P-11-12

Forsmark site investigation

Monitoring of brook water levels, electrical conductivities, temperatures and discharges January–December 2010

Per-Olof Johansson, Artesia Grundvattenkonsult

John Juston, Juston Konsult

June 2011

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

ISSN 1651-4416
SKB P-11-12

Forsmark site investigation

Monitoring of brook water levels, electrical conductivities, temperatures and discharges January–December 2010

Per-Olof Johansson, Artesia Grundvattenkonsult

John Juston, Juston Konsult

June 2011

Keywords: AP PF 400-09-009, Gauging stations, Long-throated flumes, Water level, Electrical conductivity, Temperature, Discharge.

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

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

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

Abstract

This document reports the monitoring of water levels, electrical conductivities, temperatures and discharges at four brook discharge gauging stations, and the monitoring of water electrical conductivity at the outlet of Lake Bolundsfjärden in the Forsmark area. The report presents data from 1 January through 31 December 2010 and is a continuation of reporting from Johansson and Juston (2007, 2009, 2011), which covered the periods from 1 April 2004 through 31 March 2007, 1 April 2007 through 31 December 2008, and 1 January through 31 December 2009, respectively.

Long-throated flumes equipped with automatically recording devices were used for the discharge measurements. Every c. 14 days the water depths at the upstream edge of the flumes were measured manually by a ruler as a check. Electrical conductivity and temperature were automatically recorded and these parameters were also measured manually every c. 14 days with the site investigation field devices.

SKB's Hydro Monitoring System (HMS) was used to collect and store all data. From HMS quality assured data were transferred to SKB's primary database Sicada. Measurements of levels, electrical conductivities and temperatures were made every 10 minutes (every 30 minutes for electrical conductivity at the outlet of Lake Bolundsfjärden).

For the calculation of discharge, quality assured water level data from the flumes were used. The calculation procedure included consolidation of the time series to hourly averages, screening of data for removal of short-term spikes, noise and other data that were judged erroneous. After the calculations were performed, the results were delivered to Sicada.

The amplitudes of water level variations during this reporting period were 0.41–0.55 m and the mean electrical conductivities varied between 23 and 39 mS/m at the four discharge stations. However, due to mal-function of measuring devices for electrical conductivity, data were missing for relatively long time periods. Due to large deviations between the automatic registrations and the manual measurements of electrical conductivity at the outlet of Lake Bolundsfjärden, no data from the automatic registration were accepted at the quality control, and no data were reported to Sicada from this station. The water temperatures varied between c. zero during winter up to c. 20°C during hot summer days with low discharge.

The highest recorded discharge of the largest catchment (gauging station PFM005764) during 2010 was 321 L/s and for the smallest catchment 101 L/s (gauging station PFM002668). All stations had periods of zero discharge during July–August. The specific discharge for the largest catchment was 6.53 L/s/km^2 (206 mm/yr) which is considerably higher than the estimated longterm average of 150–160 mm/yr. The specific discharge for the largest catchment, averaged over the six-year period 2005–2010 was 5.93 L/s/km^2 (187 mm/yr). The station with the lowest specific discharge during 2010 was PFM002667; 5.66 L/s/km^2 (178 mm/yr).

Sammanfattning

I föreliggande rapport redovisas mätningar av vattennivå, elektrisk konduktivitet, temperatur och vattenföring i fyra bäckar i Forsmarksområdet samt mätningar av elektrisk konduktivitet i Bolundsfjärdens utlopp. Rapporten presenterar data från perioden 2010-01-01–2010-12-31. Tidigare mätningar, från perioderna 2004-04-04–2007-03-31, 2007-04-01–2008-12-31 och 2009-01-01–2009-12-31 redovisades i Johansson och Juston (2007, 2009, 2011).

Mätrännor, av typen "long-throated flumes" med utrustning för automatisk registrering av vattennivåer, användes för vattenföringsmätningarna. Ungefär var 14:e dag kontrollerades vattendjupet manuellt med tumstock i uppströmskanten av rännorna. Elektrisk konduktivitet och temperatur registrerades automatiskt, och dessa parametrar mättes också manuellt ungefär var 14:e dag med platsundersökningens fältmätningsinstrument.

SKB:s Hydro Monitoring System (HMS) användes för insamling och lagring av data. Från HMS överfördes kvalitetssäkrade data till SKB:s primärdatabas Sicada. Mätningar av nivåer, elektrisk konduktivitet och temperatur gjordes var 10:e minut (var 30:e minut för elektriska ledningsförmågan i Bolundsfjärdens utlopp).

För beräkningarna av vattenföringen användes kvalitetssäkrade vattennivådata. Beräkningarna baserades på timmedelvärden. Kortvariga flödesspikar, brus och andra data som bedömdes som felaktiga togs bort innan beräkningarna genomfördes.

Vattennivåvariationerna i de enskilda stationerna var mellan 0,41 och 0,55 m. Medelvärdena för den elektriska ledningsförmågan i de fyra stationerna varierade mellan 23 och 39 mS/m. Funktionen hos den utrustning som använts för att mäta den elektriska konduktiviteten har emellertid tidvis varit otillfredsställande varför data saknas för relativt långa perioder. Vad gäller mätningarna av elektrisk konduktivitet i Bolundsfjärdens utlopp konstaterades stora avvikelser mellan de manuella mätningarna och de som registrerades automatiskt. Detta medförde att inga data godkändes vid kvalitetskontrollen från denna mätpunkt och därmed rapporterades inga data till Sicada. Vattentemperaturerna varierade från cirka 0 °C under vintern upp till cirka 20 °C under varma sommardagar med låga vattenflöden.

Den högsta uppmätta vattenföringen för det största avrinningsområdet (mätstation PFM005764) var 321 L/s och för det minsta 101 L/s (mätstation PFM002668). Alla stationer hade perioder med 0-flöde under juli–augusti. Den specifika avrinningen för det största avrinningsområdet var 6,53 L/s/km^2 (206 mm/år) vilket är avsevärt högre än det uppskattade långtidsmedelvärdet av 150–160 mm/år. Den specifika avrinningen för det största avrinningsområdet för femårsperioden 2005–2010 var 5,93 L/s/km^2 (187 mm/år). Mätstationen med lägst specifik avrinning under 2010 var PFM002667; 5,66 L/s/km^2 (178 mm/år).

Contents

1 Introduction

This document reports the monitoring of water levels, water electrical conductivities, temperatures and discharges at four brook discharge gauging stations, and the monitoring of water electrical conductivity at one additional location for the period of 1 January through 31 December 2010. The report presents continuations of time series data reported in P-07-135 (Johansson and Juston 2007), P-09-68 (Johansson and Juston 2009), and P-10-44 (Johansson and Juston 2011). The monitoring is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-09-009. Controlling documents for performing the activity are listed in Table 1-1. Both the activity plan and the method description are SKB's internal controlling documents. Site investigation internal reports (PIR-reports) present the results from the quality check performed once every four months, see Section 4.4.

There are no major water courses within the central part of the Forsmark site investigation area. However, a number of brooks are draining the area. Some of these carry water most of the year, while the smaller brooks are dry for long periods.

Four permanent automatic discharge gauging stations were installed in the largest brooks as a basis for water balance calculations and for calculation of mass transport of different elements. The first permanent gauging station was installed in November 2003 and measurements started in March 2004. Due to damming problems at high discharges, a reinstallation of this station was made in October 2004. In October 2004 also the three other gauging stations were installed, and measurements in these started in December 2004. A detailed description of the gauging stations is presented in Johansson (2005). The station for monitoring of water electrical conductivity located at the outlet of Lake Bolundsfjärden was installed in December 2004 when also the measurements started. The locations of the monitoring stations are shown in Figure 1-1, and the id-codes and sizes of catchment areas associated to the discharge gauging stations are presented in Table 1-2.

SKB's Hydro Monitoring System (HMS) was used to collect and store all data. From HMS quality assured data were transferred to SKB's primary database Sicada, where they are traceable by the Activity Plan number. 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. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major data revisions entail a revision of the P-report. Minor data revisions are normally presented as supplements, available at www.skb.se.

Table 1-1. Controlling documents for performance of the activity.

Activity plan	Number	Version
Platsprojekt Forsmark – Hydrologisk och hydrogeologisk monitering 2010	AP PF 400-09-009	1.0
Method description	**Number**	
Ythydrologiska mätningar	SKB MD 364.008	1.0
Site investigation Internal Report (in Swedish)	**Number**	
Platsprojekt Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: sep 2009–feb 2010	SKBdoc id 1292882	1.0
Platsprojekt Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: feb–jun 2010	SKBdoc id 1292890	1.0
Platsprojekt Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: jun–sep 2010	SKBdoc id 1292892	1.0
Platsprojekt Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: sep 2010–jan 2011	SKBdoc id 1292893	1.0

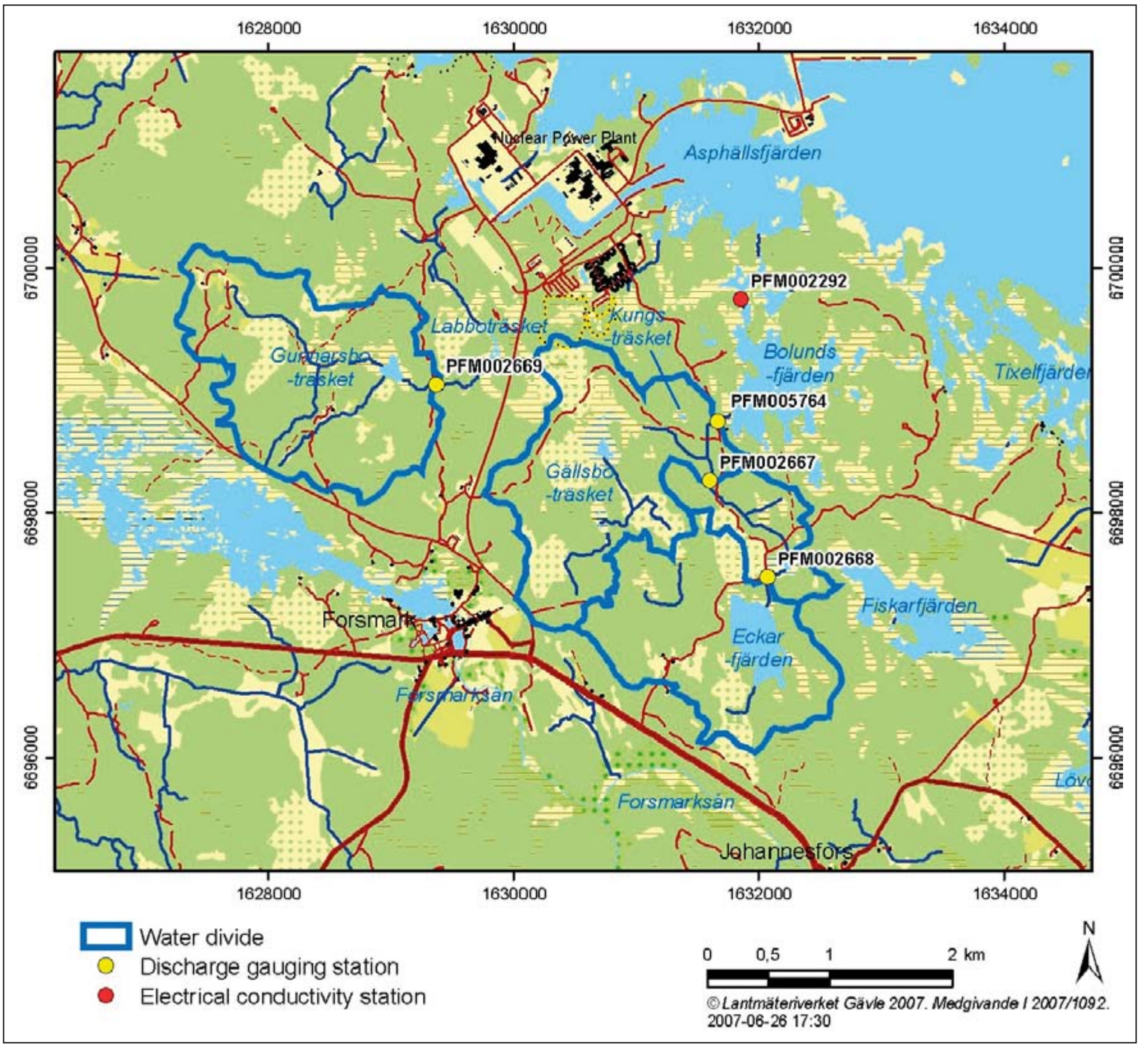


Figure 1-1. *The locations of the four discharge gauging stations and the electrical conductivity monitoring station within the Forsmark site investigation area.*

Table 1-2. Summary of catchment areas associated with the discharge gauging stations.

Gauging station ID-code	Catchment area ID-code	Catchment Area (km^2)
PFM005764	AFM001267	5.59
PFM002667	AFM001268	3.01
PFM002668	AFM001269	2.28
PFM002669	AFM001270	2.83

2 Objective and scope

Brook water levels, water electrical conductivities, temperatures and discharges were monitored at four gauging stations in the largest brooks of the central part of the Forsmark site investigation area. Furthermore, water electrical conductivity was measured at the outlet of Lake Bolundsfjärden with the main objective to identify occasions of sea water intrusion.

The objectives of the monitoring are to provide:

- Information on the spatial and temporal variation of brook water levels, water electrical conductivities, temperatures and discharges.
- Information on sea water intrusion into Lake Bolundsfjärden.
- Basis for understanding of the water balance of the area and the contact between surface water and shallow and deep groundwater.
- Basis for calculation of mass balances of different elements.
- Basis for formulation of boundary conditions, calibration and testing of the quantitative hydro(geo)logical models to be applied within the site investigation.
- Basis for transport and dose calculations included in the Safety Assessment.
- Basis for the Environmental Impact Assessment.

3 Equipment

3.1 Description of equipment

Long-throated flumes were selected for the discharge measurements, mainly due to the limitations set by the flat landscape, the need for accurate measurements, and the desire to avoid migration obstacles for the fish. Long-throated flumes give accurate measurements over relatively wide flow ranges and work under a high degree of submergence. At three of the four discharge gauging stations, two flumes were installed, with different measurement ranges, to obtain good accuracy data over the full flow range. For the station PFM005764 two standard design flumes were used, while the two large flumes at PFM002667 and PFM002669 and the single flume at PFM002668 were designed using the flume design software WinFlume (www.usbr.gov/pmts/hydraulics_lab/winflume/index.html). The flumes were manufactured in stainless steel. The design of the gauging stations is shown in Figure 3-1, illustrated by the station at PFM002667. For details on the construction of the gauging stations and drawings of the flumes see Johansson (2005).

The positions of the gauging stations, including levels of top of casing of the level observation tubes and the bottom of the flumes, are given in Table 3-1.

Table 3-1. Coordinates for the flumes (Northing and Easting: RT 90 2.5 gon W 0:-15, elevation: RHB70).

Id	Northing	Easting	Elevation
PFM005764 Nov. 27, 2003–Oct. 1, 2004			
Small flume (QFM1:1)			
Obs. tube, top of casing	6698745.4	1631660.4	1.701
Flume bottom, upstream edge	6698747.6	1631658.9	0.577
Large flume (QFM1:2)			
Obs. tube, top of casing	6698752.1	1631666.5	1.740
Flume bottom, upstream edge	6698753.1	1631665.1	0.551
PFM005764 Oct 5, 2004–			
Small flume (QFM1:1)			
Obs. tube, top of casing	6698745.4	1631660.9	2.190
Flume bottom, upstream edge	6698747.3	1631659.1	0.903
Large flume (QFM1:2)			
Obs. tube, top of casing	6698751.8	1631667.2	2.117
Flume bottom, upstream edge	6698753.0	1631666.0	0.895
PFM002667			
Small flume (QFM2:1)			
Obs. tube, top of casing	6698263.0	1631595.5	2.679
Flume bottom, upstream edge	6698264.1	1631593.5	1.502
Large flume (QFM2:2)			
Obs. tube, top of casing	6698270.2	1631598.4	2.721
Flume bottom, upstream edge	6698271.0	1631596.5	1.511
PFM002668 (QFM3)			
Obs. tube, top of casing	6697474.9	1632066.9	5.482
Flume bottom, upstream edge	6697475.5	1632065.7	4.287
QFM4 PFM002669			
Small flume (QFM4:1)			
Obs. tube, top of casing	6699047.4	1629371.7	6.994
Flume bottom, upstream edge	6699046.6	1629371.2	5.852
Large flume (QFM4:2)			
Obs. tube, top of casing	6699045.9	1629379.9	6.901
Flume bottom, upstream edge	6699043.9	1629379.1	5.843

Figure 3-1. *Discharge station PFM002667 with the large flume in the foreground, the small flume upstream in the background, and the service module with the LPG burner used for de-icing to the left. The tube in the middle of the brook, between the flumes, is screened and contains the devices for measurement of electrical conductivity and temperature.*

The equations for the water level – discharge relationships of the flumes and recommended discharge intervals for which they should be used are given in Table 3-2.

The equation errors are less than ± 2% for all of the flumes. Estimated errors at minimum and maximum discharge for the recommended interval are ± 5–10% for the different flumes (with exception of the large flume at PFM005764 for the period Nov. 2003–Oct. 2004, see Table 4-3) based on expected level measurement errors of ± 2 mm, and errors in surveyed bottom gradients and assessed Manning numbers.

The water levels in the flumes were recorded by Druck PTX 1830 pressure sensors (full scale pressure range 1.5 m H_2O, accuracy 0.1% of full scale). At the discharge stations also electrical conductivity and temperature were measured (by GLI 3442, range 0–200 mS/m, accuracy 0.1% of full scale and by Mitec, 1 MSTE106, range 0–120°C, and 3 Sat60, range –40 to +120°C, accuracy ± 0.3°C, respectively). At the electrical conductivity monitoring station at the outlet of Lake Bolundsfjärden a GLI 3422, range 0–1 000 mS/m, was used.

The accuracy of the discharge measurements is highly dependent on the accuracy of the head measurement devices, and the cleaning and maintenance of the flumes and the downstream brook reaches. Especially during winter, frequent inspections are crucial for the operation to avoid disturbances from ice.

The discharges obtained from the equations have been checked at four occasions by an area-velocity measurement instrument based on doppler technique (Isco 2150); April–May 2004, for PFM005764 only, and December 2005, April 2005, and April–May 2006 for all four stations.

The check of the flumes at PFM005764 during spring 2004 showed that the equation derived from WinFlume for the small flume could be used with good accuracy while critical flow requirement was not fulfilled in the large flume, and calculated discharge could therefore be influenced by downstream conditions. Values from the equation derived from the calibration measurements for the large flume should only be used for the interval covered by the calibration measurements (20–70 L/s) and considered as indicative and used with caution.

Table 3-2. Discharge equations for the long-throated flumes and recommended discharge interval.

Id	Discharge eq. (Q=discharge /L/s/, h=water depth /m/)	Recommended interval (L/s)
PFM005764		
Nov. 27 2003–Oct. 1 2004		
Small flume (QFM1:1)	$Q=864.9 \times h^{2.576}$	0–20
Large flume (QFM1:2)*	$Q=1175 \times h^{2.15}$	20–70
PFM005764		
Oct 5 2004 –		
Small flume (QFM1:1	$Q=864.9 \times h^{2.576}$	0–20
Large flume (QFM1:2)	$Q=2298 \times (h+0.03459)^{2.339}$	20–1400
PFM002667		
Small flume (QFM2:1)	$Q=864.9 \times h^{2.576}$	0–20
Large flume (QFM2:2)	$Q=2001.5 \times (h+0.02660)^{2.561}$	20–500
PFM002668		
(QFM3)	$Q=979.1 \times (h)^{2.574}$	0–250
PFM002669		
Small flume (QFM4:1)	$Q=864.9 \times h^{2.576}$	0–20
Large flume (QFM4:2)	$Q=1117.6 \times (h+0.02727)^{2.604}$	20–920

* Equation obtained from calibration measurements April 13–May 24, 2004. Critical value requirement was not fulfilled and calculated discharge may therefore be influenced by downstream conditions. Obtained values should be considered as indicative and be used with caution.

After re-installation of the two flumes at PFM005764, the general conclusion from the calibrations was that the derived discharge equations for all flumes showed a good agreement with the results obtained from the area-velocity method. However, from the calibration in April–May 2006, it was clear that problems occurred with downstream damming at PFM002667 at high flows. The area-velocity measurements indicated that the station worked good for discharges up to approximately 55 L/s when the downstream wetland was filled up. In the rising phase of a flow peak, when the downstream wetland is not filled up, the station most probably works satisfactorily at considerably higher flows. The difference between the inflow and outflow water levels in the flume should not be less than 30 mm to obtain measurements with acceptable accuracy.

Besides the automatic recordings of the electrical conductivity and temperature these parameters were also measured manually every c. 14 days with the site investigation field devices.

3.2 Data collection

The data collecting system, which is part of the Hydro Monitoring System (HMS), consists of one measurement station (computer) which collects data from a number of data sources. The computer is connected to the SKB Ethernet LAN.

All data were collected by means of pressure, electrical conductivity and temperature transducers connected to Mitec data loggers. The data loggers were connected on-line by means of GSM telephony. The on-line system was designed to be able to handle short interruptions in the communication. Data could be stored for, at least, a couple of hours in the loggers. All data were finally stored in the measurement station. A tape backup was made of all data.

4 Execution

4.1 General

Data on water levels, electrical conductivities and temperatures were collected to HMS as described in Chapter 3, and quality assured data were then transferred to Sicada. Discharge was calculated from quality assured water level data from the flumes. The calculated discharges were stored in Sicada.

4.2 Field work

The discharge gauging stations were inspected approximately once a week. If needed, the stations and brook reaches immediately upstream and downstream of the stations were cleaned from debris, vegetation and ice.

Every c. 14 days the water depths at the upstream edge of the flumes were measured by a ruler. The measurements were stored in SKB's database for manual level measurements, Lodis. The manual measurements were used for calibrations of the water levels automatically registered by the pressure transducers. Electrical conductivity and temperature were also measured manually every c. 14 days with the site investigation field devices and stored in Lodis.

4.3 Data handling/post processing

4.3.1 Calibration method

The pressure transducer data from the loggers were converted to water levels by means of a linear equation. The converted logger data were compared with results from the manual level measurements. If the two differed, calibration constants were adjusted until an acceptable agreement was obtained.

Linear equations were also used to convert data from the electrical conductivity and temperature transducers. No changes of calibration constants have been necessary.

4.3.2 Recording interval

Measurements of water levels, electrical conductivities and temperatures were made every 10 minutes with exception of the electrical conductivity at the outlet of Lake Bolundsfjärden (PFM002292) where the recording interval was 30 minutes.

4.3.3 Calculation of discharge

Preliminary discharge calculations, based on the equations in Table 3-2, were performed already in HMS. Calculations were carried out for all flumes also outside the discharge interval for which the equations apply. These calculations were used only internally by SKB for quick checks of present discharge and as a help to discover discrepancies between discharges recorded by the small and large flumes at a station.

For the final calculation of discharge, quality assured water level data from the flumes were used (the level data delivered to Sicada). The calculation procedure contained the following steps:

- The water level data were consolidated to hourly averages to facilitate combining data records from small and large flumes.
- The hourly water level time series were screened to remove data that were judged erroneous, such as short-term spikes, noise, and longer intervals where a sensor appeared "stuck". The principal diagnostic tools for data screening were the compiled hourly time series, and cross-plots of small and large flume water levels. The cross-plot graphs were useful for identifying time intervals where the small and large flume data were not synchronized. After these intervals were identified, the time series were examined to determine which flume was likely in error, and those data were removed. Figure 4-1 shows an example of water elevation cross-plots for the two flumes at PFM005764, before and after data screening.
- If there were missing data intervals in a time series greater than one day, then these intervals were filled, to the extent possible, using alternative data sources.

  Large flume water elevations were estimated to fill gaps using piece-wise linear relations that were fit with regression analysis to the cross-plot data. This procedure was applied only under the following conditions: large flume data were missing, small flume data were available, and the available small flume data were above the upper range for the small flume flow equation. The accuracy of this estimation technique was verified by comparing estimated values to the few manually-measured water depths that were available during these intervals.

  Manually measured water depths and flow measurements were added into time series, when available, to help fill multi-day data gaps that were still present after the data estimation step above.

  Remaining data gaps were left intact. There were no data interpolations. Interpolation can be employed at a later step at the analyst's discretion.
- Water depth time series were calculated in each flume using the measured upstream edge bottom elevations of the flumes.

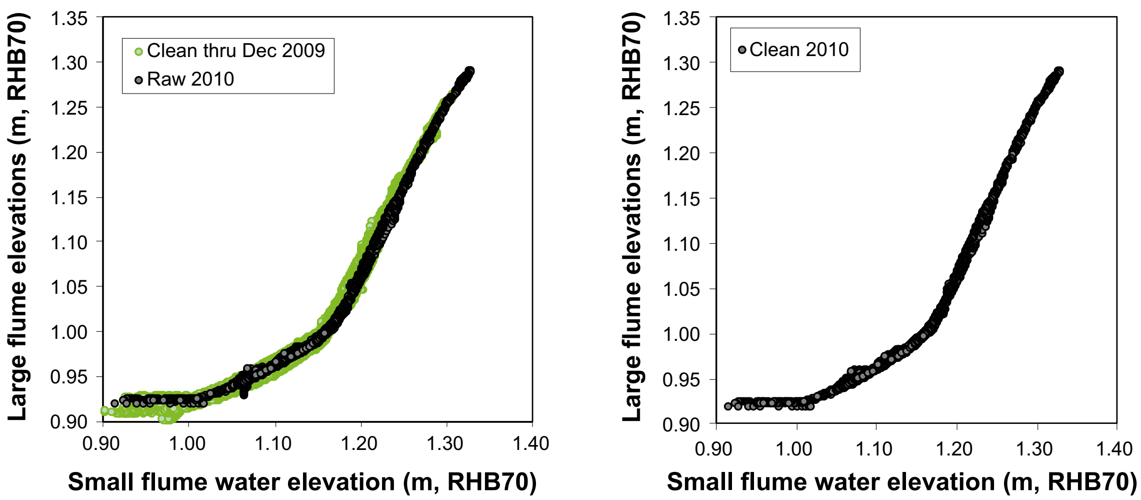


Figure 4-1. *A comparison of cross-plots between small and large flume water levels at PFM005764, before and after data screening, shown as an example of the data screening and scrutiny process. A consistent relationship between the flume water elevations would be expected if both sensors were properly functioning, and was indeed apparent in the "clean" data. The figure on left also shows "clean" data from the previous data intervals, for reference.*

For all flumes, there were discrepancies between elevations of the small flume bottoms and the elevation values that were used to represent zero discharge. These were related to installation issues with the flume instrumentation. Table 4-1 summarizes the surveyed bottom elevations (upstream edge) and the elevation values that were used in data reduction to signify zero discharge.

- Discharge rates were calculated from water depth in each flume using the appropriate discharge equations (see Table 3-2) within the specified ranges of usable water depths at each sensor location.
- For PFM002668, which was a single sensor flume, a final flow time series was produced from the single screened gauge elevation dataset.
- For the remaining three stations, single flow time series were produced by combining small and large flume flow values. In general, small flume data were used for flows of less than approximately 20 L/s, which was the upper limit of the small flumes' calibration ranges. For PFM005764 and PFM002667, large flume data were used if hourly small flume data were either missing or greater than 20 L/s *and* if calculated large flume flows were greater than 16 L/s. The overlapping transition for small and large flow data provided data filling for conditions where small flume flow data calculated greater then 20 L/s but large flume data were calculating as less than 20 L/s. At PFM002669, large flume data were used if hourly small flume data were either missing or greater than 20 L/s *and* large flume flows were greater than 20 L/s. Here, the equal transition value between large and small flume signals provided the least amount of chatter in this time series when reported flows were hovering around 20 L/s.
- Most time series required specific data treatments and screenings above and beyond the general procedure described above. These data treatments are documented for the period through December 2009 for each discharge time series in P-07-135, P-09-68 and P-10-44 and for the period January–December 2010 herein in Tables 4-2 through 4-5.

Table 4-1. Surveyed flume bottom elevations and elevations used to signify zero discharge.

Flume	Front edge bottom elevation (m RHB70)	Elevation used in data reduction for zero discharge (m, RHB70)
PFM005764	0.903	0.990*, from Sep. 13, 2006 0.903
PFM002667	1.502	1.518
PFM002668	4.287	4.296
PFM002669	5.852	5.872

* Installation error

Table 4-2. Summary of data clean-up actions for the discharge time series at PFM005764. Raw water elevation data were compressed to hourly average values, and the number of affected data points in the table refers to the total number of hourly values that were altered during each indicated interval.

Dates	Affected data points from small flume	Affected data points from large flume	Action
2010/3/6-8		54	Removed: inconsistent

Table 4-3. Summary of data clean-up actions for the discharge time series at PFM002667. Raw water elevation data were compressed to hourly average values, and the number of affected data points in the table refers to the total number of hourly values that were altered in each indicated interval.

Dates	Affected data points from small flume	Affected data points from large flume	Action
2010/4/3-29	648	648	Data inaccurate due to downstream flooding
2010/11/9		2	Appeared inconsistent

Table 4-4. Summary of data clean-up actions for the discharge time series at PFM002668. Raw water elevation data were compressed to hourly average values, and the number of affected data points in the table refers to the total number of hourly values that were altered in each indicated interval.

Dates	Affected data points	Action
No treatment required		

Table 4-5. Summary of data clean-up actions for the discharge time series at PFM002669. Raw water elevation data were compressed to hourly average values, and the number of affected data points in the table refers to the total number of hourly values that were altered in each indicated interval.

Dates	Affected data points from small flume	Affected data points from large flume	Action
2010/1/26-27		24	Appeared inconsistent
2010/2/22-26		80	Appeared inconsistent
2010/4/1-2	19		Appeared inconsistent
2010/7/26-/8/4		8	Appeared inconsistent

4.4 Quality assurance

Once every week a preliminary inspection of all collected data was performed. The purpose of this was to certify that all loggers were sending data and that all transducers were functioning.

All data collected were subject to a quality check every four months. During this quality assurance, obviously erroneous data were removed and calibration constants were corrected so that the monitored data corresponded with the manual water depth measurements. At these occasions, the status of the equipment was also checked and service was initiated if needed.

An additional quality check was performed after the full monitoring period January–December 2010 by the Activity Leader Including cross-checking between the discharge stations for preliminary calculated discharges (i.e. water level data), electrical conductivities and temperatures. The additional quality check resulted in the removal of the data listed in Table 4-6.

Table 4-6. Removal of water level, EC and temperature data judged as erroneous during the quality check performed by the Activity Leader.

Flume	Parameter	Dates (YYMMDD hh:mm:ss)	Reason for removal
PFM005764 small	Level	100201 10:30:00 – 100201 10:50:00	Disturbance coupled to manual measurements of water depth.
PFM005764 small	Level	100302 10:30:00 – 100302 13:00:00	Disturbance coupled to manual measurements of water depth.
PFM005764 small	Level	100314 01:10:00 – 100315 12:20:00	Disturbed values due to ice and cleaning of ice.
PFM005764 small	Level	100319 09:40:00 – 100324 10:10:00	Disturbed values due to ice and cleaning of ice.
PFM005764 small	Level	100713 00:00:00 – 100808 10:40:00	Level not representative for brook water level. Dry flume.
PFM005764 small	Level	101204 12:20:00 – 101204 13:10:00	Outlying values. Disturbance from ice?
PFM005764 large	Level	100108 00:50:00 – 100108 01:20:00	Single outlying values.
PFM005764 large	Level	100129 20:20:00 – 100129 22:00:00	Single outlying values.
PFM005764 large	Level	100201 10:30:00 – 100201 11:20:00	Disturbance coupled to manual measurements of water depth.

Flume	Parameter	Dates (YYMMDD hh:mm:ss)	Reason for removal
PFM005764 large	Level	100205 09:10:00 – 100205 09:30:00	Single outlying values.
PFM005764 large	Level	100302 10:30:00 – 100302 13:00:00	Disturbance coupled to manual measurements of water depth.
PFM005764 large	Level	100311 15:30:00	Single outlying value.
PFM005764 large	Level	100314 08:10:00 – 100319 23:50:00	Disturbed values due to ice and cleaning of ice.
PFM005764 large	Level	100711 04:10:00 – 100808 10:40:00	Level not representative for brook water level.
PFM005764 large	Level	101204 12:20:00 – 101204 18:50:00	Outlying values. Disturbance from ice?
PFM005764 large	Level	101217 10:40:00 – 101217 11:30:00	Single outlying values.
PFM005764	EC	100619 11:40:00 – 101121 23:50:00	No representative values due to no or very low flow.
PFM005764	Temp	100713 00:00:00 – 100808 10:40:00	No or very low flow.
PFM002667 small	Level	100130 00:10:00 – 100130 01:00:00	Single outlying values. Ice?
PFM002667 small	Level	100228 15:54:36 – 100228 18:24:36	Single outlying values. Ice?
PFM002667 small	Level	100302 13:30:00 – 100302 14:00:00	Single outlying values. Ice?
PFM002667 small	Level	100308 15:00:00 – 100308 15:50:00	Disturbance in connection to manual measurements.
PFM002667 small	Level	100704 19:40:00 – 100808 20:10:00	Level not representative for brook water level. Dry flume.
PFM002667 small	Level	101203 21:50:00 – 101203 23:50:00	Single disturbed values. Ice?
PFM002667 small	Level	101225 21:00:00 – 101225 23:10:00	Single disturbed values. Ice?
PFM002667 large	Level	100129 10:10:00 – 100129 10:40:00	Single outlying values. Ice?
PFM002667 large	Level	100130 00:10:00 – 100130 01:20:00	Single outlying values. Ice?
PFM002667 large	Level	100205 15:40:00 – 100205 20:40:00	Single outlying values.
PFM002667 large	Level	100220 17:30:00 – 100220 23:50:00	Single outlying values.
PFM002667 large	Level	100228 15:54:36 – 100228 21:34:36	Single outlying values. Ice?
PFM002667 large	Level	100302 11:10:00 – 100302 12:20:00	Single outlying values. Ice?
PMM002667 large	Level	100302 13:20:00 – 100302 14:00:00	Single outlying values. Ice?
PFM002667 large	Level	100704 00:00:00 – 100808 22:00:00	Level not representative for brook water level.
PFM002667 large	Level	101109 22:20:00 – 101109 22:50:00	Single disturbed values.
PFM002667 large	Level	101110 00:30:00 – 101110 02:20:00	Single disturbed values.
PFM002667 large	Level	101110 04:30:00 – 101110 04:40:00	Single disturbed values.
PFM002667 large	Level	101203 21:50:00 – 101203 23:20:00	Single disturbed values. Ice?
PFM002667 large	Level	101223 23:50:00 – 101224 00:40:00	Single disturbed values. Ice?

Flume	Parameter	Dates (YYMMDD hh:mm:ss)	Reason for removal
PFM002667 large	Level	101225 21:00:00 – 101225 23:10:00	Single disturbed values. Ice?
PFM002667	EC	100101 00:00:00 – 100416 09:30:00	Unreasonably low and unstable values.
PFM002667	EC	100503 11:50:00 – 101001 11:30:00	Unstable and partly unreasonably low values. Part of the period no or very low flow.
PFM002667	Temp	100701 00:00:00 – 100808 20:10:00	No or very low flow.
PFM002668	Level	100103 04:10:00	Single outlying value.
PFM002668	Level	100103 04:50:00	Single outlying value.
PFM002668	Level	100104 05:20:00	Single outlying value.
PFM002668	Level	100105 07:40:00	Single outlying value. Ice?
PFM002668	Level	100105 08:00:00	Single outlying value. Ice?
PFM002668	Level	100105 08:20:00	Single outlying value. Ice?
PFM002668	Level	100105 09:00:00 – 100105 09:10:00	Single outlying values. Ice?
PFM002668	Level	100105 11:00:00	Single outlying value. Ice?
PFM002668	Level	100105 13:40:00 – 100105 14:20:00	Single outlying values. Ice?
PFM002668	Level	100206 11:40:00	Single outlying value.
PFM002668	Level	100209 13:10:00 – 100209 13:30:00	Single outlying values.
PFM002668	Level	100323 10:30:00 – 100322 13:20:00	Single outlying values. Ice?
PFM002668	Level	100324 12:50:00 – 100324 13:00:00	Disturbance in connection to manual measurement.
PFM002668	Level	100330 14:50:00	Single outlying value.
PFM002668	Level	100401 09:10:00	Single outlying value.
PFM002668	Level	100711 00:00:00 – 100722 13:10:00	Level not representative for brook water level. Dry flume.
PFM002668	Level	100722 23:40:00 – 100725 00:40:00	Level not representative for brook water level. Dry flume.
PFM002668	Level	100725 18:10:00 – 100725 22:10:00	Level not representative for brook water level. Dry flume.
PFM002668	Level	100727 06:20:00 – 100729 12:30:00	Level not representative for brook water level. Dry flume.
PFM002668	Level	100730 10:30:00 – 100804 10:20:00	Level not representative for brook water level. Dry flume.
PFM002668	Level	100807 04:20:00 – 100808 01:10:00	Level not representative for brook water level. Dry flume.
PFM002668	Level	100816 20:50:00 – 100818 08:30:00	Level not representative for brook water level. Dry flume.
PFM002668	Level	100911 22:10:00	Single outlying value.
PFM002668	Level	100913 03:50:00 – 100913 04:00:00	Single outlying values.
PFM002668	Level	100913 15:00:00	Single outlying value.
PFM002668	Level	101103 16:20:00	Single outlying value.
PFM002668	Level	101128 01:10:00 – 101128 01:20:00	Single outlying values. Ice?
PFM002668	Level	101209 18:20:00 – 101209 19:20:00	Single outlying values. Ice?
PFM002668	Level	101213 06:10:00 – 101213 07:20:00	Single outlying values. Ice?
PFM002668	Level	101219 09:10:00 – 101219 09:40:00	Single outlying values. Ice?

Flume	Parameter	Dates (YYMMDD hh:mm:ss)	Reason for removal
PFM002668	Level	101228 14:50:00 – 101228 15:20:00	Single outlying values. Ice?
PFM002668	Level	101229 01:00:00 – 101229 03:00:00	Single outlying values. Ice?
PFM002668	EC	100406 15:20:00 – 100406 16:00:00	Single outlying values.
PFM002668	EC	100408 17:20:00 – 100408 17:30:00	Single outlying values.
PFM002668	EC	100412 13:40:00 – 100412 14:20:00	Single outlying values.
PFM002668	EC	100415 15:30:00 – 100415 21:50:00	Single outlying values.
PFM002668	EC	100420 19:00:00	Single outlying value.
PFM002668	EC	100420 22:50:00 – 100421 06:40:00	Single outlying values.
PFM002668	EC	100425 20:10:00 – 100425 20:50:00	Single outlying values.
PFM002668	EC	100429 03:50:00	Single outlying value.
PFM002668	EC	100430 00:20:00	Single outlying value.
PFM002668	EC	100503 11:00:00 – 100503 11:10:00	Single outlying values.
PFM002668	EC	100510 01:20:00	Single outlying value.
PFM002668	EC	100511 12:50:00 – 100511 14:30:00	Single outlying values.
PFM002668	EC	100512 09:30:00	Single outlying value.
PFM002668	EC	100512 11:10:00	Single outlying value.
PFM002668	EC	100518 00:00:00 – 100602 06:40:00	Unstable values.
PFM002668	EC	100701 22:10:00	Single outlying value.
PFM002668	EC	100703 00:00:00 – 100826 13:20:00	No or very low flow.
PFM002668	EC	101216 15:20:00 – 101216 16:20:00	Single outlying values.
PFM002668	Temp	101001 12:10:00 – 101231 23:50:00	Values considered not correct based on comparison with existing manual measurements (c. 2°C too high).
PFM002669 small	Level	100104 13:40:00 – 100104 14:00:00	Disturbed value in connection to manual measurements.
PFM002669 small	Level	100225 17:40:00 – 100226 01:00:00	Disturbed values. Ice?
PFM002669 small	Level	100226 02:10:00 –	Disturbed value. Ice?
PFM002669 small	Level	100301 16:20:00 – 100301 16:50:00	Disturbed values. Ice?
PFM002669 small	Level	100304 12:40:00 – 100304 14:30:00	Disturbed values. Cleaning of ice.
PFM002669 small	Level	100305 17:00:00 – 100308 14:10:00	Disturbed values. Cleaning of ice.
PFM002669 small	Level	100313 03:20:00 – 100315 08:30:00	Disturbed values. Cleaning of ice.
PFM002669 small	Level	100321 13:40:00 – 100321 23:40:00	Disturbed values. Ice?
PFM002669 small	Level	100325 14:00:00 – 100325 15:20:00	Disturbed values. Ice?
PFM002669 small	Level	100402 13:00:00 – 100404 02:40:00	Disturbed values. Ice?
PFM002669 small	Level	100715 00:00:00 – 100725 23:30:00	Level not representative for brook water level. Dry flume.

Flume	Parameter	Dates (YYMMDD hh:mm:ss)	Reason for removal
PFM002669 small	Level	100802 02:40:00 – 100804 16:00:00	Level not representative for brook water level. Dry flume.
PFM002669 small	Level	101129 05:00:00 – 101129 05:20:00	Single outlying values.
PFM002669 small	Level	101210 00:40:00 – 101210 02:30:00	Single outlying values.
PFM002669 small	Level	101216 20:40:00 – 101216 20:50:00	Single disturbed values.
PFM002669 small	Level	101220 13:00:00 – 101220 13:30:00	Single disturbed values.
PFM002669 large	Level	100104 13:30:00 – 100104 14:00:00	Disturbed value in connection to manual measurements.
PFM002669 large	Level	100224 08:50:00 – 100224 13:20:00	Disturbed values. Ice?
PFM002669 large	Level	100225 10:20:00 – 100226 02:30:00	Disturbed values. Ice?
PFM002669 large	Level	100227 19:40:00 – 100301 20:10:00	Disturbed values. Ice?
PFM002669 large	Level	100304 12:40:00 – 100304 14:30:00	Disturbed values. Cleaning of ice.
PFM002669 large	Level	100305 17:20:00 – 100308 14:10:00	Disturbed values. Cleaning of ice.
PFM002669 large	Level	100313 02:00:00 – 100315 08:20:00	Disturbed values. Cleaning of ice.
PFM002669 large	Level	100321 13:30:00 – 100322 00:40:00	Disturbed values. Ice?
PFM002669 large	Level	100325 13:00:00 – 100325 15:20:00	Disturbed values. Cleaning of flume.
PFM002669 large	Level	100403 13:10:00 – 100404 02:40:00	Disturbed values. Ice?
PFM002669 large	Level	100715 00:00:00 – 100726 02:30:00	Level not representative for brook water level.
PFM002669 large	Level	100802 02:40:00 – 100804 16:40:00	Level not representative for brook water level.
PFM002669 large	Level	100913 13:50:00	Disturbed value. Cleaning of flume.
PFM002669 large	Level	101129 05:00:00 – 101129 05:20:00	Single outlying values.
PFM002669 large	Level	101210 00:40:00 – 101210 02:30:00	Single outlying values.
PFM002669 large	Level	101216 20:40:00 – 101216 20:50:00	Single disturbed values.
PFM002669 large	Level	101220 13:00:00 – 101220 13:30:00	Single disturbed values.
PFM002669	EC	100623 01:40:00 – 101202 12:00:00	Values considered not correct (based on comparison with existing manual measurements).
PFM002669	Temp	100715 00:00:00 – 100725 23:50:00	Very low or no flow.
PFM002292	EC	100101 00:00:00 – 101231 23:30:00	Values considered not correct (based on comparison with existing manual measurements).

4.5 Nonconformities

There were intervals of missing data in most time series, ranging from several days to months, due to mal-functioning equipment. Tests were initiated in the autumn 2010 to investigate the reason for the problems with the equipment for measuring electrical conductivity.

5 Results

5.1 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. Only data from the database should be used for further analysis.

5.2 Water levels

Water levels from the four gauging stations PFM005764, PFM002667, PFM002668 and PFM002669 are presented in Appendix 1. The data shown are hourly mean values.

The water levels were measured at the upstream end of each flume. The gaps found in the data series, for short or long periods, were due to mal-function of the mechanical and/or electrical equipment or mean that the flume was dry.

Amplitudes of water levels were 0.41–0.55 in PFM005764, PFM002667 and PFM002668 (small flume data for PFM005764 and PFM002667), which are all within the same catchment. The mean water elevations were from the downstream station PMF005764, via PFM002667, to the upstream station PFM002668, 1.13, 1.69 and 4.45 m RHB70, respectively, for the January to December 2010 period (small flume data for PFM005764 and PFM002667). The amplitude of the water level at PFM002669 was 0.51 m, and the mean water elevation was 6.04 m RHB70 for January to December 2010.

5.3 Electrical conductivity

Water electrical conductivities from the four discharge gauging stations are shown in Appendix 2. The data are hourly values. No data from the station PFM002292 at the outlet of Lake Bolundsfjärden were accepted in the quality control, and accordingly no data were reported to Sicada

The gaps in the data series of PFM005764, PFM002667, PFM002668 and PFM002669 were mainly due to very low or no discharge in July and August and to mal-function of equipment.

It was not possible to exactly define a lower limit of discharge to get reliable values for electrical conductivities, but the analyst should use the values at very low discharges with caution.

The mean electrical conductivities in PFM005764, PFM002667, PFM002668 and PFM002669 were 31, 23, 28 and 39 mS/m, respectively, during this reporting period. However, due to mal-function of measuring devices data for relatively long time periods were missing.

5.4 Temperature

Water temperatures from the four discharge gauging stations are presented in Appendix 3. The data are hourly values.

The gap in the data series during July and August were due to very low or no discharge. These data were removed since the recorded values were considered not to represent surface water temperatures. It was not possible to exactly define a lower limit of discharge to get reliable values for temperatures, but the analyst should use the values at very low discharges at all stations with caution.

The water temperatures varied between c. zero during winter up to c. 20°C during hot summer days with low discharge.

5.5 Discharge

Discharges at the four gauging stations are presented in Appendix 4. The data are hourly mean values. In Table 5-1 data are shown of discharge and specific discharge for the four stations for 2010 and for the six-year period 2005–2010.

The highest recorded discharge of the largest catchment (gauging station PFM005764) was 321 L/s and for the smallest catchment 101 L/s (gauging station PFM002668). The discharge at PFM005764 is the highest recorded since the start of the measurements in 2004 and occurred on April 12. All stations had zero discharge for relatively long periods in July and August. The mean specific discharge for the largest catchment was 6.53 L/s/km^2 (206 mm) for 2010, which can be compared to the average over the six-year reporting period of 2005–2010; 5.93 L/s/km^2 (187 mm). The specific discharges of the four gauging stations were within the range of 5.66 to 7.07 L/s/km^2 (178–223 mm/yr) during 2010.

Table 5-1. Discharge characteristics for the four gauging stations for 2010 and averaged for the six-year period 2005–2010.

	PFM005764	PFM002667	PFM002668	PFM002669
Jan. 1–Dec. 31, 2010				
Mean discharge (L/s)	36.5	17.0*	13.7	20.0
Min. discharge (L/s)	0.00	0.00	0.00	0.00
Max. discharge (L/s)	321	130*	101	211
Specific discharge (L/s/km^2)	6.53	5.66*	6.02	7.07
Specific discharge (mm/yr)	206	178*	190	223
Jan. 1 2005–Dec. 31, 2010				
Mean discharge (L/s)	33.1	15.8*	12.2	17.5
Min. discharge (L/s)	0.00	0.00	0.00	0.00
Max. discharge (L/s)	321	131*	101	211
Specific discharge (L/s/km^2)	5.93	5.26*	5.34	6.19
Specific discharge (mm/yr)	187	166*	168	195

* These values are estimates and are provided as a service to the reader. There were missing data in the PFM002667 time series during peak discharge events in April 3–29 2010 as well as earlier in 2008 due to a lack of critical flow conditions for the discharge equation in Table 3-2. Flows at PFM002667 were estimated during these intervals from a linear regression to upstream flows at PFM002668. The regression had a high coefficient of correlation and maintained the mean discharge at PFM002667 during validation intervals when data were present at both stations.

6 References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications.

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

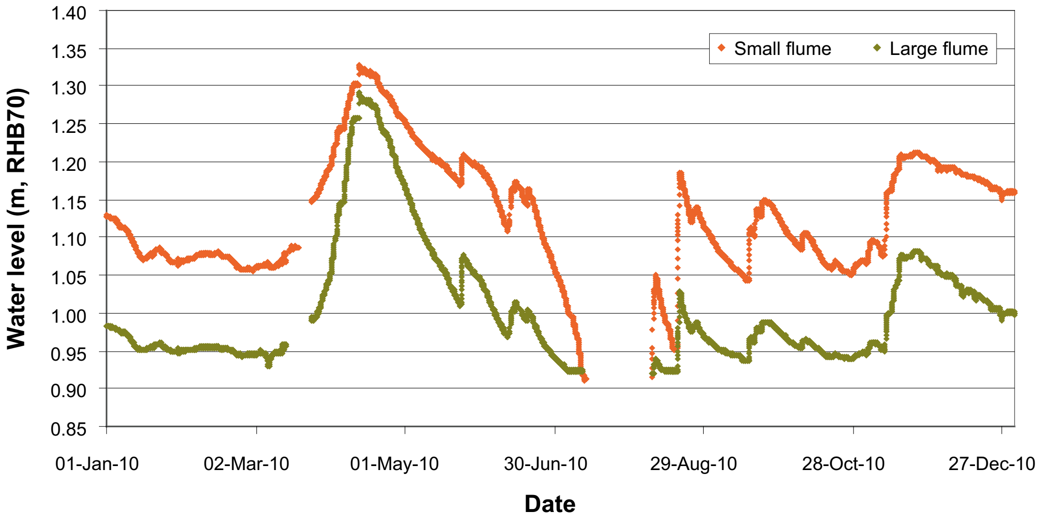
Johansson P-O, Juston J, 2007. Forsmark site investigation. Monitoring of brook levels, water electrical conductivities, temperatures and discharges from April 2004 until March 2007. (Revised May 2010.) SKB P-07-135, Svensk Kärnbränslehantering AB.

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

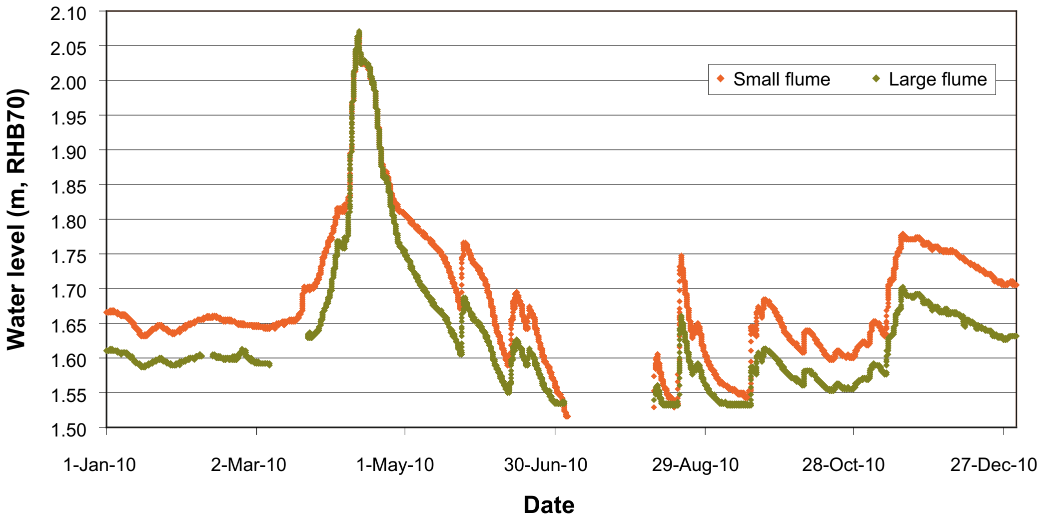
Johansson P-O, Juston J, 2011. Forsmark site investigation. Monitoring of brook water levels, electrical conductivities, temperatures and discharges January–December 2009. SKB P-10-44, Svensk Kärnbränslehantering AB.

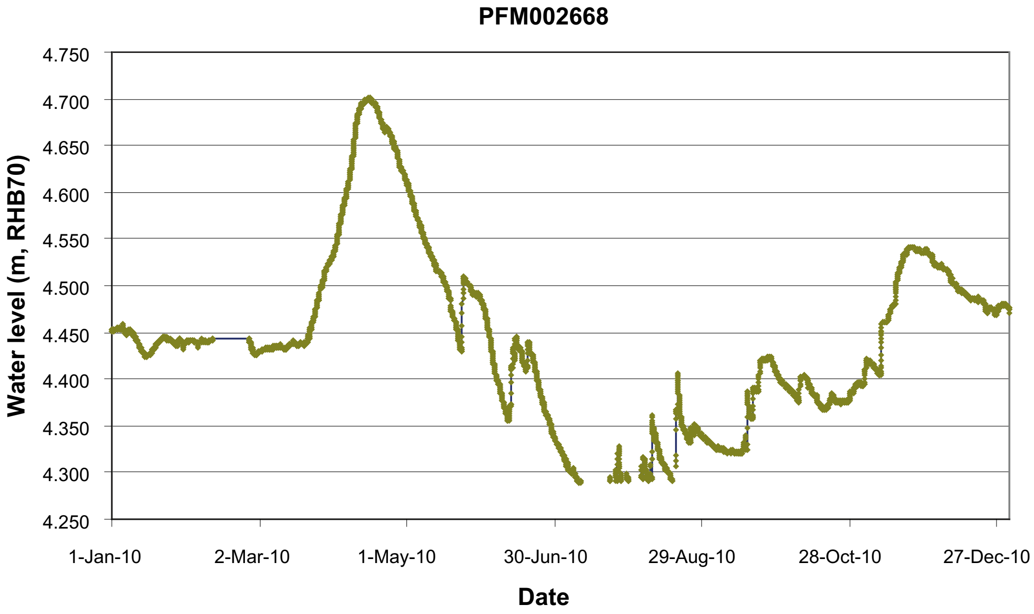
Water levels at the four gauging stations

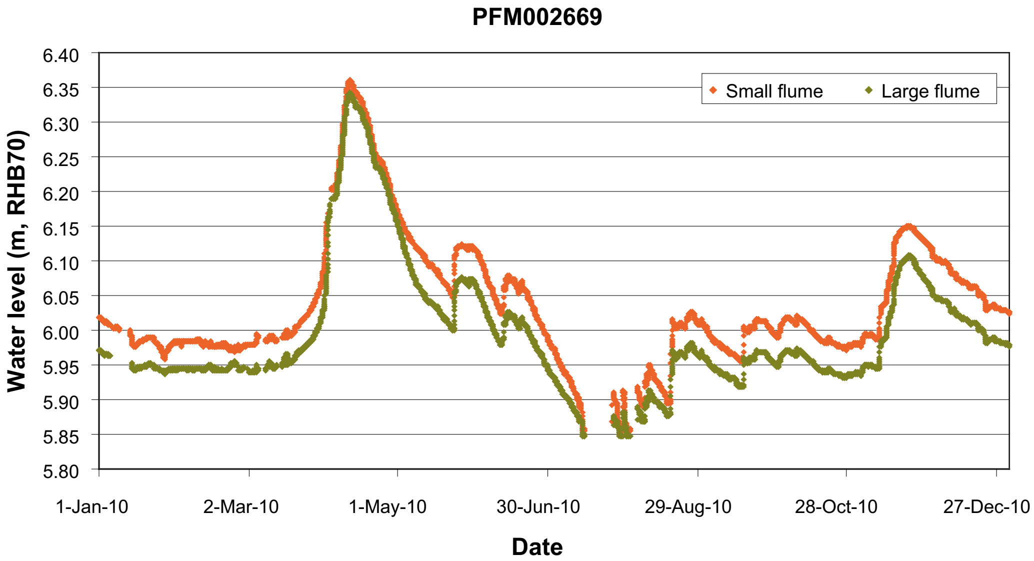
PFM005764



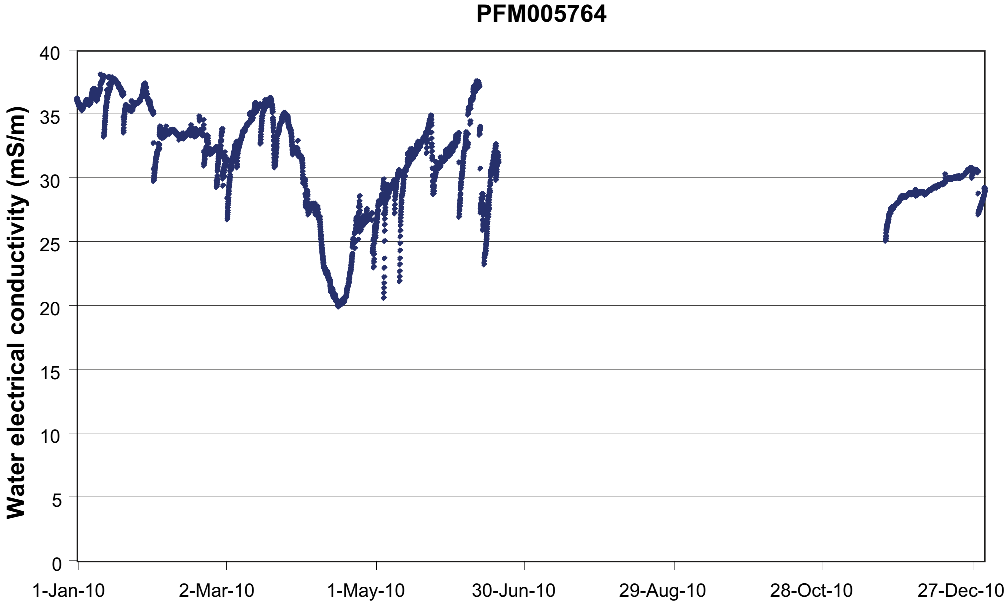
PFM002667

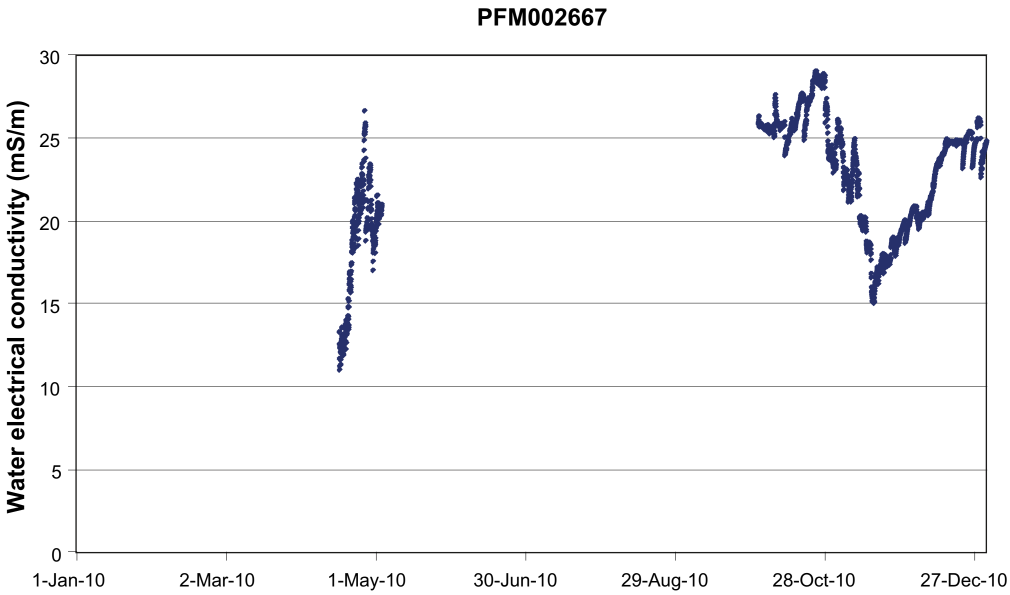


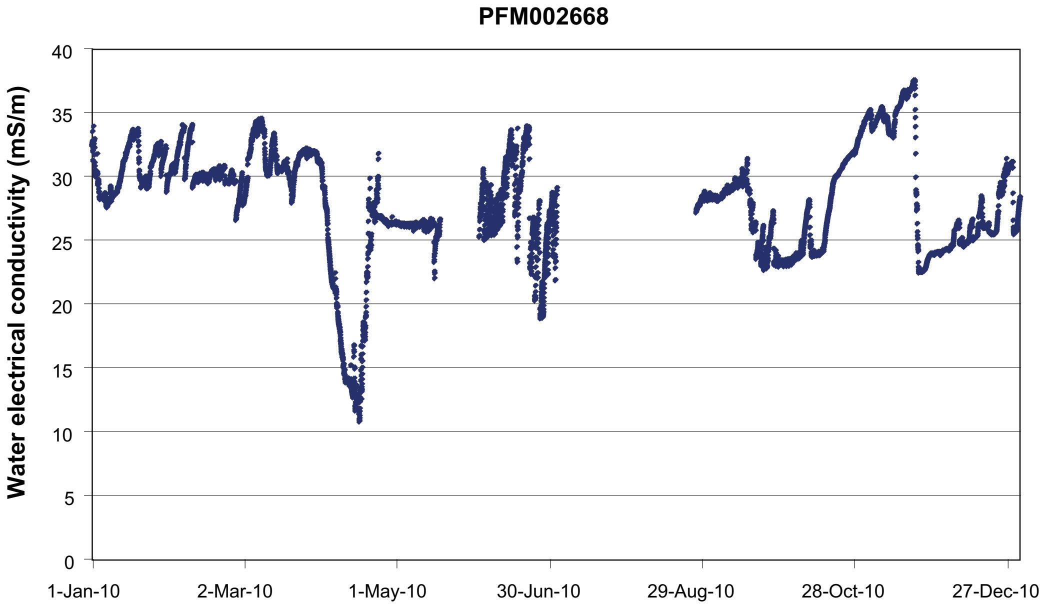

PFM002668
Water level (m, RHB70)
4.750
4.700
4.650
4.600
4.550
4.500
4.450
4.400
4.350
4.300
4.250
1-Jan-10
2-Mar-10
1-May-10
30-Jun-10
29-Aug-10
28-Oct-10
27-Dec-10
Date

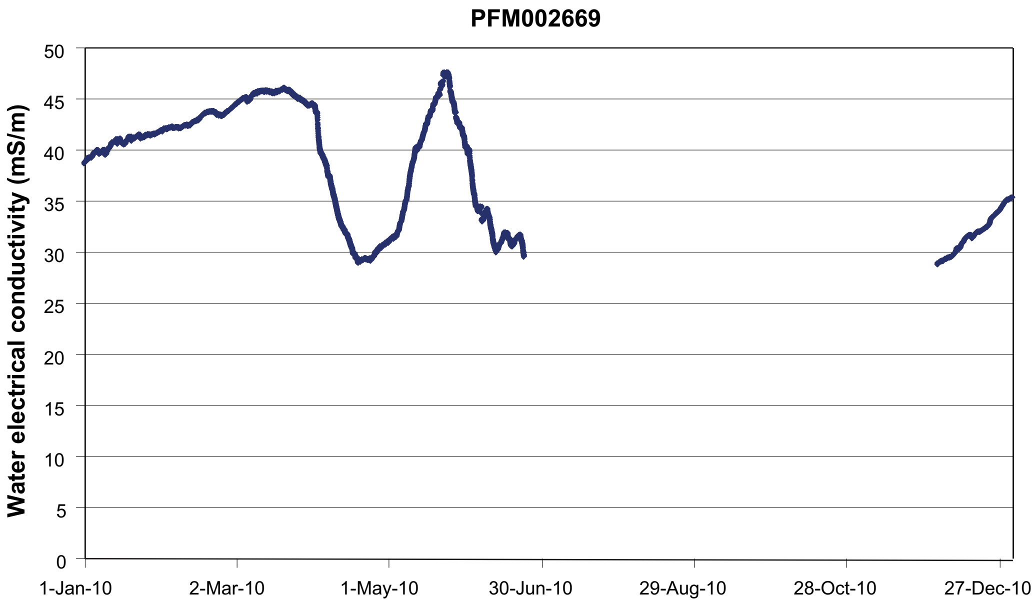

PFM002669
Water level (m, RHB70)
Small flume
Large flume
6.40
6.35
6.30
6.25
6.20
6.15
6.10
6.05
6.00
5.95
5.90
5.85
5.80
1-Jan-10
2-Mar-10
1-May-10
30-Jun-10
29-Aug-10
28-Oct-10
27-Dec-10
Date

Water electrical conductivities at the four gauging stations and at the outlet of Lake Bolundsfjärden



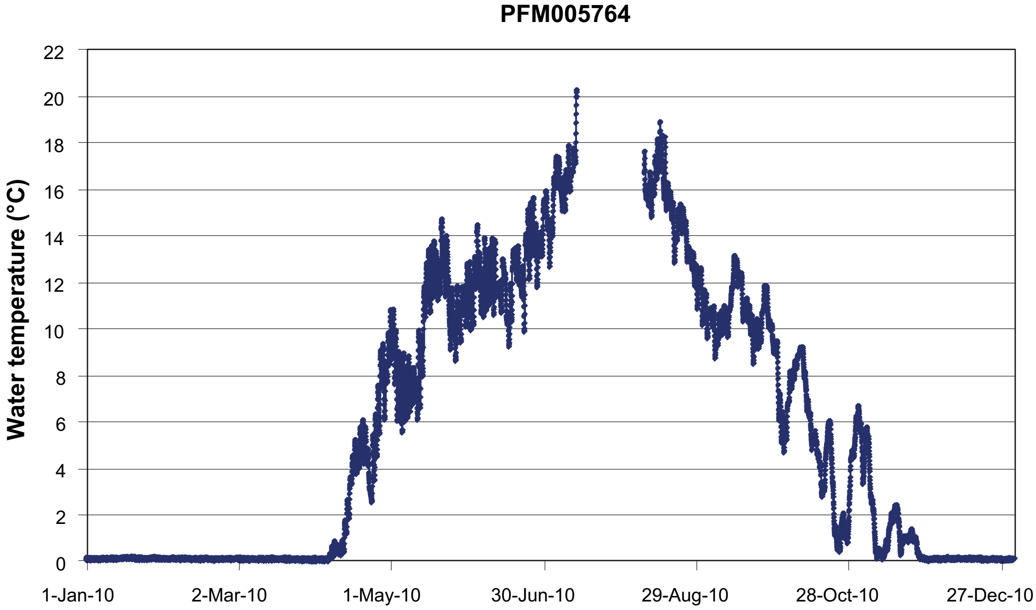


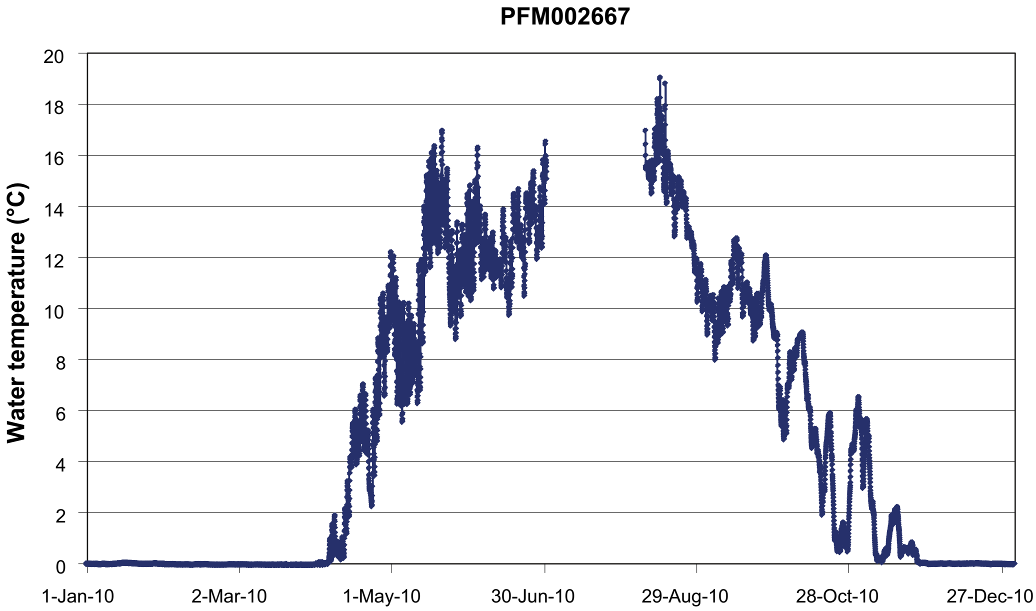

PFM002668
Water electrical conductivity (mS/m)
0
5
10
15
20
25
30
35
40
1-Jan-10
2-Mar-10
1-May-10
30-Jun-10
29-Aug-10
28-Oct-10
27-Dec-10

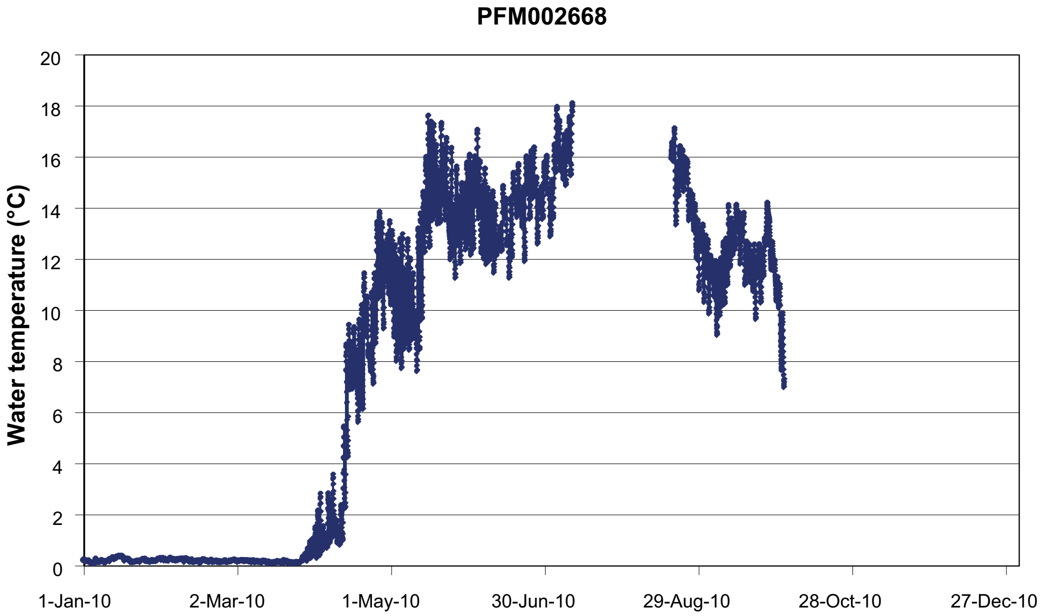

PFM002669
Water electrical conductivity (mS/m)
0
5
10
15
20
25
30
35
40
45
50
1-Jan-10
2-Mar-10
1-May-10
30-Jun-10
29-Aug-10
28-Oct-10
27-Dec-10

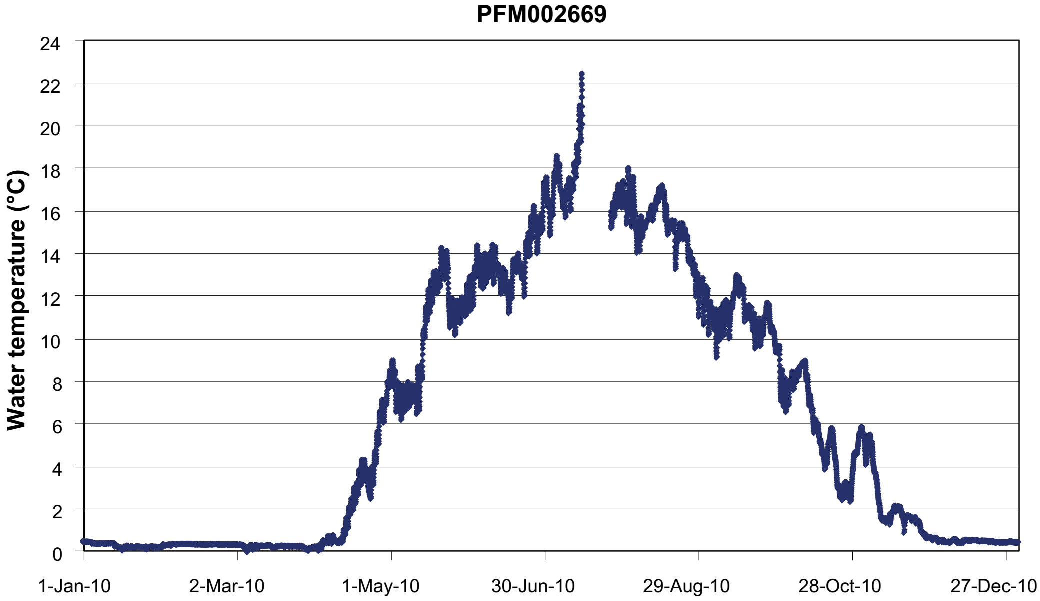
Appendix 3

Water temperatures at the four gauging stations

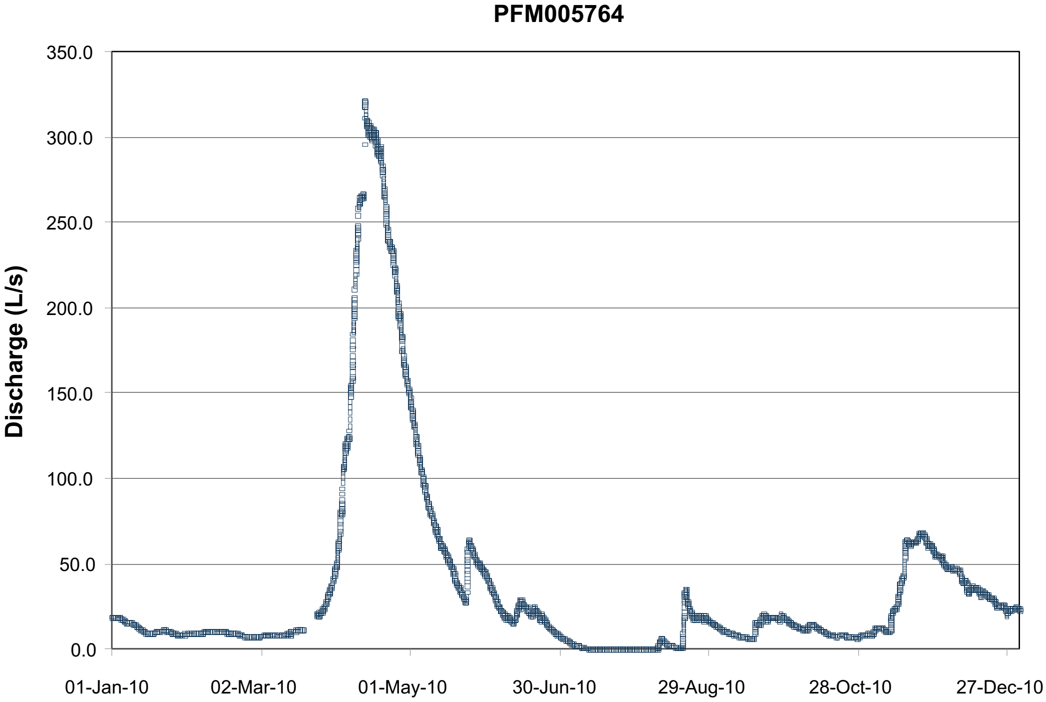


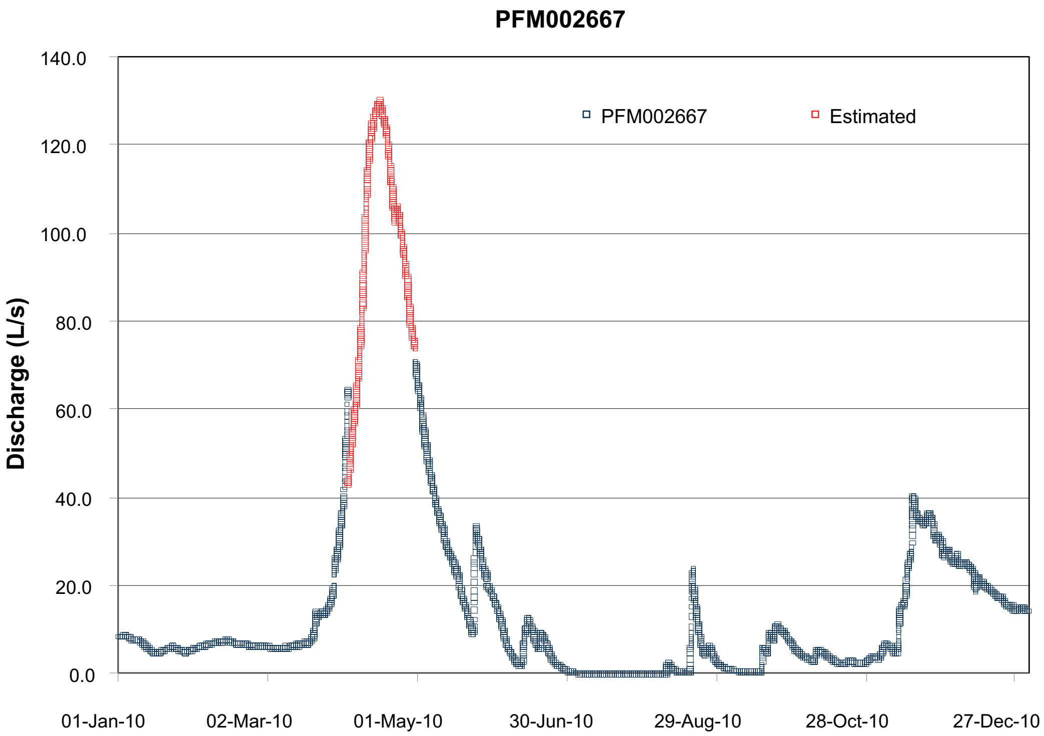


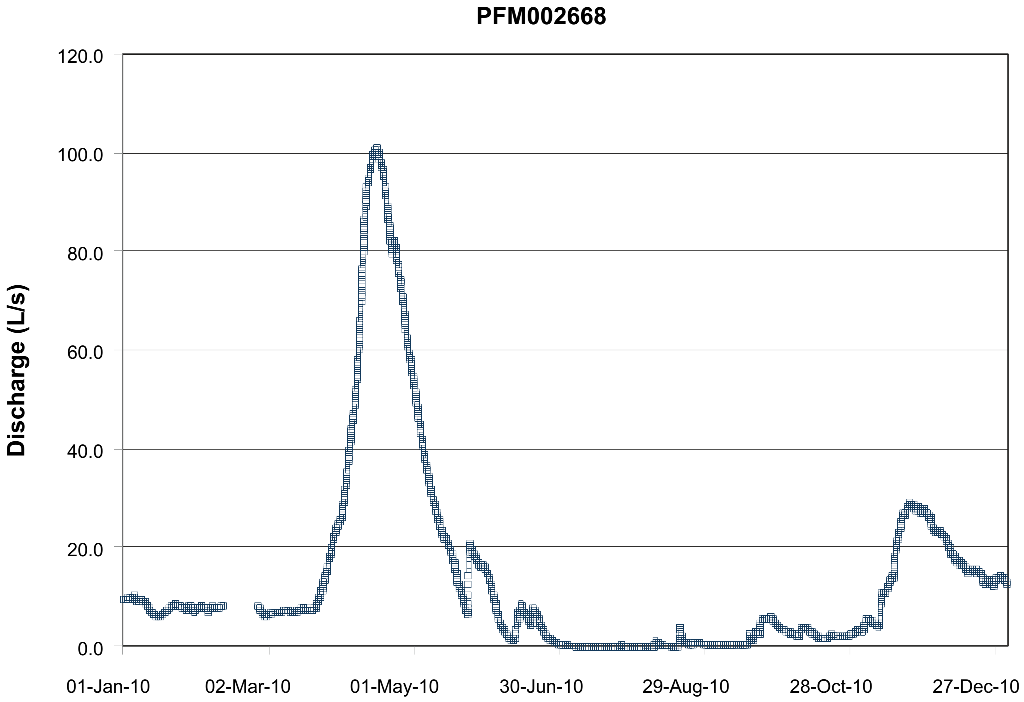

PFM002668
Water temperature (°C)
20
18
16
14
12
10
8
6
4
2
0
1-Jan-10
2-Mar-10
1-May-10
30-Jun-10
29-Aug-10
28-Oct-10
27-Dec-10

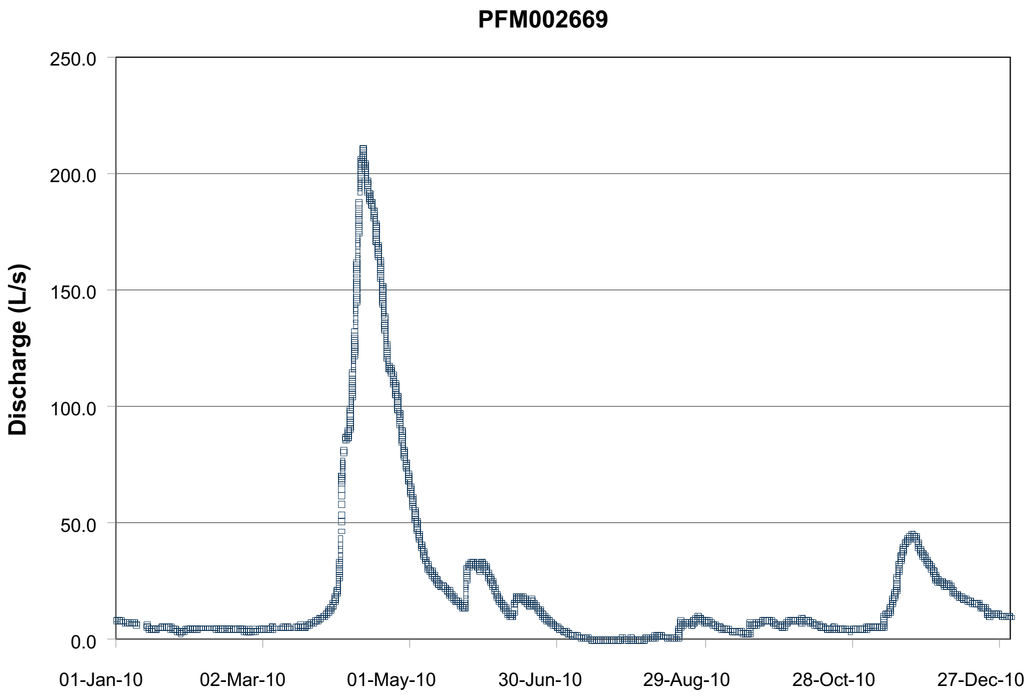

PFM002669
Water temperature (°C)
24
22
20
18
16
14
12
10
8
6
4
2
0
1-Jan-10
2-Mar-10
1-May-10
30-Jun-10
29-Aug-10
28-Oct-10
27-Dec-10

Calculated discharge time series at the four gauging stations






PFM002668
Discharge (L/s)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
01-Jan-10
02-Mar-10
01-May-10
30-Jun-10
29-Aug-10
28-Oct-10
27-Dec-10


PFM002669
Discharge (L/s)
250.0
200.0
150.0
100.0
50.0
0.0
01-Jan-10
02-Mar-10
01-May-10
30-Jun-10
29-Aug-10
28-Oct-10
27-Dec-10