P-09-68

Forsmark site investigation

Monitoring of brook water levels, electrical conductivities, temperatures and discharges from April 2007 until December 2008

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December 2009

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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 April 2007 thru 31 December 2008 and is a continuation of reporting from SKB P-07-135 /Johansson and Juston 2007/, which covered the period from 4 April 2004 thru 31 March 2007.

Long-throated flumes equipped with automatically recording devices were used for the discharge measurements. At least once a month the water depths at the upstream edge of the flumes were measured manually by a ruler as a check. The automatically recording equipment for monitoring of electrical conductivity was checked regularly against KCl standard solutions and the temperature sensors were checked against the calibrated thermometer of the site investigation field laboratory.

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. However, if the difference from the previous measurement was small, not all data were stored. However, mostly the storing interval was less than one hour and at least one value was stored every two hours.

For the calculation of discharge, quality assured water level data from the flumes were taken from Sicada. 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. From 27 November thru 26 December 2008 critical flow was not reached at PFM002667 due to too high discharge. The registered water levels could not be used for calculation of the discharge at the station for this period.

The amplitudes of water level variations during this reporting period were 0.38–0.46 m at the four stations. The mean electrical conductivities varied between 27 and 41 mS/m at the four discharge stations. The electrical conductivity at the outlet of Lake Bolundsfjärden tapered from approximately 570 mS/m to 90 mS/m during this reporting period. During the major part of the period the values fell between 70–100 mS/m. The water temperatures varied between some tenths of a degree below zero during winter up to well above 20°C during hot summer days with low discharge.

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 zero discharge for relatively long periods in late summers and early autumns. The mean specific discharge for the largest catchment, averaged over a four-year reporting period was 6.1 L/s/km^2 (192 mm/yr). The maximum single year specific discharges were observed during 2008 at all stations with range between 9.8–11.7 L/s/m^2 (308–369 mm/yr). Interstation variability for specific discharge in longterm and annual data records was less than about 15% in all cases.

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 2007-04-01 till 2008-12-31. Tidigare mätningar, från perioden 2004-04-04 till 2007-03-31, redovisades i SKB P-07-135 /Johansson and Juston 2007/.

Mätrännor, av typen "long-throated flumes" med utrustning för automatisk registrering av vattennivåer, användes för vattenföringsmätningarna. Minst en gång/månad kontrollerades vattendjupet manuellt med tumstock i uppströmskanten av rännorna. Den automatiskt registrerande utrustningen för mätning av elektrisk konduktivitet kontrollerades regelbundet mot en KCl-standardlösning och temperaturgivarna mot fältlaboratoriets kalibrerade termometer.

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. Om skillnaden från föregående värde var liten lagrades inte alla data. Lagringsintervallet var dock oftast mindre än en timme och åtminstone ett värde lagrades varannan timme.

För beräkningarna av vattenföringen hämtades kvalitetssäkrade vattennivådata från Sicada. Beräkningarna baserades på timmedelvärden. Kortvariga flödesspikar, brus och andra data som bedömdes som felaktiga togs bort innan beräkningarna genomfördes. Under perioden 2008-11-27 till 2008-12-26 var avrinningen så stor vid PFM002667 att kritiskt flöde inte uppnåddes. Någon beräkning av vattenföringen kunde därför inte göras vid stationen för denna period. Efter att vattenföringarna hade beräknats levererades data till Sicada.

Vattennivåerna i de enskilda stationerna varierade mellan 0,38 och 0,46 m. Medelvärdena för den elektriska ledningsförmågan i de fyra stationerna varierade mellan 27 och 41 mS/m. I Bolundsfjärdens utlopp minskade den elektriska ledningsförmågan under den aktuella perioden från 570 mS/m till 90 mS/m. Under större delen av observationsperioden låg värdena mellan 70 och 100 mS/m. Vattentemperaturerna varierade mellan någon tiondels grad under 0 °C upp till väl över 20 °C under varma sommardagar med lågt vattenflöde.

Den högsta uppmätta vattenföringen för det största avrinningsområdet (mätstation PFM005764) var 278 L/s och för det minsta 102 L/s (mätstation PFM002668). Samtliga mätstationer var torra under relativt långa perioder under sensommmar och tidig höst. Medelvärdet för den specifika avrinningen för det största avrinningsområdet var, för den tillgängliga fyraårsperioden 2005–2008, 6,1 L/s/km^2 (192 mm). Den specifika avrinningen var avsevärt större under 2008 jämfört med de tre andra åren med värden mellan 9,8 och 11,7 L/s/km^2 (308–369 mm/år). Variationen mellan stationerna för medelvärdena för hela den tillgängliga mätperioden och de årsvisa medelvärdena var mindre än cirka 15 % i samtliga fall.

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 April 2007 thru 31 December 2008. The report presents continuations of time series data reported in P-07-135 /Johansson and Juston 2007/. 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 plans AP PF 400-07-021 and AP PF 400-07-049, In Table 1-1 controlling documents for performing this activity are listed. Both the activity plans 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
Platsundersökning i Forsmark – Moniteringsprogram för hydrogeologi, hydrologi och meterorologi 2007	AP PF 400-07-021	1.0
Platsundersökning i Forsmark – Hydrologisk och hydrogeologisk monitering 2008	AP PF 400-07-049	1.0
Method description	**Number**	
Ythydrologiska mätningar	SKB MD 364.008	1.0
Site investigation Internal Report (in Swedish)	**Number**	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: januari–april 2007	PIR-07-23	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: april–augusti 2007	PIR-07-39	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: augusti–november 2007	PIR-07-47	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: november 2007–februari 2008	PIR-08-20	
Platsprojekt Forsmark/SFR3 – Kvalitetskontroll av yt- och grundvattenmonitering Period: februari–maj 2008	PIR-08-47	
Platsprojekt Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: maj–september 2008	PIR-08-48	
Platsprojekt Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: september 2008–januari 2009	PIR-09-05	

Figure 1-1. *The location 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 discharge gauging stations.

Gauging station ID-code	Catchment area ID-code	Catchment Area (km²)
PFM005764	AFM001267	5.59
PFM002667	AFM001268	3.01
PFM002668	AFM001269	2.28
PFM002669	AFM001270	2.83

This document details a minor revision to the calculation of discharge time series from flume water elevation time series that was previously reported in P-07-135. This revision involved a slight change of the methodology for calculation of discharge at the stations with two flumes in the discharge range in which both flumes should give accurate results. See Section 4.3.3 for a description of the revised, consistent methodology.

The revision effected time series calculations from the beginning of record for all discharge stations, so new discharge time series have been delivered to Sicada from beginning of data records thru December 2008. The net effect of this revision was indeed minor, affecting annual average discharge values by 2% and less (most often) compared to previously reported values.

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

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)*	$Q=1{,}175 \times h^{2.15}$	20–70
PFM005764 Oct 5 2004–		
Small flume (QFM1:1)	$Q=864.9 \times h^{2.576}$	0–20
Large flume (QFM1:2)	$Q=2{,}298 \times (h+0.03459)^{2.339}$	20–1,400
PFM002667		
Small flume (QFM2:1)	$Q=864.9 \times h^{2.576}$	0–20
Large flume (QFM2:2)	$Q=2{,}001.5 \times (h+0.02660)^{2.561}$	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)	$Q=1{,}117.6 \times (h+0.02727)^{2.604}$	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 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 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 occured 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.

The equipment for monitoring of electrical conductivity was checked regularly against KCl standard solutions of 0.005 and 0.01 D (PFM005764, PFM002667, PFM002668 and PFM002669), and 0.005 and 0.1 D (PFM002292), and the temperature sensors were checked against the calibrated thermometer of the site investigation field laboratory.

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. Discharge was calculated from quality assured water level data from the flumes. The quality assured level data were taken from Sicada and 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.

At least once a month 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.

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 levels, electrical conductivities and temperatures were made every 10 minutes. However, if the difference from the previous measurement was small, not all data were stored. However, mostly the storing interval was less than one hour, and at least one value was stored every two hours.

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 taken from 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. Numerous data spikes and noise could be readily identified by visual inspection in each flume time series. 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.

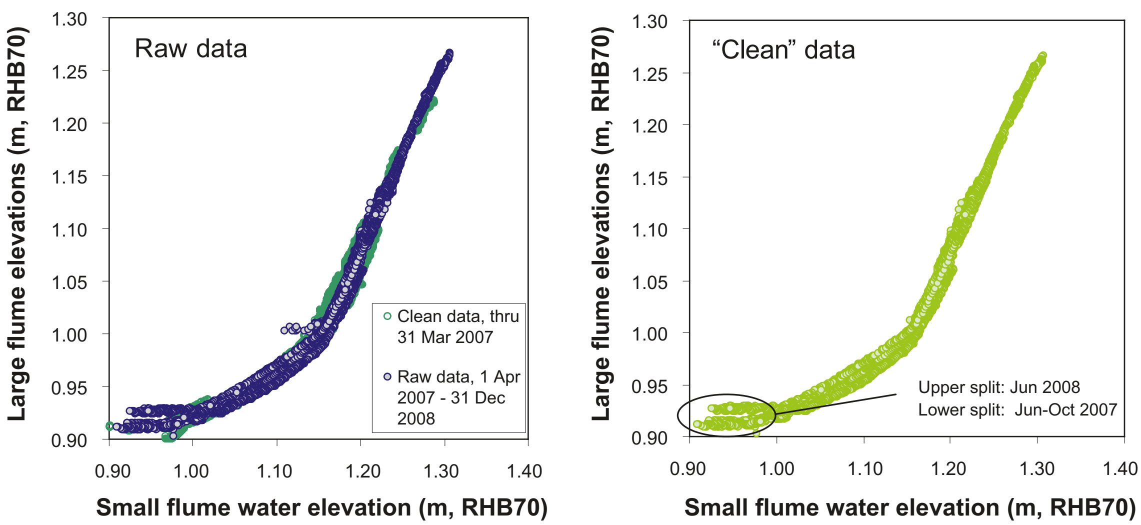


Figure 4-1. *A comparison of cross-plots between small and large flume water levels at PFM005764, before and after data screening, shown as an example of the data screening and scrutiny process. A consistent relationship between the flume water elevations would be expected if both sensors were properly 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. The table below summarizes the surveyed bottom elevations (upstream edge) and the elevation values that were used in data reduction 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.

- 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 height 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 thru March 2007 for each discharge time series in P-07-135. They are documented for the period April 2007 thru December 2008 herein in Tables 4-1 thru Table 4-4.

Table 4-1. 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.

Dates	Affected data points from small flume	Affected data points from large flume	Action
2007/6/21	13	11	Removed small spike
2007/12/07–08	33		Removed small negative spike
2008/2/14	8	8	Removed small spike
2008/8/9	2	2	Removed small negative spike
2008/11/24	3	4	Removed small negative spike

Table 4-2. 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 brown shading indicates data removal.

Dates	Affected data points from small flume	Affected data points from large flume	Action
2008/11/27–2008/12/26	720	720	Data removed due to too high discharge; critical flow was not reached in the large flume (see Section 3.1)

Table 4-3. 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 4-4. 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. Light brown shading indicates 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
2007/7/8–9	21		Removed an isolated 20 hours data spike surrounded by several days of missing data on both sides
2007/12/05–21		372	Added: response modelled based on regression to small flume data
2007/12/29–2008/2/12		1,090	Added: response modelled based on regression to small flume data

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.

Additional quality checks were performed twice, for the time periods April to June 2007 and July 2007 to December 2008, 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 4-5. The most frequent reason for data removal was too low discharge to give representative values for EC and temperature.

4.5 Nonconformities

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

Table 4-5. 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	070806 01:01:50–070905 10:11:50	No flow or insignificant flow
PFM005764 small	Level	080711 01:00:40–080809 21:31:40	No flow or insignificant flow
PFM005764 large	Level	070702 11:52:00–070708 09:02:10	Level not representative for brook water level
PFM005764 large	Level	070801 14:12:00–070804 12:52:00	Level not representative for brook water level
PFM005764 large	Level	071001 00:01:50–071016 12:31 50	Measurements disturbed by leaves in the flume. Flume cleaned 071016
PFM005764 large	Level	080618 12:51:40–080809 21:31:40	Level not representative for brook water level
PFM005764	EC	070607 00:00:00–070906 11:37:50	No or too low flow
PFM005764	EC	071001 01:01:50–071015 13:15:50	Erroneous trend, calibration/cleaning performed 2007/10/15
PFM005764	EC	080411 06:31:40–080831 24:00:00	Instable values, from unreasonably low to unreasonably high
PFM005764	Temp	070623 00:00:00–070709 24:00:00	No or too low flow
PFM005764	Temp	070722 00:00:00–070906 24:00:00	No or too low flow
PFM005764	Temp	080607 00:00:00–080809 24:00:00	No or too low flow
PFM002667 small	Level	070626 00:00:00–070709 24:00:00	Level not representative for brook water level
PFM002667 small	Level	070721 22:11:00–071014 03:17:00	No flow or insignificant flow
PFM002667 small	Level	080616 00:00:00–080809 20:35.20	No flow or insignificant flow
PFM002667 large	Level	070610 09:47:30–070709 11:26:30	Level not representative for brook water level
PFM002667 large	Level	070721 22:11:00–071014 05:07:00	No or insignificant flow
PFM002667 large	Level	080602 02:35:20–080809 22:45:30	Level not representative for brook water level
PFM002667	EC	070610 00:00:00–070709 12:36:30	No or too low flow
PFM002667	EC	070721 22:11:00–071108 13:17:20	No or too low flow
PFM002667	EC	080610 20:25:20–080809 21:45:30	No or too low flow
PFM002667	Temp	070610 00:00:00–070709 12:26:30	No or too low flow
PFM002667	Temp	070721 22:11:00–071108 13:17:20	No or too low flow
PFM002667	Temp	071115 12:42:10–071115 12:54:10	Sensor lifted out of water
PFM002667	Temp	080610 20:25:20–080809 21:45:20	No or too low flow
PFM002668	Level	070626 00:00:00–070709 06:34:40	No flow
PFM002668	Level	070720 00:00:00–070818 00:54:50	No flow
PFM002668	Level	070826 00:00:00–071104 04:44:00	No flow
PFM002668	Level	080617 00:49:20–080804 11:50:30	No or insignificant flow
PFM002668	EC	070606 00:00:00–071104 04:44:00	No or too low flow
PFM002668	EC	071201 00:00:00–080318 12:53:30	Instable values, sensor cleaned 2008/03/18
PFM002668	EC	080604 18:03:00–080805 00:20:30	No or too low flow
PFM002668	Temp	070607 00:00:00–071104 05:24:00	No or too low flow
PFM002668	Temp	071115 12:11:20–071115 12:29:20	Sensor lifted out of water
PFM002668	Temp	080604 18:03:00–080805 00:20:30	No or too low flow
PFM002669 small	Level	070627 00:00:00–070708 22:35:20	No or insignificant flow
PFM002669 small	Level	070709 19:15:20–070728 00:00:00	Unreasonably high levels
PFM002669 small	Level	080701 00:00:00–080804 11:55:10	No or insignificant flow
PFM002669 small	Level	081208 12:34:10–081208 12:44:10	Cleaning of flume
PFM002669 large	Level	070627 00:00:00–070709 03:35:20	No or insignificant flow
PFM002669 large	Level	070721 22:25:00–071009 24:00:00	No or insignificant flow
PFM002669 large	Level	080701 00:00:00–080804 11:55:10	No or insignificant flow
PFM002669 large	Level	081208 12:34:10–081208 12:44:10	Cleaning of flume
PFM002669	EC	070601 12.54:25–070708 22:35:20	No or too low flow
PFM002669	EC	070722 00:00:00–071028 15:44:30	No or too low flow
PFM002669	EC	080705 01:04:00–080810 24:00:00	No or too low flow
PFM002669	Temp	070627 00:00:00–070709 23:05:20	No or too low flow
PFM002669	Temp	070722 00:00:00–071009 24:00:00	No or too low flow
PFM002669	Temp	071115 13:27:50–071115 13:39:30	Sensor lifted out of water
PFM002669	Temp	080701 00:00:00–080804 11:55:10	No or too low flow
PFM002292	EC	070612 00:00:00–070906 10:39:20	No of too low flow (level in Lake Bolundsfjärden below threshold)
PFM002292	EC	071210 14:09:30–071215 23:34:40	Instable values from unreasonably low to unreasonably high (cleaning of sensor 2007/12/15?)
PFM002292	EC	080310 14:02:00–080315 23:44:40	Unreasonably low values, cleaning of sensor 2008/03/15
PFM002292	EC	080504 18:32:10–081017 23:38:10	Too low flows, mal-function of sensor?

5 Results

5.1 General

The results are stored in SKB's primary database Sicada where they are traceable by the Activity Plans numbers. 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. Please note that when the water levels reach the bottom level of the upstream end of the flumes (or the levels of zero discharge as described in Section 4.3.3) they do not any longer represent the actual surface water levels since the observation tubes are closed in the bottom. Any recorded decrease of the water levels below the flume bottoms were due to evaporation and/or leakage from the observation tubes.

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 generally a little greater than 0.4 m at PFM005764, PFM002667 and PFM002668, which are all within the same catchment. The mean water elevations were from the downstream station PMF005764, via PFM002667, to the upstream station PFM002668, 1.12, 1.70 and 4.46 m RHB70, respectively, for the April 2007 to December 2008 period (small flume data; levels below zero discharge not included) and 1.12. 1.68, and 4.45 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 were approximately 0.46 m, and the mean water elevation was 6.07 m RHB70 for April 2007 to December 2008 and 6.05 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 during the summers and autumns of 2007 and 2008 were due to very low or no discharge. These data were removed since the recorded values were considered not to represent surface water electrical conductivities. It was not possible to exactly define a lower limit of discharge to get reliable values for electrical conductivity, but the analyst should use the values at very low discharges with caution. The other gaps found in the data series, for short or long periods, were due to mal-function of the mechanical and/or electronical equipment.

The mean electrical conductivities in PFM005764, PFM002667, PFM002668 and PFM002669 were 41, 32, 27 and 39 mS/m, respectively, during this reporting period. The corresponding mean values for the whole period since the measurements started were 38, 27, 25 and 37 mS/m.

The electrical conductivity of the water leaving Bolundsfjärden tapered from 570 mS/m at the beginning of the data interval to approximetly 90 mS/m towards the end. There was a six-months interval in the middle of the data record where conductivity was relatively level near 300 mS/m.

5.4 Temperature

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

As for the electrical conductivity time series, the gaps in the data series of PFM005764, PFM002667, PFM002668 and PFM002669 found during the summers and autumns of 2007 and 2008 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 with caution.

The other gaps found in the data series, for short or long periods, were due to mal-function of the mechanical and/or electronical equipment.

The water temperatures varied between some tenths of a degree below zero during winter up to well above 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 zero discharge for relatively long periods in late summers and early autumns. The mean specific discharge for the largest catchment, averaged over a four-year reporting period was 6.1 L/s/km^2 (192 mm). The maximum single year specific discharges were observed during 2008 at all stations with range between 9.8–11.7 L/s/km^2 (308–369 mm/yr). Inter-station variability for specific discharge in long term and annual data records was less than about 15% in all cases.

There were some discrepancies for mean annual discharges for 2005 and 2006 as reported here (Table 5-1) and in P-07-135. Minor differences (<2 %) for all 2005 values and for 2006 values at PFM005764 and PFM002668 were due to the revision in data reduction methodology described above, see Section 4.3.3. Differences in 2006 values for PFM002667 and PFM002669 (~10%) were due to reporting errors in the P-07-135 report.

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 daily averaged values.

	PFM005764	PFM002667	PFM002668	PFM002669
Jan 1 2005–Dec 31 2008				
Mean discharge (L/s)	34.0	16.6 *	12.4	18.0
Min. discharge (L/s)	0.00	0.00	0.00	0.00
Max. discharge (L/s)	278	130.7 *	102	183
Specific discharge (L/s/km^2)	6.09	5.53 *	5.45	6.35
Specific discharge (mm/yr)	192	174 *	172	200
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	3.93	0.00	0.00
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)	10.74	9.67 *	9.76	11.70
Specific discharge (mm/yr)	338	305 *	308	369

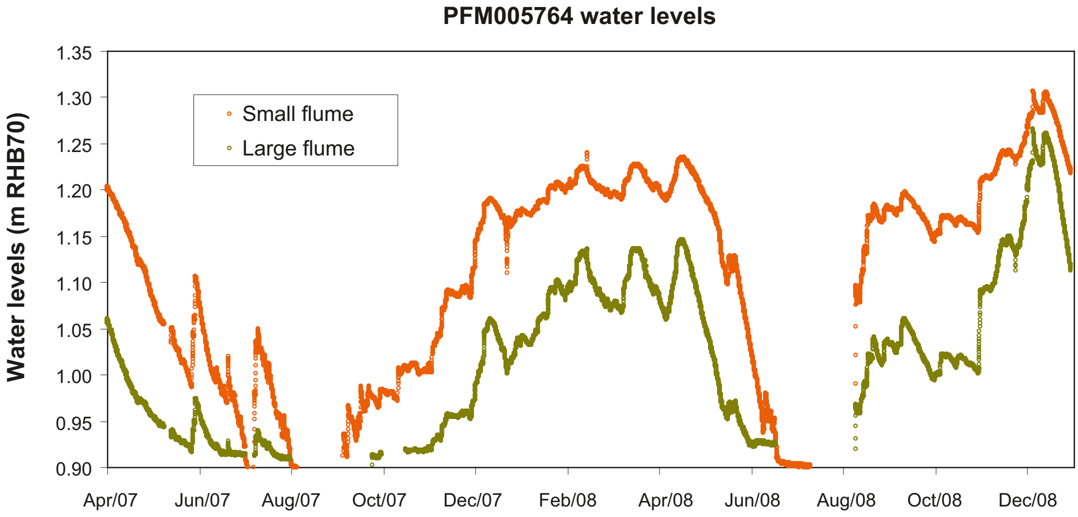
* These values are estimates and are provided as a service to the reader. There were missing data in the PFM002667 time series during a peak flow event Nov 27–Dec 26 2008 due to a lack of critical flow conditions for the discharge equation in Table 3.2. Flow at PFM002667 was estimated during this interval 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.

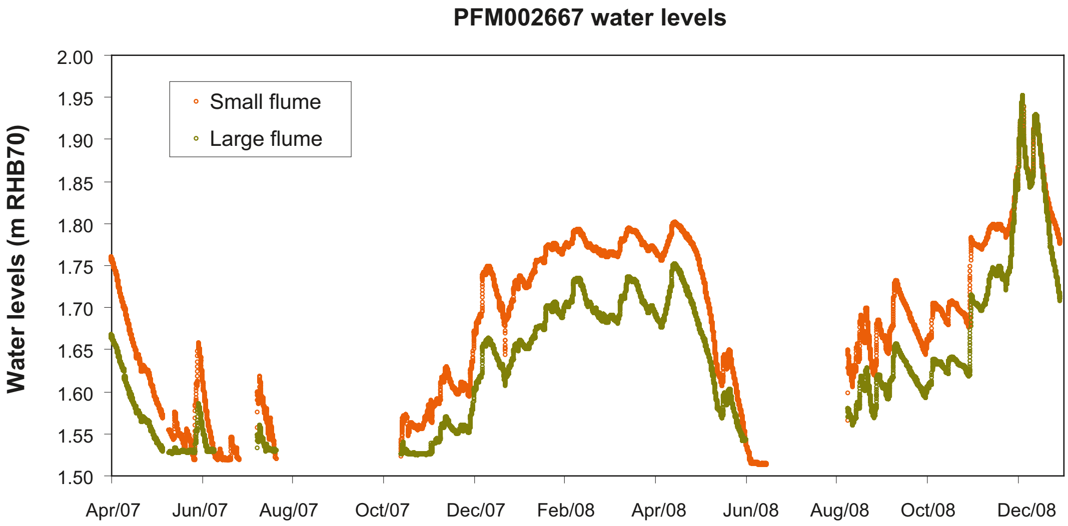
6 Reference

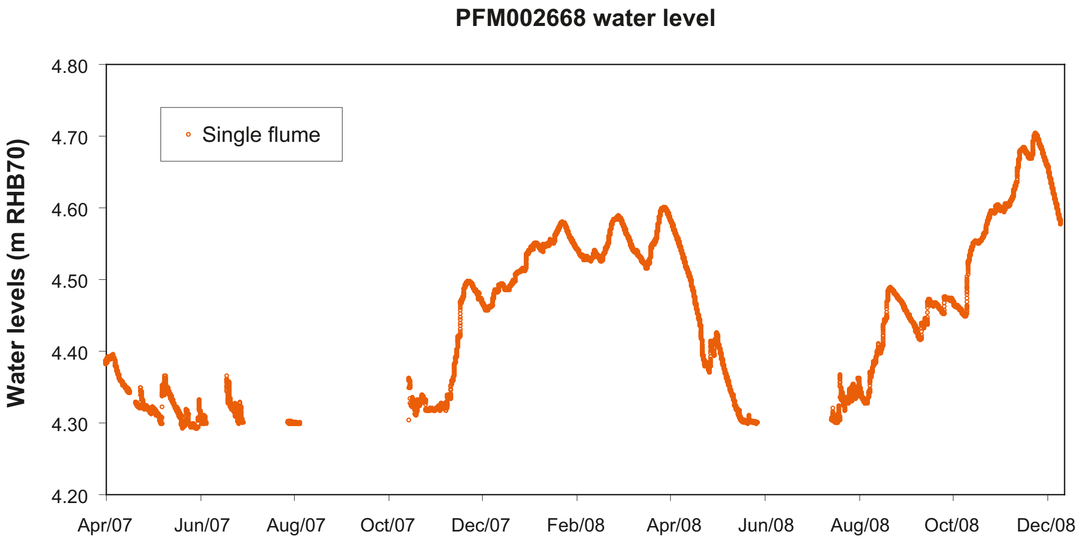
Johansson P-O, 2005. Forsmark site investigation. Installation of brook discharge gauging stations. SKB P-05-154, Svensk Kärnbränslehantering AB.

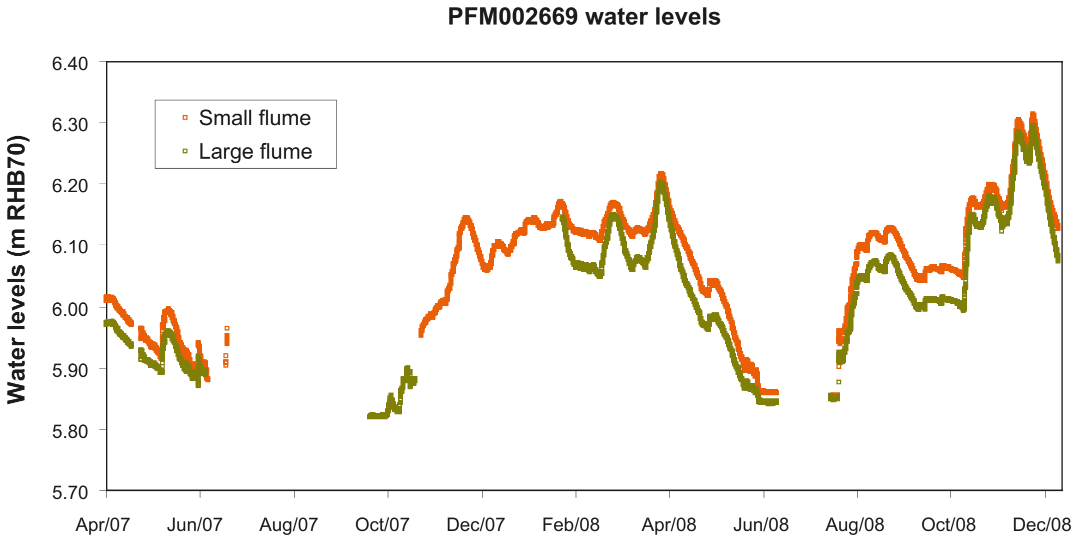
Johansson P-O, Juston J, 2007. Forsmark site investigation. Monitoring of brook levels, water electrical conductivities, temperatures and discharges from April 2004 until March 2007. SKB P-07-135, Svensk Kärnbränslehantering AB.

Water levels at the gauging stations

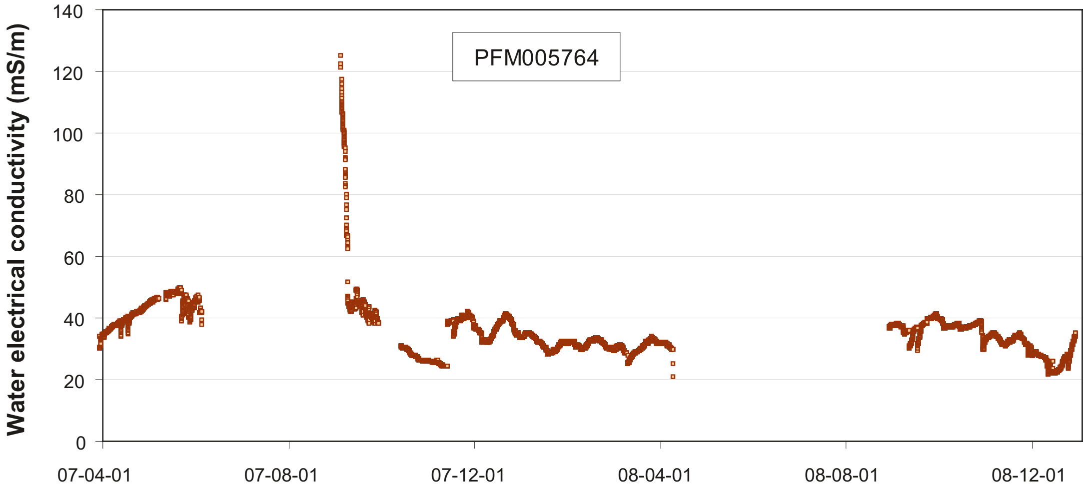


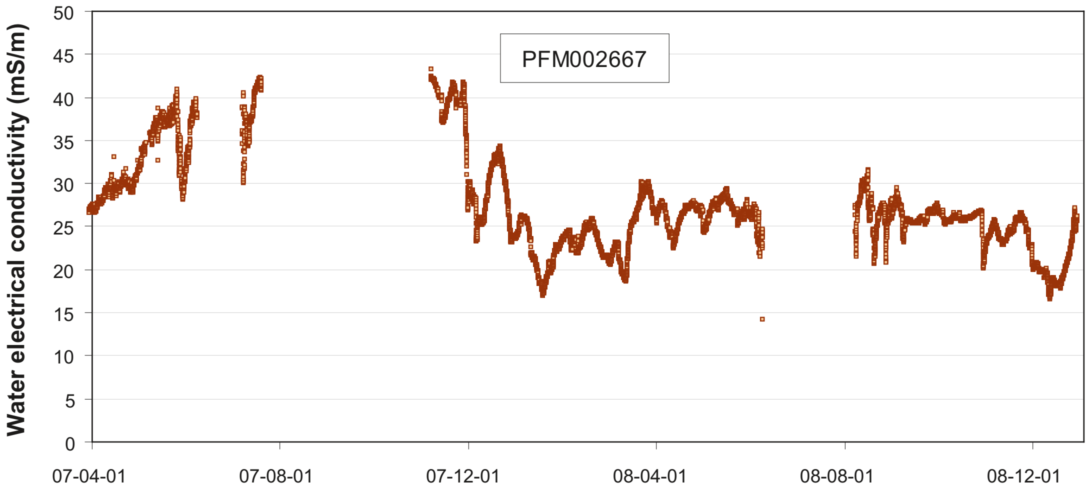


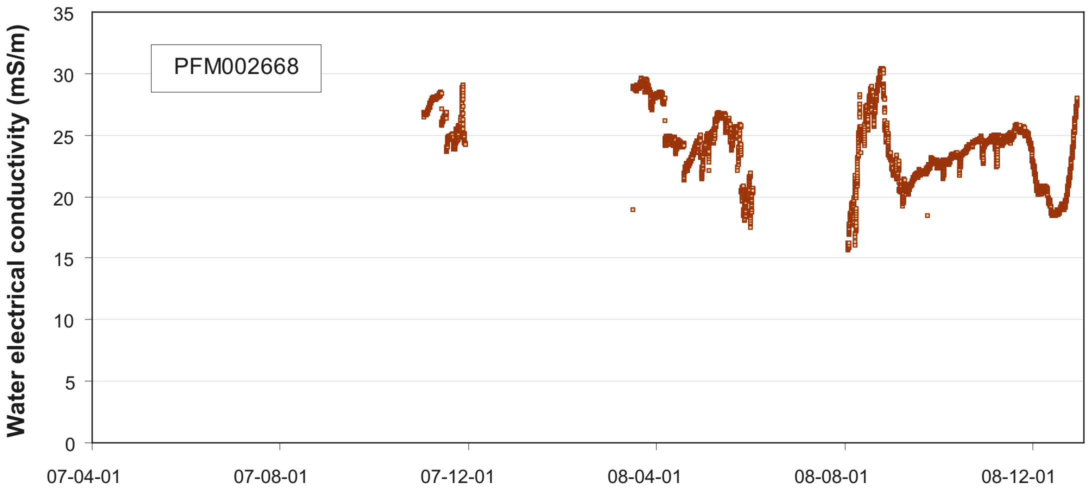


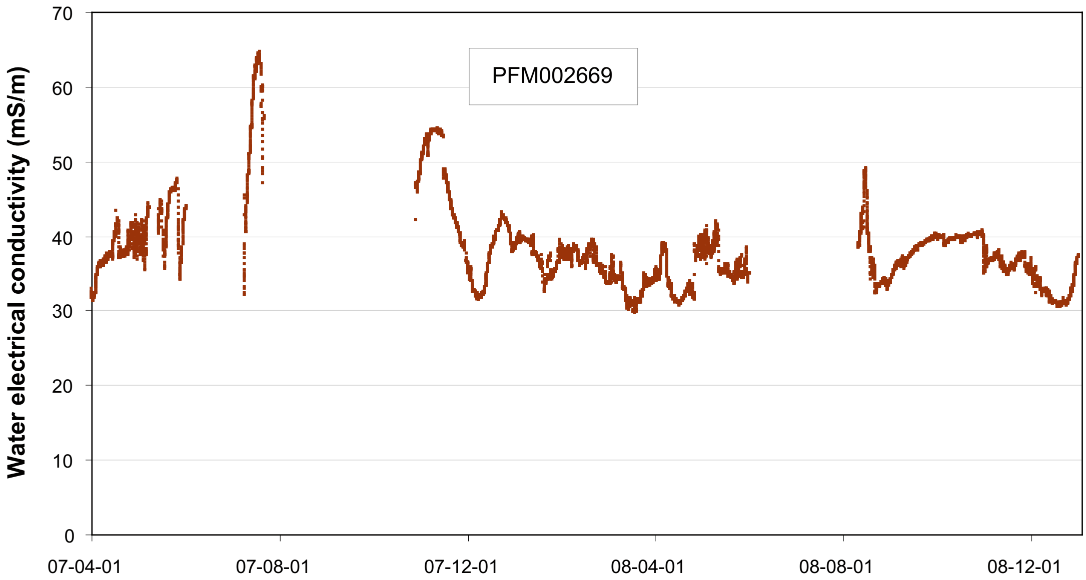

PFM002669 water levels
Small flume
Large flume
Water levels (m RHB70)
6.40
6.30
6.20
6.10
6.00
5.90
5.80
5.70
Apr/07
Jun/07
Aug/07
Oct/07
Dec/07
Feb/08
Apr/08
Jun/08
Aug/08
Oct/08
Dec/08

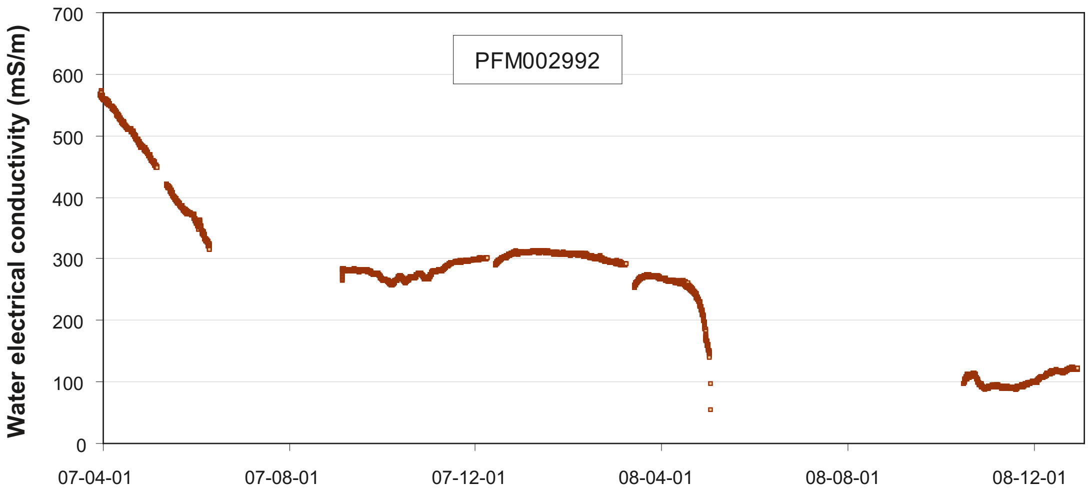
Water electrical conductivities at the four gauging stations and at the outlet of Lake Bolundsfjärden



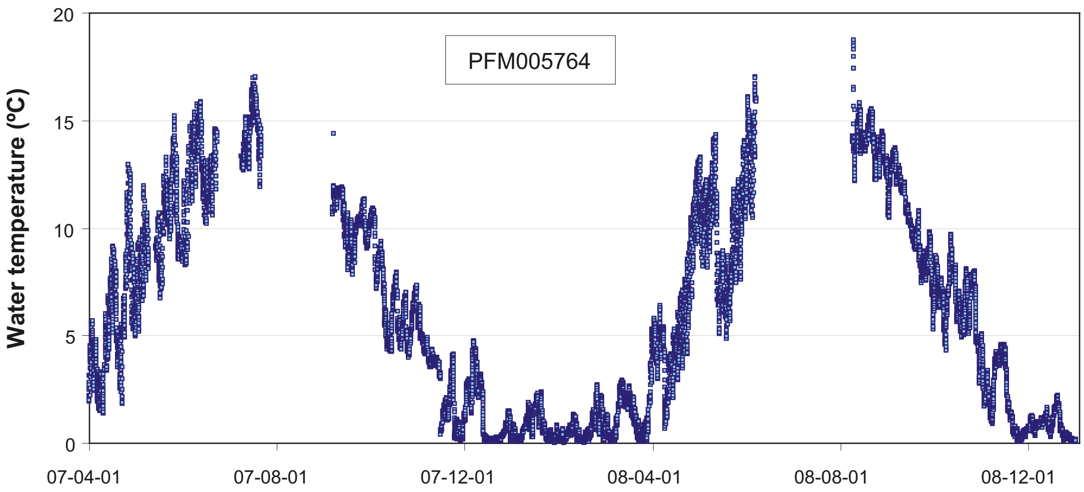


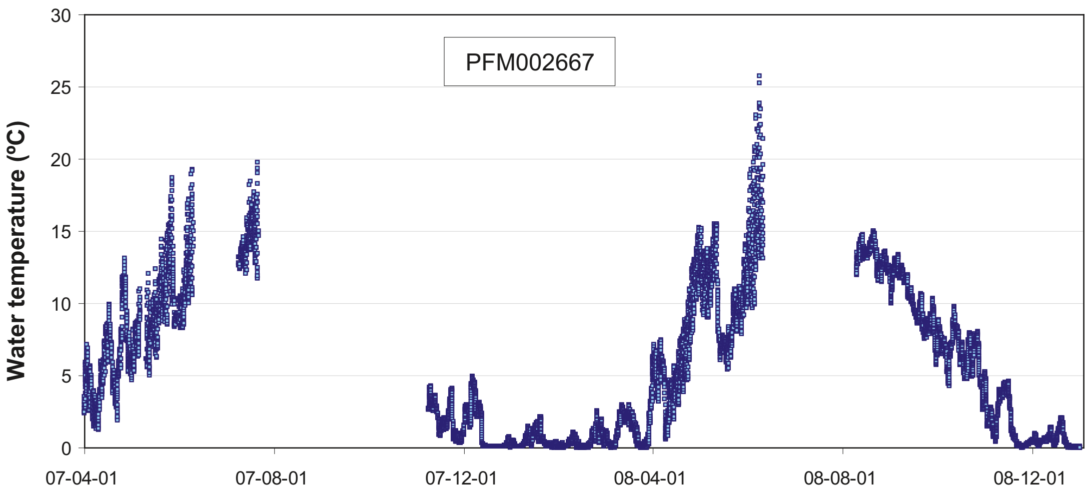


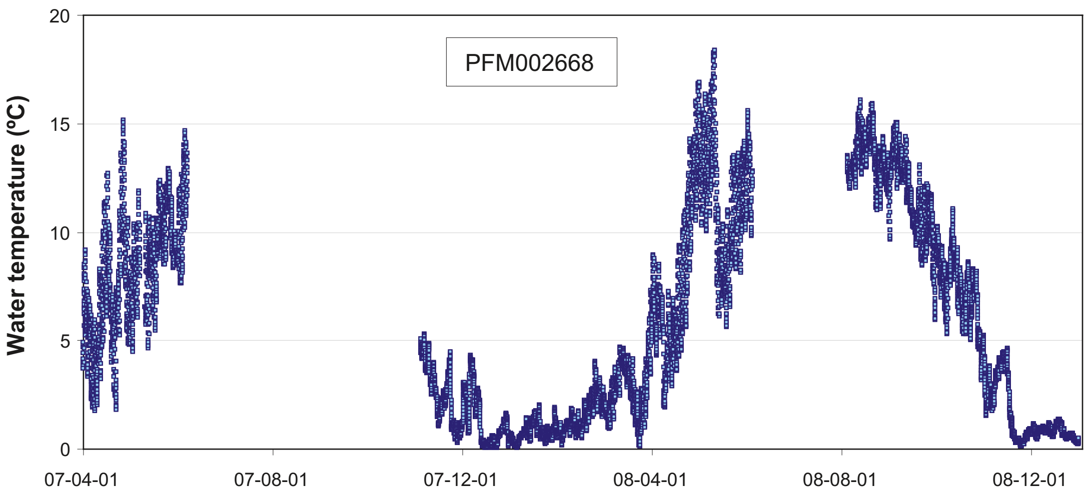

70
60
50
40
30
20
10
0
Water electrical conductivity (mS/m)
PFM002669
07-04-01
07-08-01
07-12-01
08-04-01
08-08-01
08-12-01

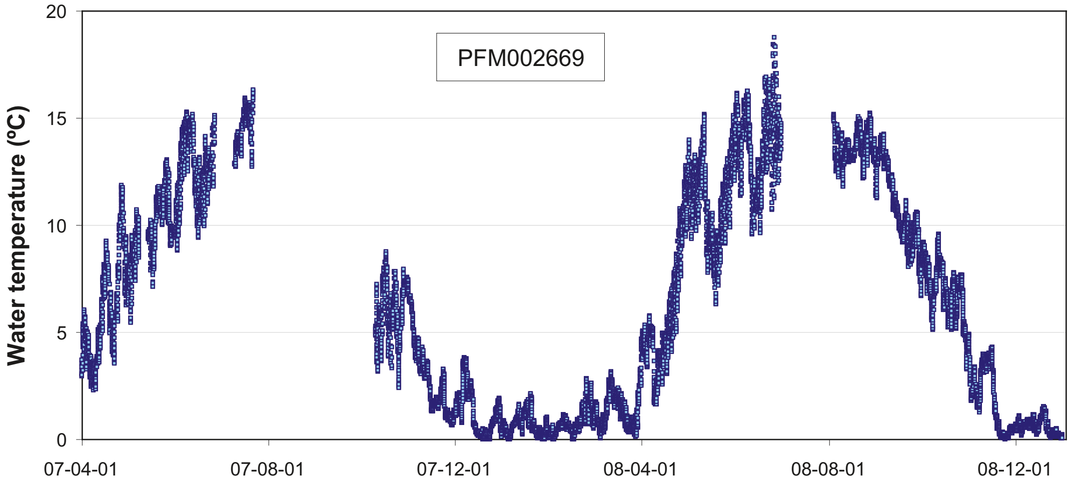

700
600
500
400
300
200
100
0
Water electrical conductivity (mS/m)
PFM002992
07-04-01
07-08-01
07-12-01
08-04-01
08-08-01
08-12-01

Water temperatures at the four gauging stations



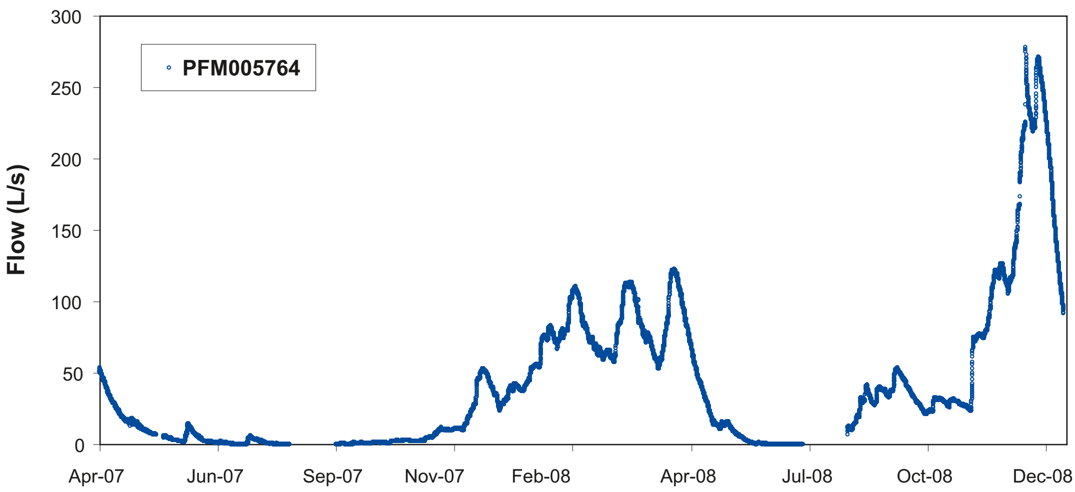


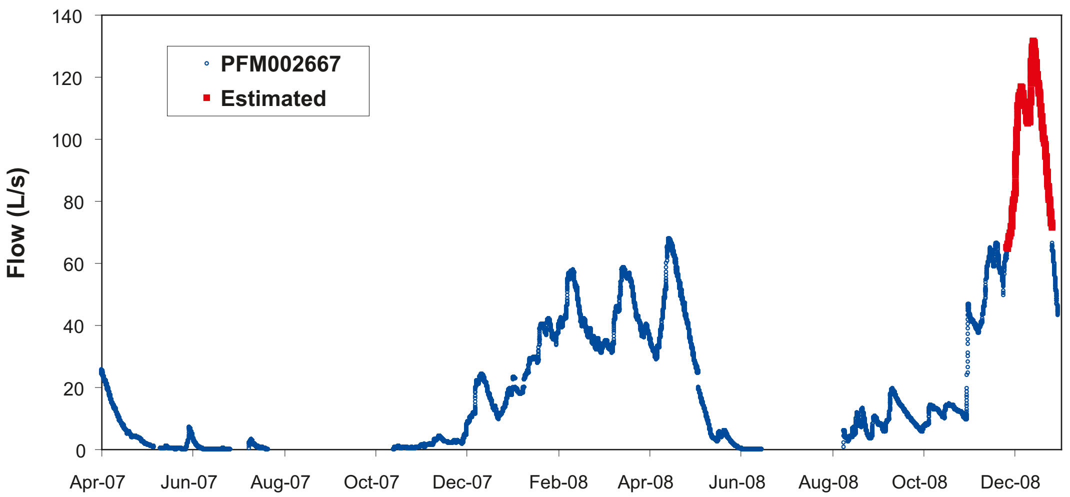


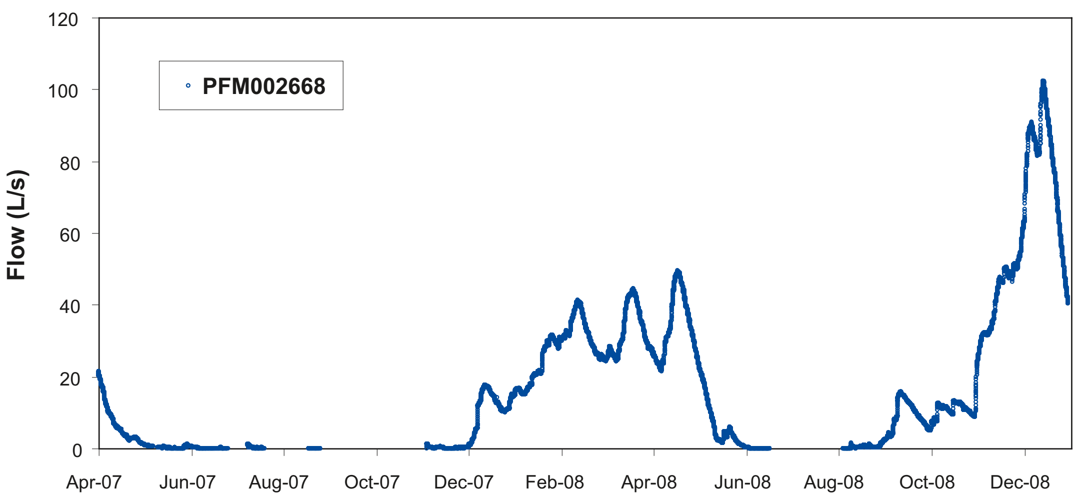

PFM002669
Water temperature (ºC)
20
15
10
5
0
07-04-01
07-08-01
07-12-01
08-04-01
08-08-01
08-12-01

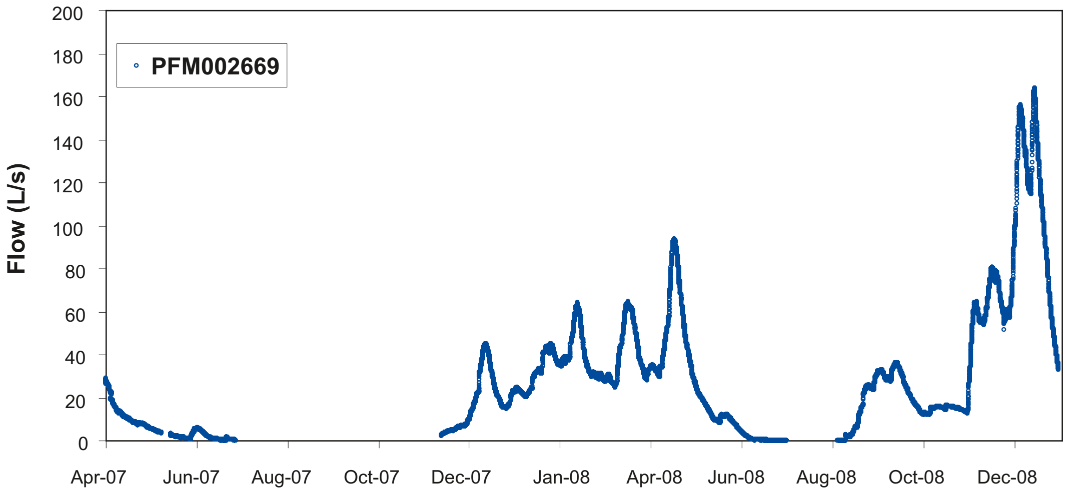
Appendix 4

Calculated discharge time series at the four gauging stations








PFM002669
Flow (L/s)
200
180
160
140
120
100
80
60
40
20
0
Apr-07
Jun-07
Aug-07
Oct-07
Dec-07
Jan-08
Apr-08
Jun-08
Aug-08
Oct-08
Dec-08