based on 2–4 salt-dilution measurements (SD) and 1–2 Doppler measurements (DM) per gauging station. In the bullet list, WD = water depth (m), and WA = weighted average discharge and CD = calculated discharge (L/s). It is noted that the prevailing discharge was above the discharge interval for the small flumes. Weighted average discharges (WA) are 1–9 % higher than calculated discharges, with the largest discrepancies at PFM005764 (8 %) and PFM002667 (9 %), and the smallest at PFM002668 and -2669 (1–2 %).

- PFM005764: SD = 52.6, DM = 49.4, WA = 51.0. WD = 0.155 m, CD = 47.1.
- PFM002667: SD = 28.2, DM = 27.5, WA = 27.9. WD = 0.155 m, CD = 25.4.
- PFM002668: SD = 17.0, DM = 16.6, WA = 16.8. WD = 0.205 m, CD = 16.6.
- PFM002669: SD = 38.3, DM = 33.7 , WA = 36.8. WD = 0.240 m, CD = 36.0.

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. 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.

2.4 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. This section 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.

Figure 2-1 plots the cumulative frequency distribution of calculated hourly average discharge at PFM002667, from start of measurements in November 2004 to the end of 2015. The plots are divided into the discharge intervals 0–200 (full range), 0–5, 5–20, and 20–200 L/s. In addition, one plot of Figure 2-1 shows the interval 18–22 L/s, i.e. the discharge interval within which artificial, short-term discharge fluctuations may occur. For comparison, Figure 2-2 shows the corresponding cumulative frequency distribution for PFM002668, located upstream of PFM002667. PFM002668 is equipped with a single flume, i.e. without occurences of artificial, short-term discharge fluctuations. Table 2-2 presents statistics of calculated hourly average discharges at both stations for the period November 2004–December 2015.

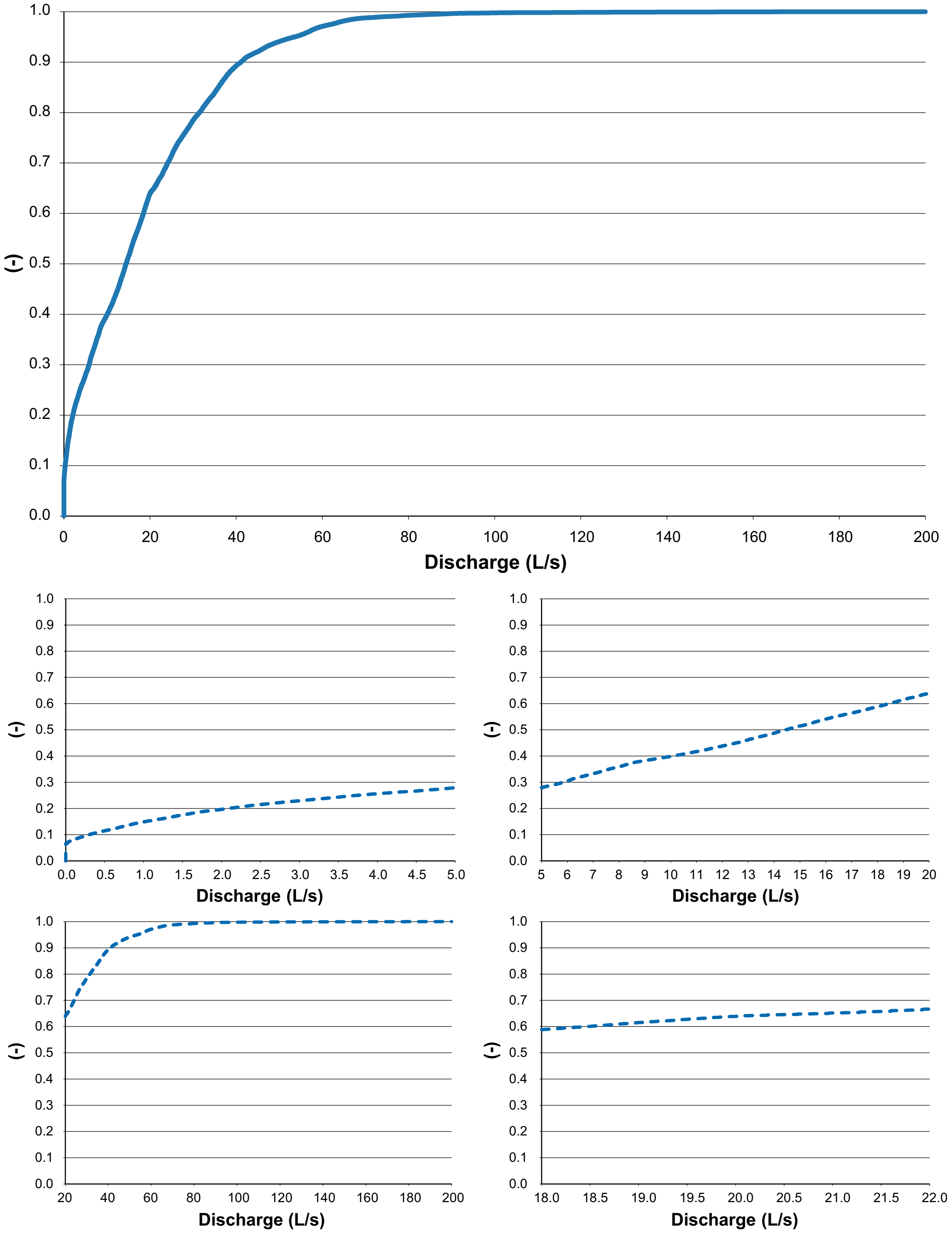


Figure 2-1. *Cumulative frequency distribution of calculated hourly average discharge at PFM002667 during the period November 2004–December 2015, divided into discharge intervals 0–200 (full range), 0–5, 5–20, 20–200, and 18–22 L/s.*

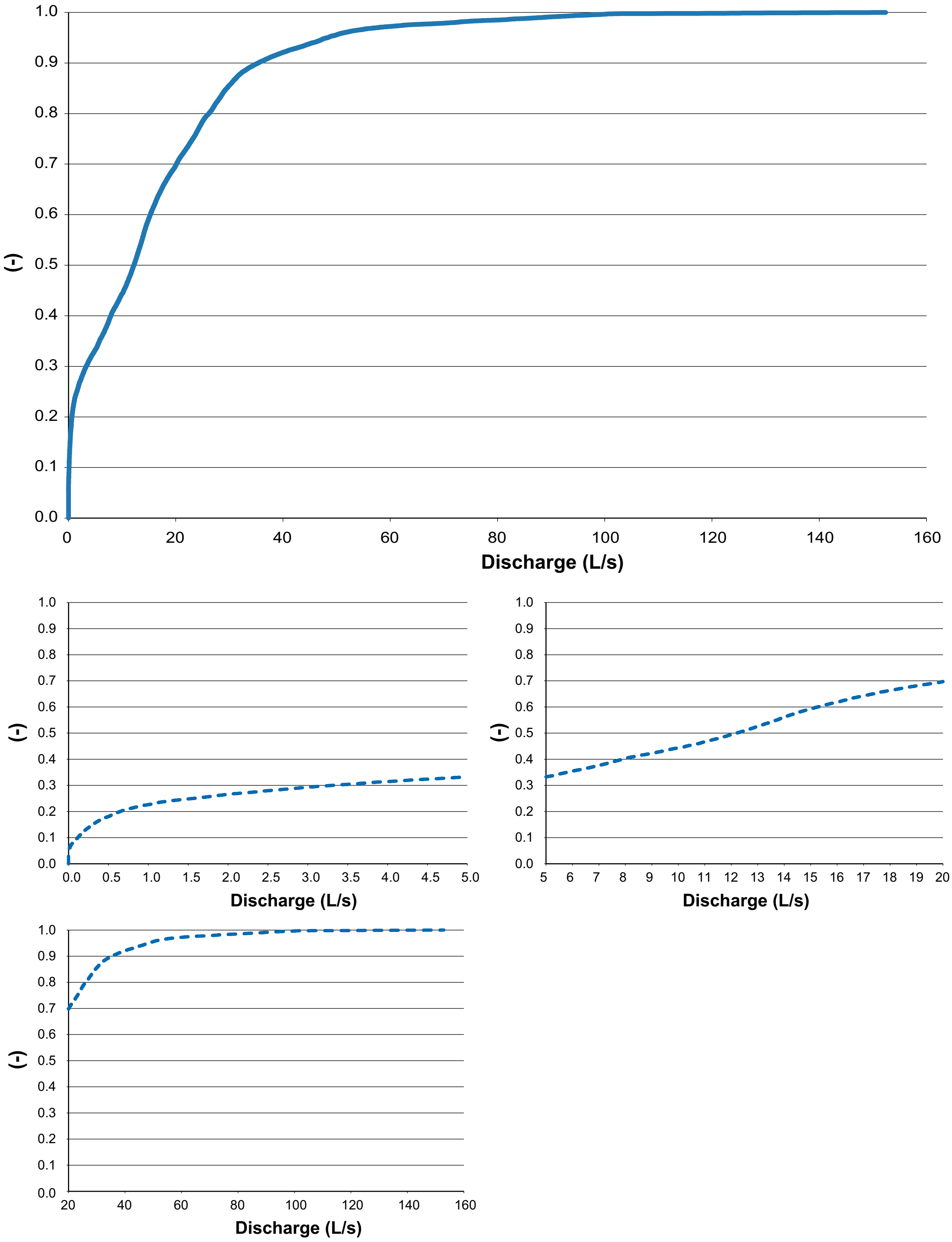


Figure 2-2. *Cumulative frequency distribution of calculated hourly average discharge at PFM002668, upstream from PFM002667, during the period November 2004–December 2015, divided into discharge intervals 0–160 (full range), 0–5, 5–20 and 20–160 L/s.*

Table 2-2. Statistics of calculated hourly average discharges (L/s) at PFM002667 and the upstream station PFM002668 during the period November 2004–December 2015.

	PFM002667	PFM002668
Min	0	0
Max	199.96	152.89
$Q_{average}$	18.28	15.79
Q_{50} (median)	14.42	12.20
Q_{15}	1.00	0.30
Q_{23}	3.02	1.00
Q_{28}	5.00	2.50
Q_{33}	6.87	5.00
Q_{90}	41.08	35.36
Q_{95}	53.53	48.24
Q ≈ 100 L/s	$Q_{99.77}$	$Q_{99.64}$
Q ≈ 150 L/s	$Q_{99.95}$	$Q_{99.98}$
$Q_{99,9}$	128.80	131.47

The maximum discharge at both stations (200 and 153 L/s) occurred in connection to the same discharge peak in spring 2013 (Werner 2014a). As part of the quality control of the 2013 dataset, PFM002667 discharges > 200 L/s were removed during the rising phase, based on the same-time maximum discharge at PFM002668 (153 L/s) and the ratio between the catchment areas of the two stations (3.01/2.28 ≈ 1.3). The influence of the difference in catchment-area size can be noted also for e.g. average and median discharges, which are higher at PFM002667 than at PFM002668.

According to Figure 2-1, the calculated PFM002667 discharge is below 20 L/s c 64 % of the time and hence above 20 L/s c 36 % of the time. The calculated discharge is in the interval 18 to 22 L/s during c 8 % of the time, i.e. the discharge interval within which artificial, short-term discharge fluctuations may occur with the current two flumes. During the period November 2004–December 2015, the calculated hourly average discharge at PFM002667 is below 1 and 5 L/s during 15 % and 28 % of the time, respectively. The discharge is above 100 L/s c 0.2 % of the time (in total 190 hours during the whole data period, or on average c 20 hours per year) and above 150 L/s c 0.054 % of the time (in total 45 hours during the whole data period, or on average c 5 cohesive hours per year). Moreover, the calculated discharge has been above 175 L/s 0.011 % of the time (in total 10 hours during the whole data period, or on average < 1 hour per year).

The calculated discharge is above 55 L/s, above which flooding occur if the downstream wetland is filled up, during 4.6 % of the time (on average c 400 hours or two weeks per year). According to Table 2-2, a single flume with a maximum discharge capacity of 100 L/s would be sufficient for c 99.8 % of all discharges during the analysed data period, a maximum capacity of 150 L/s would be sufficient for more than 99.9 % of all discharges, and a maximum capacity of 300 L/s is well above all discharges during the data period. According to preliminary plans, the two flumes at PFM002667 will be replaced with a single flume of the same type as the flume at PFM002668 (Table 2-1). The new flume will be attached by welding on the inside of the large flume. To allow this, the flume needs to be c 0.1 m lower than the flume at PFM002668, providing a discharge range of 0–150 L/s.

2.5 Continued 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 (Werner 2017). Loggers and other equipment were installed inside the cottage, and infra heaters were installed above the flume. The objectives of the cottage and its installations are to reduce maintenance needs during both winter (removal of snow and ice) and summer (on growth due to direct sunlight), to provide physical protection for equipment, and to improve working conditions at field inspections.

This section provides a continued follow-up (cf. Werner 2016, 2017) of the station refurbishment by analysing 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. Data for the analysis are taken from the 2013–2015 monitoring reports (Werner 2014a, b, 2016, 2017). As described in these reports, there are data gaps (data are missing in HMS) and erroneous data have also been excluded from the HMS to Sicada transferral.

Figure 2-3 shows water depths (upper plots) and the water-depth difference (large flume minus small flume) as function of the large-flume (middle plot) and small-flume water depth (lower plot) at PFM005764. Data are divided into the one-year pre-refurbishment period (blue) and the one-year post-refurbishment period (red). Figure 2-4 presents a similar analysis, in terms of differences in calculated discharge as function of the large-flume (upper plot) and small-flume discharge (lower plot).

At small water depths (and hence small discharges, below the range of the large flume) the water depth in the large flume is much less sensitive to the discharge compared to the water depth in the small flume. In addition, at small water depths large-flume water-depth data also demonstrate some hysteresis and scatter. Due to flume shapes and associated discharge ranges, the water-depth difference increases but at a lower rate at increasing discharge. At a water depth of c 0.24 m in the small flume, and c 0.1 m in the large flume, the small flume is flooded and discharge takes place across the whole cross section of the stream. Hence, the water-depth difference decreases with discharge at flooded conditions at the small flume. The calculated large-flume discharge is higher than the calculated small-flume discharge for discharges up to c 5 L/s, and relatively similar at higher discharge up to c 20 L/s (Figure 2-4). The discharge difference increases at discharges above 20 L/s, as the small flume is flooded at the associated water depth is controlled by the stream cross section (cf. above).

The different pre- and post-refurbishment relations at flooded conditions between water-depth/discharge difference and water depth are likely attributed to the pool between the two flumes and the larger cross-sectional area of the stream after refurbishment. Moreover, in Figure 2-3 and Figure 2-4 it is seen that the large-flume post-refurbishment water depth, and hence the calculated discharge, demonstrate hysteresis and scatter at and above water depths of 0.1 m and discharges above 20 L/s. It is recommended that the latter behaviour is investigated further. For instance, it should be investigated whether temperature, air pressure and/or moisture conditions inside the cottage above the large flume may influence measurements using a vented pressure sensor. This issue can be investigated by installing 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.

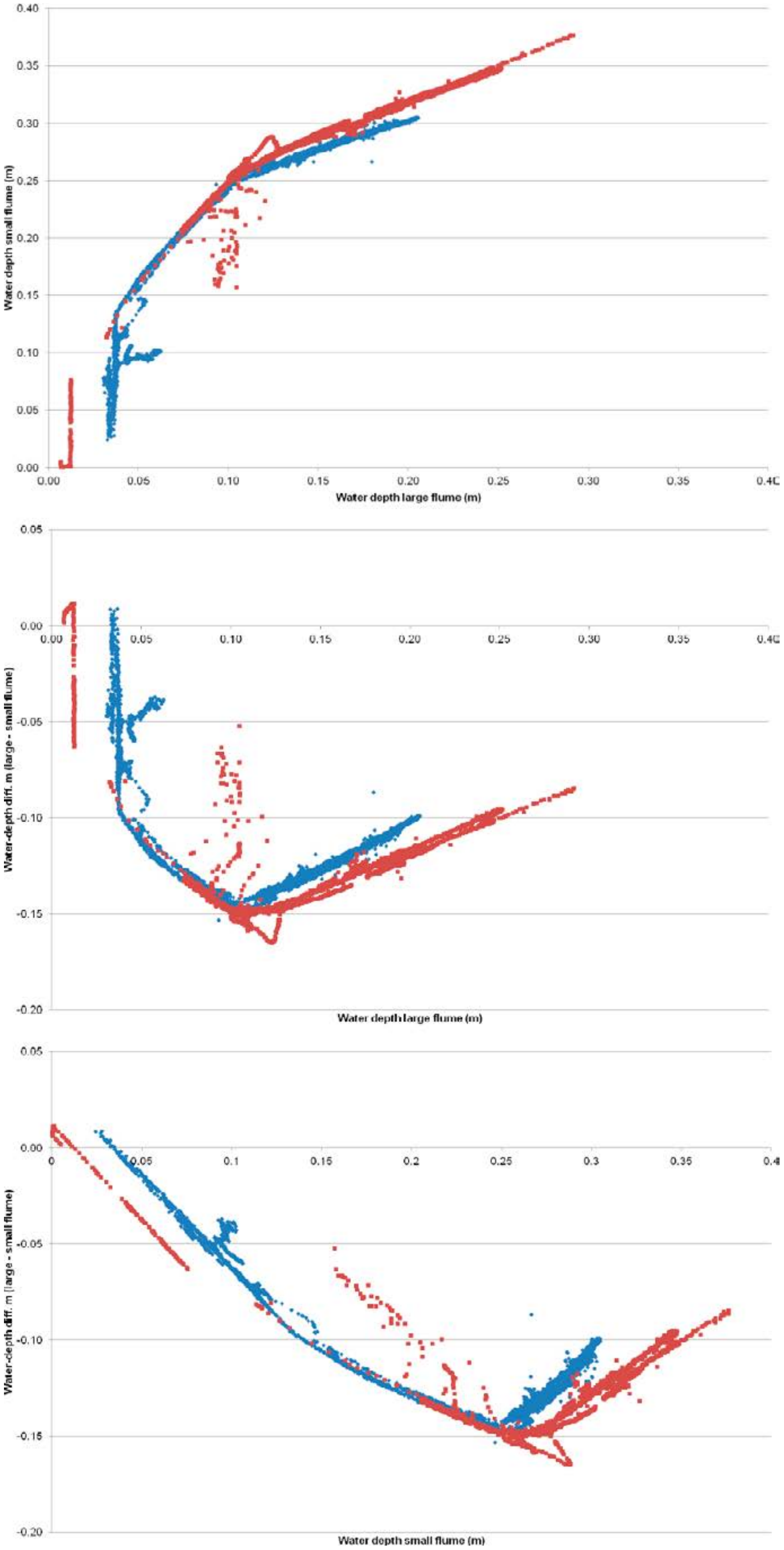


Figure 2-3. *Water depths (upper plot), water-depth difference (large flume minus small flume) as function of large-flume (middle plot) and small-flume water depth (lower plot). Data are divided into a one-year pre-refurbishment period (blue) and a one-year post-refurbishment period (red).*

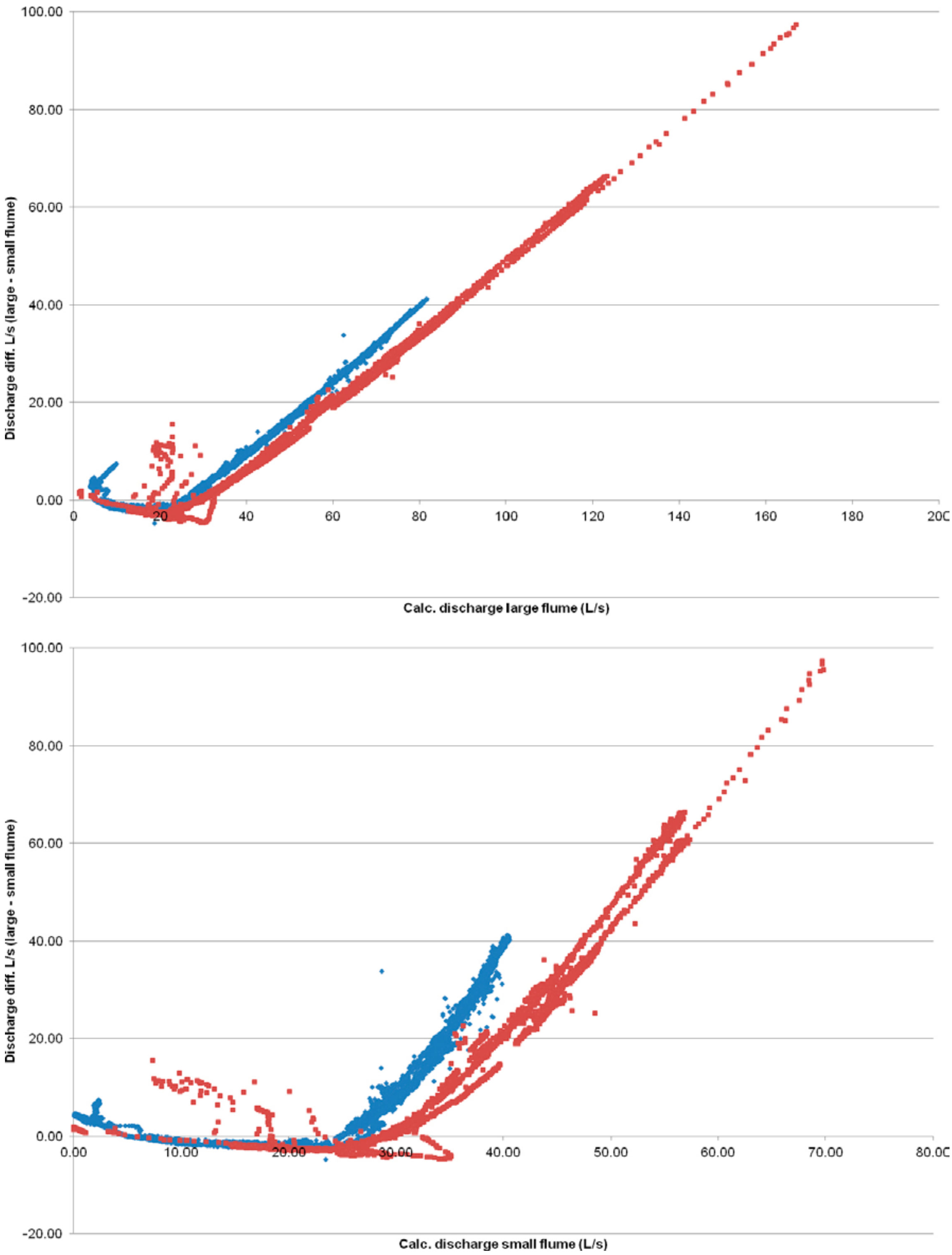


Figure 2-4. *Difference in calculated discharge (large flume minus small flume) as function of large-flume (upper plot) and small-flume discharge (lower plot). Data are divided into a one-year pre-refurbishment period (blue) and a one-year post-refurbishment period (red).*

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

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, 2015–September 30, 2016, manual measurements of the water depth at the upstream edge of each flume were done using a folding rule on only 3–6 occasions (the number of occasions varies between gauging stations), and EC and temperature were measured using a hand-held instrument (HACH HQ 14D) on only 1–3 occasions. Hence, the measurement frequency was quite low during the hydrological year 2015/2016 (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 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, 2016 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, 2016. 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
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, 2015-10-02
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 measured outside of tubes using a hand-held instrument. No changes of calibration constants have been done during the 2015/2016 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 (4 minutes at PFM002668) 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 October 1, 2015–September 30, 2016 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 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 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 2015/2016 discharge at PFM002667 was c 50 L/s (Appendix 3), i.e. less than the discharge when the downstream wetland typically is filled up.

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 2015/2016 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 February–April 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.

3.4.2 Quality control of the 2015/2016 dataset

Apart from the regular quality control described above, an additional quality control was done of the whole 2015/2016 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.

It is also noted that Werner (2017) presents a quality control of the 2015 dataset, at which point not all data were yet approved for transferral to Sicada. Hence, there is a temporal overlap between the current report and the report for 2015 (Werner 2017), which results are not repeated in the current report.

Table 3-3. Water-level data excluded from the HMS to Sicada data transferral, as a result of the quality control of the 2015/2016 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)	2015-10-28 05:00–2015-10-31 13:02, 2016-06-14–2016-06-16 13:00, 2016-06-29 21:00–2016-07-03 01:00, 2016-07-04 07:00–2016-08-30 21:00, 2016-09-07 13:00–2016-09-30 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 2015/2016 dataset.

Gauging station	Dates and times (YYYY-MM-DD hh:mm)	Reason for exclusion (WL = water level)
PFM005764	2016-04-13 11:35	Negative EC value (reason unknown)
PFM005764	2016-07-27 14:04–2016-08-29 19:00, 2016-10-10 06:51–2016-09-30 23:50	Low/negative EC values (likely due to low WL)
PFM002667	2016-07-15 15:00–2016-08-30 01:00, 2016-09-22 18:10–2016-09-30 23:00	Negative EC values (likely due to low WL)
PFM002668	2016-06-14 12:50–2016-06-20 09:10, 2016-06-26 22:50–2016-06-28 19:00, 2016-07-05 18:10–2016-07-06 18:00, 2016-07-07 14:30–2016-07-08 21:00, 2016-07-11 10:00–17:30, 2016-07-12 10:30–2016-07-30 15:00, 2016-07-30 23:00–2016-08-19 07:00, 2016-08-19 22:20–2016-08-29 14:10, 2016-09-13 17:00–2016-09-30 23:00	Low/negative EC values (likely due to low WL)
PFM002669	2016-07-20 07:00–2016-08-10 14:30, 2016-09-08 12:00–2016-09-30 23:50	Negative EC values (likely due to low WL)

Table 3-5. Temperature data excluded from the HMS to Sicada data transferral, as a result of the quality control of the 2015/2016 dataset.

Gauging station	Dates and times (YYYY-MM-DD hh:mm)	Reason for exclusion (WL = water level)
PFM005764	2016-07-21 00:01–2016-08-29 23:00	Fluctuating/high temp. values (likely due to low WL)
PFM002667	2016-07-10 00:00–2016-08-19 14:30, 2016-08-27 11:40–13.00	As above
PFM002668	2016-07-24 00:00–2016-07-26 23:40	As above
PFM002669	2016-07-20 00:00–2016-08-10 14:30	As above

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

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

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

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

3.5 Nonconformities

The Activity 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 3–6 occasions during the period October 1, 2015–September 30, 2016 (Section 3.2).

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

Water level data are stored in Sicada as Sicada Activity Type HY096–HMS monitoring surf. w level-small flume and HY097–HMS monitoring surface w level-big flume. During the period of this report, there are some water-level data gaps, i.e. data are missing in HMS, in particular for the gauging station PFM005764:

- **PFM005764:**
  - Small flume: Water-level data gap December 31, 2015–January 3, 2016.
  - Large flume: Water-level data gap December 31, 2015–April 13, 2016.
- **PFM002667 and -2668:** Water-level data gap October 1, 2015.
- **PFM002669:** Water-level data gap August 11–31, 2016 (both flumes).

As mentioned in Section 3.4.2, for the 2015/2016 period no water-level data were excluded from the HMS to Sicada data transferral. As a result of the quality control of the 2015/2016 dataset (Section 3.4.2), PFM002667 water-level data were excluded from the HMS to Sicada data transferral during periods when the large-flume water level is "frozen" and higher than the small-flume water level. Missing and excluded data, 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 48 % of the time for the PFM005764 station during the period October 1, 2015–September 30, 2016. The corresponding fraction for the other stations is 33–37 %.

Appendix 2 presents high-resolved water-level data from the four gauging stations during the 2015/2016 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 2015/2016 period, calculated based on the discharge equations of Table 2-1. Average, minimum and maximum discharges, affected by large data gaps, are shown in Table 4-1. It is noted that the maximum and average discharge for PFM005764 is affected by a long data gap during the spring of 2016 (cf. Appendix 3). It is also noted that the summer of 2016 was very dry, with zero discharge more that lasted more or less to the end of the 2015/2016 hydrological year (see examples in Figure 4-1 and Figure 4-2).

Table 4-1. Average, minimum and maximum discharges (screened data, rounded to integers) during the hydrological year October 1, 2015–September 30, 2016. The statistics are affected by data gaps (data are missing in HMS), in particular for the PFM005764 station.

	PFM005764	PFM002667	PFM002668	PFM002669
Average discharge (L/s)	14	10	8	16
Min. discharge (L/s)	0	0	0	0
Max. discharge (L/s)	59	49	49	80

Figure 4-1. *Dry flume and zero discharge at gauging station PFM005764 on August 5, 2016.*

Figure 4-2. *Dry flume and zero discharge at gauging station PFM002668 on August 5, 2016.*

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 2015/2016 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 2015/2016 dataset (Section 3.4.2), EC data were excluded from the HMS to Sicada data transferral during periods with low or negative EC values, likely associated to low water levels during summer and early autumn.

Table 4-2. Average, minimum and maximum EC (screened data, rounded to integers) during the hydrological year October 1, 2015–September 30, 2016. The statistics are affected by data gaps.

	PFM005764	PFM002667	PFM002668	PFM002669
Average EC (mS/m)	38	33	31	34
Min. EC (mS/m)	15	6	10	21
Max. EC (mS/m)	51	57	61	43

4.5 Temperature

Temperature data are stored in Sicada as Sicada Activity Type HY093–HMS Monitoring river water temperature. Appendix 5 presents high-resolved water-temperature data from the four gauging stations during 2015, 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 2015/2016 dataset (Section 3.4.2), EC data were excluded from the HMS to Sicada data transferral during periods with high or fluctuating temperature values, likely associated to low water levels during summer and early autumn.

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, 2015–September 30, 2016. The statistics are affected by data gaps.

	PFM005764	PFM002667	PFM002668	PFM002669
Average temp. (°C)	8	8	10	9
Min. temp. (°C)	0	0	0	0
Max. temp. (°C)	22	22	21	22

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 (SMHI 2016, 2017), monitoring of snow and ice (Wass 2016, 2017), and monitoring of the near-coastal sea, lakes and ponds, and near-surface groundwater (Geosigma 2016, 2017).

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

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 (Appendix 4).

Figure 4-3 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 (SMHI 2016, 2017) during the period October 1, 2015–September 30, 2016. The figure also indicates the snow-covered period in Forsmark and the ice-free period in Lake Eckarfjärden (Wass 2016, 2017), located upstream from PFM002668.

As shown in Figure 4-3, the discharge increases in response to precipitation and/or minor snow-melt events during autumn and winter. During 2016, there was a snow cover from the beginning of January to the middle of March, whereas Lake Eckarfjärden was totally free from ice in the beginning of April. Hence, the increasing discharge during March 2016 is likely a response to snow and ice melt.

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 2016, 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 4-4, 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 2016, 2017). It is noted that there is no ongoing monitoring in three groundwater-monitoring wells (SFM0016–18) that are also located within the station catchment.

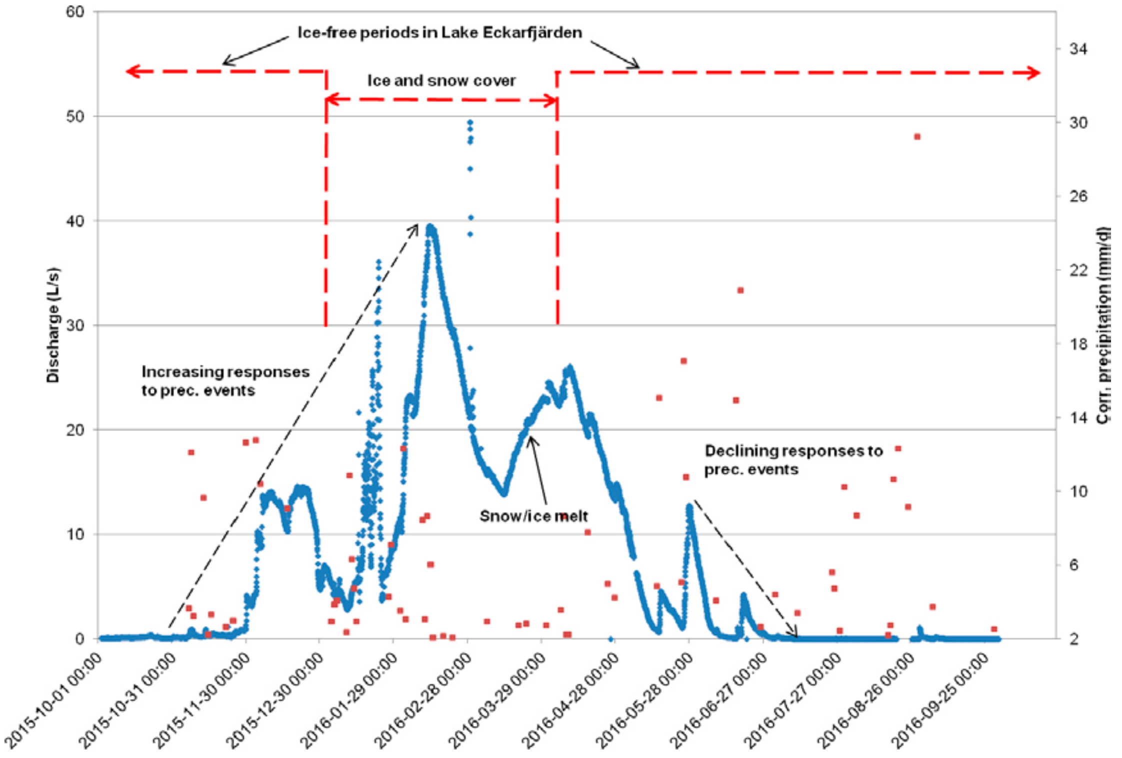


***Figure 4-3.** Hourly average stream discharge at gauging station PFM002668 (blue dots) and daily sums of corrected precipitation measured at the Labbomasten meteorological station (PFM006281, red dots) during the hydrological year 2015/2016. The figure also indicates the snow- and ice-covered period in Forsmark and ice-free periods in Lake Eckarfjärden, located upstream from PFM002668.*

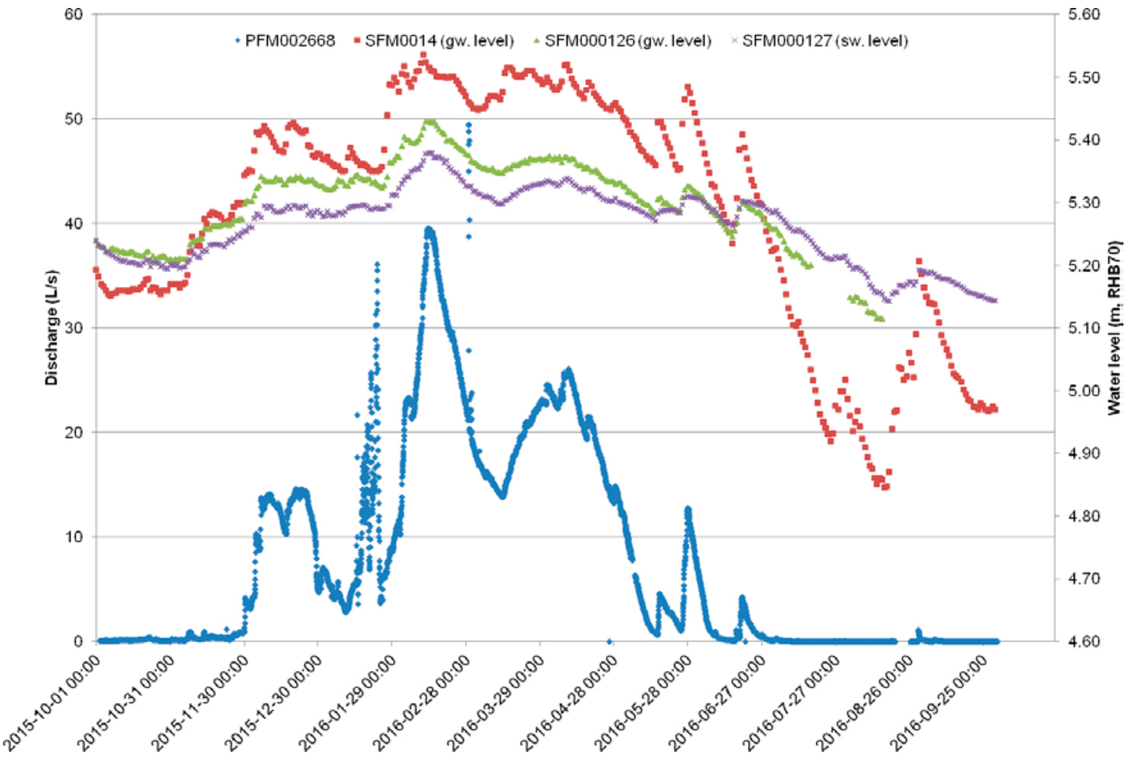


Figure 4-4. *Hourly average stream discharge at gauging station PFM002668 (blue dots), daily average groundwater levels (gw. level) in monitoring wells SFM0014 and SFM000126 (the latter installed below the bottom of Lake Eckarfjärden) and daily average surface-water level (sw. level) in the lake (SFM000127) during the hydrological year 2015/2016.*

According to Figure 4-4, ground- and surface-water level data demonstrate a similar temporal variability pattern as the stream discharge, with increasing levels during autumn and winter in response to precipitation and/or snow and ice melt. There are decreasing levels during March and April, in particular 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 4-4, 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 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 May, whereas the gradient has the opposite direction during the rest of the data period of this report.

Comparison between stream discharge (Appendix 3) and EC (Appendix 4) indicates that there are important discharge-hydrochemistry relationships. Specifically, EC decreases during high-discharge periods, 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 Gällsboträsket 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.

4.7 Prerequisites for completion of missing discharge data

As noted in Section 3.3.4, days with missing discharge data are not filled in, as such data filling is not an objective of the hydrological monitoring. This section analyses prerequisites to complete (fill in) missing discharge data, given that four stations are operated in parallel at the same site. Specifically, a high degree of inter-station discharge co variation would enable missing discharge data at one gauging station to be completed, using discharge data from one of the other stations or from a combination of them.

Figure 4-5 plots hydrographs, based on daily average calculated discharges, for the 2015/2016 hydrological year for all gauging stations. For comparison, the figure also shows the average hydrograph (black dashed line), which is based on available daily averages. For clarity, separate plots for each station are presented in Appendix 6. As shown in Figure 4-5, the temporal variability of the calculated discharge is similar at all four gauging stations. Inter-station correlations (in terms of correlation coefficients, $0 \leq r \leq 1$, based on daily data) are high or very high, varying between c 0.90–0.99. These findings indicate that e.g. regression analysis could be applied on available datasets to obtain mathematical expressions for completion of missing discharge data.

The high degree of inter-station co variation is further illustrated in Figure 4-6, which shows corresponding cumulative discharges for the same period. However, as the objective of Figure 4-6 is inter-station comparison, the figure only considers days when data are available from all stations. It is noted that the ratio between the cumulative discharge at station PFM002667 and that at station PFM005764 is c 0.41, whereas the catchment-area ratio is c 0.54 (Table 1-1). The corresponding cumulative discharge ratios for stations PFM002668 and -2669 are c 0.31 and 0.67 (the average cumulative discharge has a ratio of c 0.60), whereas the catchment-area ratios are c 0.41 and 0.51, respectively.

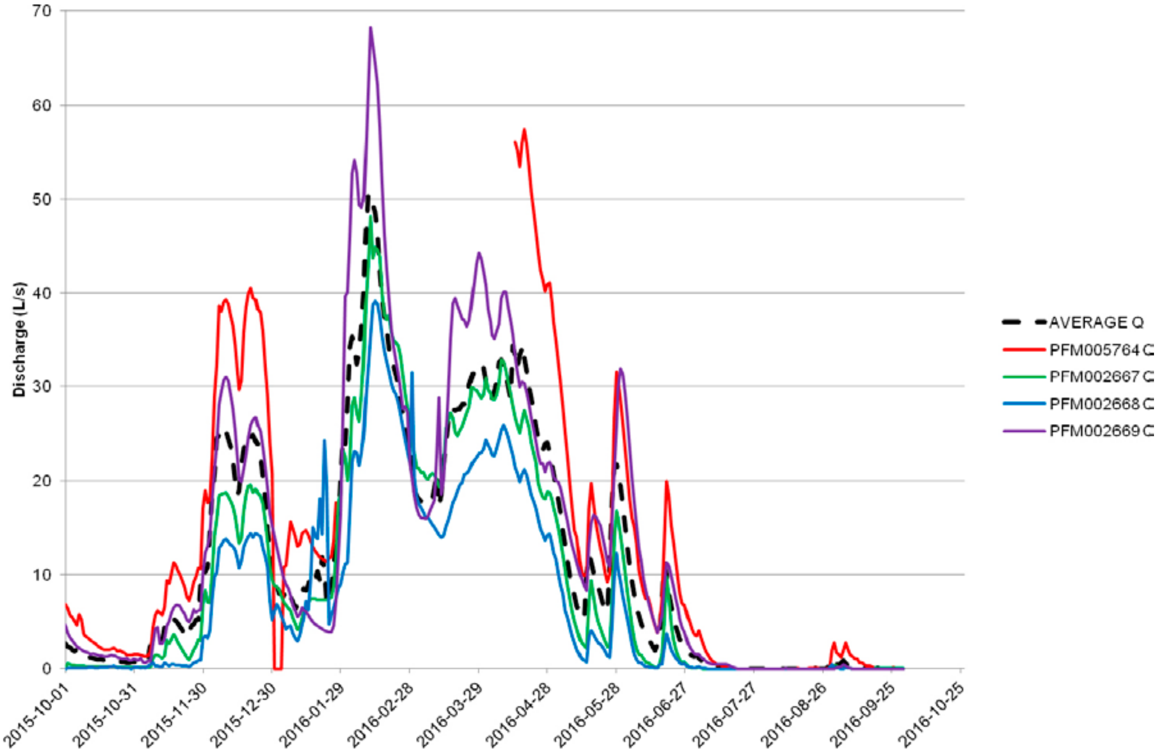


Figure 4-5. *Hydrographs (daily average stream discharges, Q, in L/s) for the hydrological year 2015/2016. The average hydrograph, based on available daily averages, is shown as a black dashed line.*

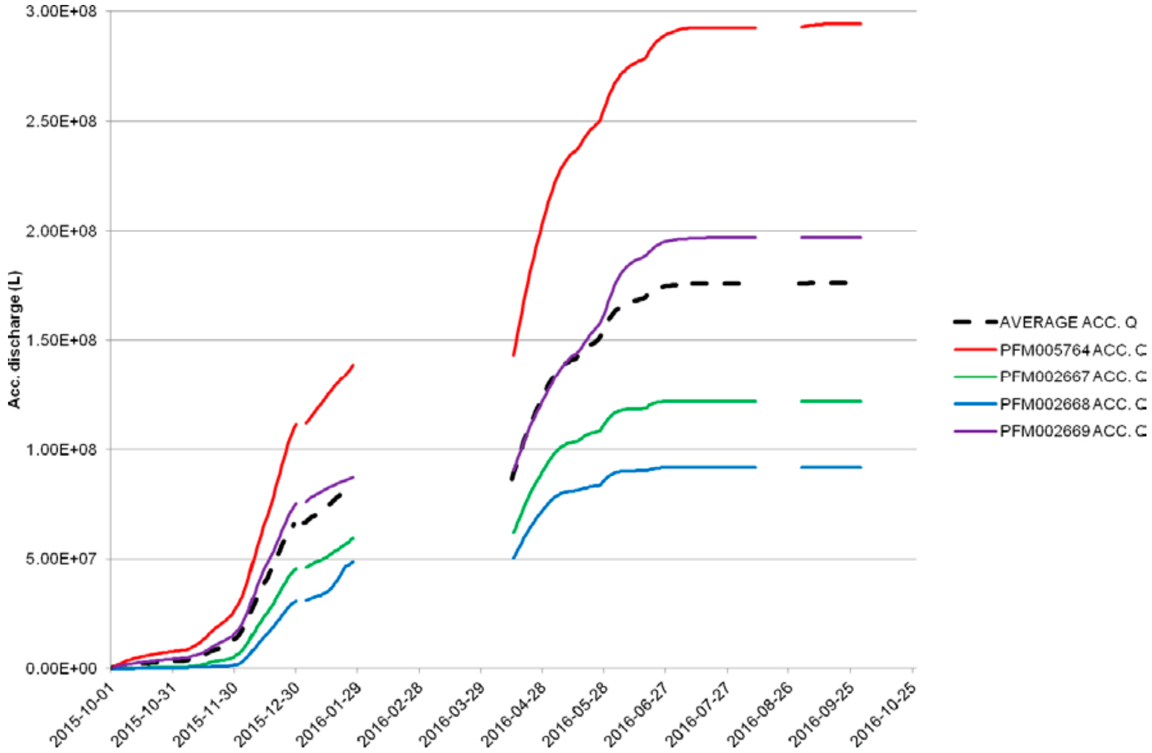


Figure 4-6. *Cumulative daily average discharges (acc. Q, in L) for the hydrological year 2015/2016. The average cumulative daily average discharge is shown as a black dashed line. To facilitate inter-station comparison, the figure only considers days when data are available from all stations.*

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 VP3 2013-12-16. SKBdoc 1445903 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

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

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

Bergström S, 1993. Sveriges hydrologi: grundläggande hydrologiska förhållanden. Norrköping: Sveriges meteorologiska och hydrologiska institut. (In Swedish.)

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

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

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

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

Edvardson K, 2015. SKB höjdkontroll GV-rör, bäckrännor. Uppföljande höjdbestämning av 30 grundvattenrör och fem bäckrännor. SKBdoc 1593195 ver 1.0. SWECO Civil AB. Svensk Kärnbränslehantering AB. (In Swedish.)

Geosigma, 2016. Monitering Forsmark och SFR. Kvalitetskontroll av yt- och grundvatten-monitering. Period: september 2015 – februari 2016. SKBdoc 1540762 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Geosigma, 2017. Monitering Forsmark och SFR. Kvalitetskontroll av yt- och grundvattenmonitering. Period: mars 2016 – oktober 2016. SKBdoc 1579384 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.

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

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

Rehmel M, 2007. Application of acoustic doppler velocimeters for streamflow measurements. Journal of Hydraulic Engineering 133, 1433–1438.

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

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

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

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.

SMHI, 2016. Meteorological monitoring at the Högmasten and Labbomasten stations in Forsmark during January–December 2015. SKBdoc 1540483 ver 1.0, Svensk Kärnbränslehantering AB.

SMHI, 2017. Meteorological monitoring at the Labbomasten station in Forsmark January–December 2016. SKBdoc 1591136 ver 1.0, 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 Proceedings of the 4th Decennial National Irrigation Symposium, Phoenix, Arizona, 14–16 November 2000, 606–601.

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

Wass E, 2017. Snow depth and ice cover during the winter 2016/2017. SKBdoc 1599508 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, 2015. Flödesmätningar i bäckar i Forsmark – mätningar med saltutspädningsmetoden 2014-12-09. SKBdoc 1467666 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

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.

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

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)

Id	Northing (m)	Easting (m)	Elevation (m)
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 2012–2016. 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, and the PFM005764 and PFM002669 stations were refurbished i Aug. 2014 and Aug.–Sep. 2015, respectively. The results of the 2013 levelling are somewhat dubious. Also note that PFM002667 and -2668 were not included in the 2016 levelling campaign. 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 since original levelling (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	+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 Aug. 2014 Used for discharge calc. and as ref. level for man. meas. in HMS 2014-08-26–
Large flume	0.889	0.897	0.893	As above
2016:				
Small flume	0.924	0.923	0.924	0 (level change since refurbishment)
Large flume	0.889	0.896	0.893	0 (as above)

Gauging station and flume)	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. 2004-12-08–2015-09-14 and as reference point in HMS 2004-11-03–2015-09-14 (obs. well before that)	
Large flume	5.843		As above	
2012:				
Small flume	5.438	5.439	5.439	–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
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 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–

Table A1-3. Results of the levelling of top of casing of observation wells (m) at flumes in 2012–2016. 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, 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. Also note that PFM002667 and -2668 were not included in the 2016 levelling campaign. 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	+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 Aug. 2014
Large flume	2.131	Station refurbished in Aug. 2014
2016:		
Small flume	2.085	
Large flume	2.132	
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	+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

Gauging station and well	Original levelling Point I (RHB 70)	Comment on original levelling Level change since original levelling (m)
PFM002668		
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	–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 2004-10-01–2004-11-02 (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 Aug.–Sep. 2015
Large flume	6.501	Refurbished Aug.–Sep. 2015

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, 2015–October 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 2015/2016 water-level dataset. Note that water levels for September 2015 and October 2016 are shown for reference only.

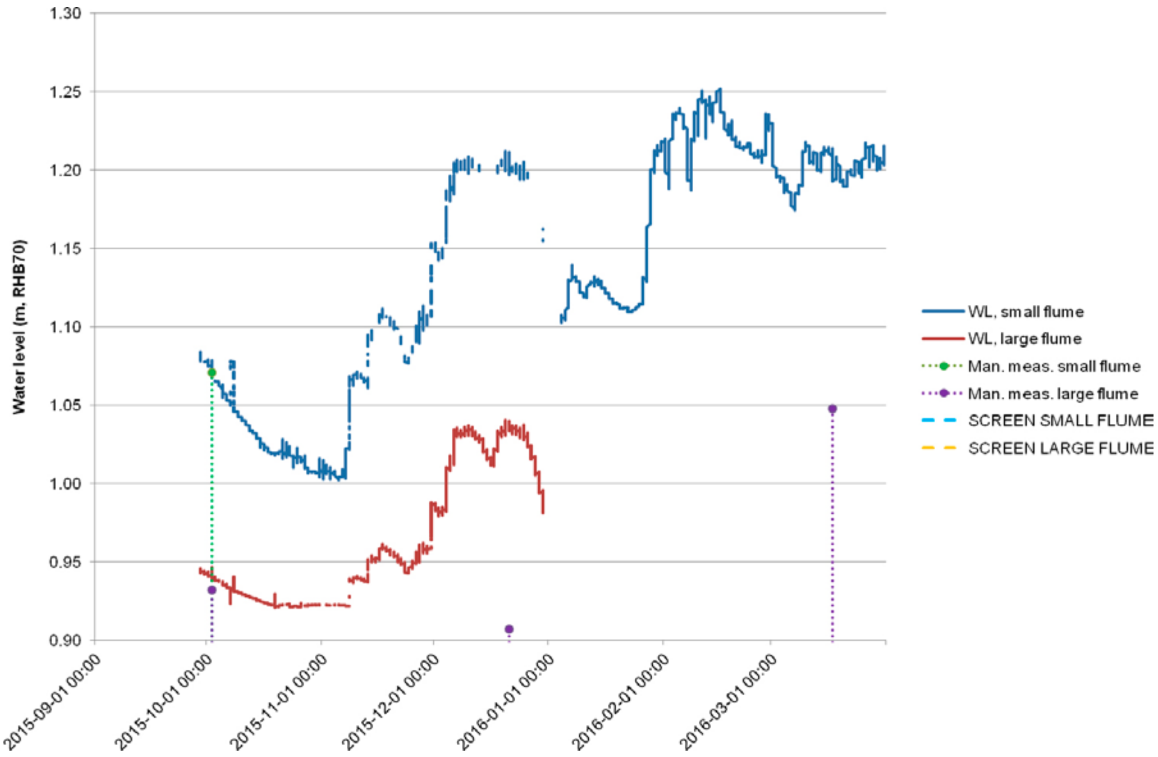


Figure A2-1. *Water-level time series for the flumes at gauging station PFM005764 for the period Sep. 1, 2015–Mar. 31, 2016.*

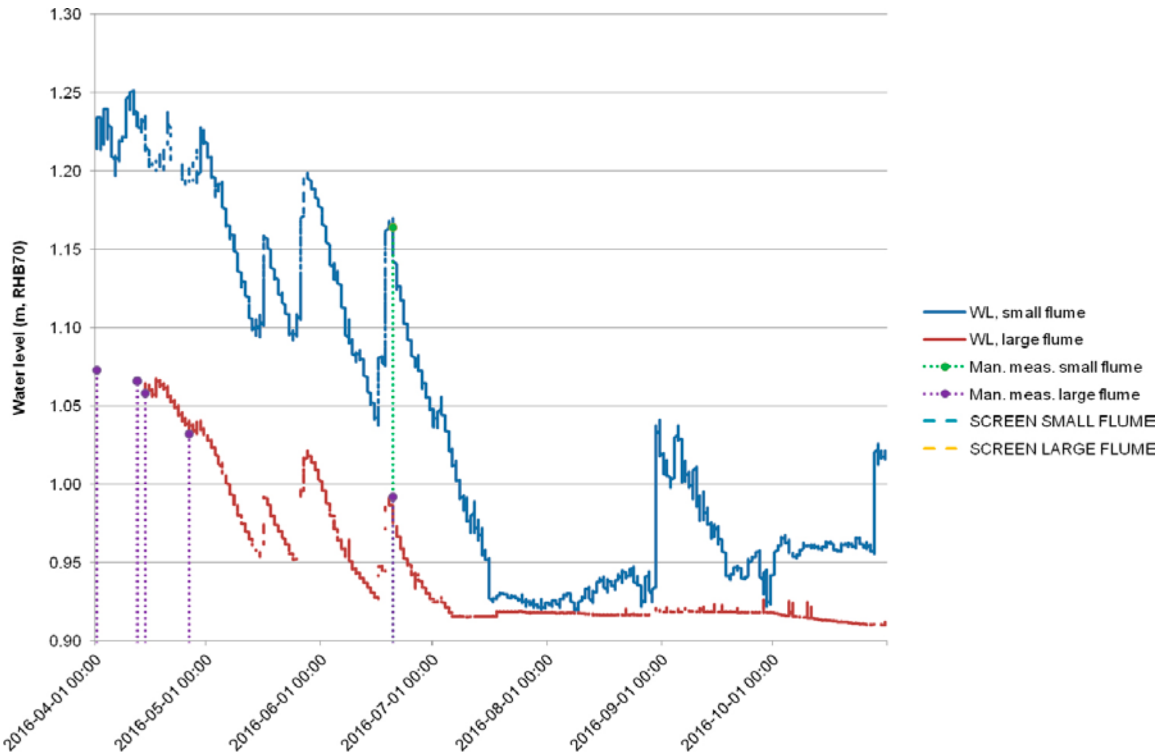


Figure A2-2. *Water-level time series for the flumes at gauging station PFM005764 for the period Apr. 1–Oct. 31, 2016.*

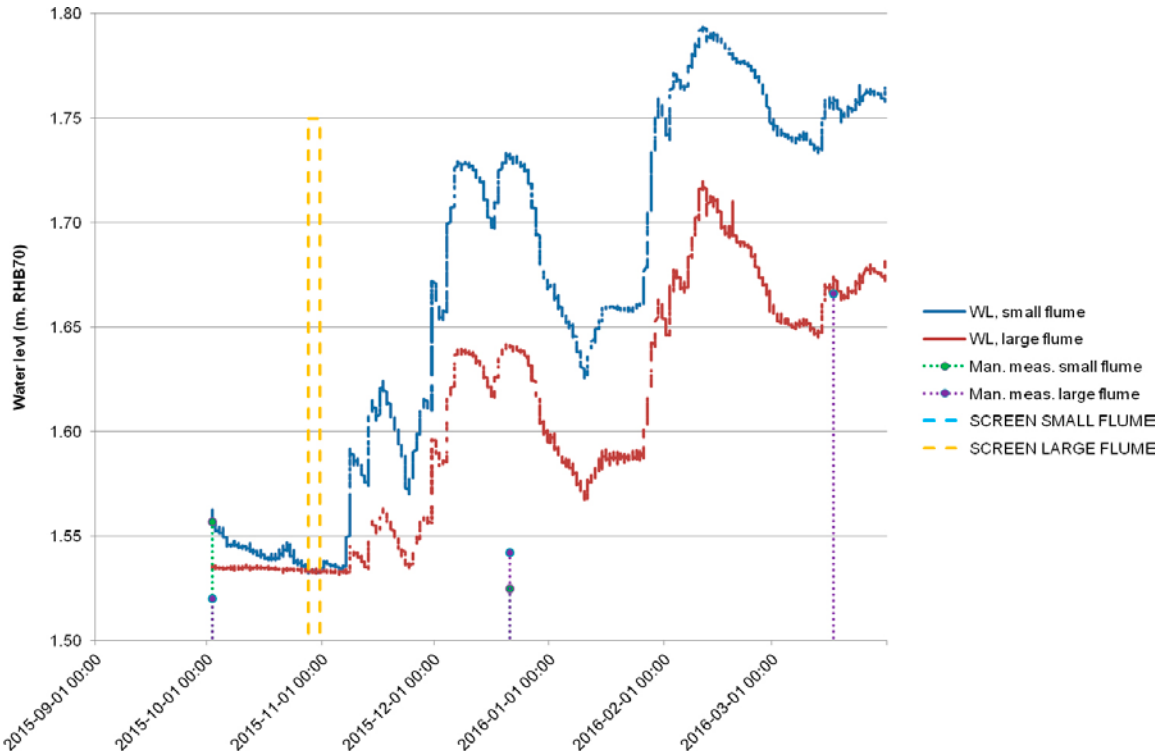


Figure A2-3. *Water-level time series for the flumes at gauging station PFM002667 for the period Sep. 1, 2015–Mar. 31, 2016.*

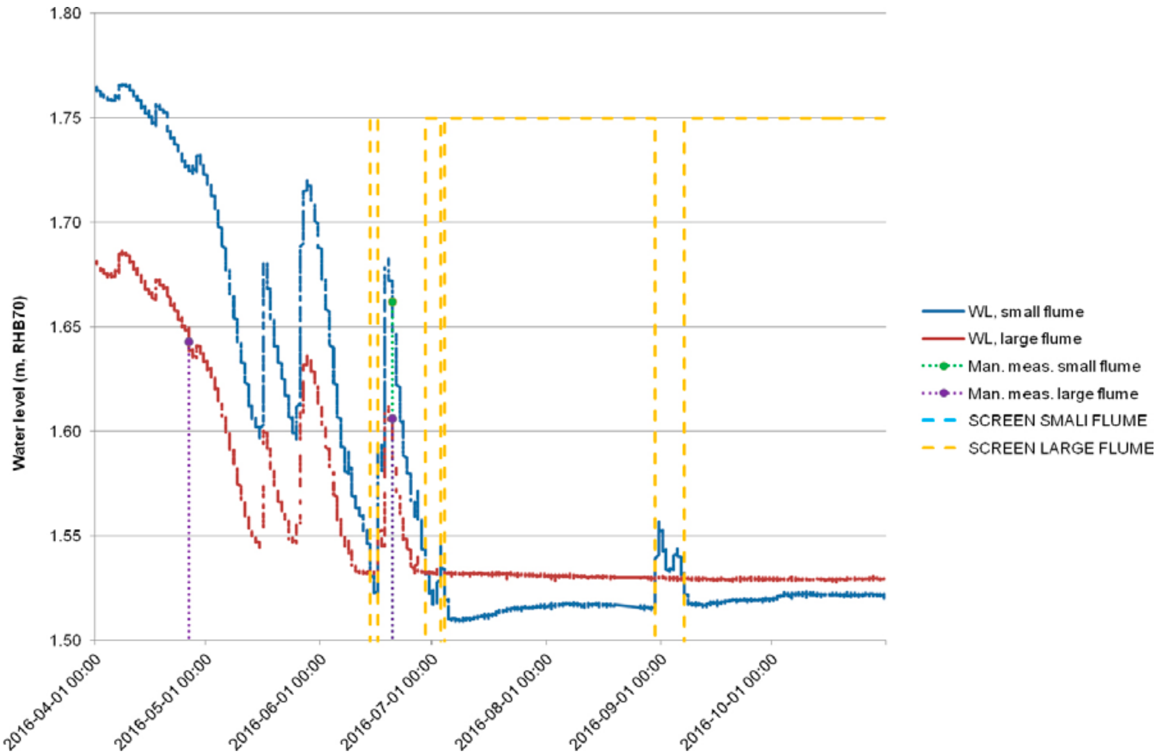


Figure A2-4. *Water-level time series for the flumes at gauging station PFM002667 for the period Apr. 1–Oct. 31, 2016.*

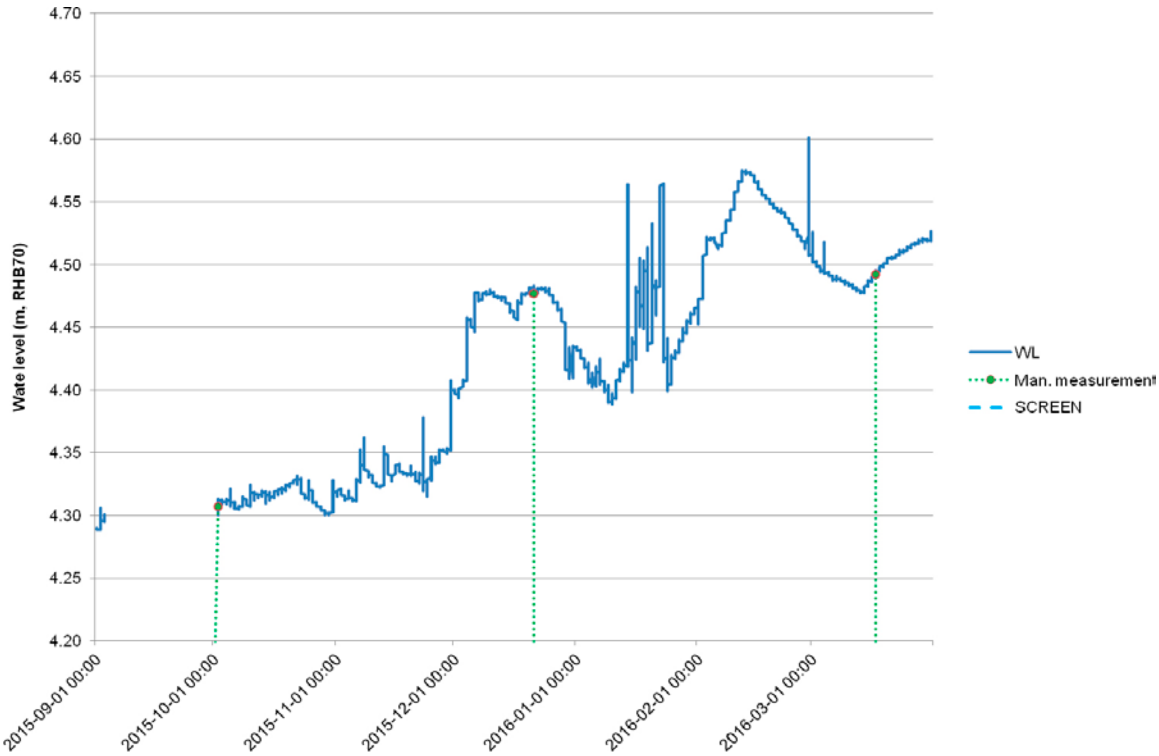


Figure A2-5. *Water-level time series for the flume at gauging station PFM002668 for the period Sep. 1, 2015–Mar. 31, 2016.*

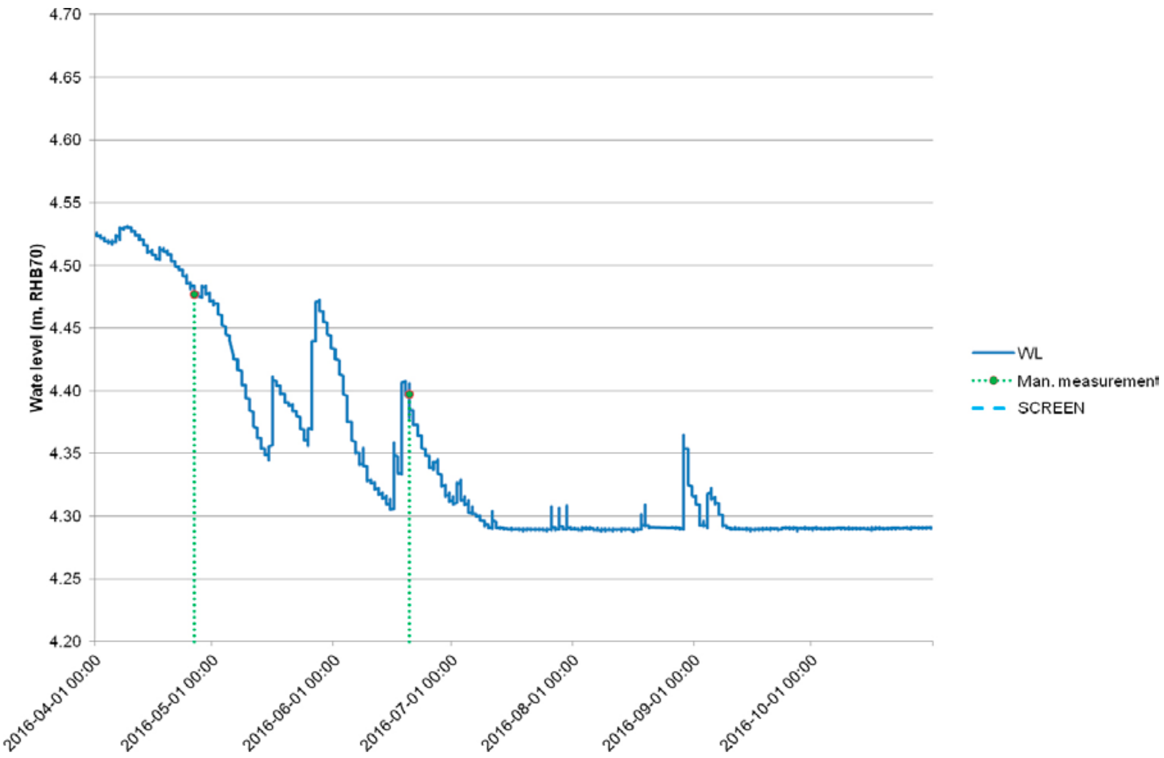


***Figure A2-6.** Water-level time series for the flume at gauging station PFM002668 for the period Apr. 1–Oct. 31, 2016.*

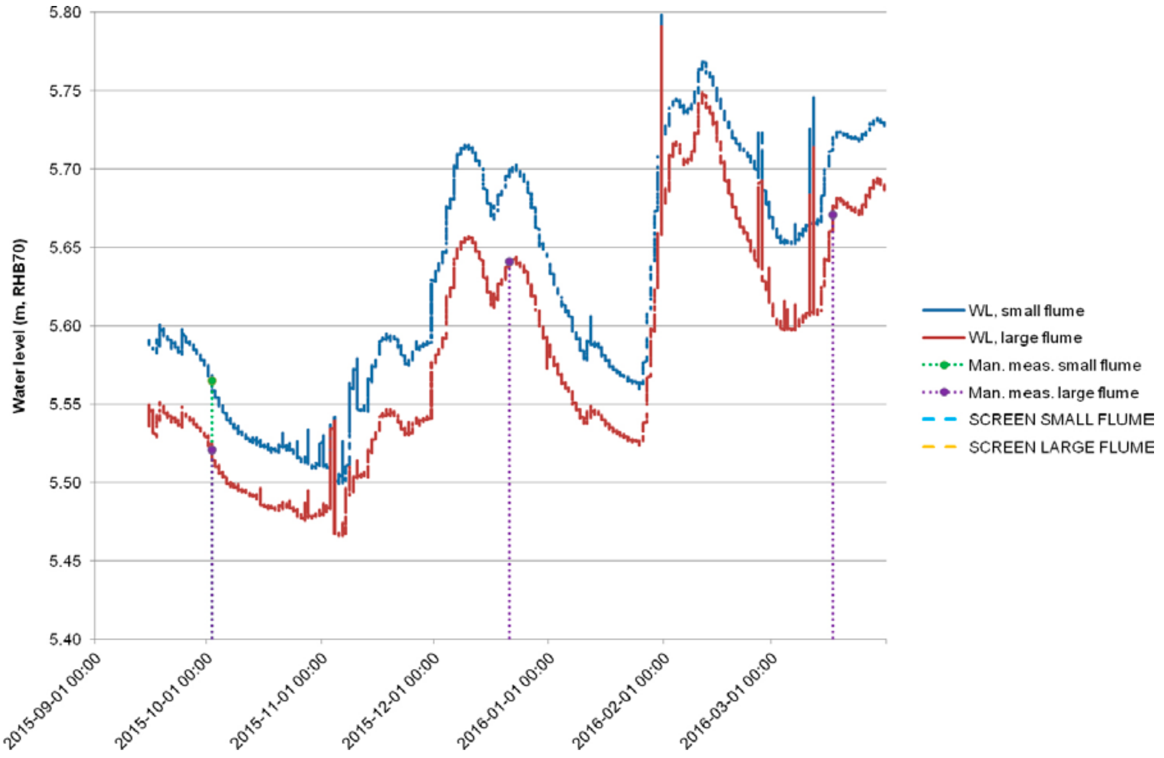


***Figure A2-7.** Water-level time series for the flumes at gauging station PFM002669 for the period Sep. 1, 2015–Mar. 31, 2016.*

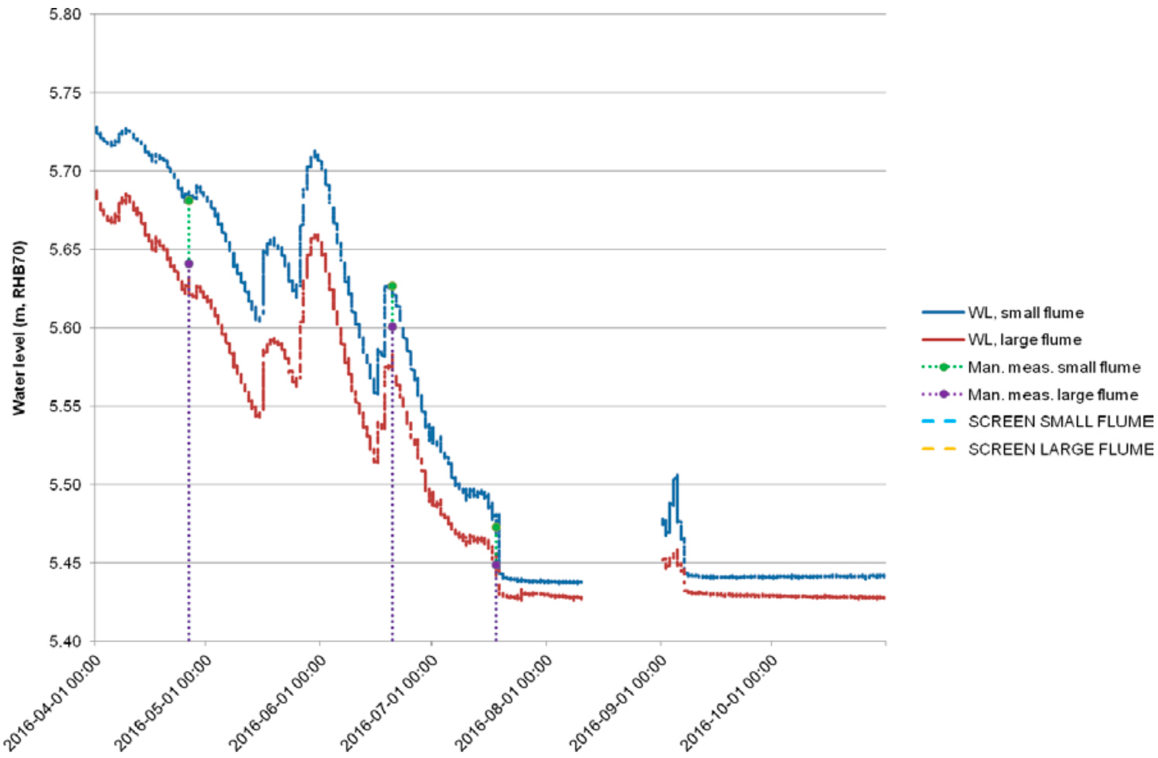


Figure A2-8. *Water-level time series for the flumes at gauging station PFM002669 for the period Apr. 1–Oct. 31, 2016.*

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, 2015–September 30, 2016. Hourly averages are calculated without the data periods excluded as a result of the regular quality control and the quality control of the 2015/2016 water-level dataset (Appendix 2).

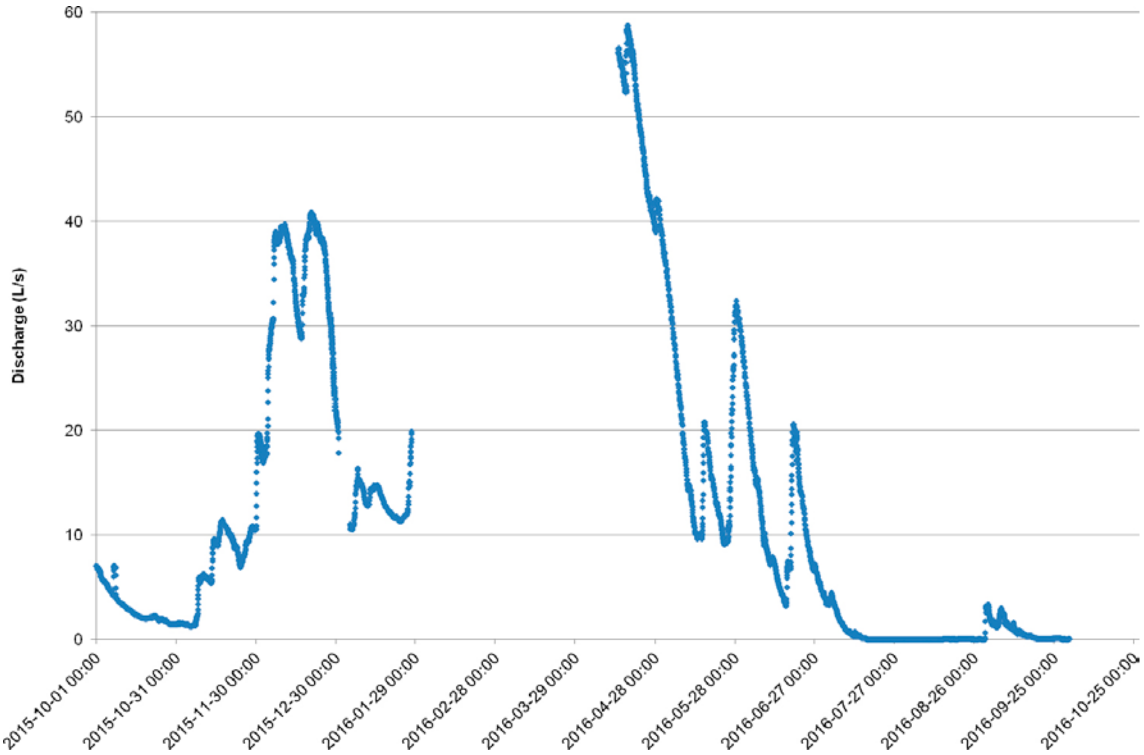


Figure A3-1. *Hourly average stream discharge at gauging station PFM005764 for the period Oct. 1, 2015–Sep. 30, 2016.*

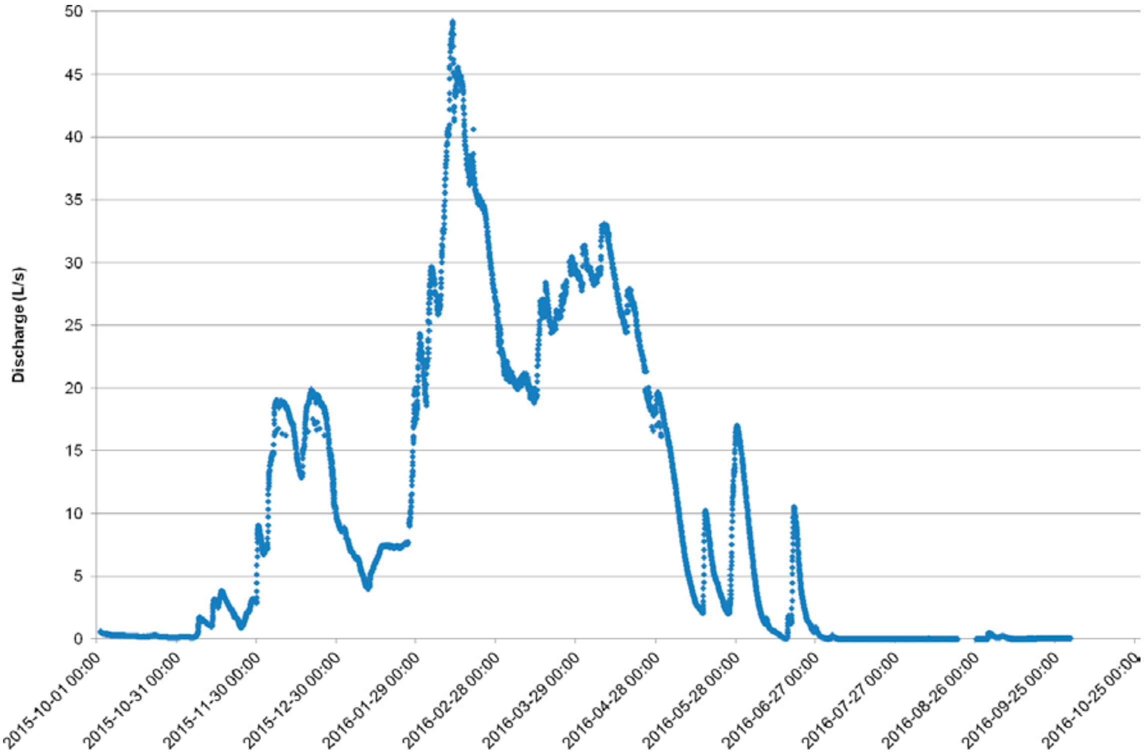


Figure A3-2. *Hourly average stream discharge at gauging station PFM002667 for the period Oct. 1, 2015–Sep. 30, 2016.*

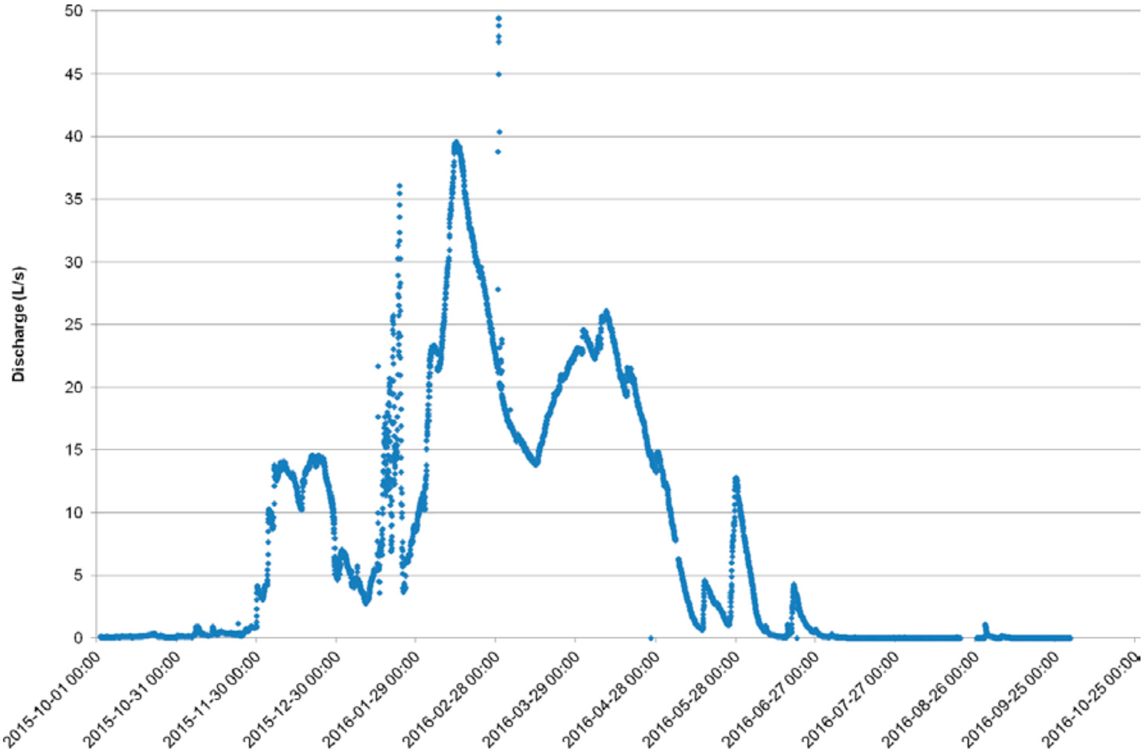


Figure A3-3. *Hourly average stream discharge at gauging station PFM002668 for the period Oct. 1, 2015–Sep. 30, 2016.*

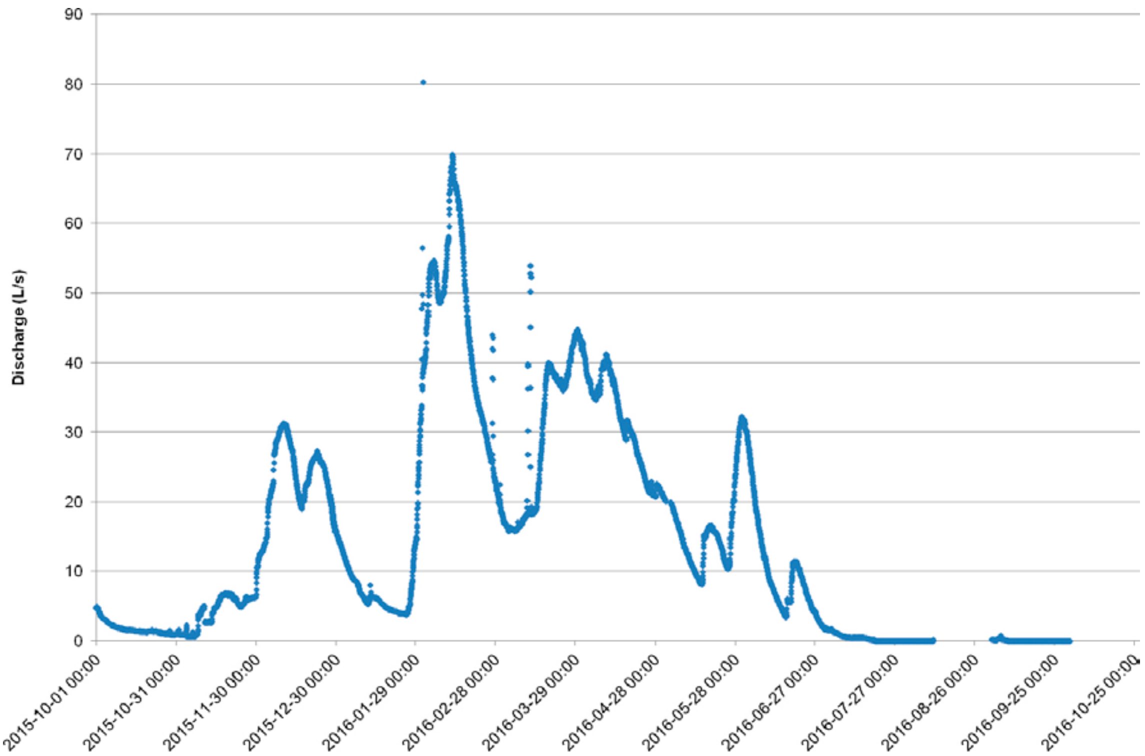


***Figure A3-4.** Hourly average stream discharge at gauging station PFM002669 for the period Oct. 1, 2015–Sep. 30, 2016.*

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, 2015–October 31, 2016. The plots also show manually measured EC values and data periods excluded (SCREEN) as a result of the quality control of the 2015/2016 EC dataset. Note that EC values for September 2015 and October 2016 are shown for reference only.

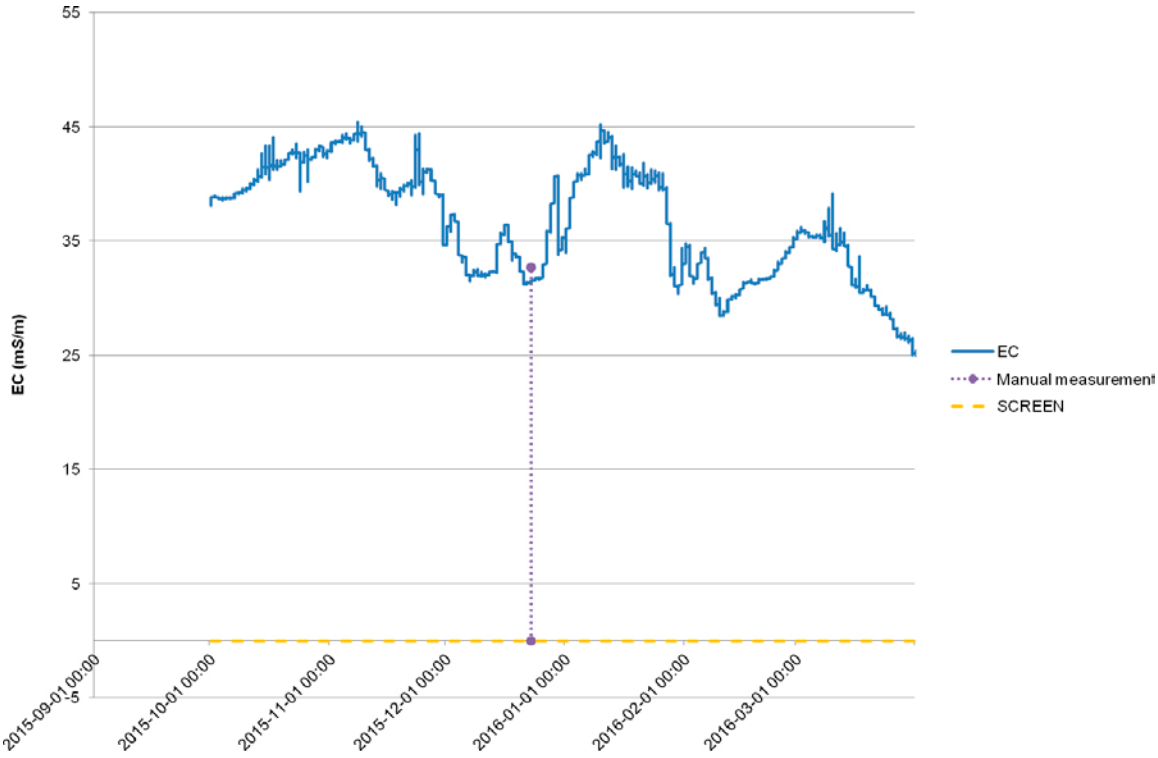


Figure A4-1. *EC time series for gauging station PFM005764 for the period Sep. 1, 2015–Mar. 31, 2016.*

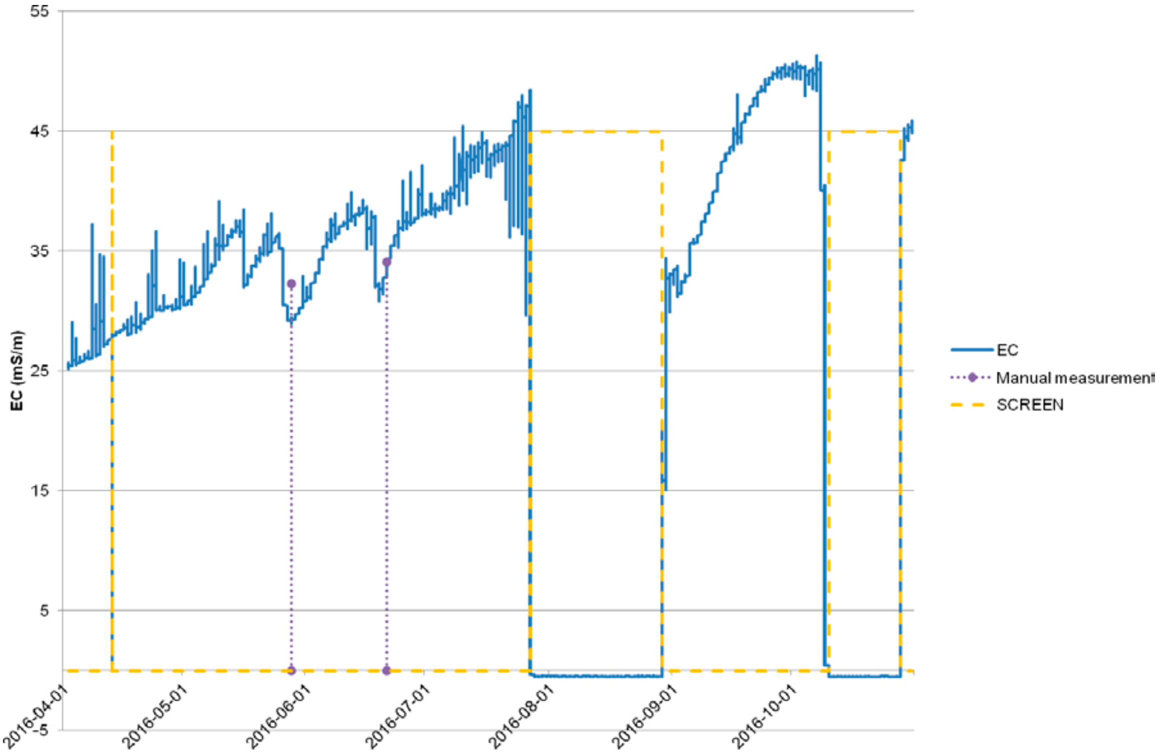


***Figure A4-2.** EC time series for gauging station PFM005764 for the period Apr. 1–Oct. 31, 2016.*

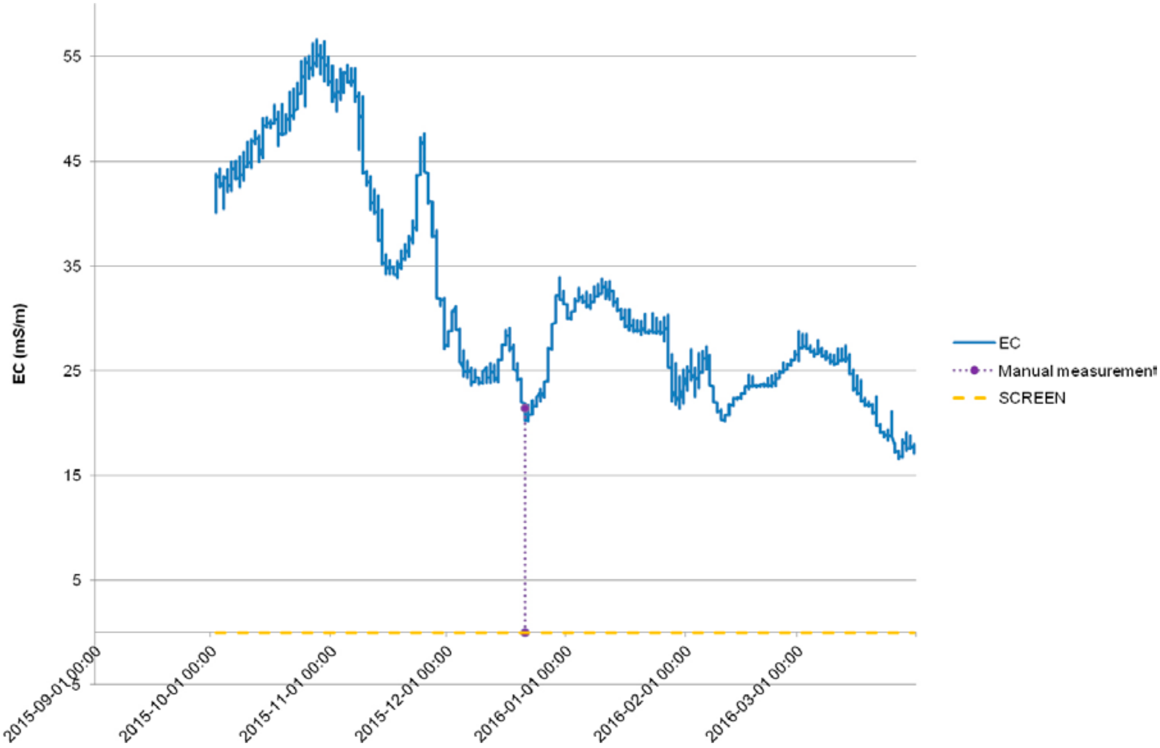


***Figure A4-3.** EC time series for gauging station PFM002667 for the period Sep. 1, 2015–Mar. 31, 2016.*

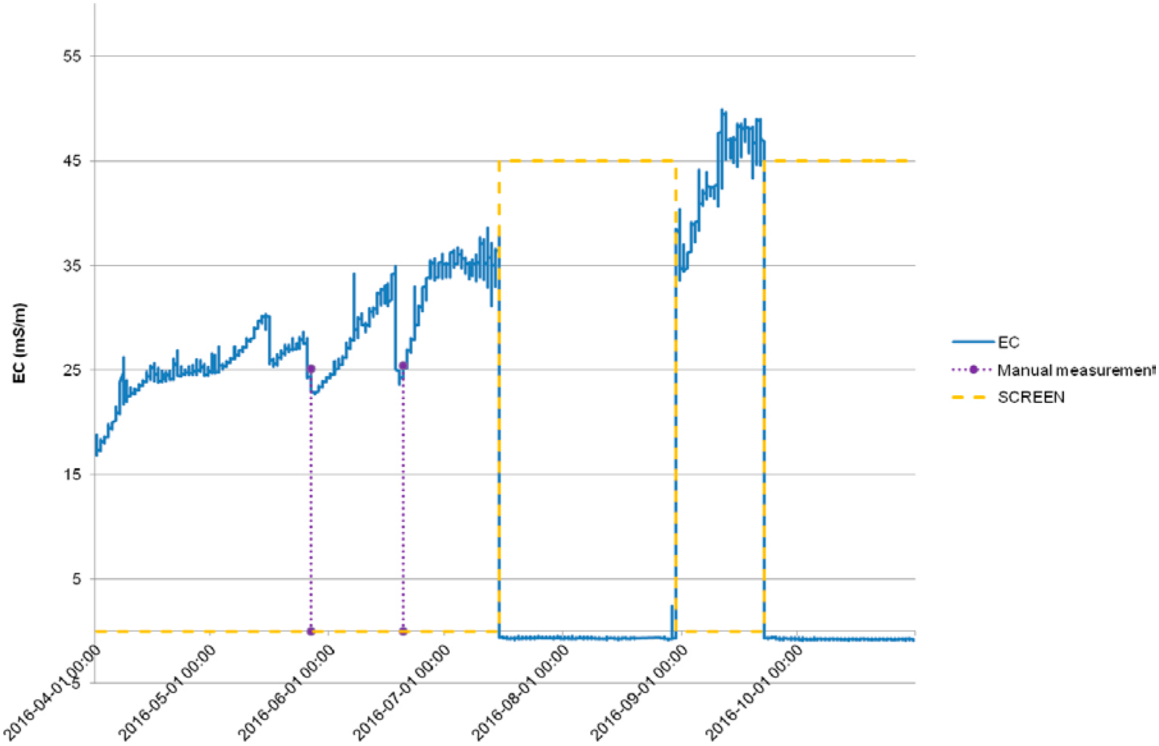


Figure A4-4. *EC time series for gauging station PFM002667 for the period Apr. 1–Oct. 31, 2016.*

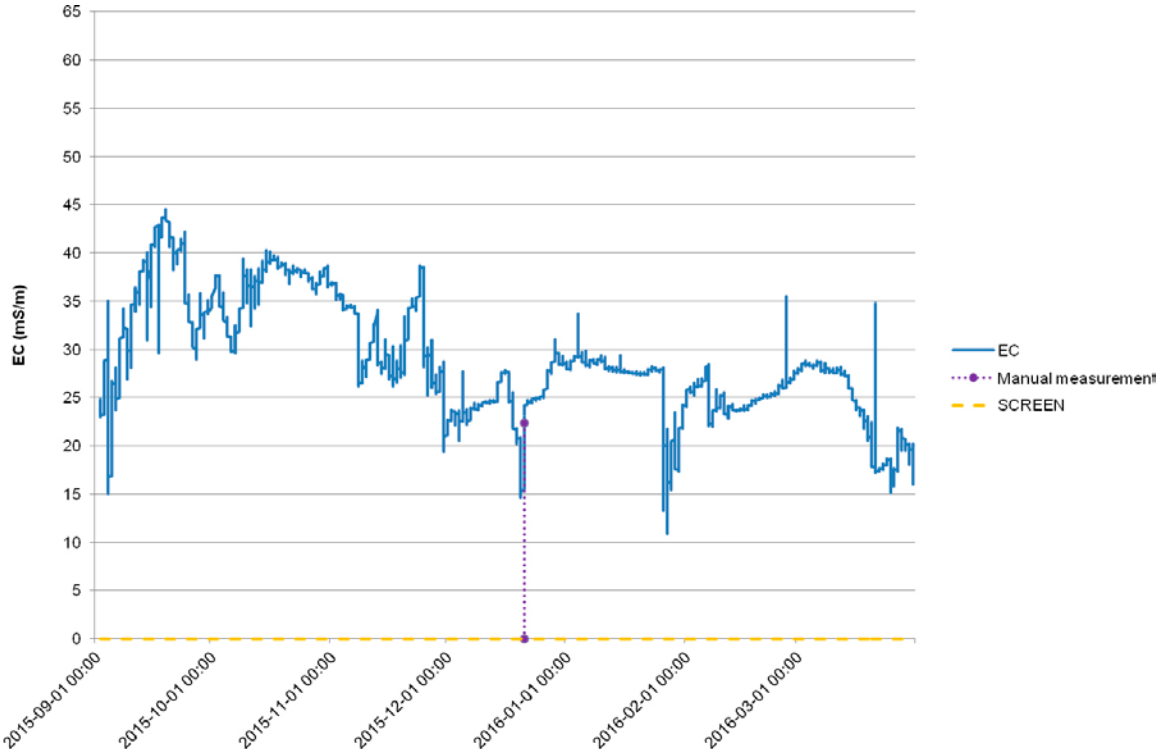


Figure A4-5. *EC time series for gauging station PFM002668 for the period Sep. 1, 2015–Mar. 31, 2016.*

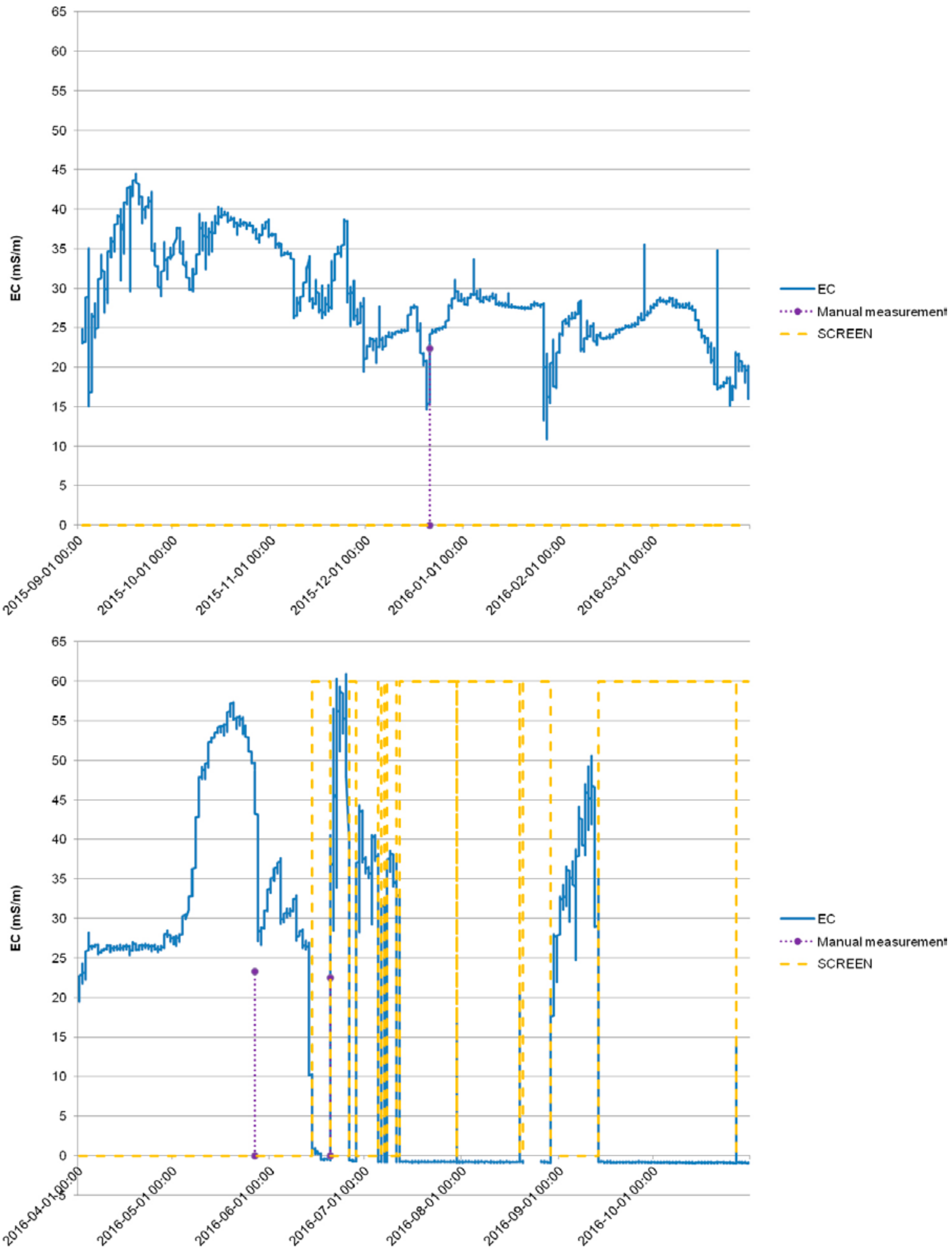


***Figure A4-6.** EC time series for gauging station PFM002668 for the period Apr. 1–Oct. 31, 2016.*

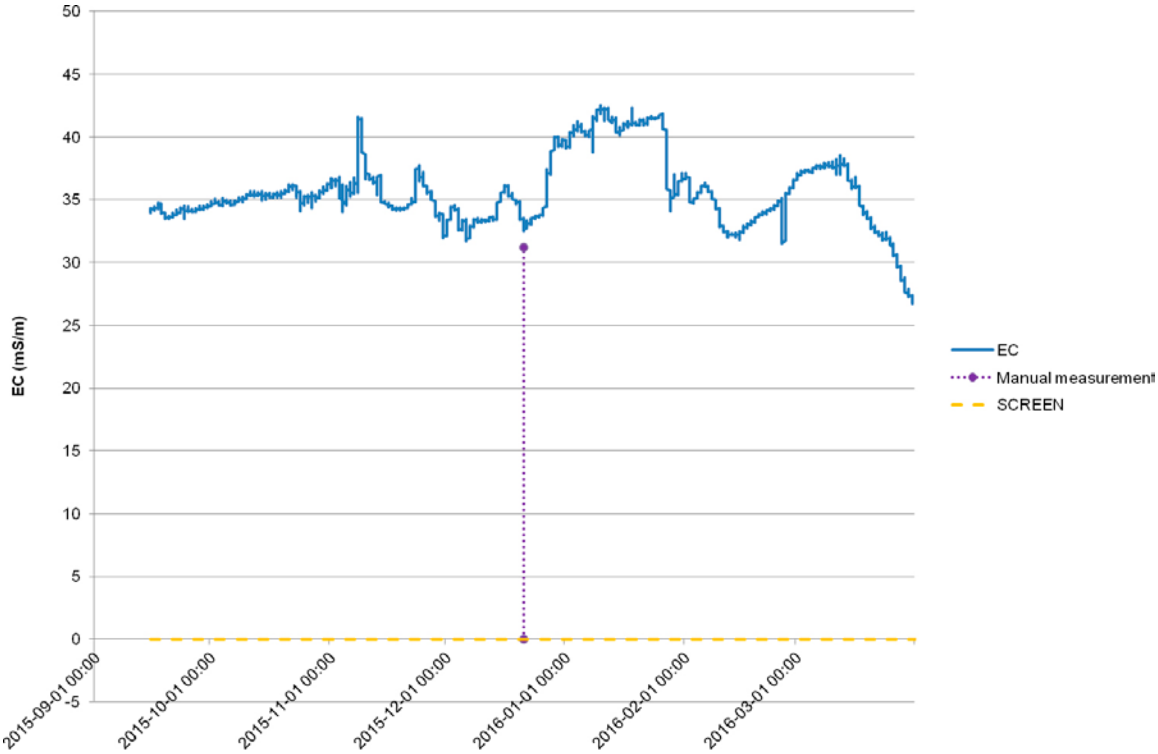


Figure A4-7. *EC time series for gauging station PFM002669 for the period Sep. 1, 2015–Mar. 31, 2016.*

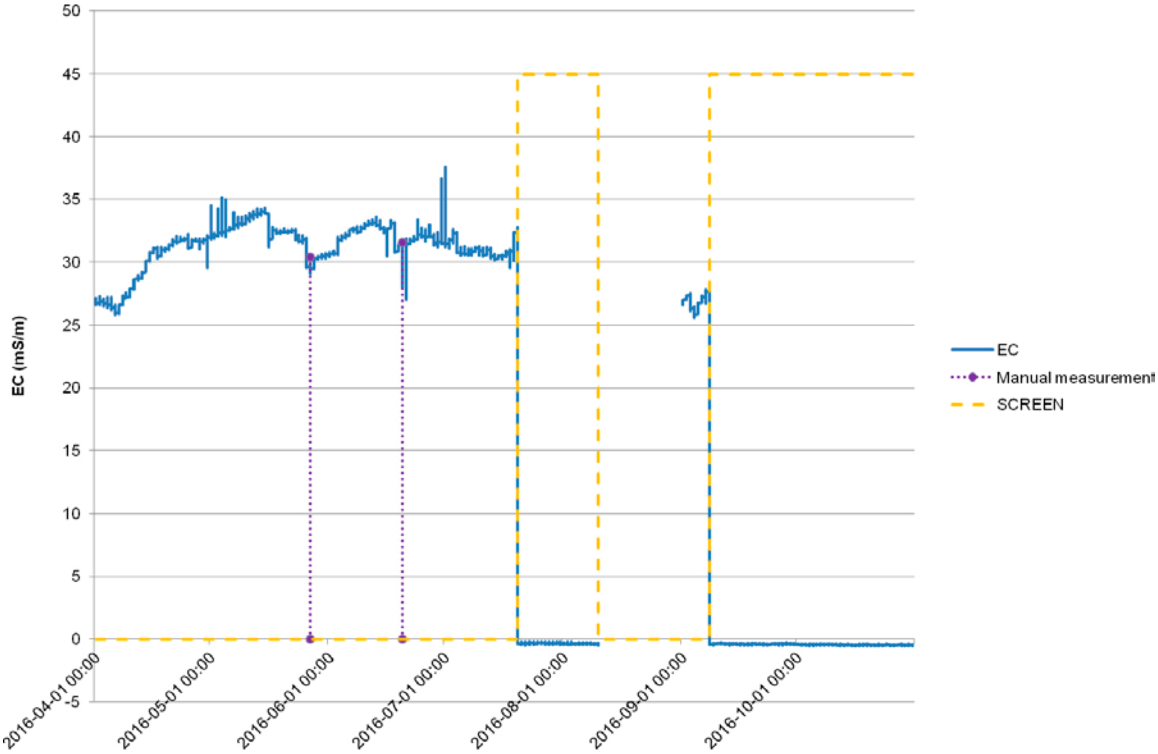


Figure A4-8. *EC time series for gauging station PFM002669 for the period Apr. 1–Oct. 31, 2016.*

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, 2015–October 31, 2016. The plots also show manually measured temperature values and data periods excluded (SCREEN) as a result of the quality control of the 2015/2016 temperature dataset. Note that temperature values for September 2015 and October 2016 are shown for reference only.

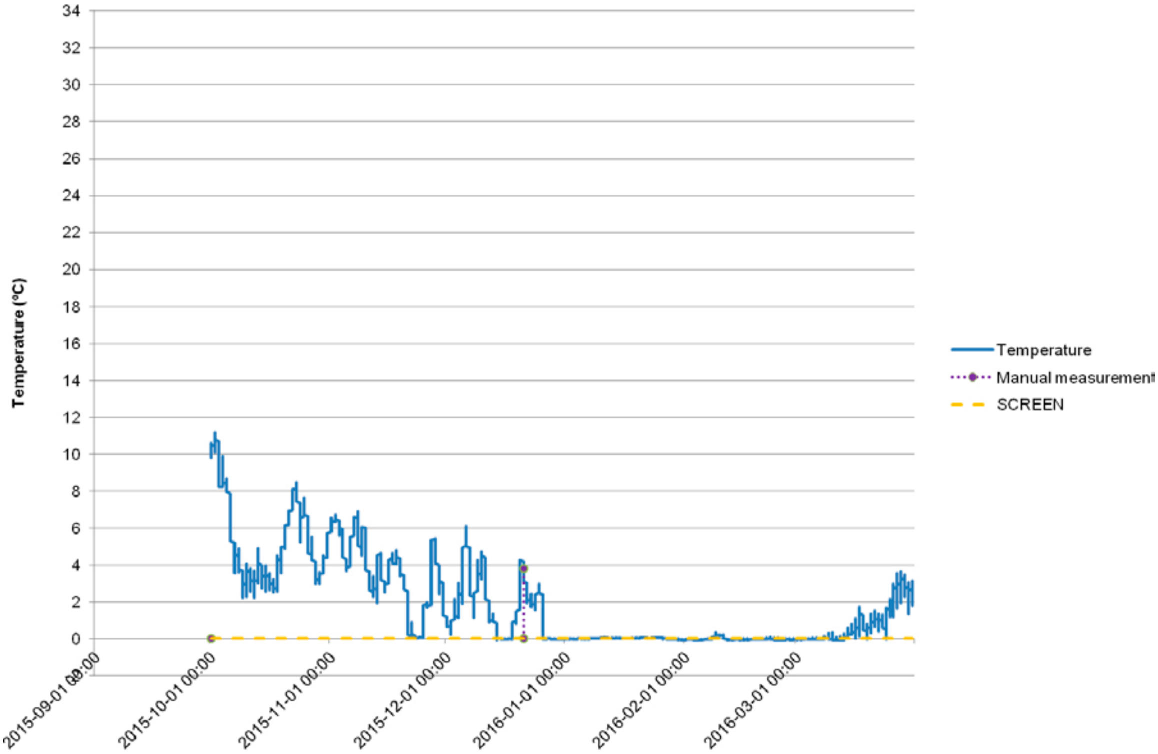


Figure A5-1. *Temperature time series for gauging station PFM005764 for the period Sep. 1, 2015–Mar. 31, 2016.*

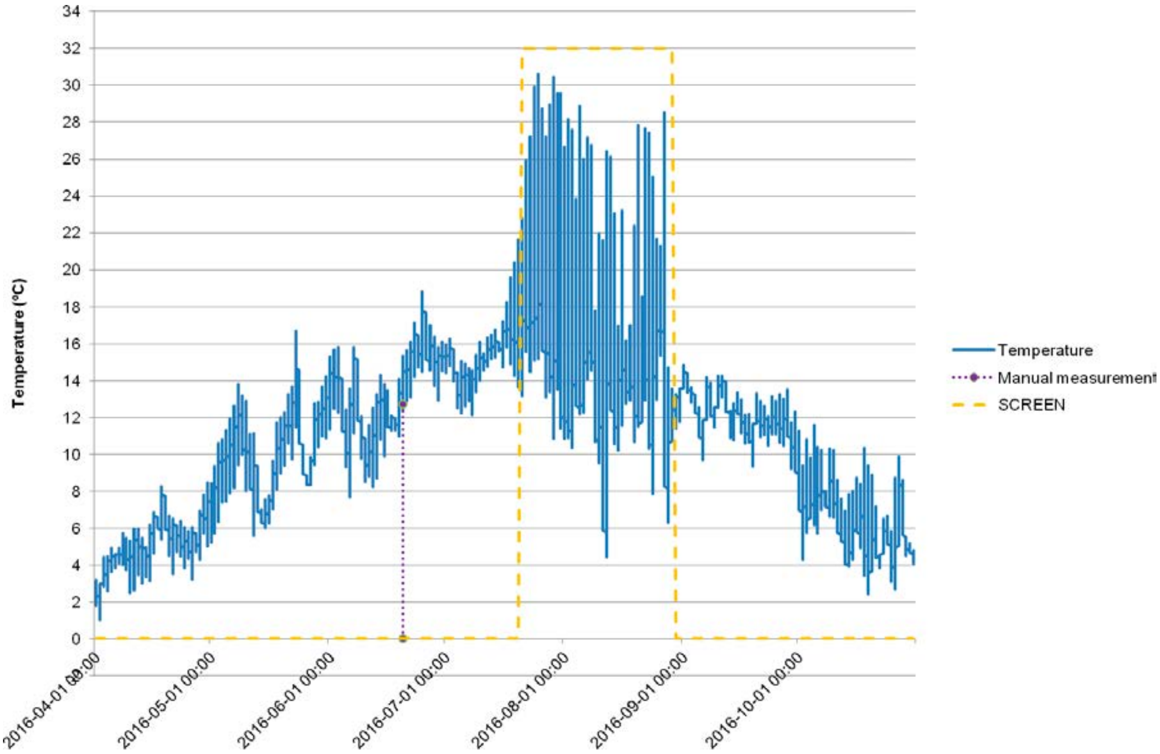


Figure A5-2. *Temperature time series for gauging station PFM005764 for the period Apr. 1–Oct. 31, 2016.*

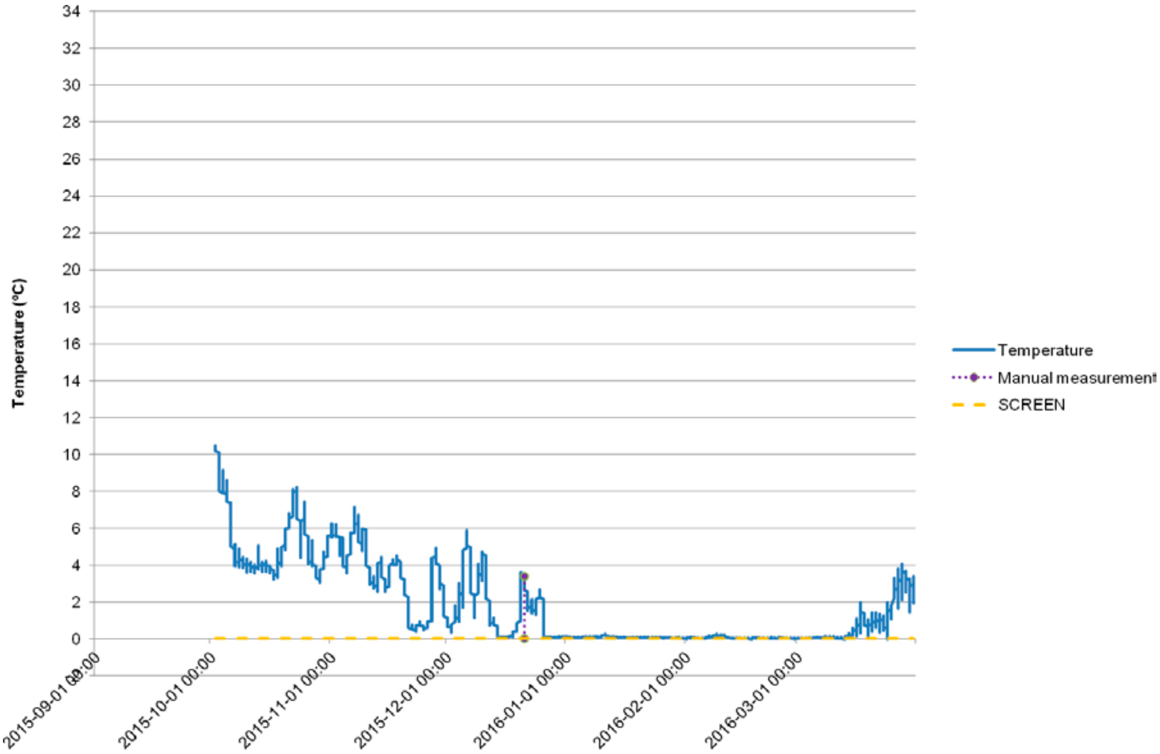


Figure A5-3. *Temperature time series for gauging station PFM002667 for the period Sep. 1, 2015–Mar. 31, 2016.*

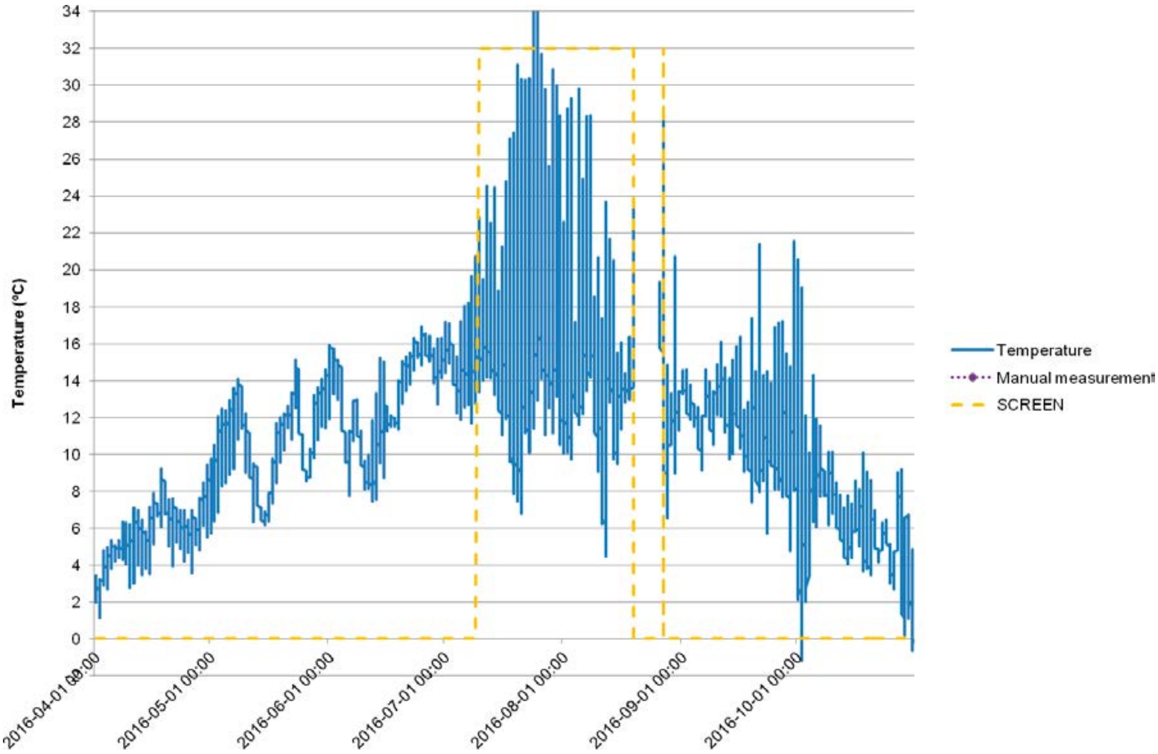


***Figure A5-4.** Temperature time series for gauging station PFM002667 for the period Apr. 1–Oct. 31, 2016.*

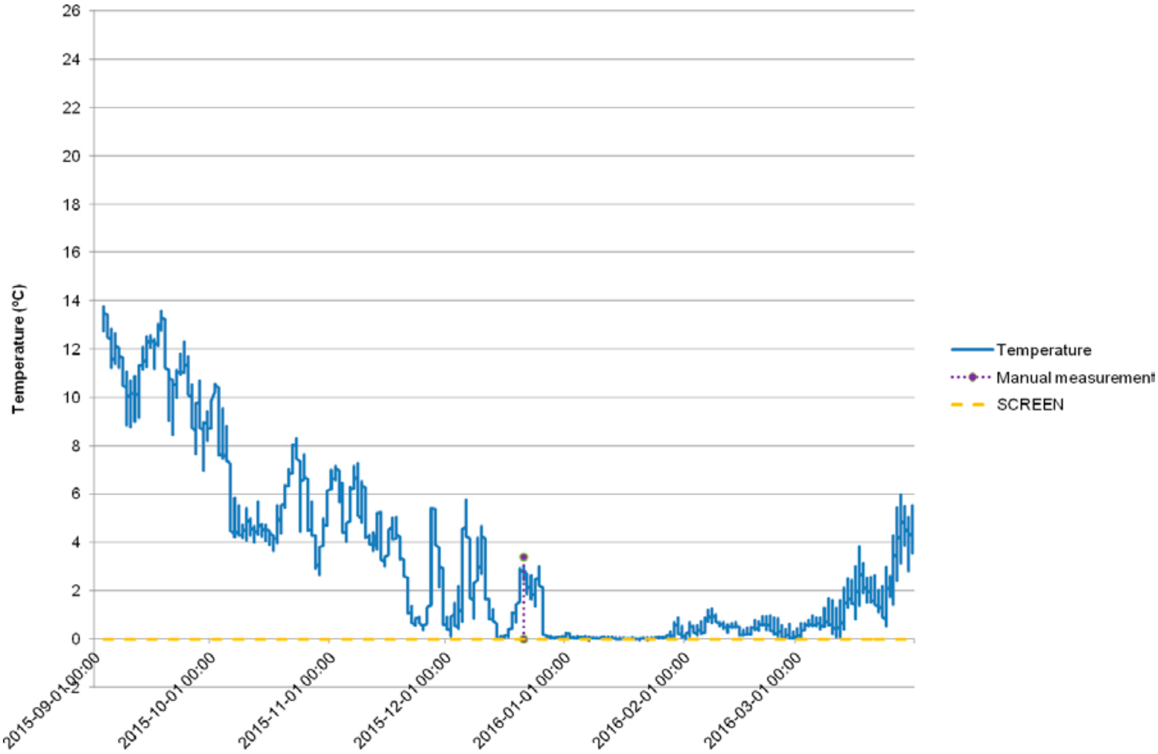


***Figure A5-5.** Temperature time series for gauging station PFM002668 for the period Sep. 1, 2015–Mar. 31, 2016.*

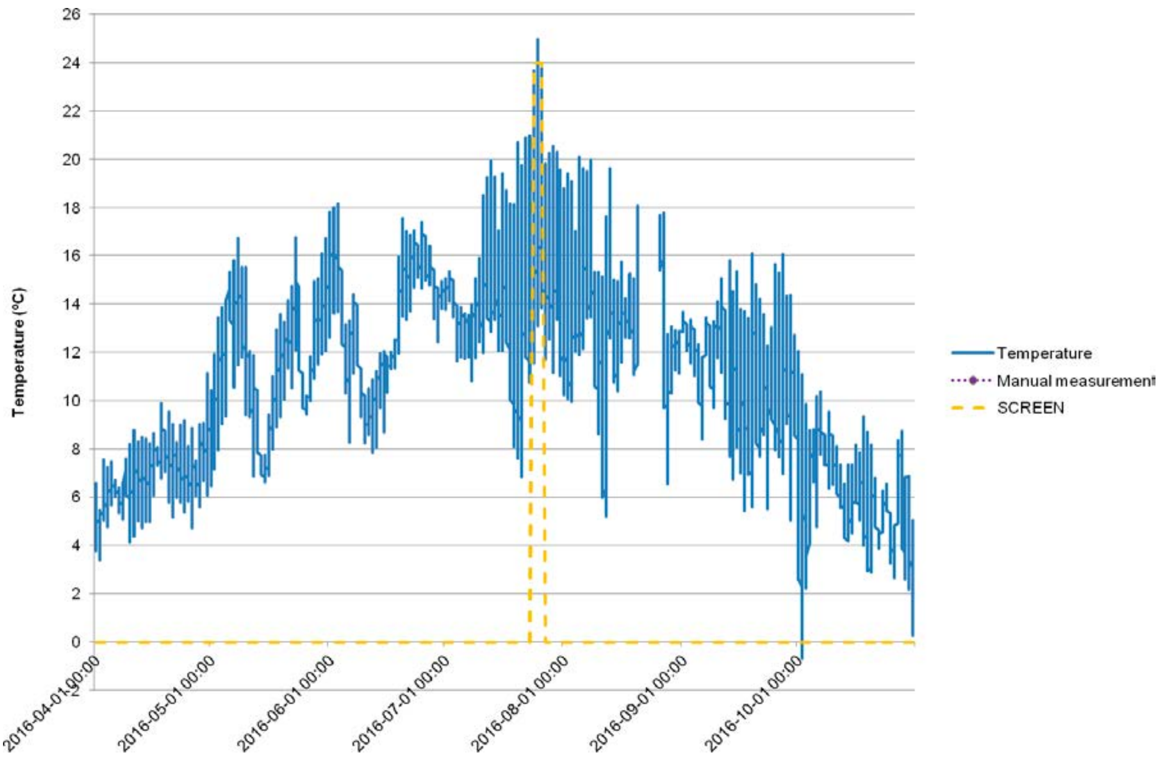


Figure A5-6. *Temperature time series for gauging station PFM002668 for the period Apr. 1–Oct. 31, 2016.*

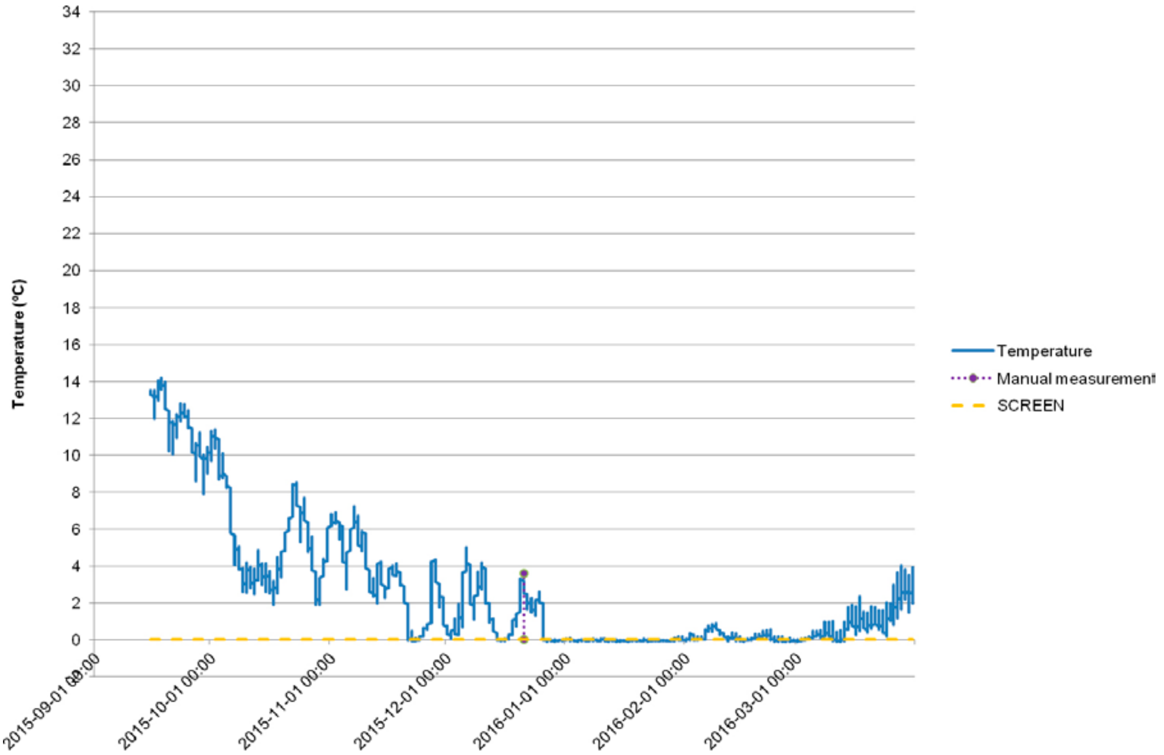


Figure A5-7. *Temperature time series for gauging station PFM002669 for the period Sep. 1, 2015–Mar. 31, 2016.*

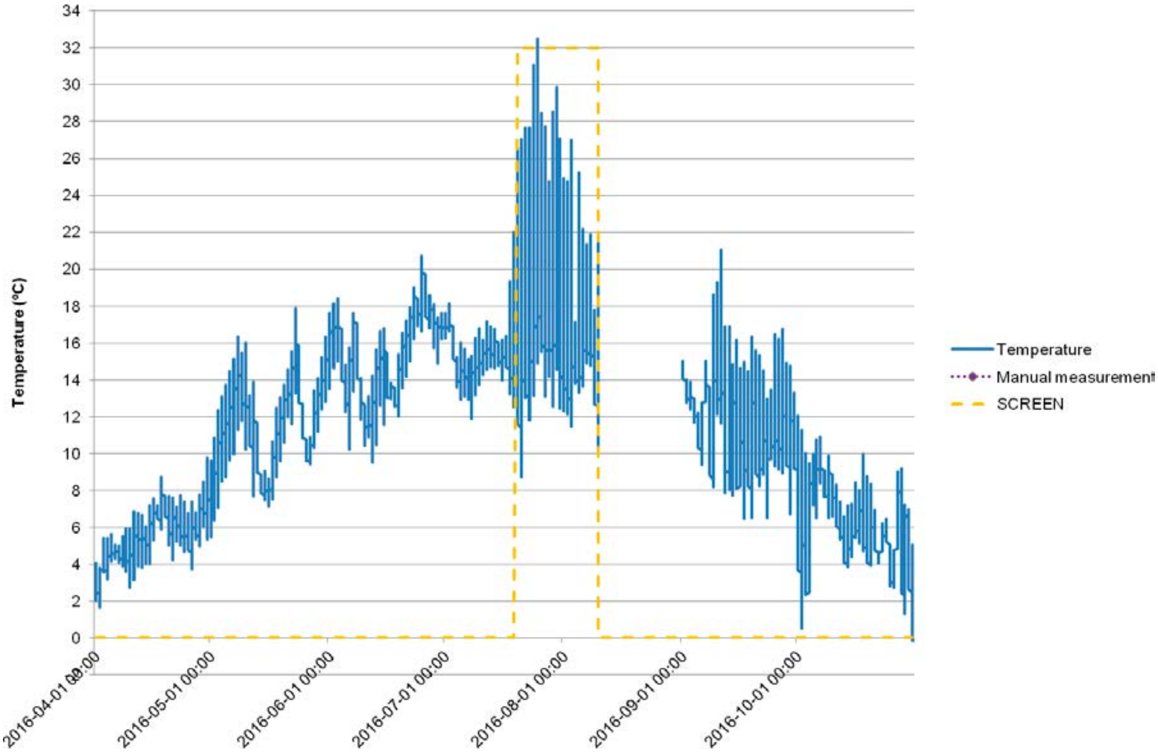


Figure A5-8. *Temperature time series for gauging station PFM002669 for the period Apr. 1–Oct. 31, 2016.*

Appendix 6

Hydrograph comparisons

Figures A6-1 to A6-4 show co-plots of hydrographs, based on daily average discharges (Q), at gauging stations PFM005764, -2667, -2668 and -2669, respectively, and the average hydrograph based on available daily averages.

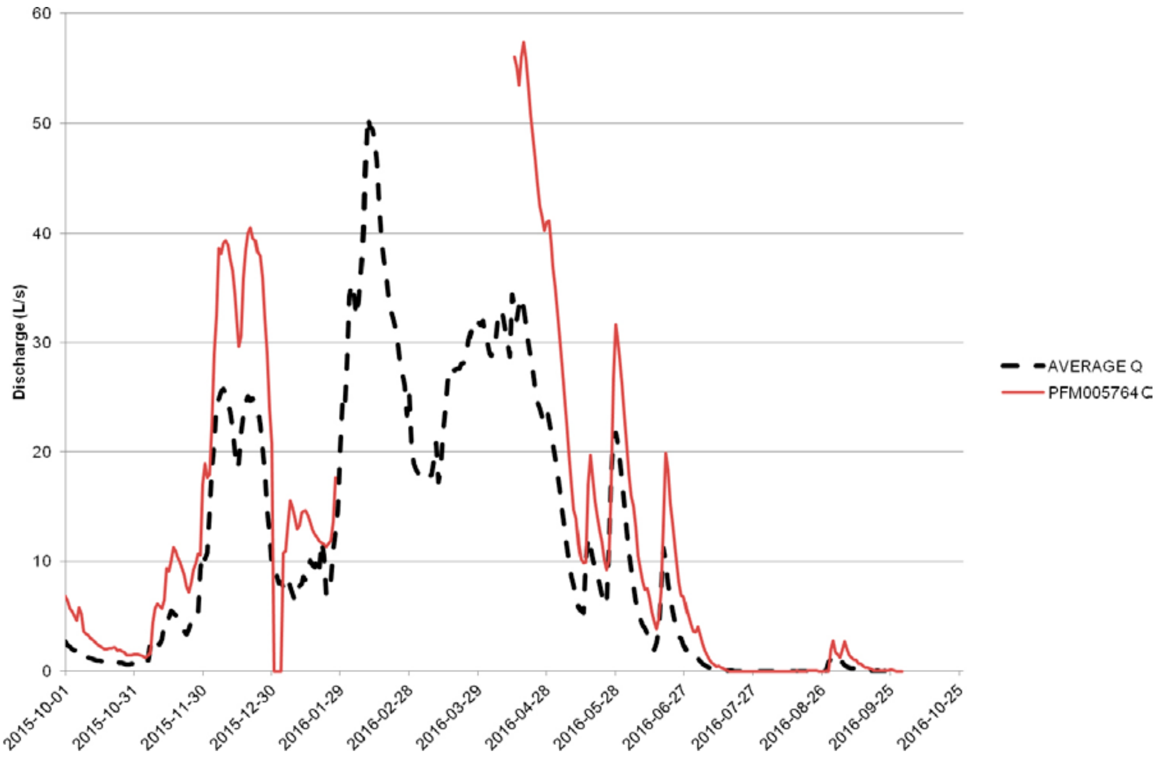


Figure A6-1. Co-plot of the PF005764 and average hydrographs.

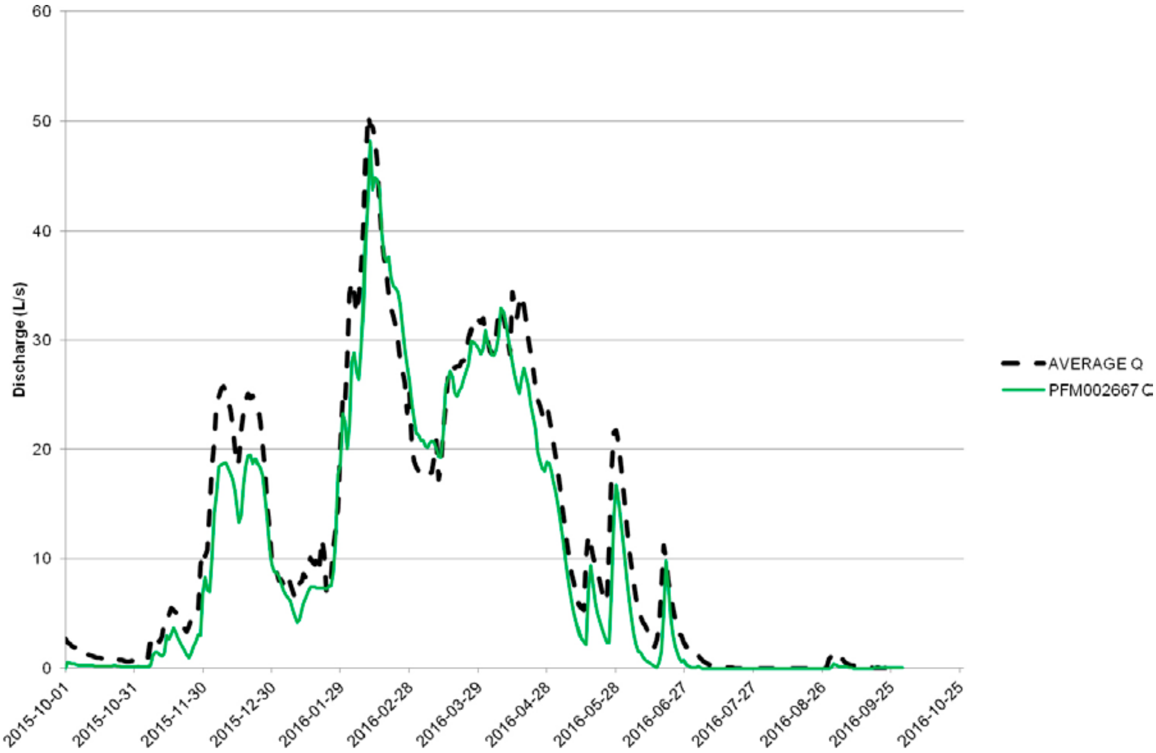


***Figure A6-2.** Co-plot of the PF002667 and average hydrographs.*

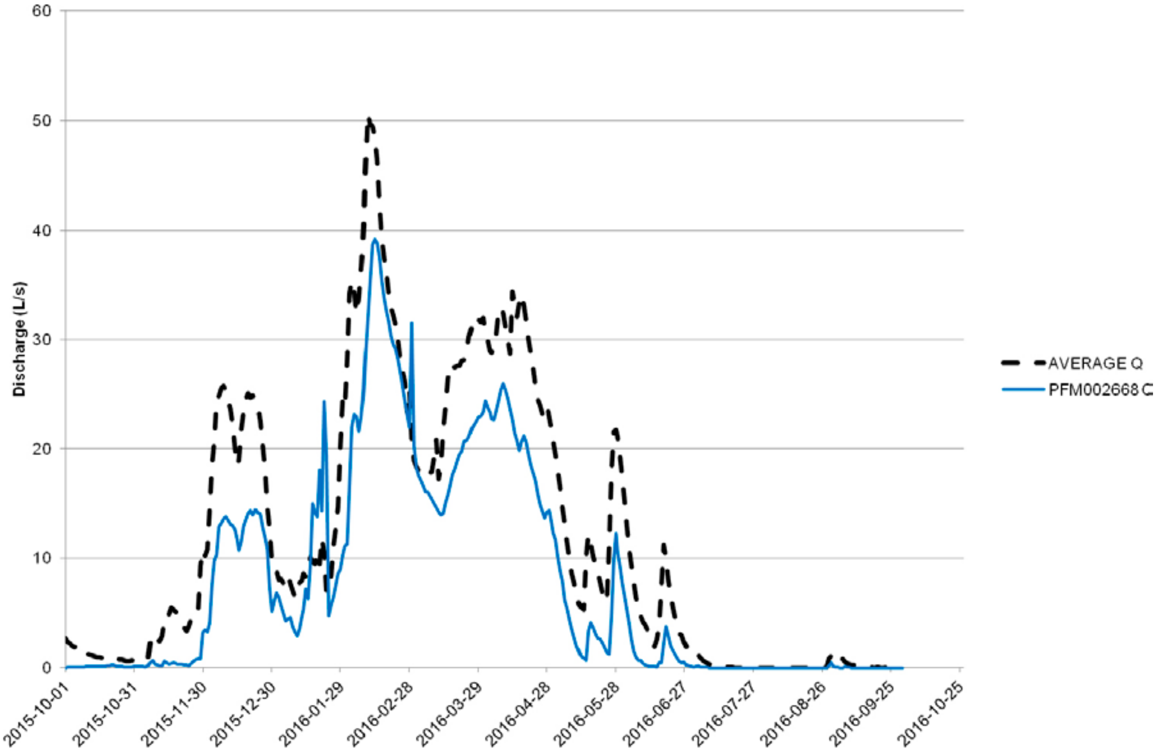


***Figure A6-3.** Co-plot of the PF002668 and average hydrographs.*

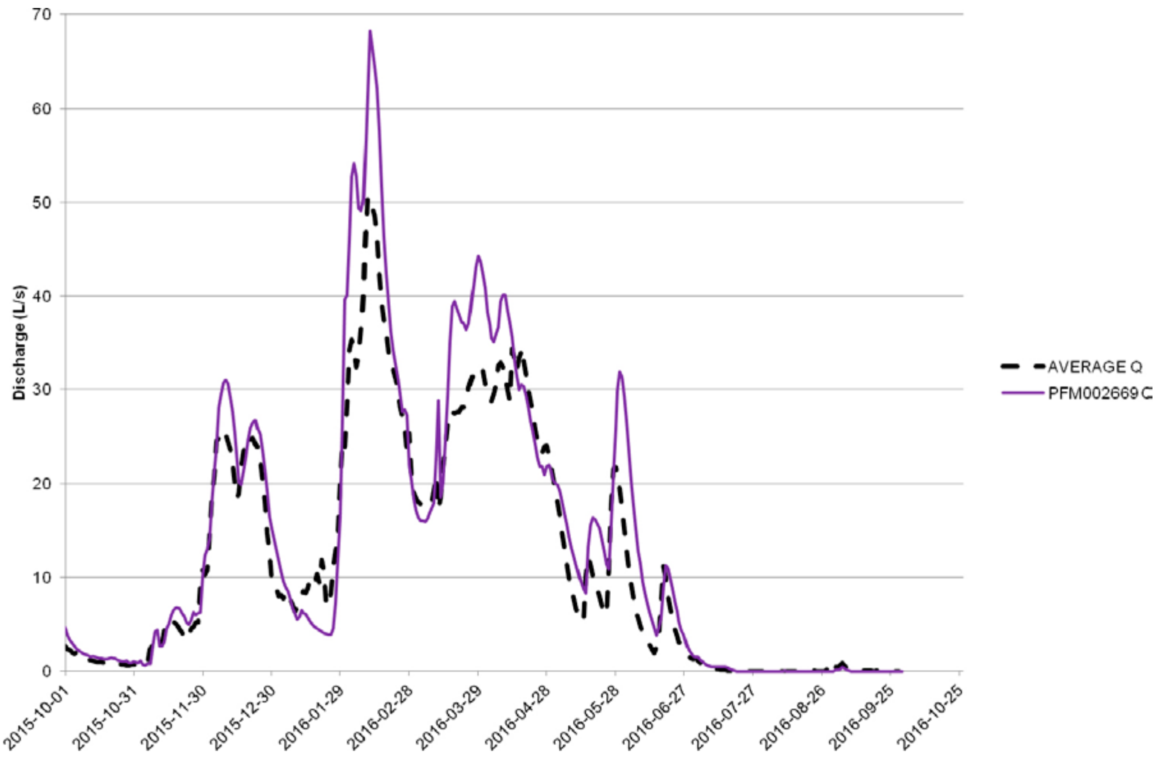


Figure A6-4. *Co-plot of the PF002669 and average hydrographs.*

Arkitektkopia AB, Bromma, 2018

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