P-07-135

Revised May 2010

Forsmark site investigation

Monitoring of brook levels, water electrical conductivities, temperatures and discharges from April 2004 until March 2007

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June 2007

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Keywords: AP PF 400-04-31, AP PF 400-04-120, AP PF 400-05-120, AP PF 400-07-021, Gauging stations, Long-throated flumes, Water level, Electrical conductivity, Temperature, Discharge.

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.

Reading instruction

In the process of calculating the surface water discharge at the Forsmark stations PFM005764, PFM002667, PFM002668 and PFM002669 for the period April 1, 2007–December 31, 2008 it was decided to make a minor revision of the methodology for calculation of the discharge. The revision applied to the transition from use of water level data from the small flume to use of data from the large flume for discharge calculations at the stations with two flumes (PFM005764, PFM002667 and PFM002669). The revision was made after an analysis of the time series from the start of the measurements until December 31, 2008 with the purpose to minimize short term oscillations in calculated discharge at the transition but still retain a consistent methodology for all stations and over time. A detailed description of the revised methodology is presented in P-09-68.

A new data set of discharge data for all four stations from the start of the measurements in 2004 until December 2008 was delivered to Sicada in April 2010.

The revised methodology gave minor (< 3%) changes in mean discharge and specific discharge values reported in Section 5.5.

Furthermore, calculation errors were discovered in the review for the October 1, 2005–September 30, 2006 mean and specific discharge values for PFM005764 and the corresponding values for PFM002667 and PFM002669 for the calendar year of 2006 (~10%).

In this revision, Table 5-1 has been updated, as well as Sections 5.5, Abstract and Sammanfattning.

Abstract

This document reports the monitoring of water levels, electrical conductivities, temperatures and discharges at four brook discharge gauging stations in the Forsmark area, and the monitoring of water electrical conductivity at the outlet of Lake Bolundsfjärden. This is one of the activities performed within the site investigation at Forsmark.

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. The discharges obtained from the flume equations were checked at four occasions by an area-velocity measurement instrument based on doppler technique.

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. Data gaps were filled by manual measurements when available. After the calculations were performed, the results were delivered to Sicada.

One of the gauging stations (PFM005764) had to be re-installed since critical flow was not reached at high flows. Before the re-installation in October, 2004, the highest discharge measured with acceptable accuracy was approximately 70 L/s.

The temporal variations in of the water levels were 0.4–0.5 m at the four stations. The mean electrical conductivities varied between 25 and 39 mS/m at the four stations. The electrical conductivity at the outlet of Lake Bolundsfjärden was for most of the observation period between 70 and 100 mS/m. However, during events of extremely high sea water levels, saline water flowed in to the lake. The highest recorded electrical conductivity was almost 900 mS/m. The water temperatures varied between some tenths of a degree below zero during winter up to well above 20 degrees C during hot summer days with low discharge.

The highest recorded discharge of the largest catchment (gauging station PFM005764) was 212 L/s and for the smallest catchment 75.9 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, which had a 35.5 months' time series, was 4.87 L/s/km^2 (154 mm). The variation of mean specific discharge for a specific station was, for the annual time periods selected for comparison, 24–33% while the variation between stations for the same time period was 9–13%.

Sammanfattning

I föreliggande dokument redovisas mätningar av vattennivå, elektrisk konduktivitet, temperatur och vattenföring i fyra bäckar i Forsmarksområdet samt mätningar av elektrisk konduktivitet i Bolundsfjärdens utlopp. Mätningarna har utförts inom ramen för platsundersökningen i Forsmark.

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. Vattenföringen, som beräknades utifrån mätrännornas flödesekvationer, kontrollerades vid fyra tillfällen med ett area-hastighetsinstrument baserat på doppler-teknik.

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 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 flödespikar, brus och andra data som bedömdes som felaktiga togs bort innan beräkningarna gjordes och hål i dataserierna fylldes med manuella mätningar när sådana fanns tillgängliga. Efter beräkningarna levererades vattenföringarna till Sicada.

En av mätstationerna (PFM005764) ominstallerades eftersom kritiskt flöde inte erhölls vid höga flöden. Före ominstallationen, i oktober 2004, var den högsta vattenföring som mättes med acceptabel noggrannhet cirka 70 L/s.

Vattennivåerna i de enskilda stationerna varierade 0,4-0,5 m. Medelvärdena för den elektriska ledningsförmågan i de fyra stationerna varierade mellan 25 och 39 mS/m. I Bolundsfjärdens utlopp varierade den elektriska ledningsförmågan under större delen av observationsperioden mellan 70 och 100 mS/m. Under episoder med mycket högt havsvattenstånd strömmande emellertid saltvatten in i sjön och den högsta uppmätta elektriska konduktiviteten var nästan 900 mS/m. Vattentemperaturerna varierade mellan någon tiondels grad under 0 upp till väl över 20 °C under varma sommardagar med lågt vattenflöde.

Den högsta uppmätta vattenföringen för det största avrinningsområdet (mätstation PFM005764) var 212 L/s och för det minsta 75,9 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 35,5 månader långa tidsserien, 4.87 L/s/km^2 (154 mm). Variationen av medelvärdet för den specifika avrinningen för en enskild station var, under de årsvisa tidsperioder som valts för jämförelser, 24–33 % medan variationen mellan stationerna för samma tidsperiod var 9–13 %.

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. This is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with Activity Plans AP PF 400-04-31, AP PF 400-04-120, AP PF 400-05-120 and AP PF 400-07-021. 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. The site investigation internal reports present the results from the quality check performed once every three 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 2004	AP PF 400-04-31	1.0
Platsundersökning i Forsmark – Moniteringsprogram för hydrogeologi, hydrologi och meterorologi 2005	AP PF 400-04-120	1.0
Platsundersökning i Forsmark – Moniteringsprogram för hydrogeologi, hydrologi och meterorologi 2006	AP PF 400-05-120	1.0
Platsundersökning i Forsmark – Moniteringsprogram för hydrogeologi, hydrologi och meterorologi 2007	AP PF 400-07-021	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: april–augusti 2004	PIR-04-21	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: augusti–november 2004	PIR-04-22	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: november 2004–januari 2005	PIR-05-02	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: februari–maj 2005	PIR-05-08	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: maj–augusti 2005	PIR-05-31	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: augusti–oktober 2005	PIR-05-38	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: november 2005–februari 2006	PIR-06-07	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: februari–maj 2006	PIR-06-20	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: maj–augusti 2006	PIR-06-33	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: augusti–oktober 2006	PIR-06-37	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: oktober 2006–januari 2007	PIR-07-08	
Platsundersökning i Forsmark – Kvalitetskontroll av yt- och grundvattenmonitering Period: januari–april 2007	PIR-07-23	

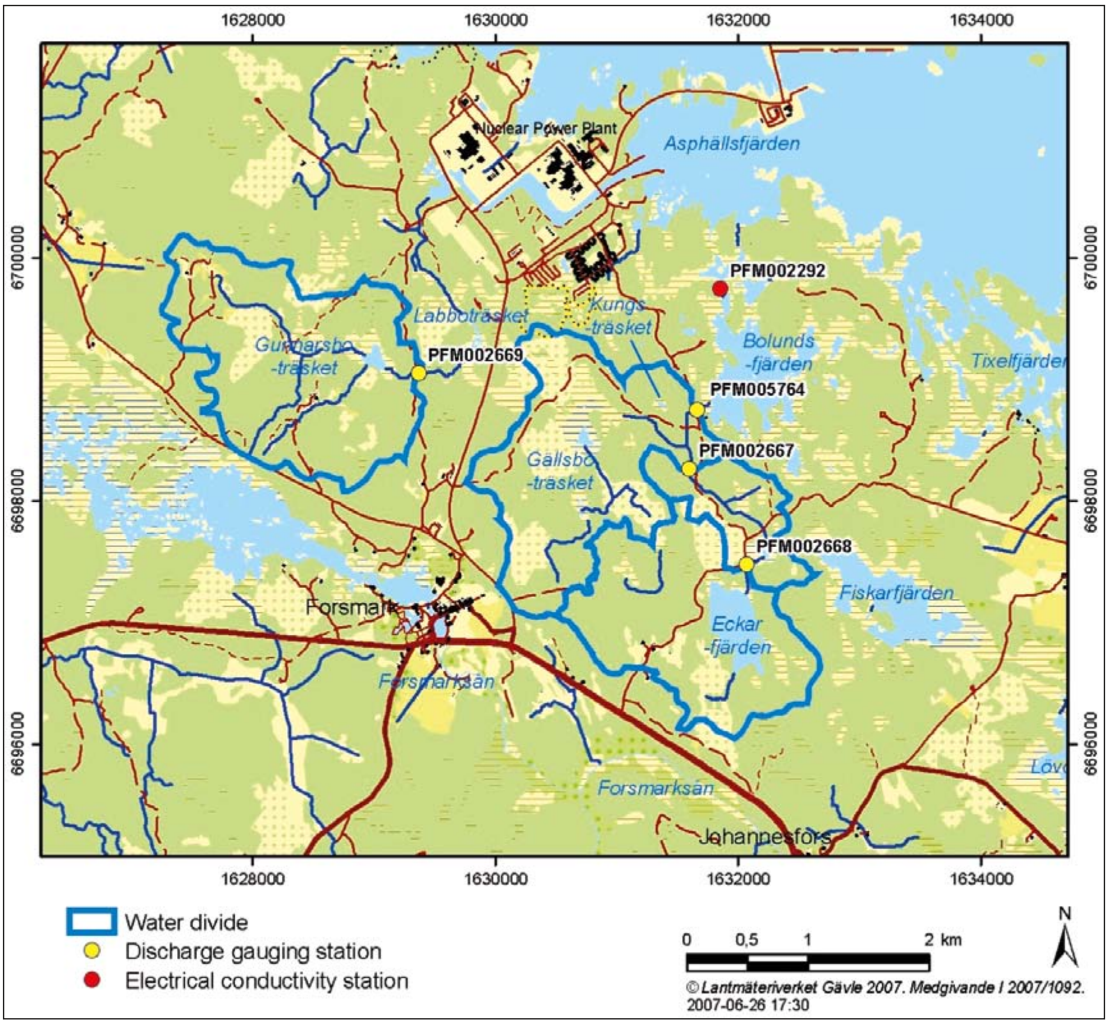


Figure 1-1. *The location of the four discharge gauging stations and the electrical conductivity monitoring station.*

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

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

2 Objective and scope

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

The objectives of the monitoring are to provide:

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

3 Equipment

3.1 Description of equipment

Long-throated flumes were selected for the discharge measurements, mainly due to the limitations set by the flat landscape, the need for accurate measurements, and the desire to avoid migration obstacles for the fish. Long-throated flumes give accurate measurements over relatively wide flow ranges and work under a high degree of submergence. At three of the four discharge gauging stations, two flumes were installed, with different measurement ranges, to obtain good accuracy data over the full flow range. For the station PFM005764 two standard design flumes were used, while the two large flumes at PFM002667 and PFM002669 and the single flume at PFM002668 were designed using the flume design software WinFlume (www.usbr.gov/pmts/hydraulics_lab/winflume/index.html). The flumes are 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 the re-installation of the two flumes at PFM005764, the general conclusion from the calibrations was that the derived discharge equations for all the 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. More extensive maintenance was performed when decided by the activity leader.

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 performed 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.
- 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.

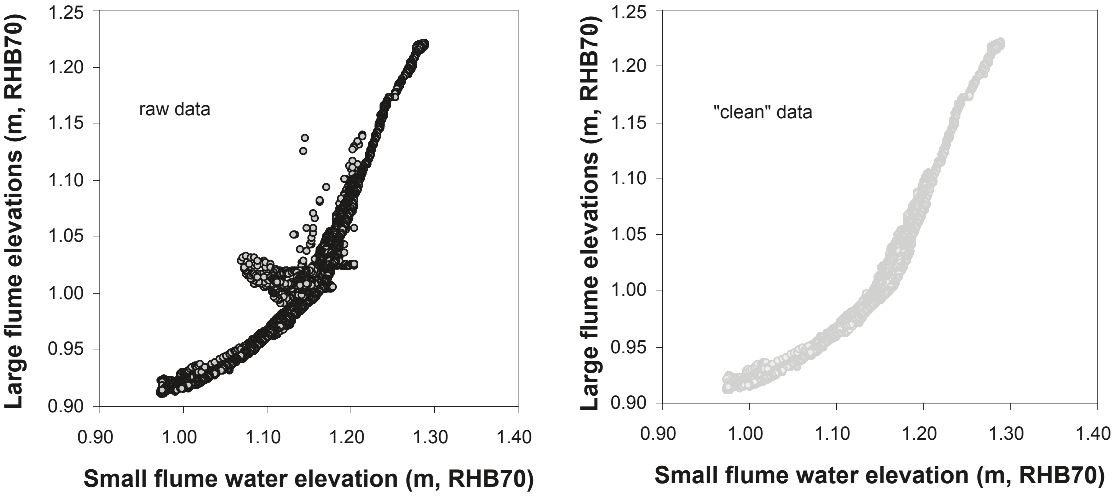


Figure 4-1. *A comparison of cross-plots between small and large flume water levels at PFM005764, before and after data screening. A consistent relationship between the flume water elevations would be expected if both sensors were properly functioning, and was indeed apparent in the "clean" data.*

- Discharge rates were calculated from water depth in each flume using the appropriate discharge equations within the specified ranges of usable water depths at each sensor location.
- A single discharge time series was produced for each gauging station by combining small and large flume discharge values. In general, small flume data were used for discharge of less than approximately 20 L/s, which was the upper limit of the small flumes' calibration ranges, and large flume data were used for discharges greater than 20 L/s. The following special rules applied to this method:

  Data gaps of greater than one-day in the small flume time series during continuous flows less than 20 L/s were filled with the available large flume flows. However, large flume data were not used to fill in gaps of less than one day in otherwise continuous small flume signal to prevent short-term jitter in the final discharge time series that would result from jumping between signals on semi-hourly basis. This was only an issue in the PFM002669 time series.
- A summary of specific data screening and cleanup for each discharge station is given in the four tables below.

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 highlighting indicates data removal, and light green highlighting indicates data addition based on a calibrated regression model.

Dates	Affected data points from small flume	Affected data points from large flume	Action
2004/04/24	2	4	Removed: data spike
2004/06/10–29		349	Removed: not in trend with small flume, appeared stuck
2004/12/02–03		7	Removed: data spike
2004/12/31–2005/01/12		206	Removed: not in trend with small flume, appeared stuck
2004/12/31–2005/01/11		180	Added: response modelled based on regression to small flume data
2005/01/15	7	20	Removed: noise
2005/01/22–23	4	11	Removed: noise
2005/01/25	9	10	Removed: noise
2005/02/19	1	1	Data spike
2005/02/28–04/03		642	Removed: not in trend with small flume, appeared stuck
2005/02/28–03/02		53	Added: response modelled based on regression to small flume data
2005/03/25–04/03		154	Added: response modelled based on regression to small flume data
2005/03/03	11		Removed: data spike
2006/01/03–05	49		Removed: not in trend with large flume: possibly stuck
2006/01/11		1	Removed: date spike
2006/01/16–03/28		1,300	Removed: not in trend with small flume: sensor appeared stuck
2006/01/16–21		109	Added: response modelled based on regression to small flume data
2006/01/24–04/15		1,186	Added: response modelled based on regression to small flume data, and compared to manual measurements with good agreements
2006/02/21–22	13		Removed: noise
2006/03/08	1		Removed: data spike
2006/03/12–13	17		Removed: noise
2006/03/17	10		Removed: noise
2006/03/21	5		Removed: noise
2006/03/21–27	141		Removed: appeared stuck
2006/12/20		11	Removed: not in trend with small flume
2007/02/01		2	Removed: data spike
2007/02/18		1	Removed: data spike
2007/02/27		1	Removed: data 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, light green shading indicates data addition based on a calibrated regression model, and light blue shading indicates addition of manually measured data to fill in data gaps.

Dates	Affected data points from small flume	Affected data points from large flume	Action
2004/12/29		12	Removed: data spike
2005/01/01–02	12		Removed: noise
2005/02/18	5	5	Removed: data spike
2005/02/19			Removed: data spike
2005/03/149	1	1	Removed: data spike
2005/03/15		11	Removed: noise
2005/03/16		4	Removed: data spike
2005/03/21		6	Removed: data spike
2005/03/22	2	5	Removed: data spike
2005/08/07		1	Removed: data spike
2005/12/21		7	Removed: data spike
2005/12/30		1	Removed: data spike
2006/01/21–23		47	Removed: noise
2006/02/07		3	Removed: data spike
2006/02/15	1	1	Added: manual measurements of flume water depth used to help fill 20-days gap
2006/02/24	1	1	Added: manual measurements of flume water depth used to help fill 20-days gap
2006/03/10		1	Removed: data spike
2006/03/12–13	6	6	Removed: noise
2006/03/13–14		25	Removed: data spike
2006/04/07–13		109	Added: response modelled based on regression to small flume data, and compared to manual measurements with good agreements
2006/04/19		1	Added: manual flow measurement used to fill 16-days gap
2006/04/20		1	Added: manual flow measurement used to fill 16-days gap
2006/04/23–29		142	Removed: values exceeded upper range for sensor
2006/10/30–/11/02	74		Removed: noise
2006/12/19	7		Removed: noise
2007/02/09		2	Removed: data spike

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. Light brown shading indicates data removal.

Dates	Affected data points	Action
2005/01/24	2	Removed: data spike
2005/02/17–18	3	Removed: data spike
2005/03/07–08	10	Removed: data spike
2005/03/15–16	22	Removed: noise
2005/03/21	3	Removed: data spike
2005/03/22	1	Removed: data spike
2005/07/23	8	Removed: noise
2005/12/29	4	Removed: noise
2006/01/03–11	172	Removed: noise
2006/01/21–24	57	Removed: noise
2006/02/13	6	Removed: noise
2006/02/22	5	Removed: data spike
2006/02/26	4	Removed: noise
2006/03/04	4	Removed: data spikes
2006/03/13–15	35	Removed: noise
2006/03/16	4	Removed: noise
2006/03/26	5	Removed: data spike

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, light green shading indicates data addition based on a calibrated regression model, and light blue shading indicates addition of manually measured data to fill in data gaps.

Dates	Affected data points from small flume	Affected data points from large flume	Action
2004/12/08–10		4	Removed: use small flume only during continuous intervals with flow < 20 L/s
2004/12/21–26		30	Removed: use small flume only during continuous intervals with flow < 20 L/s
2005/01/01	7	7	Removed: data spike
2005/01/08		2	Removed: use small flume only during continuous intervals with flow < 20 L/s
2005/01/29–02/06		20	Removed: use small flume only during continuous intervals with flow < 20 L/s
2005/03/01	7	7	Removed: data spike
2005/03/05	1	4	Removed: noise
2005/03/06–08	40		Removed: noise
2005/03/09–10	19	2	Removed: noise
2005/03/15–16	22		Removed: noise
2005/03/21	3		Removed: data spike
2005/03/22	1	1	Removed: data spike
2005/03/23		1	Removed: data spike

Dates	Affected data points from small flume	Affected data points from large flume	Action
2005/06/19–20		6	Removed: use small flume only during continuous intervals with flow < 20 L/s
2005/06/24		3	Removed: use small flume only during continuous intervals with flow < 20 L/s
2005/08/01	1	1	Added: manual measurements of flume water depth used to help fill 20-days gap
2005/08/08	1	1	Added: manual measurements of flume water depth used to help fill 20-days gap
2005/09/14		2	Removed: noise
2005/10/24–11/15		205	Removed: not in trend with small flume, appeared stuck
2005/10/25–26	15		Removed: noise
2005/12/06		1	Removed: use small flume only during continuous intervals with flow < 20 L/s
2005/12/20–26		14	Removed: use small flume only during continuous intervals with flow < 20 L/s
2005/12/29	3	3	Removed: noise
2005/12/31	4	3	Removed: data spike
2006/01/02	1		Removed: data spike
2006/01/04	5	2	Removed: noise
2006/01/09	2		Removed: data spike
2006/02/09–13		5	Removed: use small flume only during continuous intervals with flow < 20 L/s
2006/02/10	16	21	Removed: noise
2006/02/23	3	3	Removed: data spike
2006/02/25–26	10	13	Removed: data spike
2006/02/23–28		15	Removed: use small flume only during continuous intervals with flow < 20 L/s
2006/03/08	1	1	Removed: data spike
2006/03/22	9		Removed: data spike
2006/03/23	9		Removed: data spike
2006/03/24	6		Removed: data spike
2006/03/25	8		Removed: data spike
2006/04/09–13		83	Added: response modeled based on regression to small flume data, and compared to manual measurements with good agreements
2007/03/01	2	2	Removed: data spike
2007/03/02	2	2	Removed: data spike

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 three-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.

4.5 Nonconformities

The gauging station at PFM005764 had to be re-installed since critical flow was not reached at high flows. Before the re-installation in October, 2004, the highest discharge measured with acceptable accuracy was approximately 70 L/s (see Section 3.1). At the re-installation, the inlet to the observation tube of the small flume was placed at an erroneously high elevation (0.990 m, RHB70) compared with the flume bottom elevation of 0.903 m (RHB70).

Beside the above-mentioned nonconformities only data losses for relatively short time periods have occurred 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 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 electronical equipment.

The jumps in the water level time series of PFM005764 in October 2004 were due to the re-installation of the flumes. The bottom elevations of the flumes were raised by approximately 0.3 m (see Table 3-1). The jump in the water level of the small flume in September 2006 was the result of a re-installation of the observation tube of the flume to correct an error in the elevation of the tube. This error prevented the water level in the tube to decrease below 0.99 m RHB70 (see Section 4.5). This error only had an impact at very low flows and erroneous data were removed when discharge was calculated.

The temporal variations in of the water levels were approximately 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, 1.14, 1.70 and 4.45 m RHB70, respectively (small flume data; levels below zero discharge not included; for PFM005764 only the time period after the installation in October 2004, was included). The temporal variations of the water levels at PFM002669 were approximately 0.5 m, and the mean water elevation was 6.05 m RHB70.

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 2005 and 2006 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.

No data were removed from the PFM002292 time series due to low or no discharge since discharge was not measured at the outlet of Lake Bolundsfjärden. However, the low and no discharge time periods approximately coinsided with the low and no discharge periods of the discharge gauging stations. An indication of low and no discharge periods could also be obtained from the water level of Lake Bolundsfjärden when compared with the surveyed lake threshold of 0.28 m RHB70.

The mean electrical conductivities in PFM005764, PFM002667, PFM002668 and PFM002669 were 39, 26, 25 and 36 mS/m, respectively.

The electrical conductivity of the water leaving Bolundsfjärden was for most of the observation period between 70 and 100 mS/m. However, during events of extremely high sea water levels, saline water flowed in to the lake. Such events appeared during December and January 2006 and November and January of 2006. The highest recorded electrical conductivity was almost 900 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 2005 and 2006 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 degrees 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 212 L/s and for the smallest catchment 75.9 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, which had a 35.5 months' time series, was 4.87 L/s/km^2 (154 mm). The variation of specific discharge for a specific station for the time periods selected for comparison was 24-33% while the variation between stations for the same time period was 9-13%.

Table 5-1. Discharge characteristics for the four gauging stations for various time periods (* total available time series for PFM00576, ** total available time series for PFM002667, PFM002668 and PFM002669).

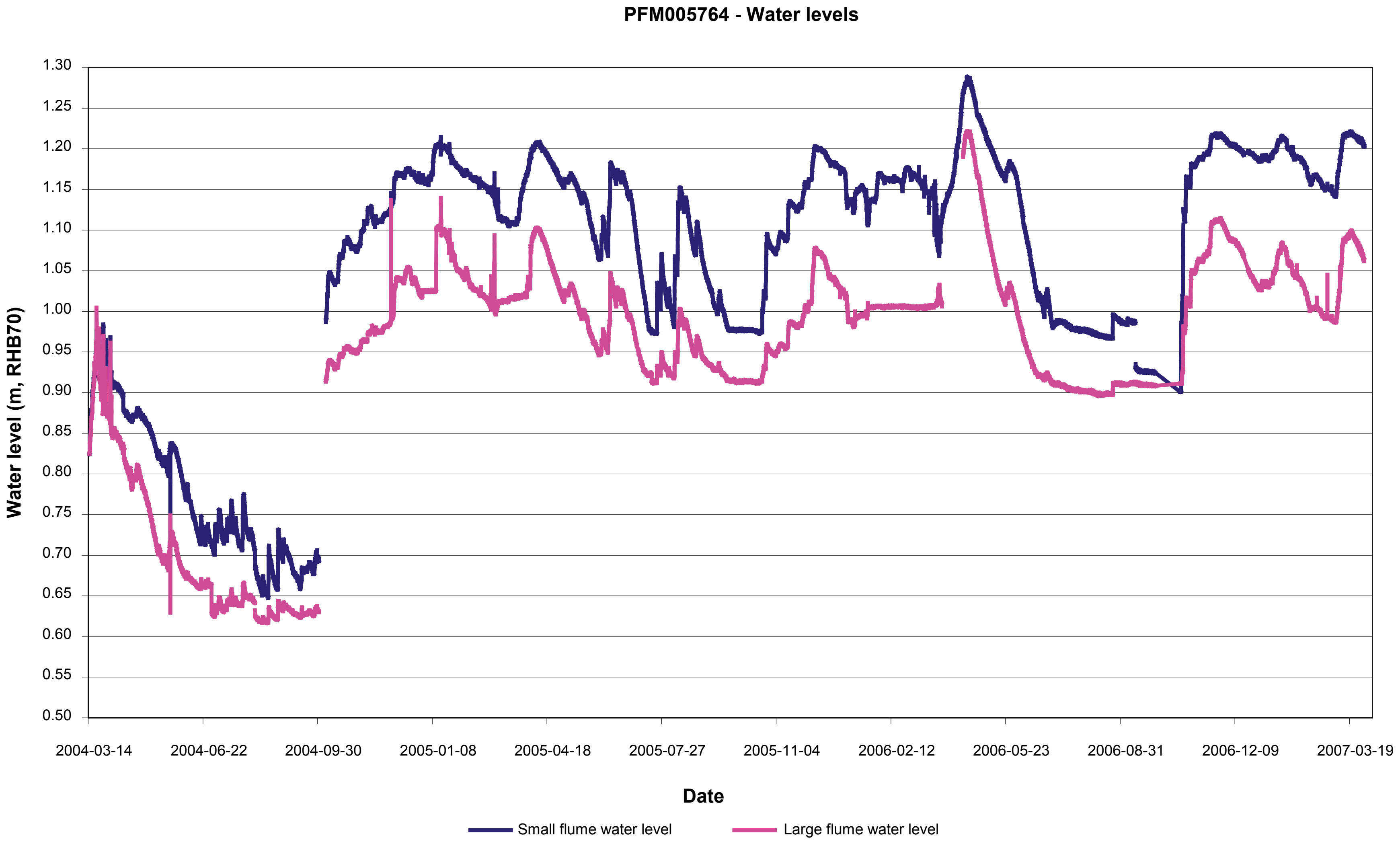
	PFM005764	PFM002667	PFM002668	PFM002669
Apr 15, 2004-Mar 31, 2007*				
Mean discharge (L/s)	27.2			
Min. discharge (L/s)	0.00			
Max. discharge (L/s)	212			
Specific discharge (L/s/km^2)	4.87			
Specific discharge (mm/yr)	154			
Dec 8, 2004-Mar 31, 2007**				
Mean discharge (L/s)	31.0	15.6	11.6	15.8
Min. discharge (L/s)	0.00	0.00	0.00	0.00
Max. discharge (L/s)	212	131	75.9	183
Specific discharge (L/s/km^2)	5.54	5.19	5.07	5.57
Specific discharge (mm/yr)	175	164	160	176
Jan 1-Dec 31, 2005				
Mean discharge (L/s)	25.2	12.1	9.09	11.6
Min. discharge (L/s)	0.00	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)	0.00	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
Oct 1, 2004-Sep 30, 2005				
Mean discharge (L/s)	24.7			
Min. discharge (L/s)	0.00			
Max. discharge (L/s)	85.3			
Specific discharge (L/s/km^2)	4.42			
Specific discharge (mm/yr)	139			
Oct 1, 2005-Sep 30, 2006				
Mean discharge (L/s)	27.3	14.3	10.3	14.1
Min. discharge (L/s)	0.00	0.00	0.00	0.00
Max. discharge (L/s)	212	131	75.9	183
Specific discharge (L/s/km^2)	4.88	4.74	4.53	4.96
Specific discharge (mm/yr)	154	149	143	157

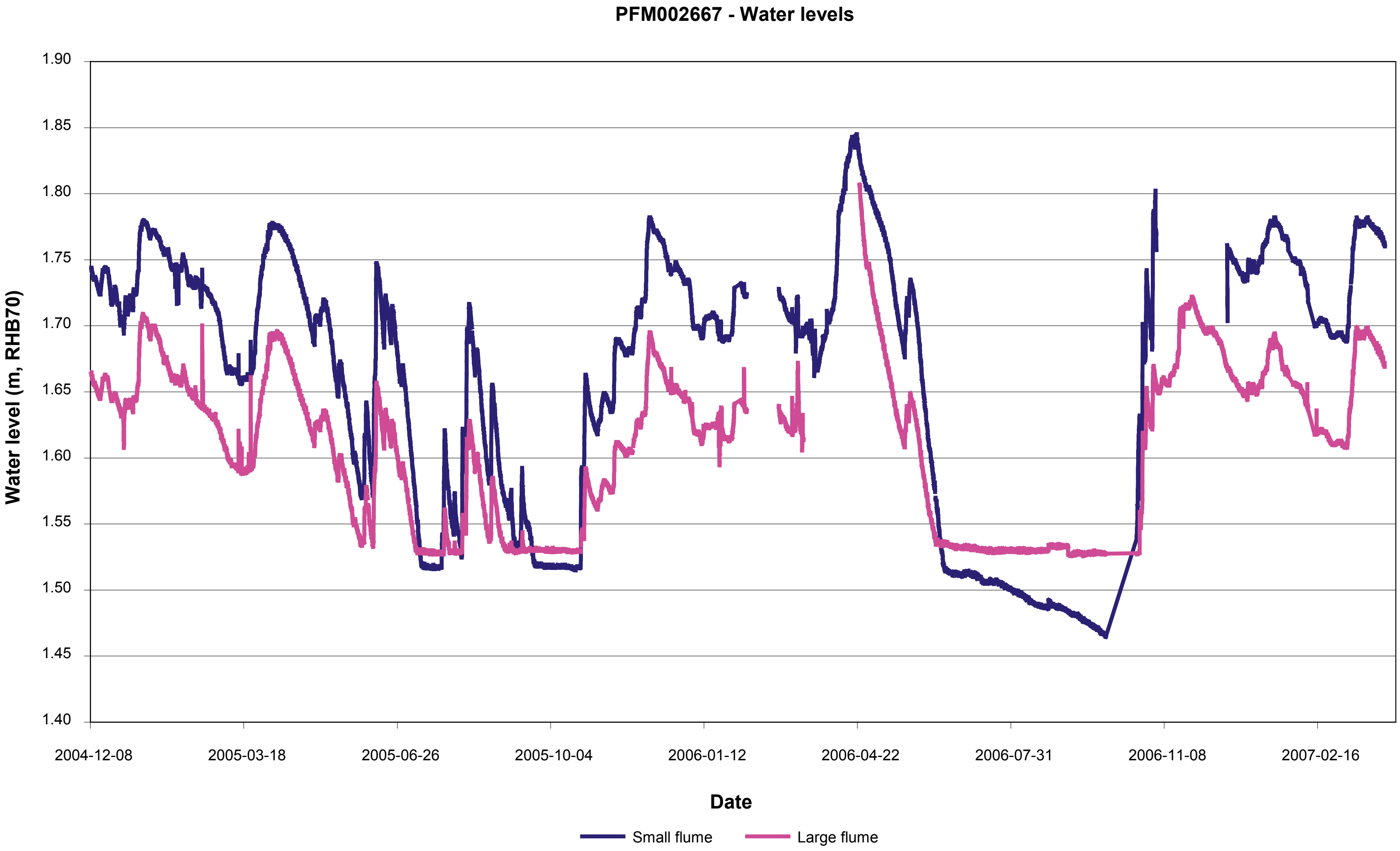
Reference

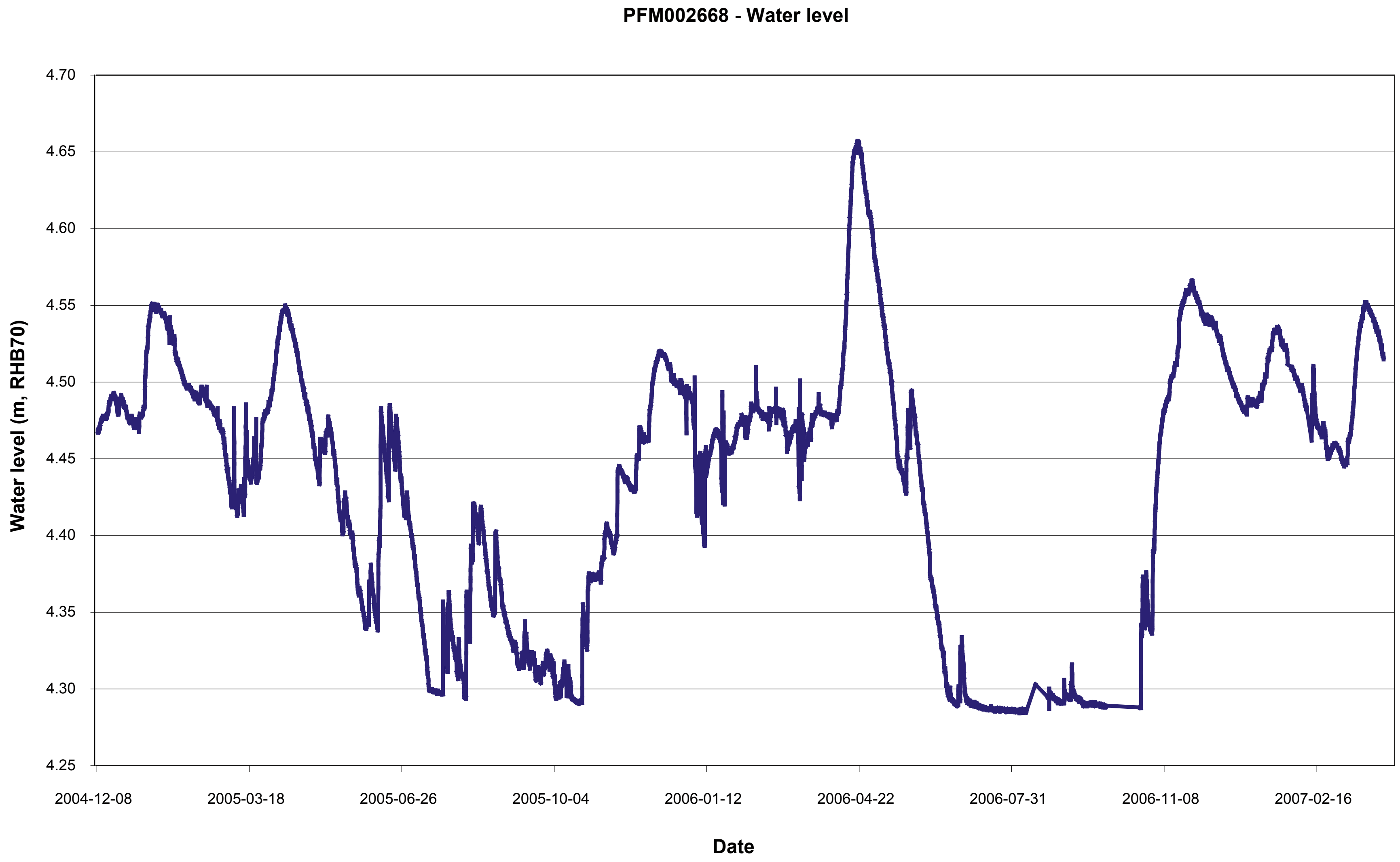
Johansson P O, 2005. Forsmark site investigation. Installation of brook discharge gauging stations. SKB P-05-154, Svensk Kärnbränslehantering AB.

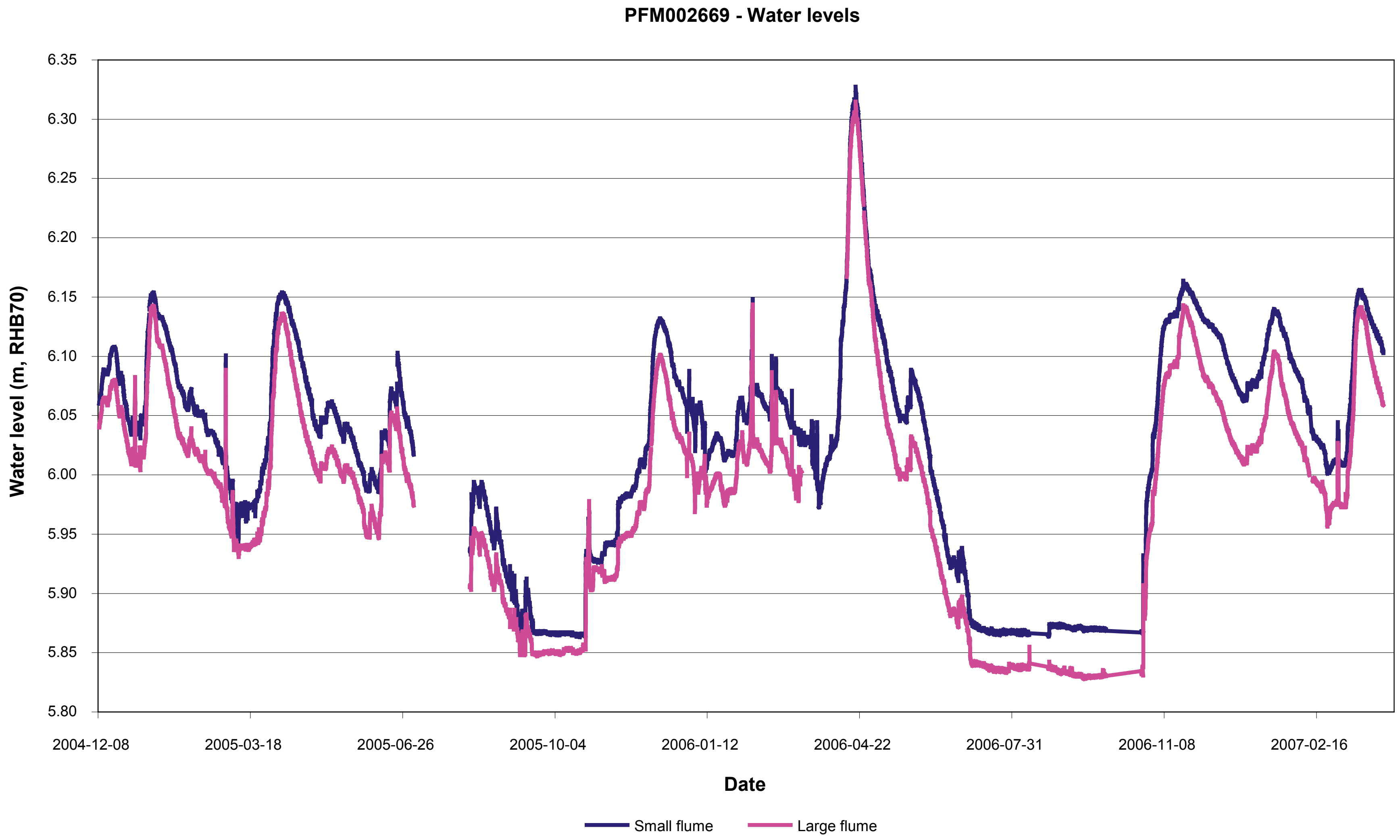
Appendix 1

Water levels at the gauging stations


PFM005764 - Water levels
Water level (m, RHB70)
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
2004-03-14
2004-06-22
2004-09-30
2005-01-08
2005-04-18
2005-07-27
2005-11-04
2006-02-12
2006-05-23
2006-08-31
2006-12-09
2007-03-19
Date
Small flume water level
Large flume water level

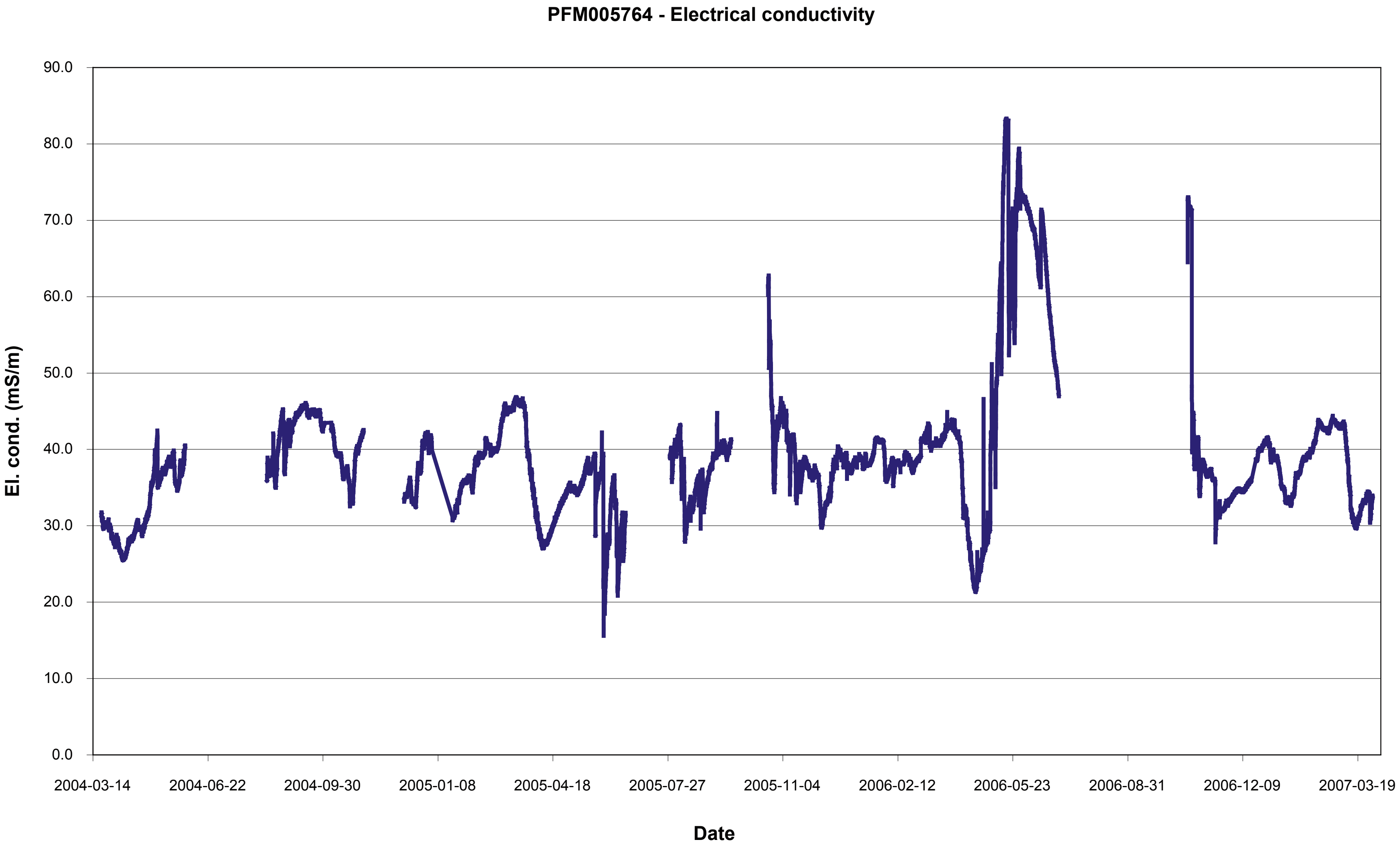

PFM002667 - Water levels
Water level (m, RHB70)
1.90
1.85
1.80
1.75
1.70
1.65
1.60
1.55
1.50
1.45
1.40
2004-12-08
2005-03-18
2005-06-26
2005-10-04
2006-01-12
2006-04-22
2006-07-31
2006-11-08
2007-02-16
Date
Small flume
Large flume

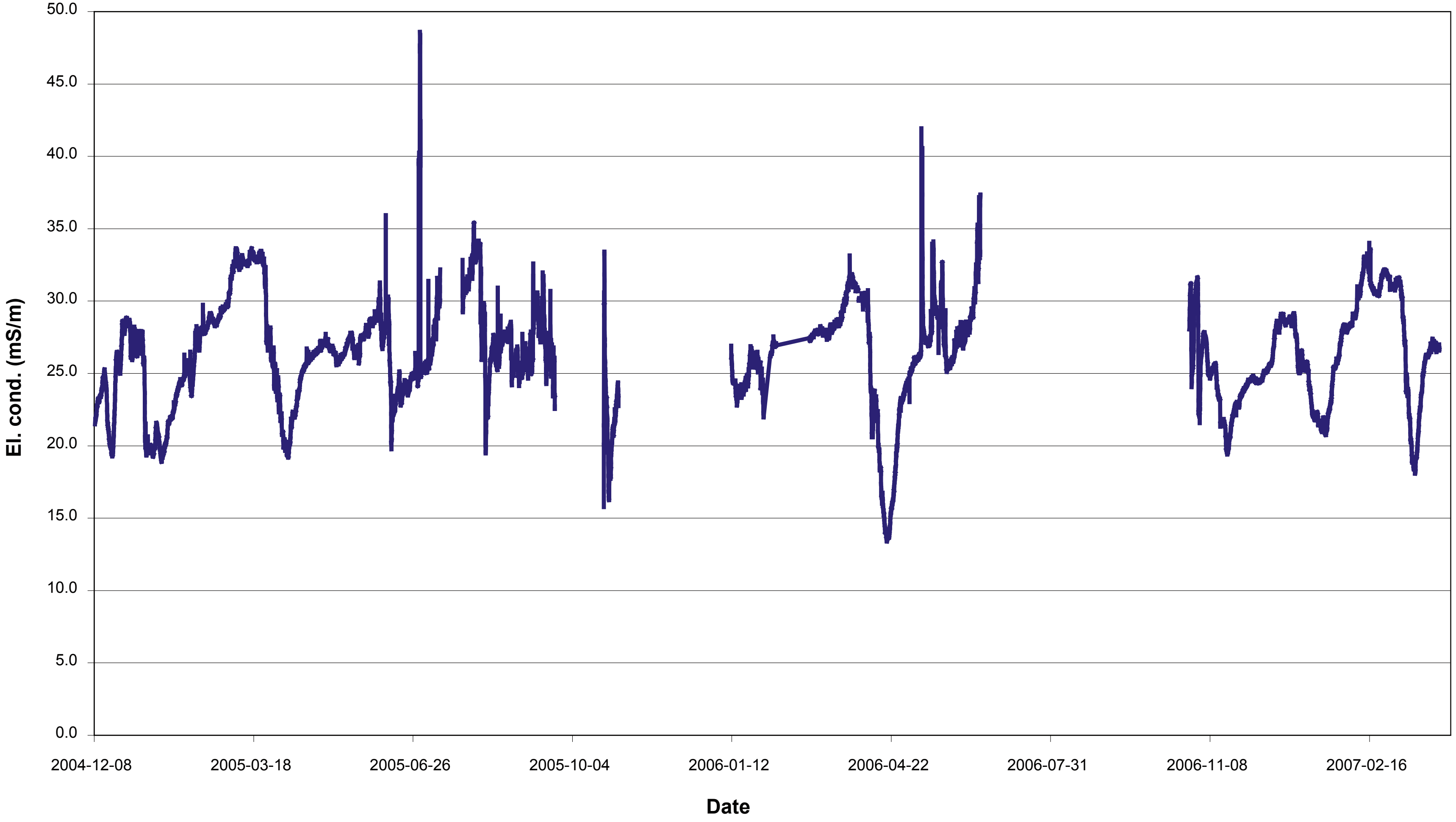

PFM002668 - Water level
Water level (m, RHB70)
4.70
4.65
4.60
4.55
4.50
4.45
4.40
4.35
4.30
4.25
2004-12-08
2005-03-18
2005-06-26
2005-10-04
2006-01-12
2006-04-22
2006-07-31
2006-11-08
2007-02-16
Date


PFM002669 - Water levels
Water level (m, RHB70)
6.35
6.30
6.25
6.20
6.15
6.10
6.05
6.00
5.95
5.90
5.85
5.80
2004-12-08
2005-03-18
2005-06-26
2005-10-04
2006-01-12
2006-04-22
2006-07-31
2006-11-08
2007-02-16
Date
Small flume
Large flume

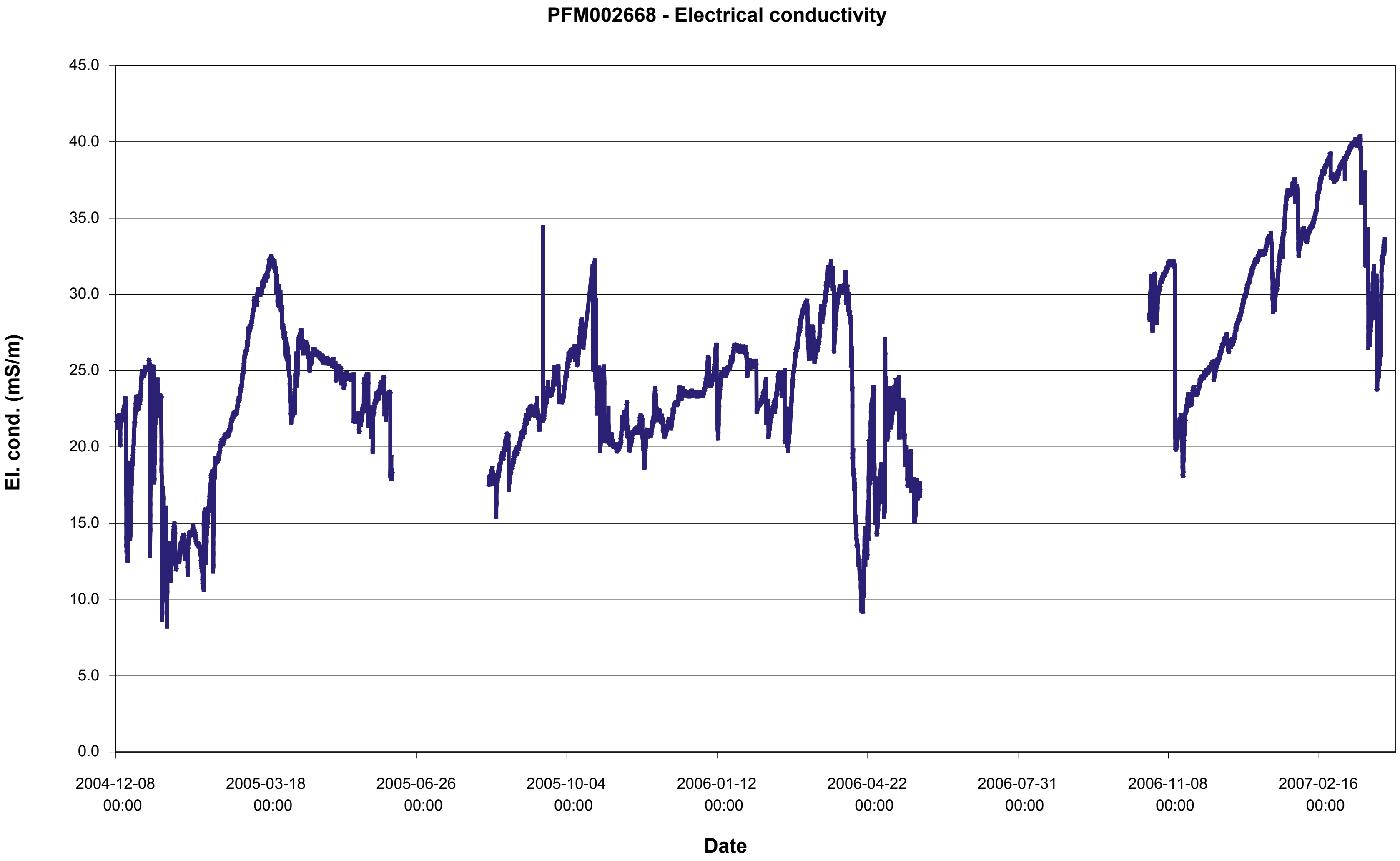
Appendix 2

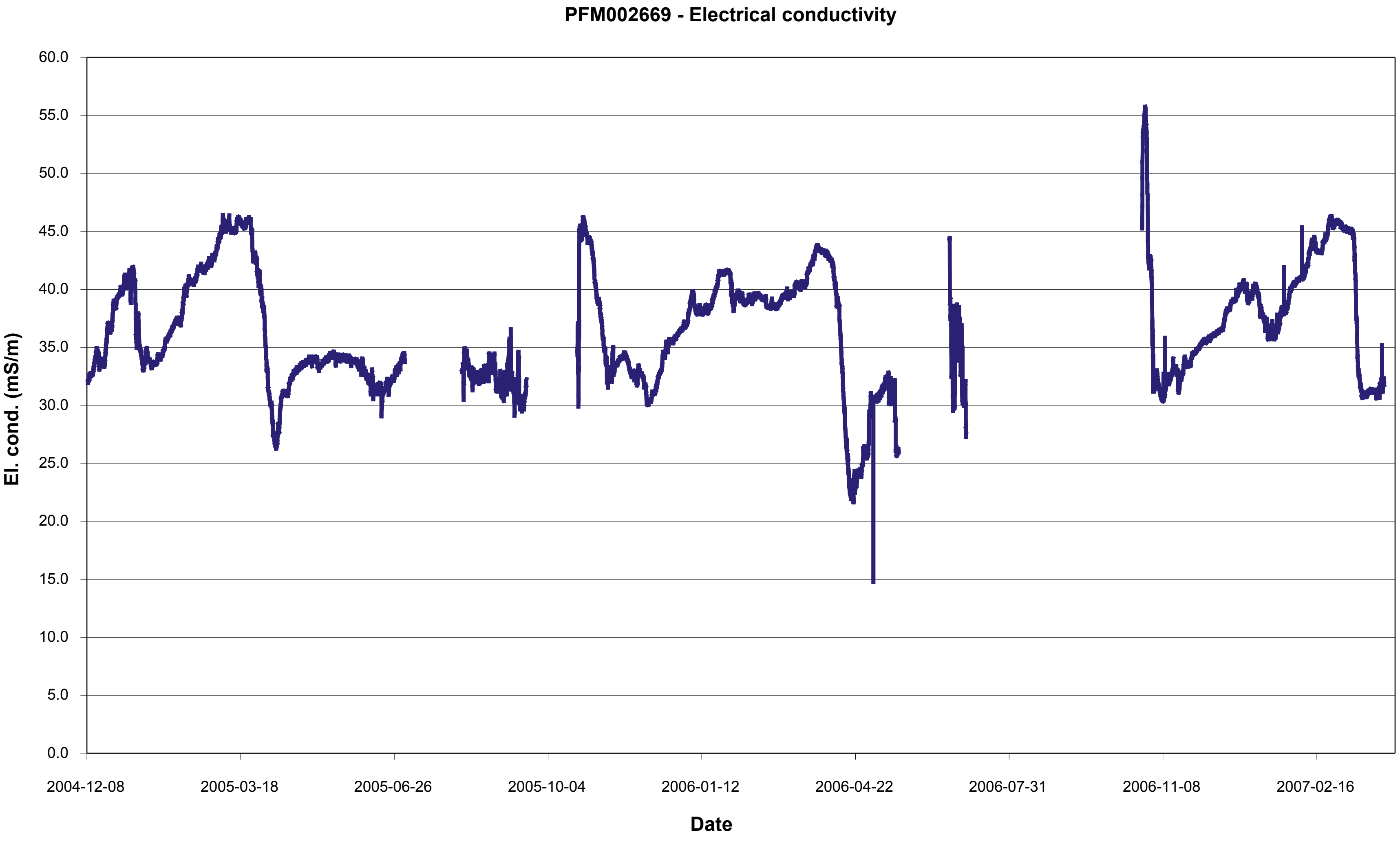
Water electrical conductivities at the four gauging stations and at the outlet of Lake Bolundsfjärden


PFM005764 - Electrical conductivity
El. cond. (mS/m)
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
2004-03-14
2004-06-22
2004-09-30
2005-01-08
2005-04-18
2005-07-27
2005-11-04
2006-02-12
2006-05-23
2006-08-31
2006-12-09
2007-03-19
Date

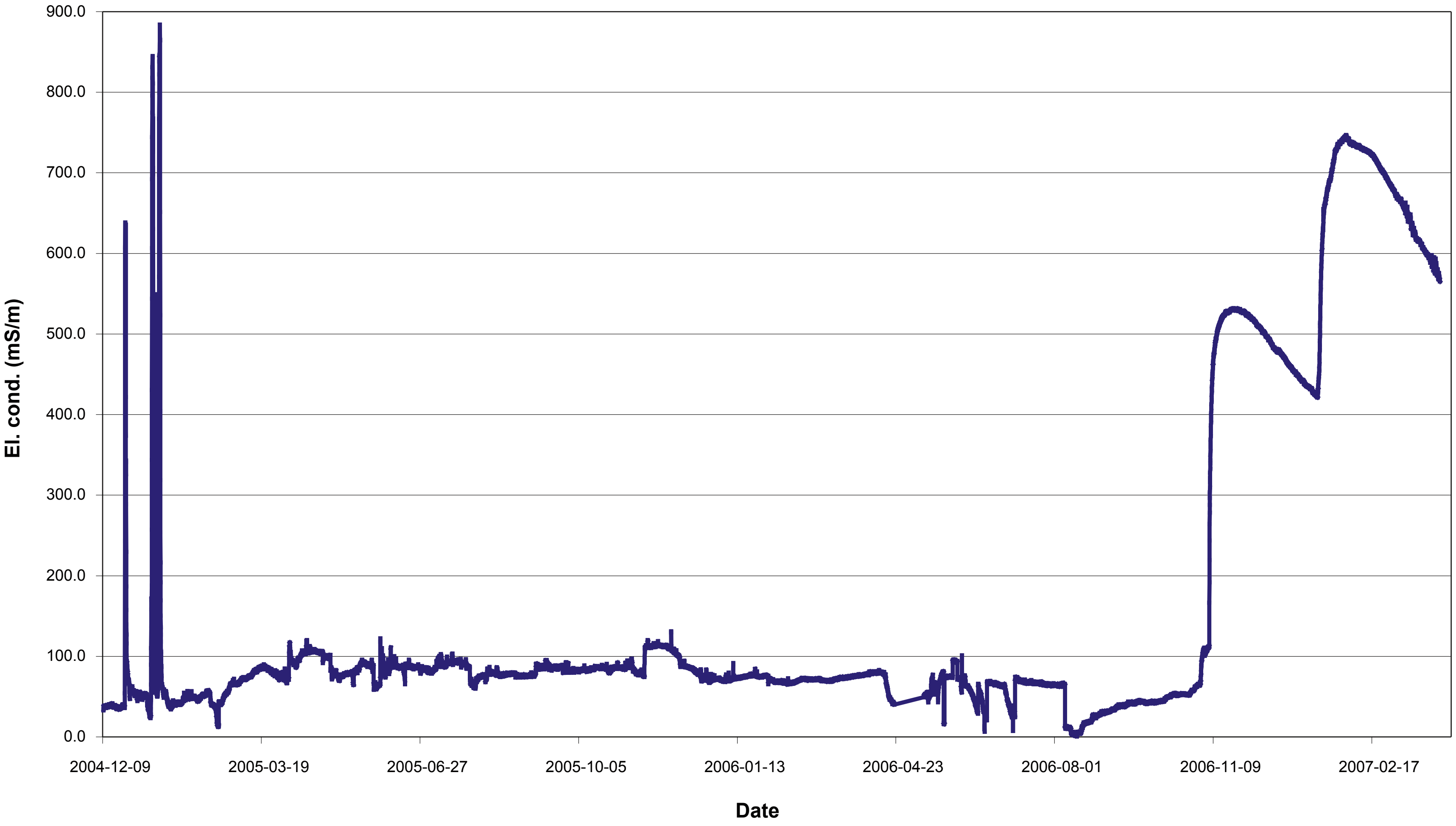


PFM002667 - Electrical conductivity


PFM002668 - Electrical conductivity
El. cond. (mS/m)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2004-12-08 00:00
2005-03-18 00:00
2005-06-26 00:00
2005-10-04 00:00
2006-01-12 00:00
2006-04-22 00:00
2006-07-31 00:00
2006-11-08 00:00
2007-02-16 00:00
Date

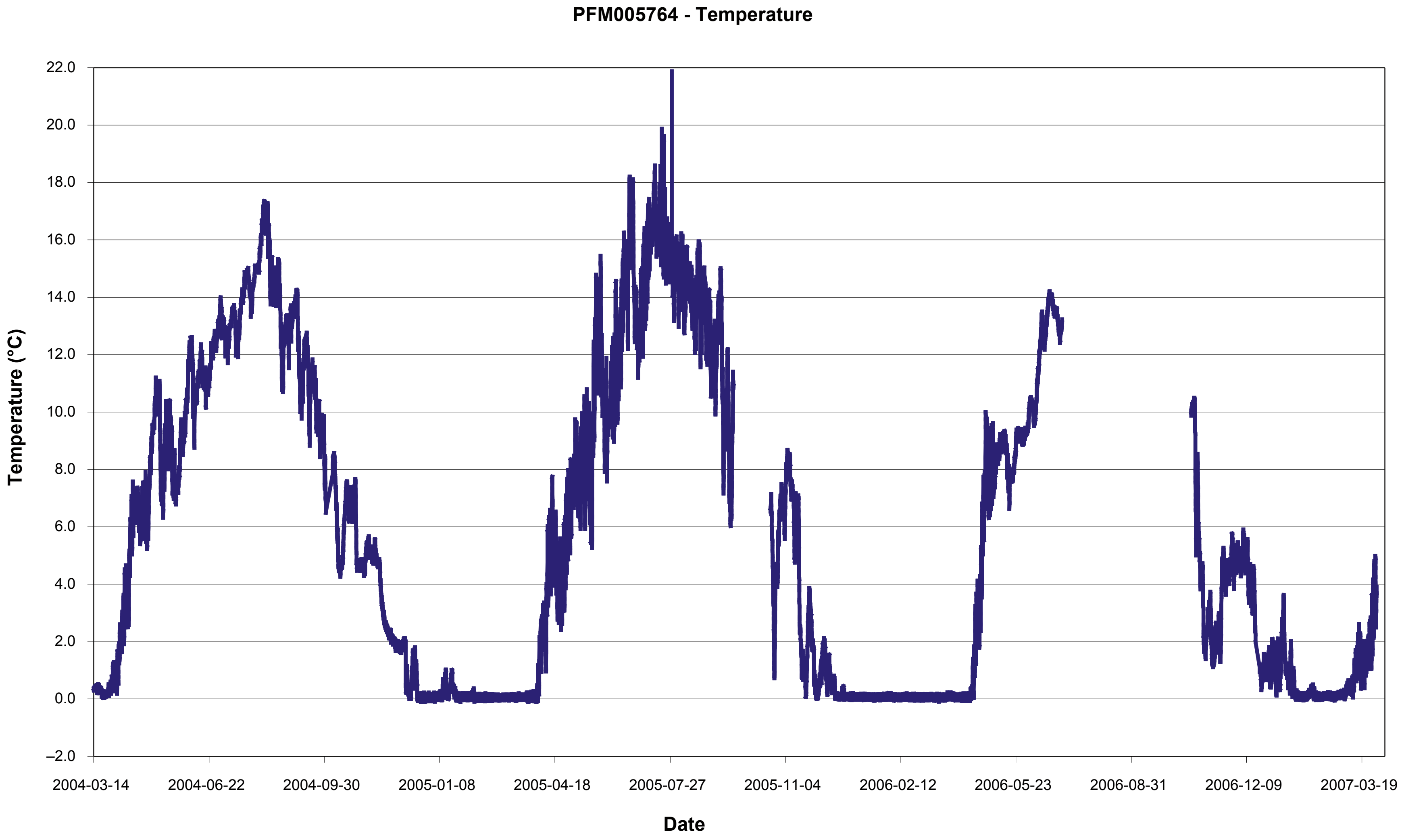

PFM002669 - Electrical conductivity
El. cond. (mS/m)
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2004-12-08
2005-03-18
2005-06-26
2005-10-04
2006-01-12
2006-04-22
2006-07-31
2006-11-08
2007-02-16
Date

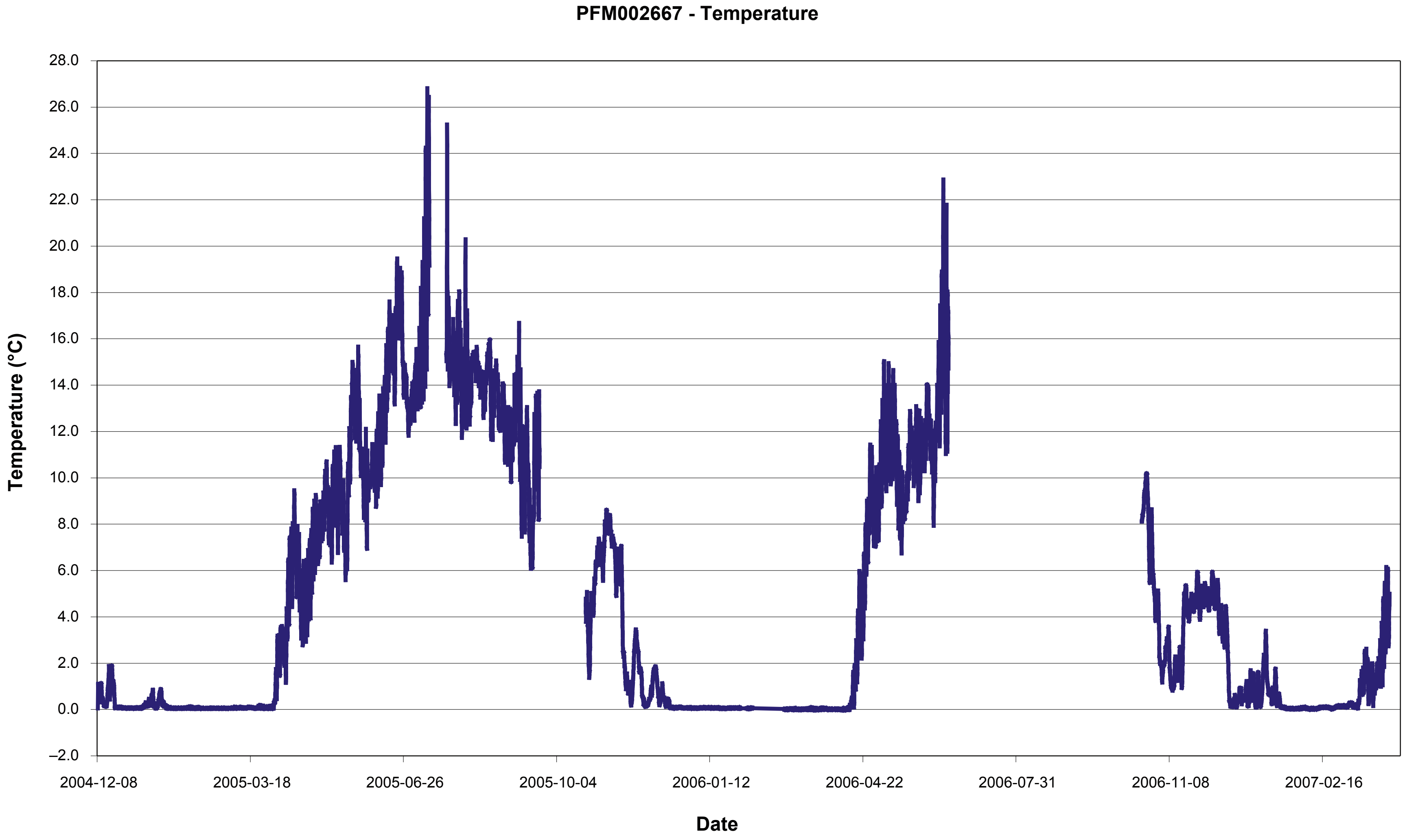
PFM002292 - Electrical conductivity



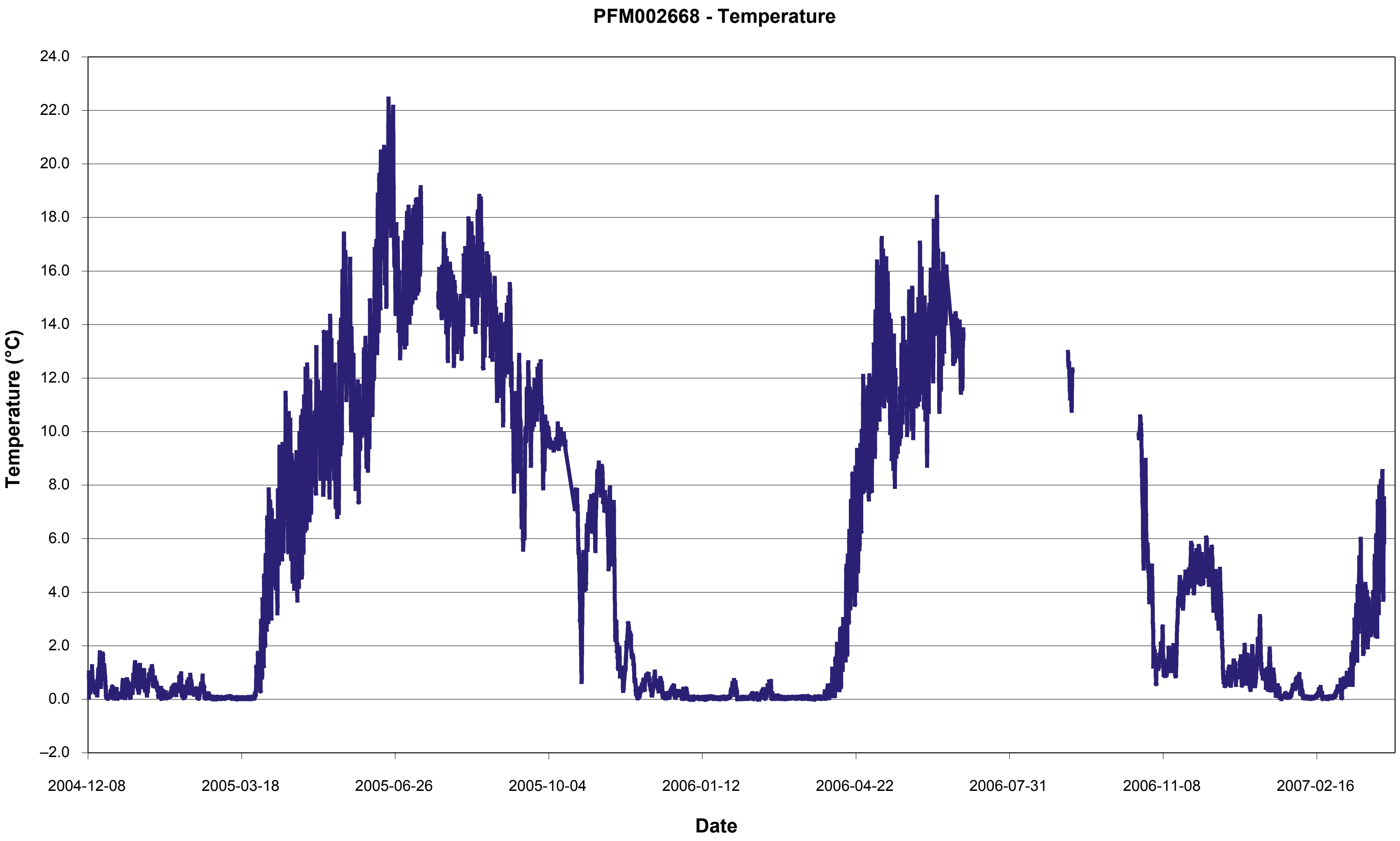
Appendix 3

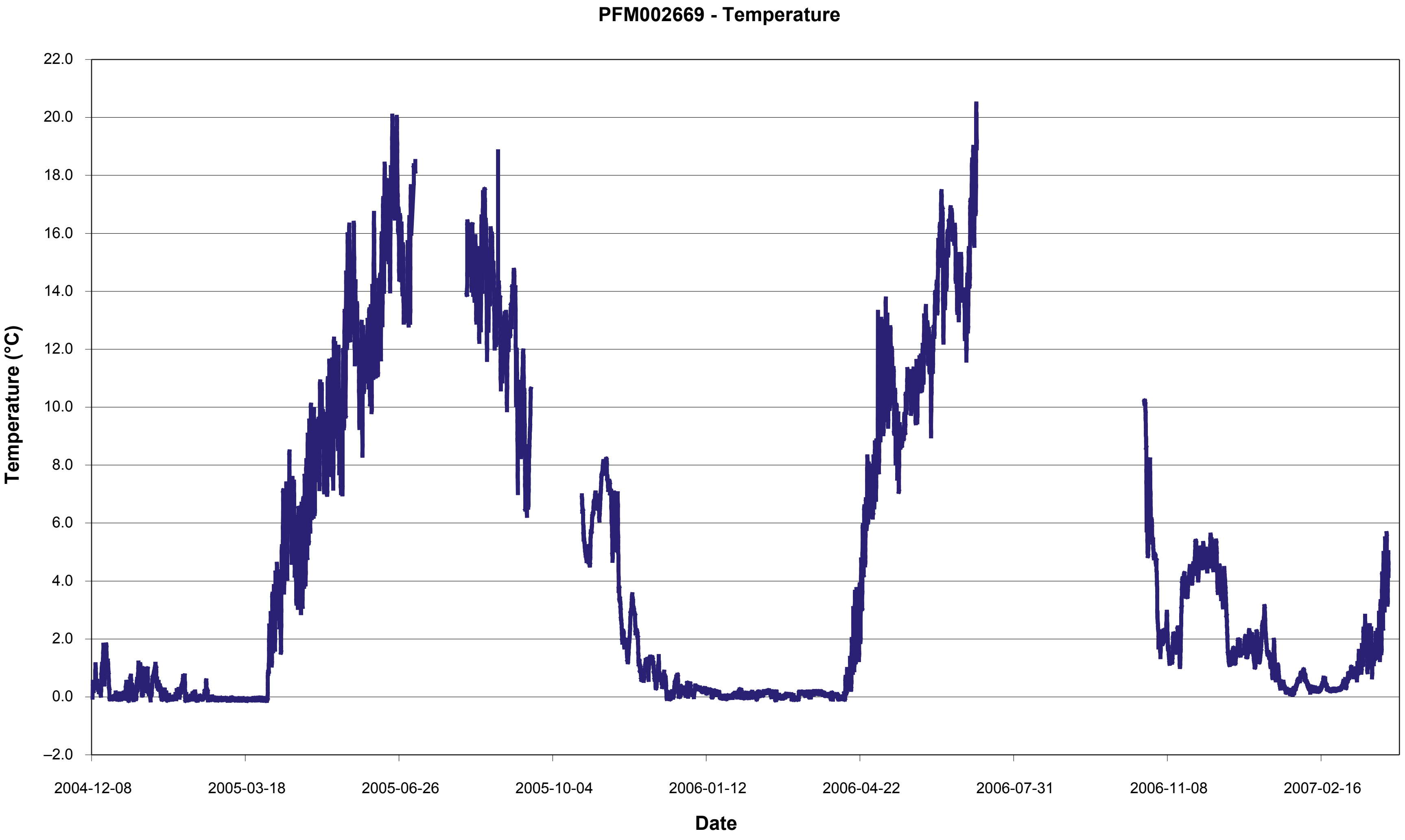
Water temperatures at the four gauging stations


PFM005764 - Temperature
Temperature (°C)
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
−2.0
2004-03-14
2004-06-22
2004-09-30
2005-01-08
2005-04-18
2005-07-27
2005-11-04
2006-02-12
2006-05-23
2006-08-31
2006-12-09
2007-03-19
Date



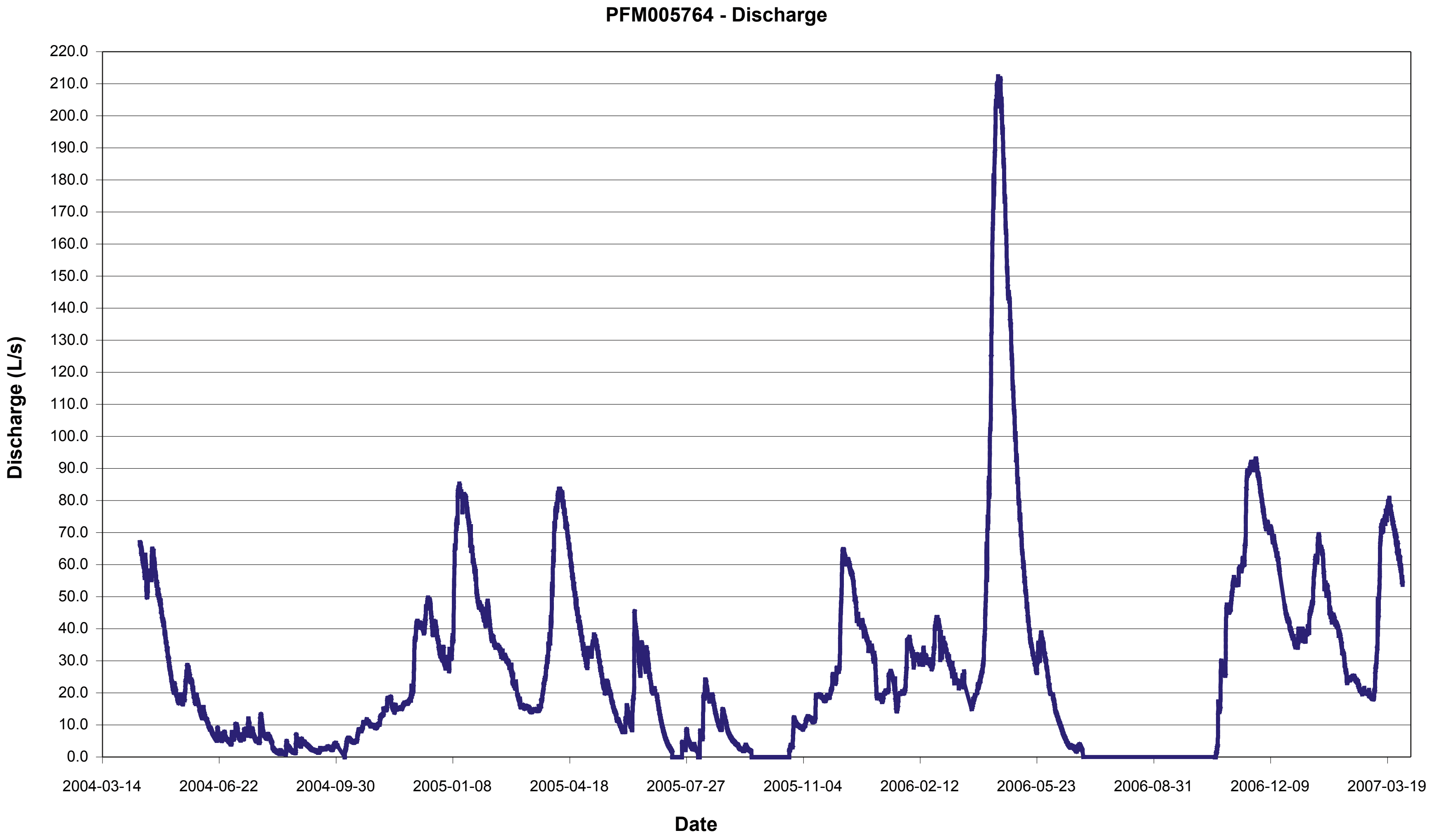
PFM002667 - Temperature

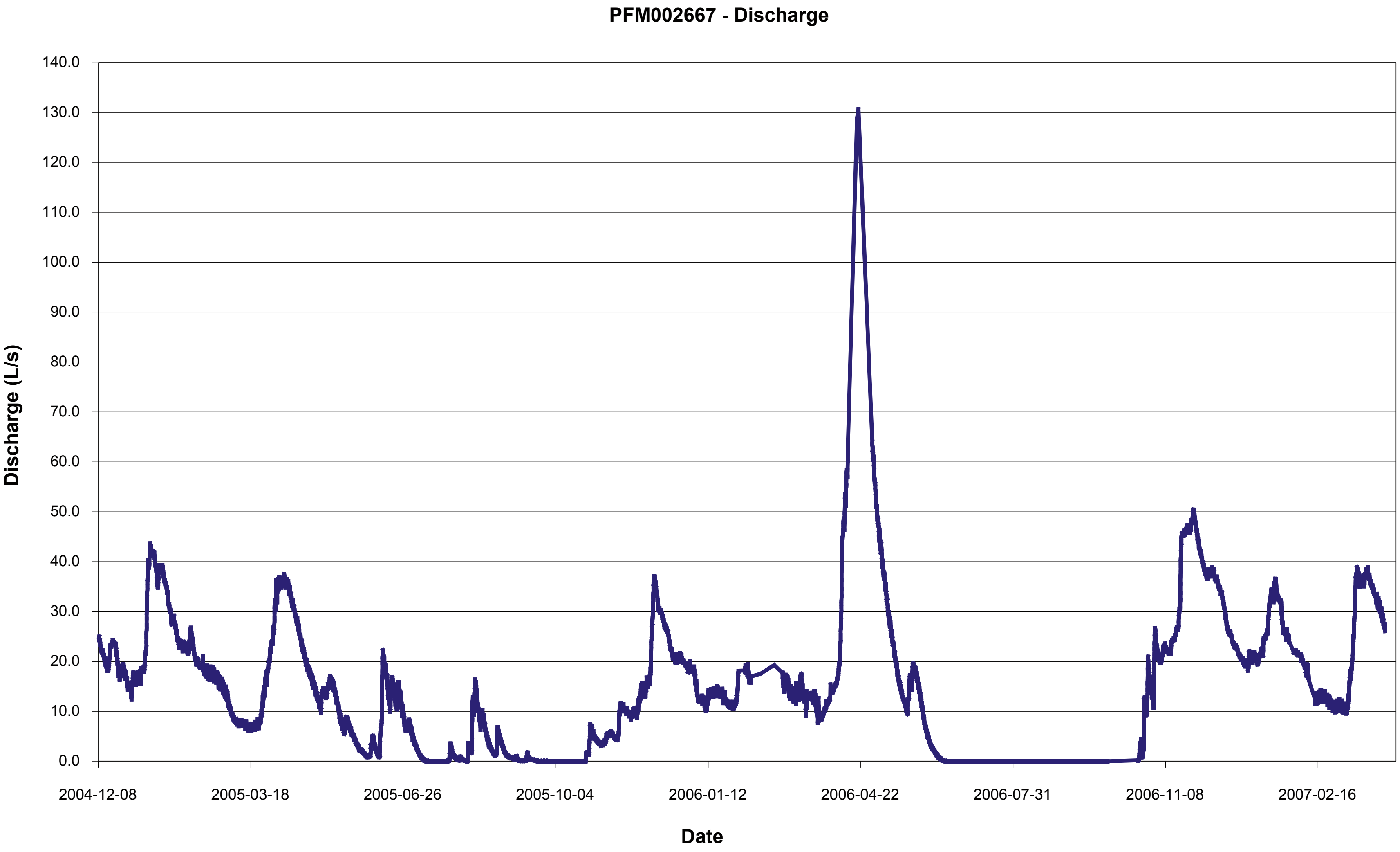

PFM002668 - Temperature
Temperature (°C)
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
–2.0
2004-12-08
2005-03-18
2005-06-26
2005-10-04
2006-01-12
2006-04-22
2006-07-31
2006-11-08
2007-02-16
Date

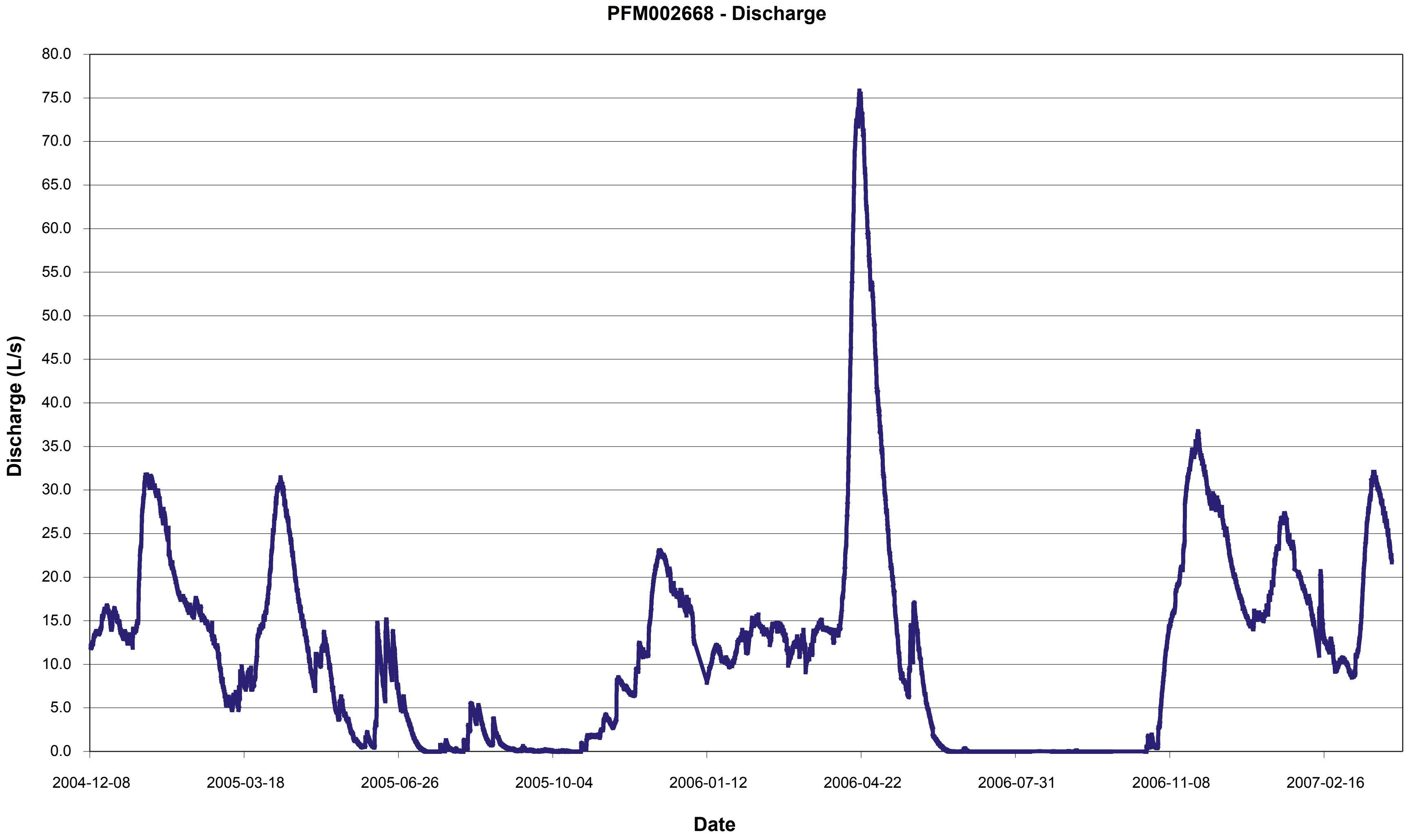

PFM002669 - Temperature
Temperature (°C)
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
−2.0
2004-12-08
2005-03-18
2005-06-26
2005-10-04
2006-01-12
2006-04-22
2006-07-31
2006-11-08
2007-02-16
Date

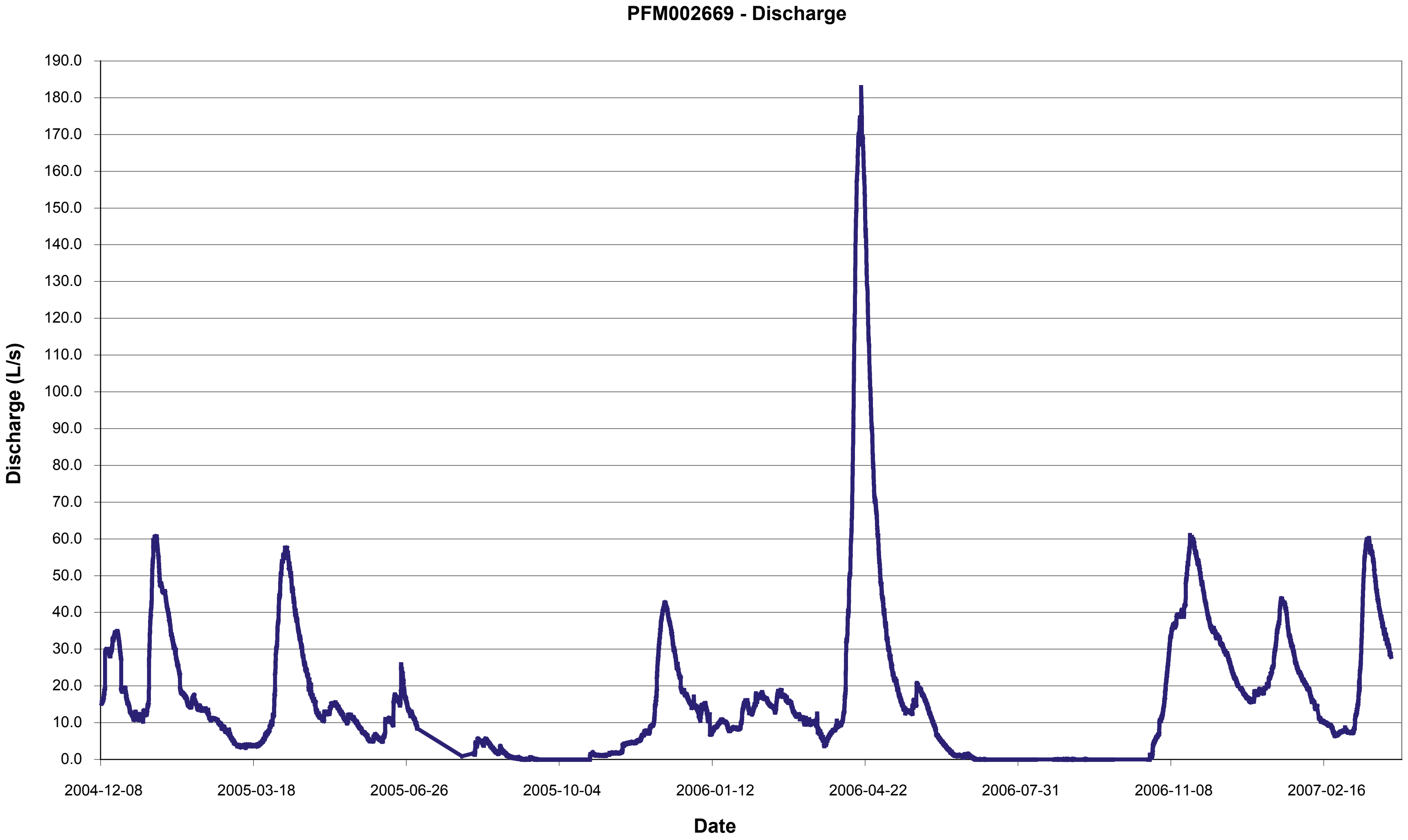
Appendix 4

Discharge at the four gauging stations


PFM005764 - Discharge
Discharge (L/s)
220.0
210.0
200.0
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
2004-03-14
2004-06-22
2004-09-30
2005-01-08
2005-04-18
2005-07-27
2005-11-04
2006-02-12
2006-05-23
2006-08-31
2006-12-09
2007-03-19
Date


PFM002667 - Discharge
Discharge (L/s)
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
2004-12-08
2005-03-18
2005-06-26
2005-10-04
2006-01-12
2006-04-22
2006-07-31
2006-11-08
2007-02-16
Date


PFM002668 - Discharge
Discharge (L/s)
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2004-12-08
2005-03-18
2005-06-26
2005-10-04
2006-01-12
2006-04-22
2006-07-31
2006-11-08
2007-02-16
Date


PFM002669 - Discharge
Discharge (L/s)
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
2004-12-08
2005-03-18
2005-06-26
2005-10-04
2006-01-12
2006-04-22
2006-07-31
2006-11-08
2007-02-16
Date