P-10-44

Forsmark site investigation

Monitoring of brook water levels, electrical conductivities, temperatures and discharges January–December 2009

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March 2011

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Keywords: AP PF 400-08-009, Gauging stations, Long-throated flumes, Water level, Electrical conductivity, Temperature, Discharge.

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 2009 and is a continuation of reporting from Johansson and Juston (2007, 2009), which covered the periods from 1 April 2004 through 31 March 2007 and 1 April 2007 through 31 December 2008, 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 0.26–0.33 m at the four stations. The mean electrical conductivities varied between 26 and 41 mS/m at the four discharge stations. The electrical conductivity at the outlet of Lake Bolundsfjärden varied between 53 and 188 mS/m during the period with the higher values at the end of the year and was on average 113 mS/m. 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) was 109 L/s and for the smallest catchment 38.2 L/s (gauging station PFM002668). The station PFM002667 was the only station that had a period with zero discharge; Sep. 19 – Oct. 8. However, the discharges in all stations were very low in late September and early October. The specific discharge for the largest catchment was 4.74 L/s/km^2 (149 mm/yr) which is close to the estimated longterm average of 150–160 mm/yr. The specific discharge for the largest catchment, averaged over the five-year period 2005–2009 was 5.81 L/s/km^2 (183 mm/yr). The station with the lowest specific discharge during 2009 was PFM002667; 3.79 L/s/km^2 (120 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 2009-01-01–2009-12-31. Tidigare mätningar, från perioderna 2004-04-04–2007-03-31 och 2007-04-01–2008-12-31, redovisades i Johansson och Juston (2007, 2009).

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 0,26–0,33 m. Medelvärdena för den elektriska ledningsförmågan i de fyra stationerna varierade mellan 26 och 41 mS/m. I Bolundsfjärdens utlopp varierade den elektriska ledningsförmågan under året mellan 53 mS/m och 188 mS/m med de högre värdena under senare delen av året och medelvärdet var 113 mS/m. Vattentemperaturerna varierade från ca 0 °C under vintern upp till ca 20 °C under varma sommardagar med låga vattenflöden.

Den högsta uppmätta vattenföringen för det största avrinningsområdet (mätstation PFM005764) var 109 L/s och för det minsta 38,2 L/s (mätstation PFM002668). Stationen PFM002667 var den enda av stationerna som hade en period med 0-flöde; 19 sept – 8 okt. Flödena var emellertid mycket små i samtliga mätstationer under senare delen av september och i början av oktober. Den specifika avrinningen för det största avrinningsområdet var 4,74 L/s/km^2 (149 mm/år) vilket är nära det uppskattade långtidsmedelvärdet av 150–160 mm/år. Den specifika avrinningen för det största avrinningsområdet för femårsperioden 2005–2009 var 5,81 L/s/km^2 (183 mm/yr). Mätstationen med lägst specifik avrinning under 2009 var PFM002667; 3,79 L/s/km^2 (120 mm/yr).

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 2009. The report presents continuations of time series data reported in P-07-135 (Johansson and Juston 2007) and P-09-68 (Johansson and Juston 2009). Monitoring these time series data is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-08-009. 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 is located at the outlet of Lake Bolundsfjärden and 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.

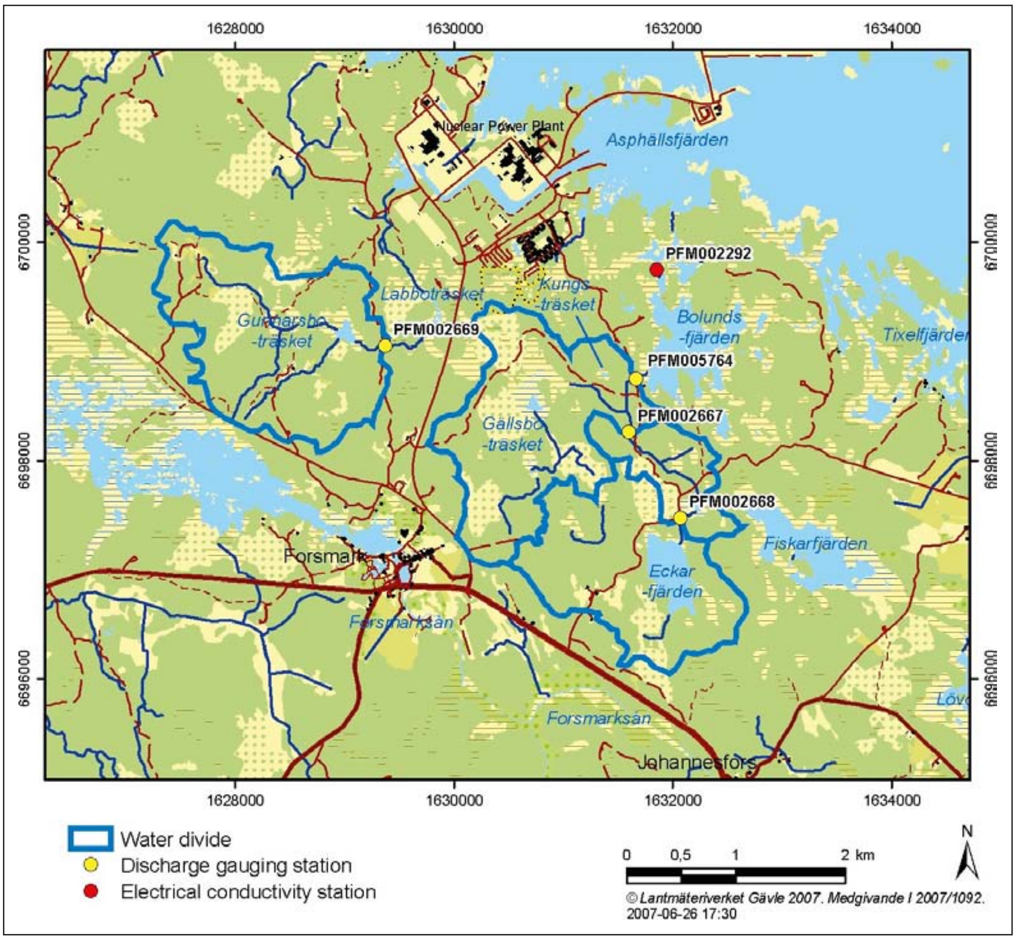
SKB's Hydro Monitoring System (HMS) was used to collect and store all data. From HMS quality assured data were transferred to SKB's primary database Sicada, where they are traceable by the Activity Plan numbers. Only data in Sicada are accepted for further interpretation and modelling. The data presented 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 2009.	AP PF 400-08-009	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: september 2008 – januari 2009.	PIR-09-05	
Platsprojekt Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering. Period: januari – maj 2009.	SKBdoc id 1292846	
Platsprojekt Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering. Period: maj – september 2009.	PIR-09-13	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering. Period: september 2009 – februari 2010.	SKBdoc id 1292882	

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



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2007-06-26 17:30

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

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.

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.

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.*

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

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 – +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.

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)	$Q = 864.9 \cdot h^{2.576}$	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

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

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 was not reached 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.

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 discharge was 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.

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 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.

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.
- Each 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 2008 for each discharge time series in P-07-135 and P-09-68 and for the period January – December 2009 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.

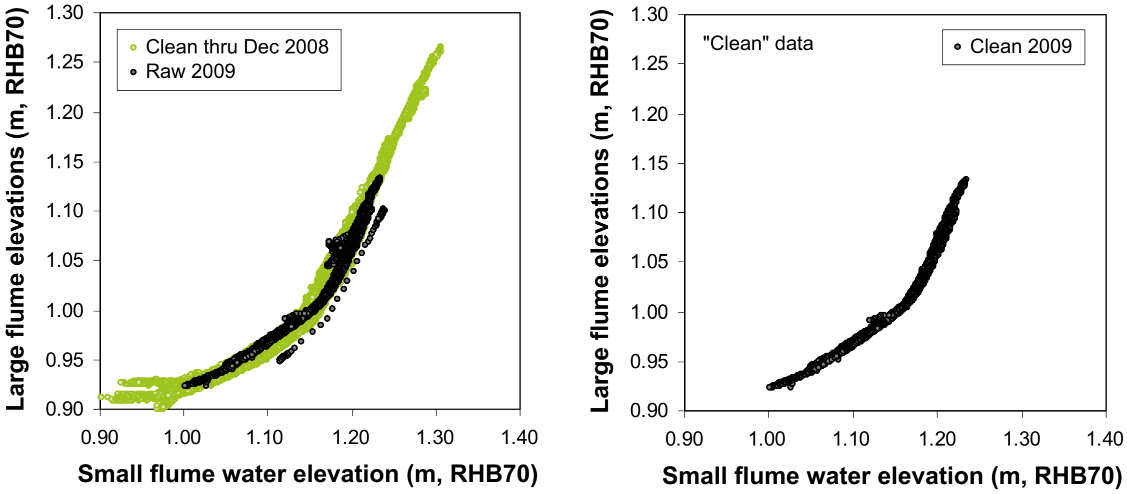


Figure 4-1. *A comparison of cross-plots between small and large flume water levels at PFM005764, before and after data screening, shown as an example of the data screening and scrutiny process. A consistent relationship between the flume water elevations would be expected if both sensors were properly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

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. Light brown shading highlighting indicates intervals with data removal, and light green shading indicates data addition based on a calibrated regression model.

Dates	Affected data points from small flume	Affected data points from large flume	Action
2009/1/4–21		420	Removed: inconsistent.
2009/1/4–2/14		983	Added: response modelled based on regression to small flume data.
2009/6/10–17	160		Removed: appeared stuck.

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. Light green shading indicates data addition based on a calibrated regression model.

Dates	Affected data points from small flume	Affected data points from large flume	Action
2009/1/23 – 3/10	5		5 data points added from manually measured gauge heights to fill in an ~8-weeks data gap.

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	Action
No treatment required.		

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 2009 by the Activity Leader. Cross-checking was performed between the discharge stations for preliminary calculated discharges (i.e. water level data), electrical conductivities and temperatures. The cross-checking 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	090116 14:32:10	Single outlying value.
PFM005764 small	Level	090201 00:08:00 – 090201 05:28:00	Short period of outlying values.
PFM005764 small	Level	090214 13:41:40	Single outlying value.
PFM005764 small	Level	090214 14:11:40	Single outlying value.
PFM005764 small	Level	090215 15:41:40 – 090221 23:31:40	Disturbed values due to ice.
PFM005764 small	Level	090314 04:41:40 – 090314 05:01:40	Single outlying values.
PFM005764 small	Level	090716 12:01:40 – 090716 12:21:40	Disturbed values, cleaning of flume.
PFM005764 small	Level	090824 13:21:40 – 090826 11:45:40	Debris in flume. Cleaned.
PFM005764 small	Level	091219 08:10:00 – 091220 05:00:00	Disturbed values.
PFM005764 small	Level	091223 04:40:00 – 091223 11:30:00	Flume blocked by ice. Cleaned.
PFM005764 large	Level	090115 00:01:40 – 090121 11:41:40	Rising level before sensor failure.
PFM005764 large	Level	090602 14:15:20	Single outlying value.
PFM005764 large	Level	090610 19:22:00 – 090610 20:52:00	Single outlying values.
PFM005764 large	Level	090716 12:01:40 – 090716 12:21:40	Disturbed values, cleaning of flume.
PFM005764 large	Level	090727 09:01:40	Single outlying value.
PFM005764 large	Level	090824 13:21:40 – 090824 14:41:40	Single low values caused by debris in PFM005764 small.
PFM005764 large	Level	090826 10:55:40 – 090826 11:45:40	Single high values caused by cleaning of debris in PFM005764 small.
PFM005764 large	Level	090901 09:31:40 – 090901 11:31:40	Single outlying values.
PFM005764 large	Level	090909 18:01:40 – 091017 04:30:00	Level not representative for brook water level.
PFM005764 large	Level	091223 04:40:00 – 091223 11:30:00	Flume blocked by ice? Cleaned.

Flume	Parameter	Dates (YYMMDD hh:mm:ss	Reason for removal
PFM005764 large	Level	091231 11:20:00 – 091231 14:40:00	Single outlying values.
PFM005764	EC	090411 04:51:40	Single outlying value.
PFM005764	EC	090515 11:31:50	Single outlying value.
PFM005764	EC	090604 00:05:20 – 090915 14:11:40	Unreasonably low and unstable values.
PFM005764	EC	090929 09:01:40	Disturbed value. Cleaning of sensor.
PFM005764	EC	091223 02:20:00	Single outlying value.
PFM002667 small	Level	090918 23:34:50 – 091008 01:35:00	Level not representative for brook water level.
PFM002667 small	Level	091219 01:00:00 – 091219 06:30:00	Disturbed values. Ice?
PFM002667 large	Level	090313 09:45:40	Single outlying value.
PFM002667 large	Level	090314 04:06:00 – 090314 05:26:00	Single outlying values.
PFM002667 large	Level	090526 12:45:00	Single outlying value.
PFM002667 large	Level	090722 10:25:10	Single outlying value.
PFM002667 large	Level	090727 09:19:32	Single outlying value.
PFM002667 large	Level	090813 01:45:30 – 090818 15:25:30	Level not representative for brook water level.
PMM002667 large	Level	090907 08:49:32 – 090911 23:59:32	Level not representative for brook water level.
PFM002667 large	Level	091219 01:00:00 – 091219 14:00:00	Disturbed values. Ice?
PFM002667	EC	090414 23:25:10	Single outlying value.
PFM002667	EC	090425 21:35:30	Single outlying value.
PFM002667	EC	090519 11:35:00 – 091231 23:59:48	Unreasonably low and unstable values.
PFM002667	Temp	090918 23:34:50 – 091008 01:35:00	No or too low flow.
PFM002668	Level	090109 11:22:50	Single outlying value.
PFM002668	Level	090109 14:52:50	Single outlying value.
PFM002668	Level	090118 03:33:00 – 090118 09:13:00	Disturbed values. Ice?
PFM002668	Level	090131 22:23:10 – 090201 10:23:10	Disturbed values. Ice?
PFM002668	Level	090205 13:03:10 – 090205 13:13:10	Single outlying values.
PFM002668	Level	090209 02:52:50 – 090209 09:12:50	Disturbed values. Ice?
PFM002668	Level	090215 18:13:20 – 090216 13:33:20	Disturbed values. Ice?
PFM002668	Level	090219 14:59:10 – 090220 15:13:00	Disturbed values. Ice?
PFM002668	Level	090311 07:43:00 – 090311 08:53:00	Single outlying values.
PFM002668	Level	090312 09:13:20 – 090312 10:43:30	Single outlying values.
PFM002668	Level	090326 22:13:30 – 090327 08:43:30	Disturbed values. Ice?
PFM002668	Level	090717 09:43:00	Disturbed value. Cleaning of flume.
PFM002668	Level	090731 11:23:00	Single outlying value.
PFM002668	Level	090816 11:33:20	Single outlying value.
PFM002668	Level	090917 10:33:10 – 090917 12:23:10	Single outlying values.
PFM002668	Level	090929 14:03:20 – 091001 14:13:20	Disturbed values?
PFM002668	Level	091008 20:39:30	Single outlying value.
PFM002668	Level	091012 11:09:30 – 091013 12:53:00	Disturbed values?
PFM002668	Level	091219 01:10:00 – 091220 09:00:00	Disturbed values. Ice?
PFM002668	EC	090111 21:23:00 – 090117 10:53:00	Unreasonable drop in values.
PFM002668	EC	090120 14:43:20 – 090218 23:53:30	Unreasonably low values.

Flume	Parameter	Dates (YYMMDD hh:mm:ss	Reason for removal
PFM002668	EC	090316 21:33:10 – 090929 14:03:20	Unreasonably unstable and low values.
PFM002668	EC	091224 10:50:00 – 091231 14:10:00	Unreasonably high values.
PFM002668	EC	091217 08:00:00	Single outlying value.
PFM002668	EC	091224 03:00:00	Single outlying value.
PFM002669 small	Level	090716 11:11:50	Disturbed value. Cleaning of flume.
PFM002669 small	Level	090831 09:09:30 – 090831 11:29:30	Disturbed values. Flume maintenance.
PFM002669 small	Level	091219 20:40:00 – 091219 22:00:00	Single outlying values.
PFM002669 small	Level	091224 18:40:00 – 091224 19:40:00	Disturbed values. Ice?
PFM002669 large	Level	090113 07:14:30	Single outlying value.
PFM002669 large	Level	090116 06:30:00 – 090116 13:10:00	Disturbed values.
PFM002669 large	Level	090206 10:04:30	Single outlying value.
PFM002669 large	Level	090210 16:54:50 – 090211 10:24:50	Disturbed values. Ice?
PFM002669 large	Level	090214 04:04:50 – 090216 10:54:20	Disturbed values. Ice?
PFM002669 large	Level	090218 19:54:50 – 090223 10:24:10	Disturbed values. Ice. Flume cleaned 090223.
PFM002669 large	Level	090222 21:54:10 – 090222 23:14:10	Disturbed values. Ice?
PFM002669 large	Level	090223 10:04:10	Single outlying value.
PFM002669 large	Level	090716 11:11:50 – 090716 11:21:50	Disturbed values. Cleaning of flume.
PFM002669 large	Level	090731 10:44:10	Single outlying value.
PFM002669 large	Level	090804 09:54:10	Single outlying value.
PFM002669 large	Level	090826 09:49:30	Single outlying value.
PFM002669 large	Level	090831 09:09:30 – 090831 14:09:30	Disturbed values. Flume maintenance.
PFM002669 large	Level	091012 13:24:30 – 091012 13:34:30	Single outlying values.
PFM002669 large	Level	091102 13:30:00	Single outlying value.
PFM002669 large	Level	091224 18:10:00 – 091224 19:30:00	Disturbed values. Ice?
PFM002669	EC	090514 07:31:40	Single outlying value.
PFM002669	EC	090526 03:13:50	Single outlying value.
PFM002669	EC	090716 17:31:50 – 090929 09:21:20	Unreasonably low values.
PFM002669	EC	091004 15:33:40 – 091004 17:33:40	Single outlying values.
PFM002669	EC	091005 00:23:40 – 091005 00:33:40	Single outlying values.
PFM002669	EC	091005 02:13:40 – 091005 02:23:40	Single outlying values.
PFM002669	EC	091005 03:23:40	Single outlying value.
PFM002669	EC	091014 12:24:10 – 091014 12:34:10	Single outlying values.
PFM002669	EC	091025 20:30:00 – 091025 20:40:00	Single outlying values.
PFM002292	EC	090602 15.37:00 – 090610 09:02:00	Unreasonably low values.
PFM002292	EC	090708 05:09:00 – 090914 13:44:20	Unreasonably low values. Sensor cleaned 090914.
PFM002292	EC	091118 14:00:00	Single outlying value.

4.5 Nonconformities

There were intervals of missing data in most time series, ranging from several days to months, due to mal-functioning equipment.

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.

Amplitudes of water level variations were 0.26–0.33 m at the four stations. The mean water elevations for the three stations located in the same catchment were from the downstream station PMF005764, via PFM002667, to the upstream station PFM002668, 1.11, 1.66 and 4.43 m RHB70, respectively, for the January to December 2009 period (small flume data; levels below zero discharge not included) and 1.12, 1.67, and 4.44 m, respectively, for the entire period of record (for PFM005764 only data from after re-installation in October 2004 were used). The temporal variations of the water levels at PFM002669, located in a separate catchment, were approximately 0.32 m, and the mean water elevation was 6.02 m RHB70 for January to December 2009 and 6.04 m RHB70 for the period of record.

5.3 Electrical conductivity

Water electrical conductivities from the four discharge gauging stations and the electrical conductivity monitoring station at the outlet of Lake Bolundsfjärden are shown in Appendix 2. The data are hourly values.

The gaps in the data series of PFM005764, PFM002667, PFM002668 and PFM002669 found were mainly due 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 38, 28, 26 and 41 mS/m, respectively, during this reporting period. The corresponding mean values for the whole period since the measurements started were 38, 27, 25 and 38 mS/m.

The electrical conductivity at the outlet of Lake Bolundsfjärden varied between 53 and 188 mS/m during the period with the higher values at the end of the year and was on average 113 mS/m.

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 of PFM002667 found during September–October 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 various time periods of available data.

The highest recorded discharge of the largest catchment (gauging station PFM005764) was 278 L/s and for the smallest catchment 102 L/s (gauging station PFM002668). All stations had close to zero or zero discharge for relatively long periods in late summers and early autumns. The mean specific discharge for the largest catchment, averaged over the five-year reporting period of Jan. 2005 – Dec. 2009, was 5.81 L/s/km^2 (183 mm). The maximum single year specific discharges were observed during 2008 at all stations with range between 9.67–11.7 L/s/km^2 (308–369 mm/yr). Inter-station variability for specific discharge in longterm and annual data records was less than about 15% in all cases.

Peak discharges at all stations occurred in the vicinity of December 14–15, 2008. Prior to this event, highest measured flows occurred at all stations in the vicinity of April 19–21, 2006. Peak discharge values are given by calendar year in Table 5-1.

Table 5-1. Discharge characteristics for the four gauging stations for various time periods based on hourly averaged values.

	PFM005764	PFM002667	PFM002668	PFM002669
Jan. 1 2005 – Dec. 31, 2009				
Mean discharge (L/s)	32.5	15.6*	11.9	17.0
Min. discharge (L/s)	0.00	0.00	0.00	0.00
Max. discharge (L/s)	278	131	102	183
Specific discharge (L/s/km^2)	5.81	5.18	5.20	6.01
Specific discharge (mm/yr)	183	163	164	190
Jan. 1 – Dec. 31, 2005				
Mean discharge (L/s)	25.2	12.1	9.09	11.6
Min. discharge (L/s)	0.0	0.00	0.00	0.00
Max. discharge (L/s)	85.3	43.7	31.8	60.7
Specific discharge (L/s/km^2)	4.51	4.01	3.99	4.10
Specific discharge (mm/yr)	142	127	126	129
Jan. 1 – Dec. 31, 2006				
Mean discharge (L/s)	32.9	17.1	12.1	17.4
Min. discharge (L/s)	0.0	0.00	0.00	0.00
Max. discharge (L/s)	212	131	75.9	183
Specific discharge (L/s/km^2)	5.89	5.67	5.31	6.13
Specific discharge (mm/yr)	186	179	167	193
Jan. 1 – Dec. 31, 2007				
Mean discharge (L/s)	17.9	8.3	6.2	9.87
Min. discharge (L/s)	0.00	0.00	0.00	0.00
Max. discharge (L/s)	80.9	38.9	32.1	60.2
Specific discharge (L/s/km^2)	3.20	2.75	2.74	3.48
Specific discharge (mm/yr)	101	87.0	86.0	110
Jan. 1 – Dec. 31, 2008				
Mean discharge (L/s)	59.9	29.1 *	22.3	33.2
Min. discharge (L/s)	0.00	0.00	0.00	0.00
Max. discharge (L/s)	278	132 *	102	164
Specific discharge (L/s/km^2)	10.7	9.67 *	9.76	11.7
Specific discharge (mm/yr)	338	305 *	308	369
Jan 1 – Dec 31, 2009				
Mean discharge (L/s)	26.5	11.4	9.66	13.2
Min. discharge (L/s)	0.00	0.00	0.10	0.10
Max. discharge (L/s)	109	51.7	38.2	84.5
Specific discharge (L/s/km^2)	4.74	3.79	4.24	4.64
Specific discharge (mm/yr)	149	120	134	146

* These values are estimates and are provided as a service to the reader. There were missing data in the PFM002667 time series during a peak flow event Nov. 27 – Dec. 26 2008 due to a lack of critical flow conditions for the discharge equation in Table 3-2. Flow at PFM002667 was estimated during this interval from a linear regression to upstream flows at PFM002668. The regression had a high coefficient of correlation (R^2=0.97) and maintained the mean discharge at PFM002667 during validation intervals when data were present at both stations.

6 References

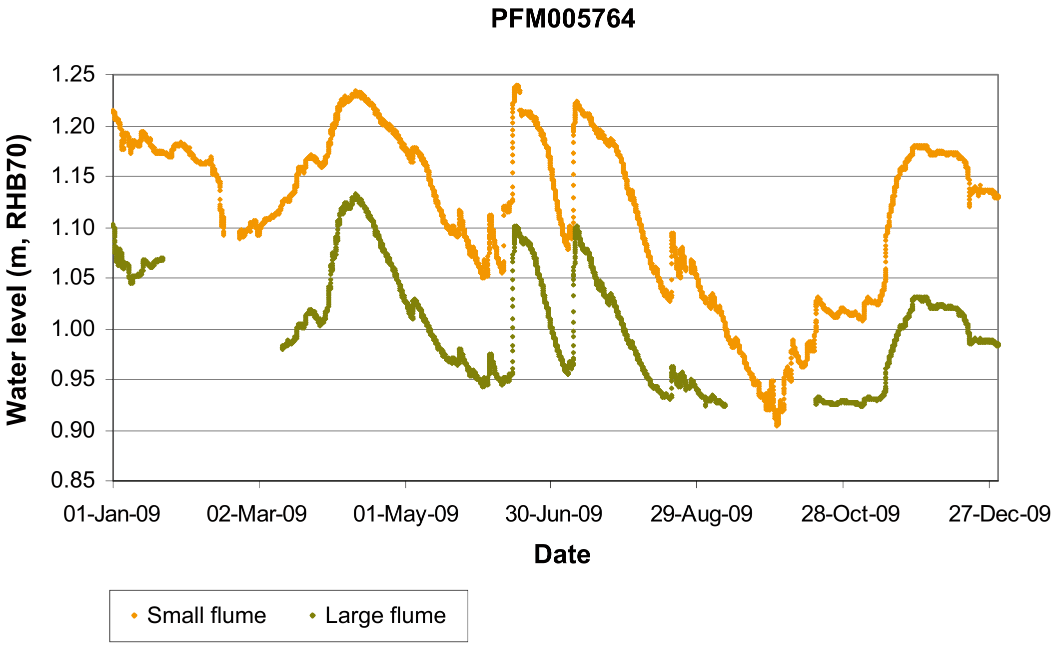
SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications.

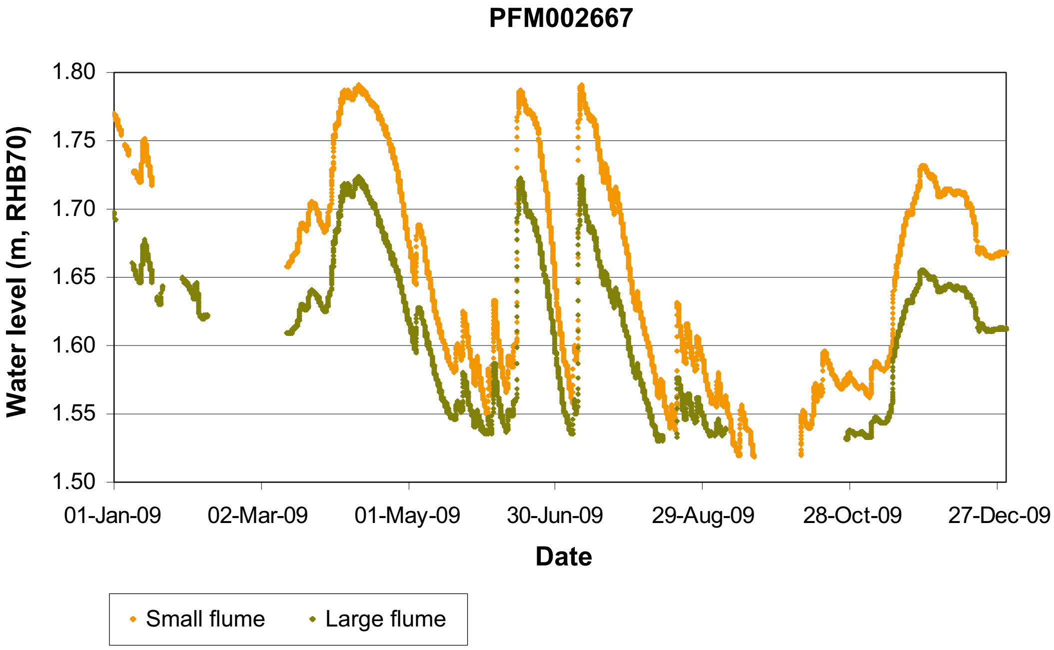
Johansson P-O, 2005. Forsmark site investigation. Installation of brook discharge gauging stations. SKB P-05-154, Svensk Kärnbränslehantering AB.

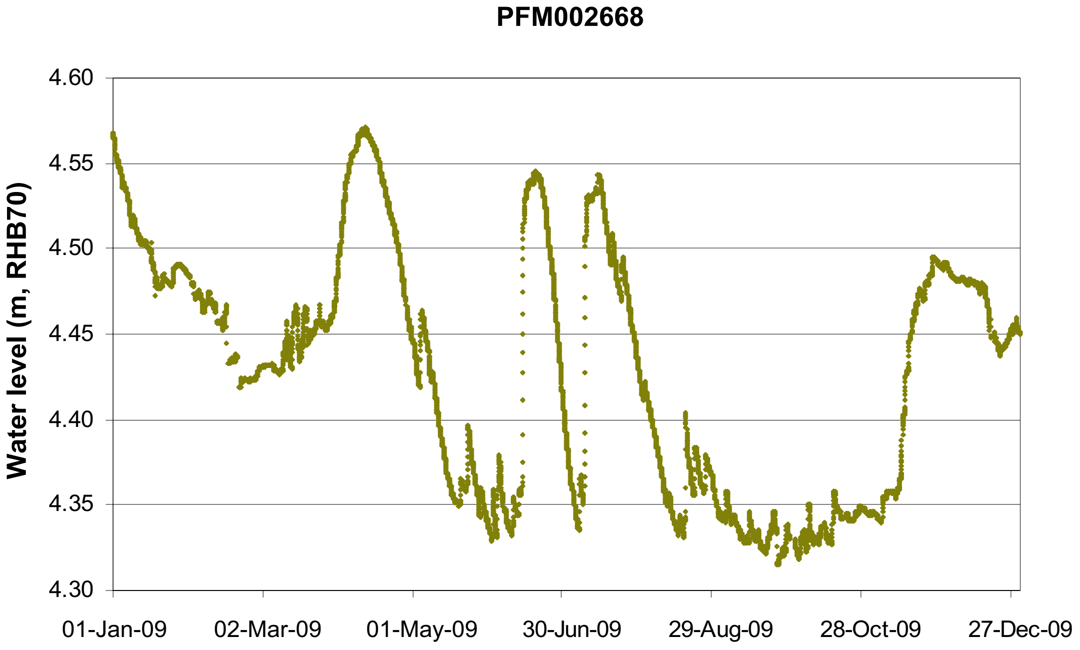
Johansson P-O, Juston J, 2007. Forsmark site investigation. Monitoring of brook levels, water electrical conductivities, temperatures and discharges from April 2004 until March 2007. (Revised May 2010.) SKB P-07-135, Svensk Kärnbränslehantering AB.

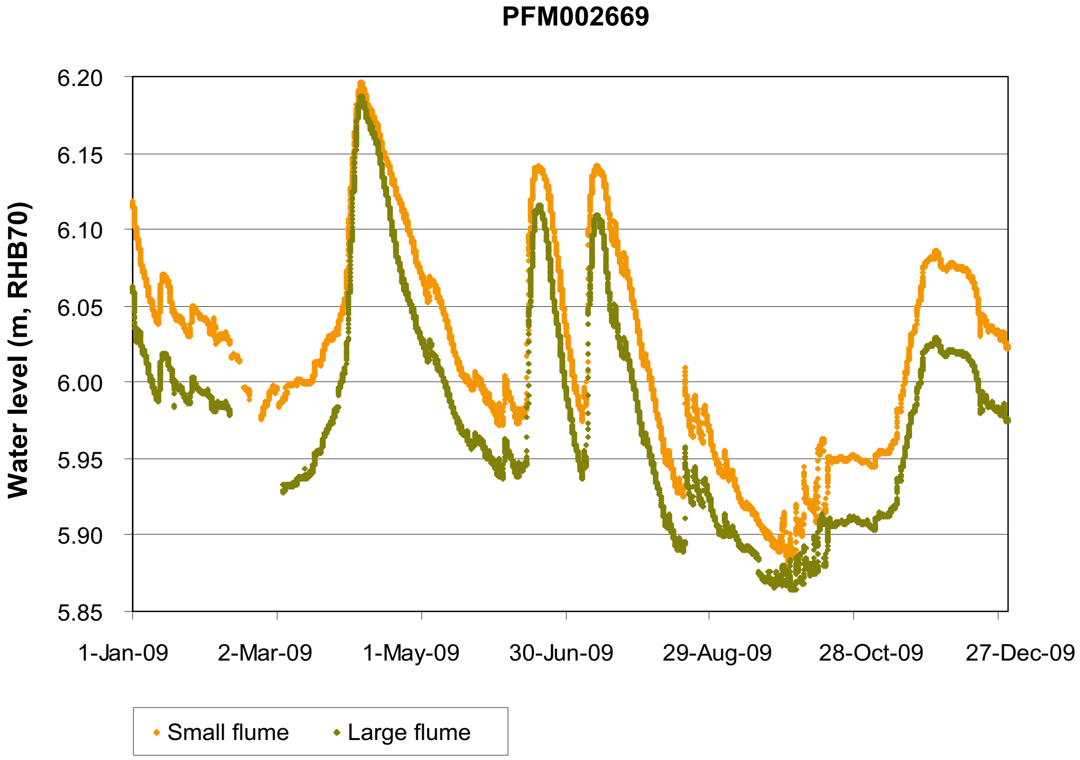
Johansson P-O, Juston J, 2009. Forsmark site investigation. Monitoring of brook water levels, electrical conductivities, temperatures and discharges from April 2007 until December 2008. SKB P-09-68, Svensk Kärnbränslehantering AB.

Water levels at the four gauging stations



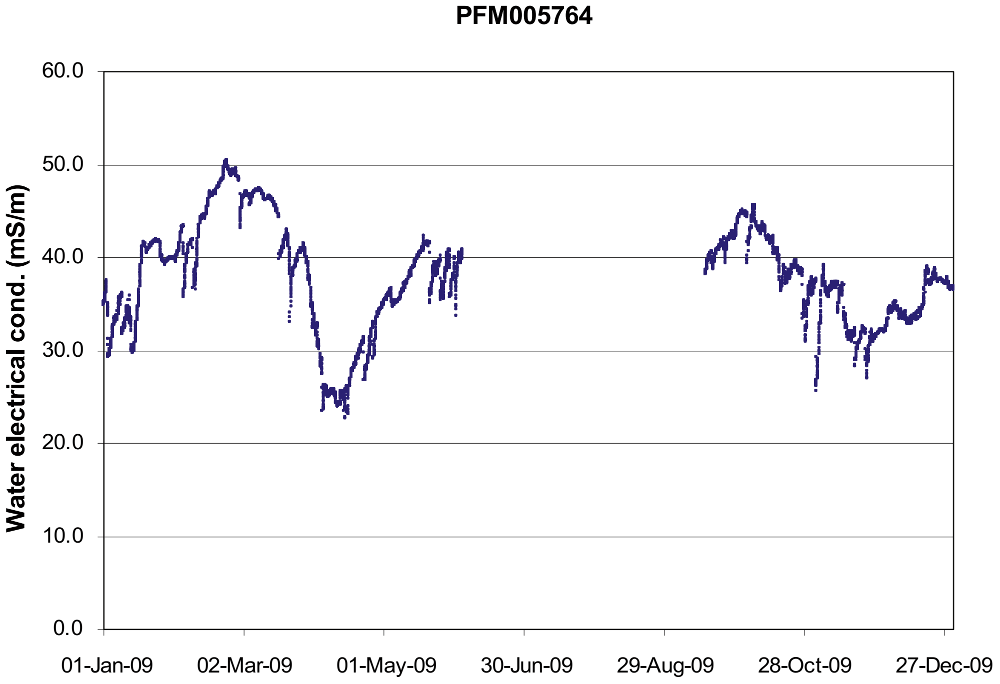


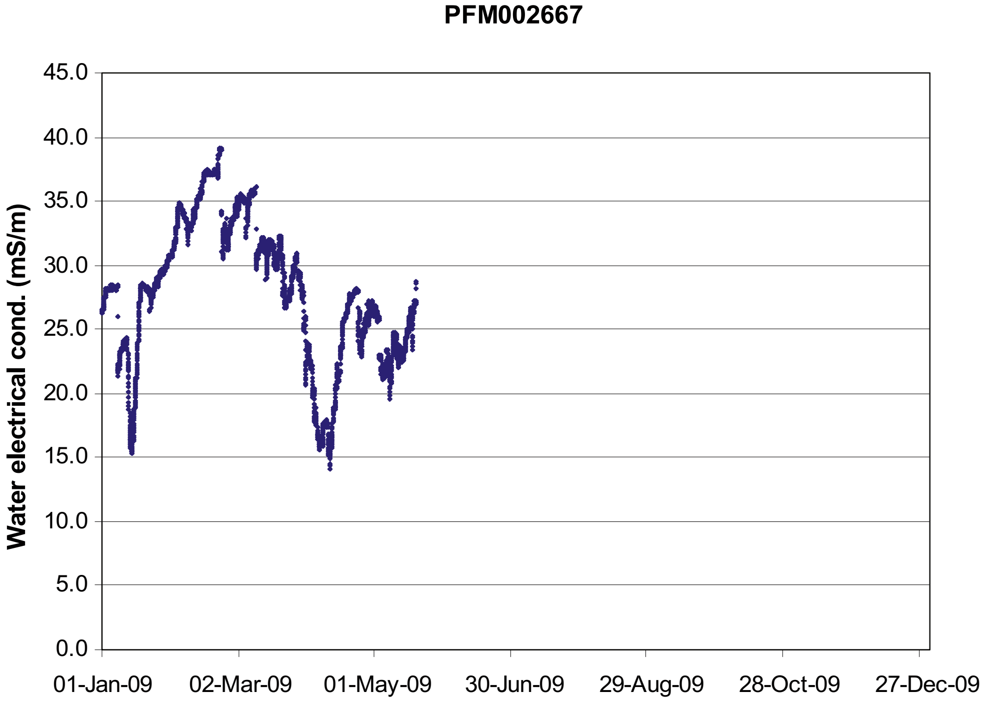

PFM002668
Water level (m, RHB70)
4.60
4.55
4.50
4.45
4.40
4.35
4.30
01-Jan-09
02-Mar-09
01-May-09
30-Jun-09
29-Aug-09
28-Oct-09
27-Dec-09

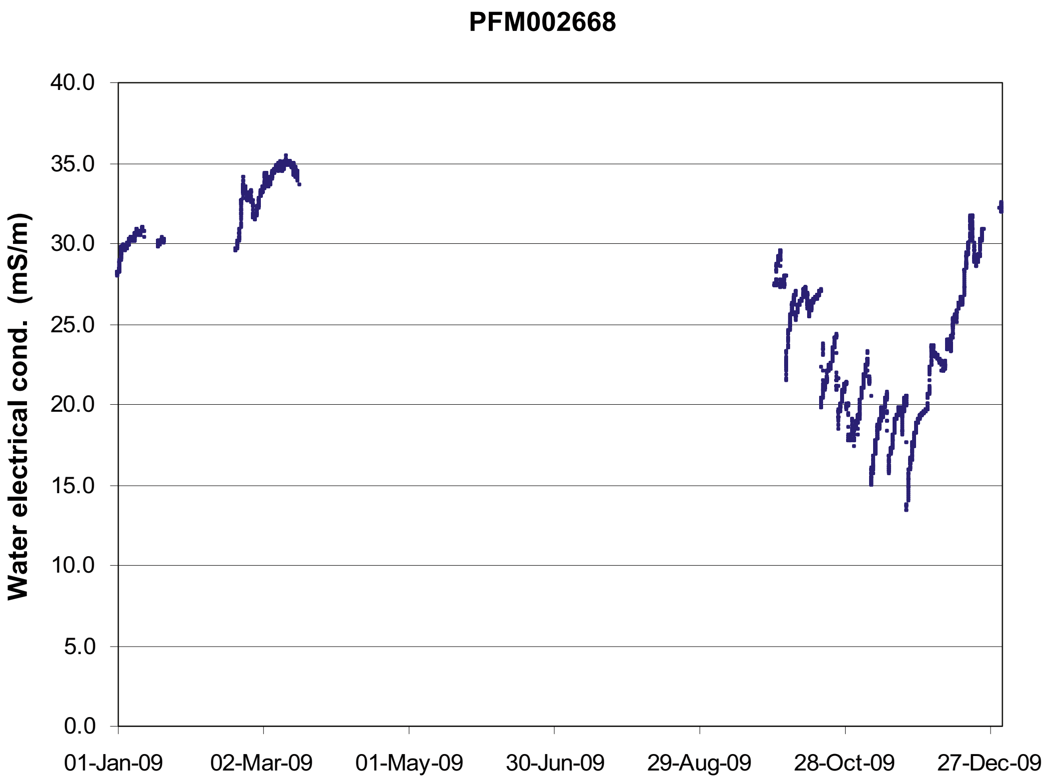

PFM002669
Water level (m, RHB70)
6.20
6.15
6.10
6.05
6.00
5.95
5.90
5.85
1-Jan-09
2-Mar-09
1-May-09
30-Jun-09
29-Aug-09
28-Oct-09
27-Dec-09
Small flume
Large flume

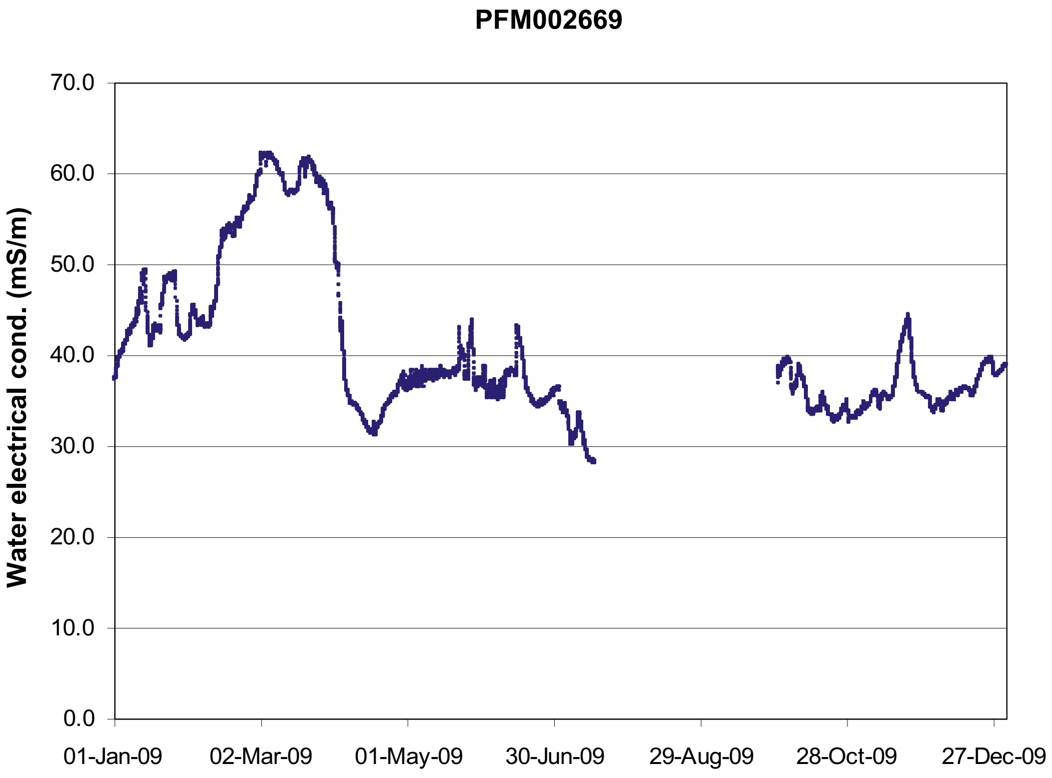
Appendix 2

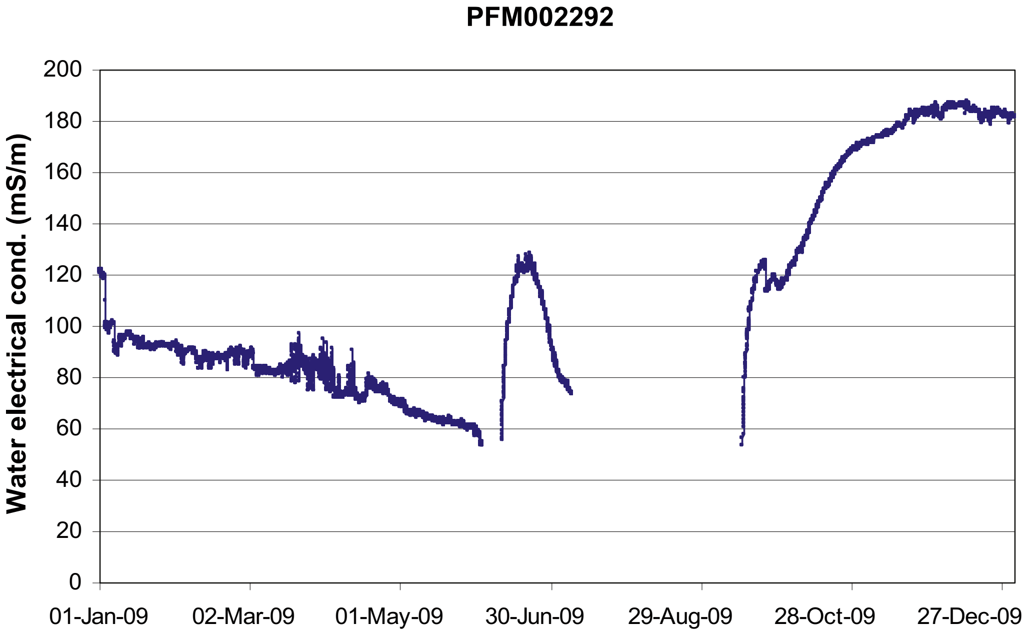
Water electrical conductivities at the four gauging stations and at the outlet of Lake Bolundsfjärden



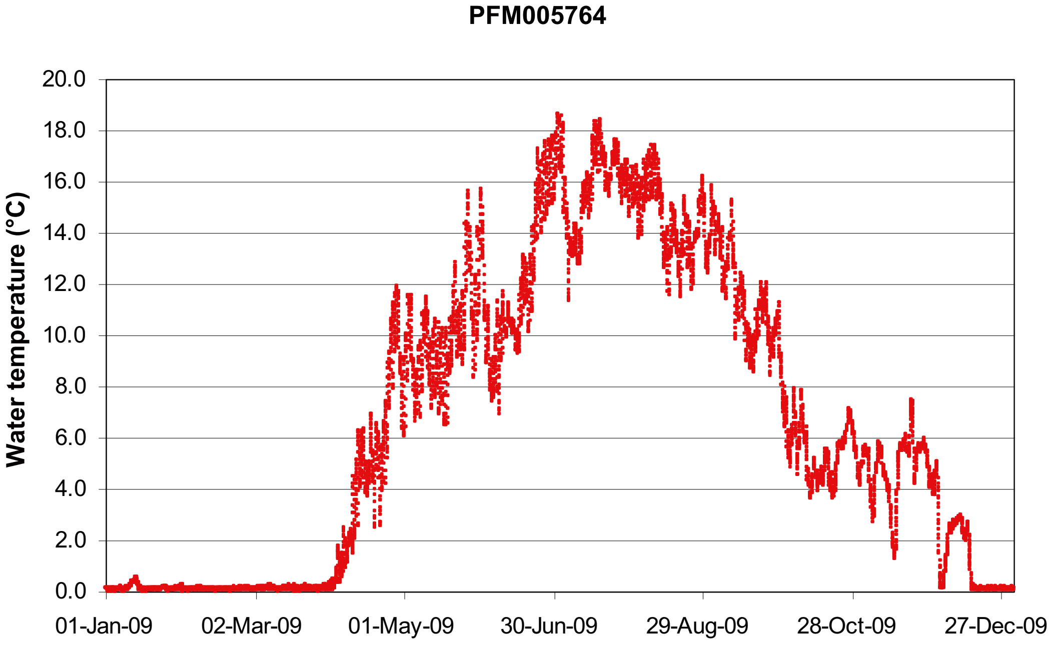


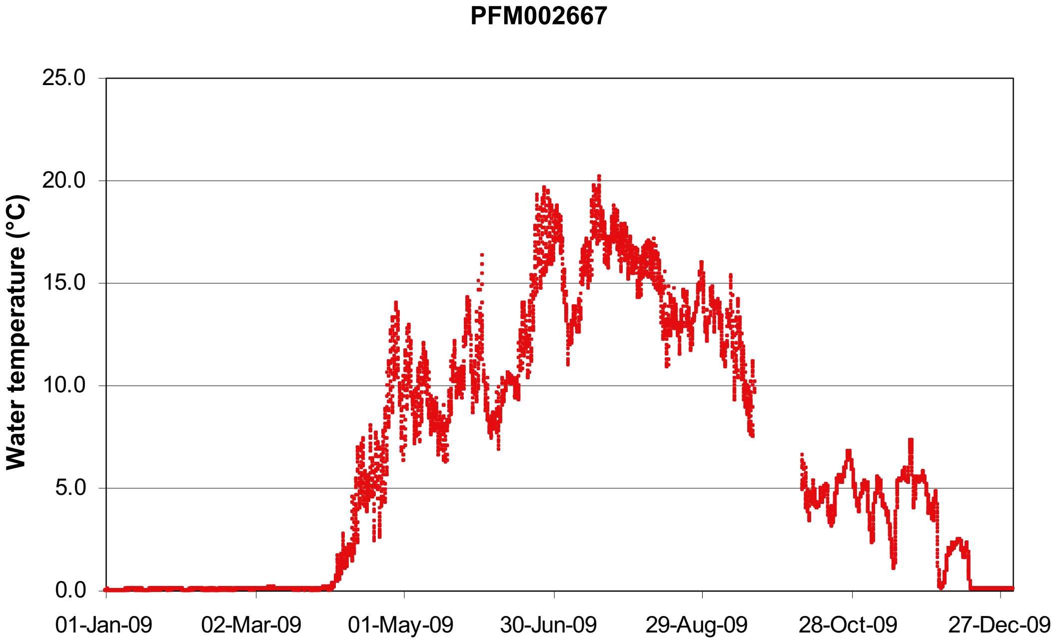

PFM002668
Water electrical cond. (mS/m)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
01-Jan-09
02-Mar-09
01-May-09
30-Jun-09
29-Aug-09
28-Oct-09
27-Dec-09

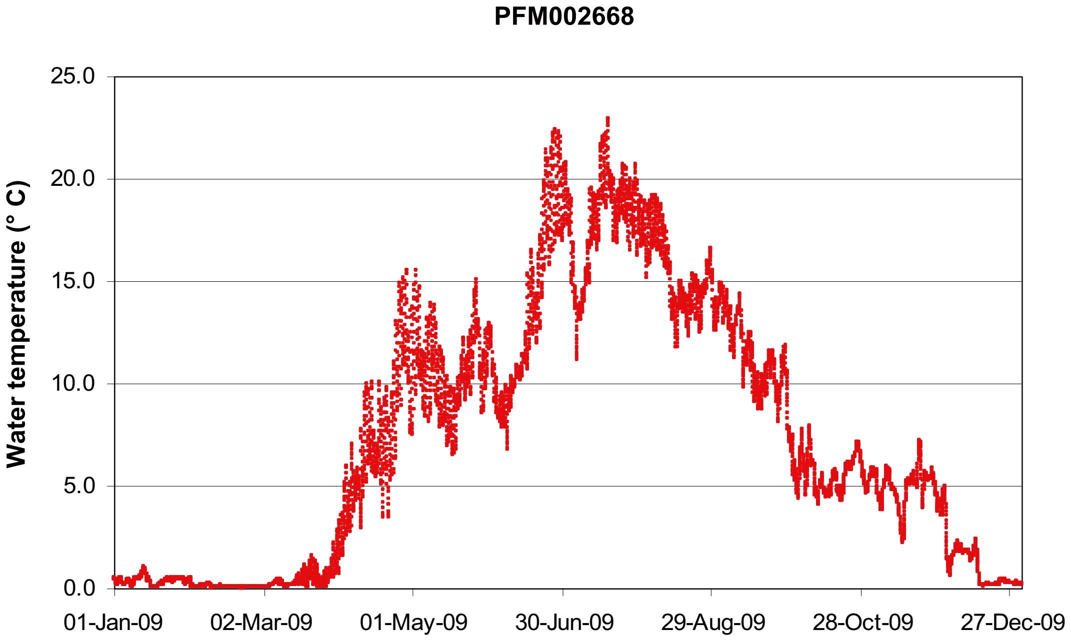

PFM002669
Water electrical cond. (mS/m)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
01-Jan-09
02-Mar-09
01-May-09
30-Jun-09
29-Aug-09
28-Oct-09
27-Dec-09

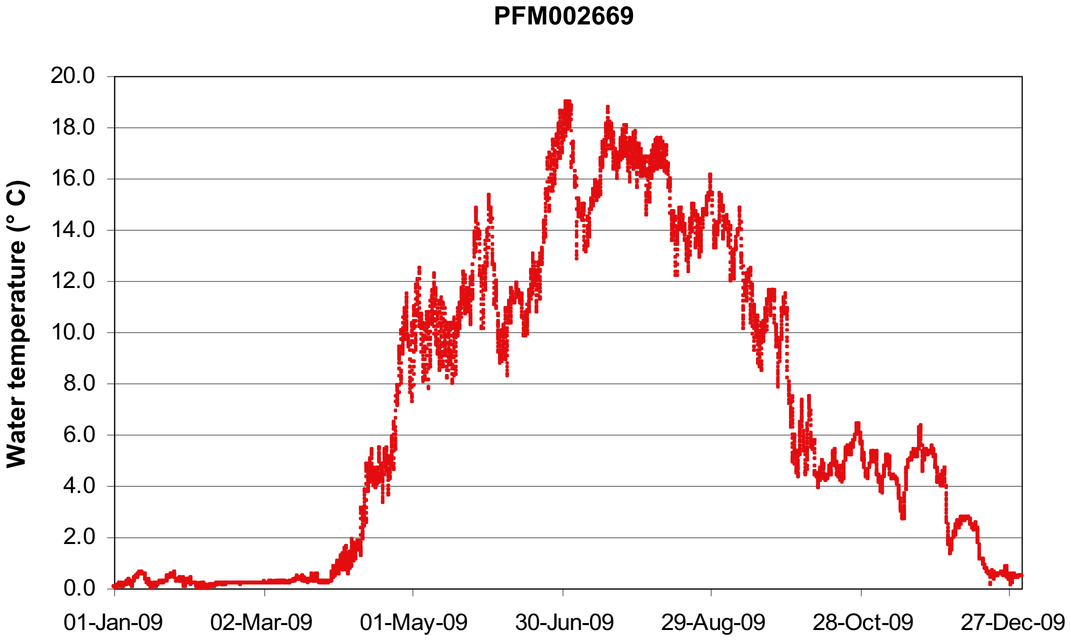

PFM002292
Water electrical cond. (mS/m)
200
180
160
140
120
100
80
60
40
20
0
01-Jan-09
02-Mar-09
01-May-09
30-Jun-09
29-Aug-09
28-Oct-09
27-Dec-09

Water temperatures at the four gauging stations





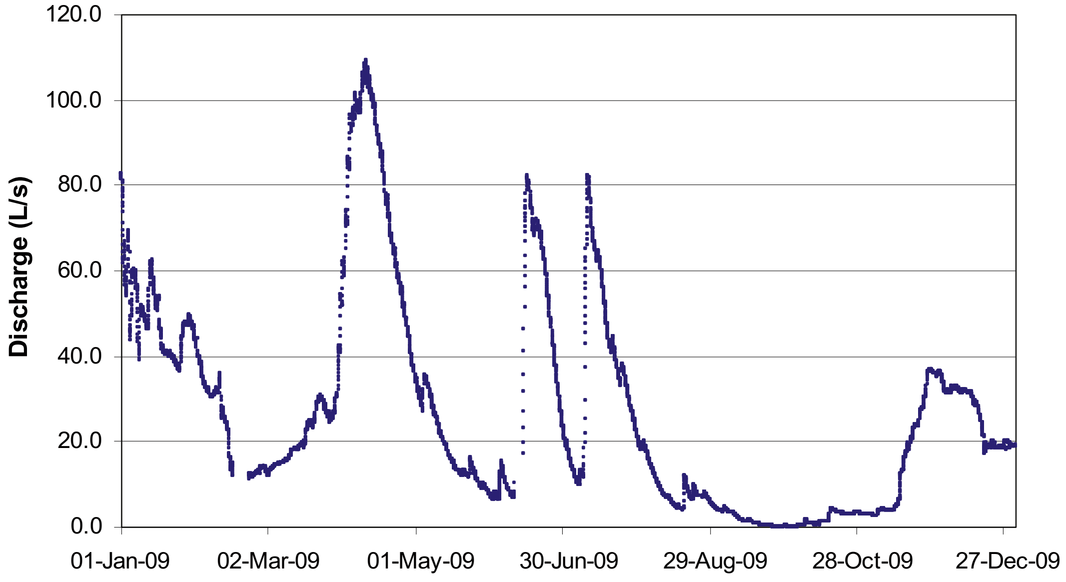

PFM002668
Water temperature (° C)
25.0
20.0
15.0
10.0
5.0
0.0
01-Jan-09
02-Mar-09
01-May-09
30-Jun-09
29-Aug-09
28-Oct-09
27-Dec-09


PFM002669
Water temperature (° C)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
01-Jan-09
02-Mar-09
01-May-09
30-Jun-09
29-Aug-09
28-Oct-09
27-Dec-09

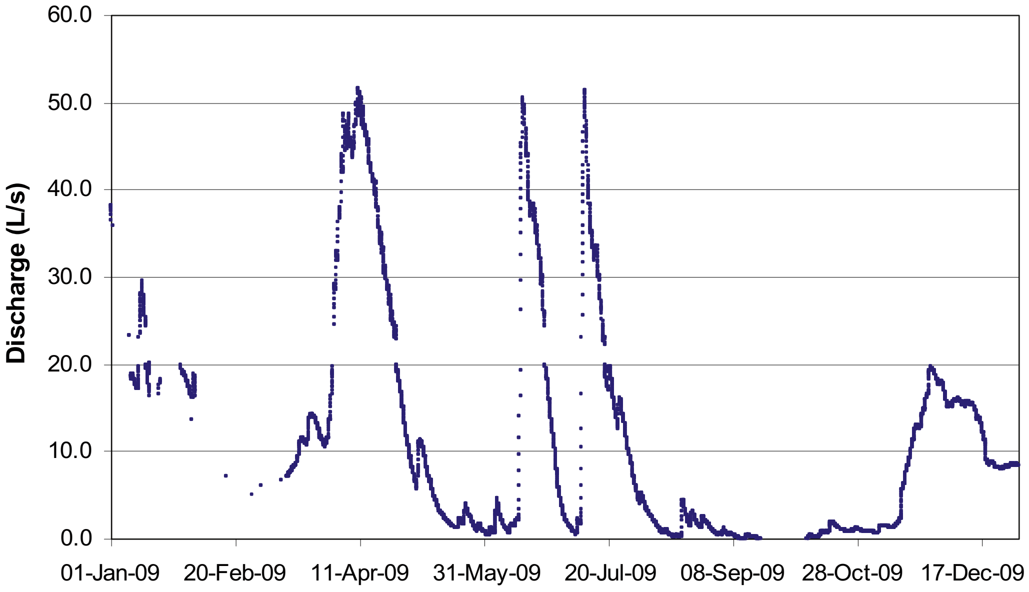
Appendix 4

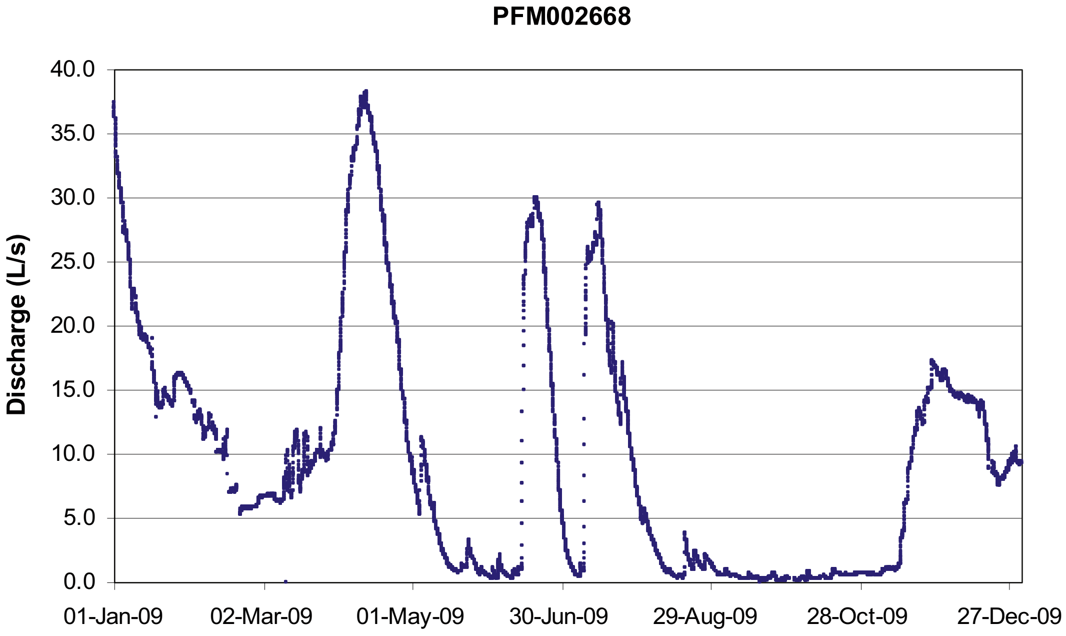
Calculated discharge time series at the four gauging stations

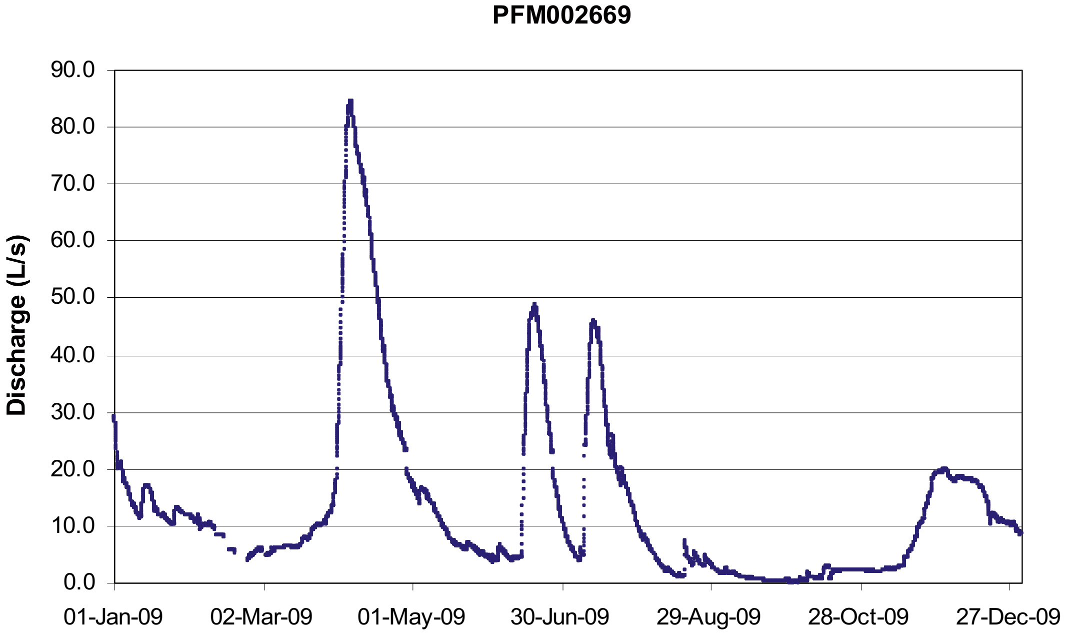
PFM005764



PFM002667




PFM002668
Discharge (L/s)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
01-Jan-09
02-Mar-09
01-May-09
30-Jun-09
29-Aug-09
28-Oct-09
27-Dec-09


PFM002669
Discharge (L/s)
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
01-Jan-09
02-Mar-09
01-May-09
30-Jun-09
29-Aug-09
28-Oct-09
27-Dec-09