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Forsmark site investigation

Installation of brook discharge gauging stations

Per-Olof Johansson, Artesia Grundvattenkonsult AB

June 2005

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Keywords: AP PF 400-02-32, Discharge, Gauging stations, Long-throated flumes.

Abstract

There are no major water courses within the central part of the Forsmark site investigation area. However, there are a number of brooks 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 have been installed in the large brooks. The first permanent gauging station was installed in November, 2003. However, 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.

Long-throated flumes were selected for the discharge measurements, mainly due to the limitations set by the flat landscape and the need for accurate measurements. Long-throated flumes have several advantages as the cross-sectional design is quite flexible and computational design can be used. Long-throated flumes give accurate measurements over relatively wide flow ranges and work under a high degree of submergence.

The accuracy of the discharge measurements is, however, 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 performed calibrations with an area-velocity method show a good accuracy of the discharge calculated by the equations derived for the flumes by the WinFlume software. However, additional calibrations are desirable for high discharges, especially to verify that the measurements are not disturbed by tailwater conditions.

Sammanfattning

Det finns inga större vattendrag i de centrala delarna av platsundersökningsområdet i Forsmark. Av de bäckar som dränerar området för några vatten större delen av året medan de mindre bäckarna är torra under långa perioder.

Fyra permanenta automatiska vattenföringsstationer har installerats i de större bäckarna. Den första stationen installerades i november 2003. På grund av dämningsproblem vid höga vattenföringar utfördes en ominstallation av denna station i oktober 2004 då också de tre andra mätstationerna installerades.

På grund av den flacka terrängen och behovet av noggranna mätningar valdes mätrännor av typen ”long-throated flumes”. Denna typ av rännor kan utformas efter vattendraget och datorprogram kan användas för designen. Rännorna kräver en liten dämning och fungerar över ett relativt brett mätintervall.

Vattenföringsmätningarnas noggrannhet är starkt beroende av vattennivåmätningarnas noggrannhet och av rensning och underhåll av mätrännorna och vattendragen närmast nedströms rännorna. Särskilt under vintern är det viktigt med täta inspektioner för att undvika störningar i driften orsakade av is.

De kalibreringsmätningar som har utförts med en area-hastighetsmetod visade på en god noggrannhet för de vattenföringar som beräknas med de flödesekvationer som tagits fram för rännorna med programvaran WinFlume. Ytterligare kalibreringar vid höga vattenföringar rekommenderas dock, främst för att kontrollera att mätningarna inte störs av nedströmsförhållandena.

Contents

1 Introduction

This document reports the installation of four brook discharge gauging stations, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-02-32. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

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 have been installed in the large 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. However, 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 all installed. The locations of the four discharge gauging stations are shown in Figure 1-1. Detailed data on the positions of the discharge gauging stations are stored in SKB's SICADA database and are traceable by the activity plan number.

Before the permanent gauging stations were installed, manual discharge measurements were performed at eight locations. The permanent stations were installed at three of the locations of the manual measurements. The manual discharge measurements are reported in /Johansson, 2005/ where also a comparison of results from the manual and automatic discharge measurements is made for a time period with overlapping measurements.

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

Activity plan	Number	Version
Anläggning av stationer för mätning av vattenföring	AP PF 400-02-32	1.0
Method description	**Number**	**Version**
Ythydrologiska mätningar	SKB MD 364.008	1.0

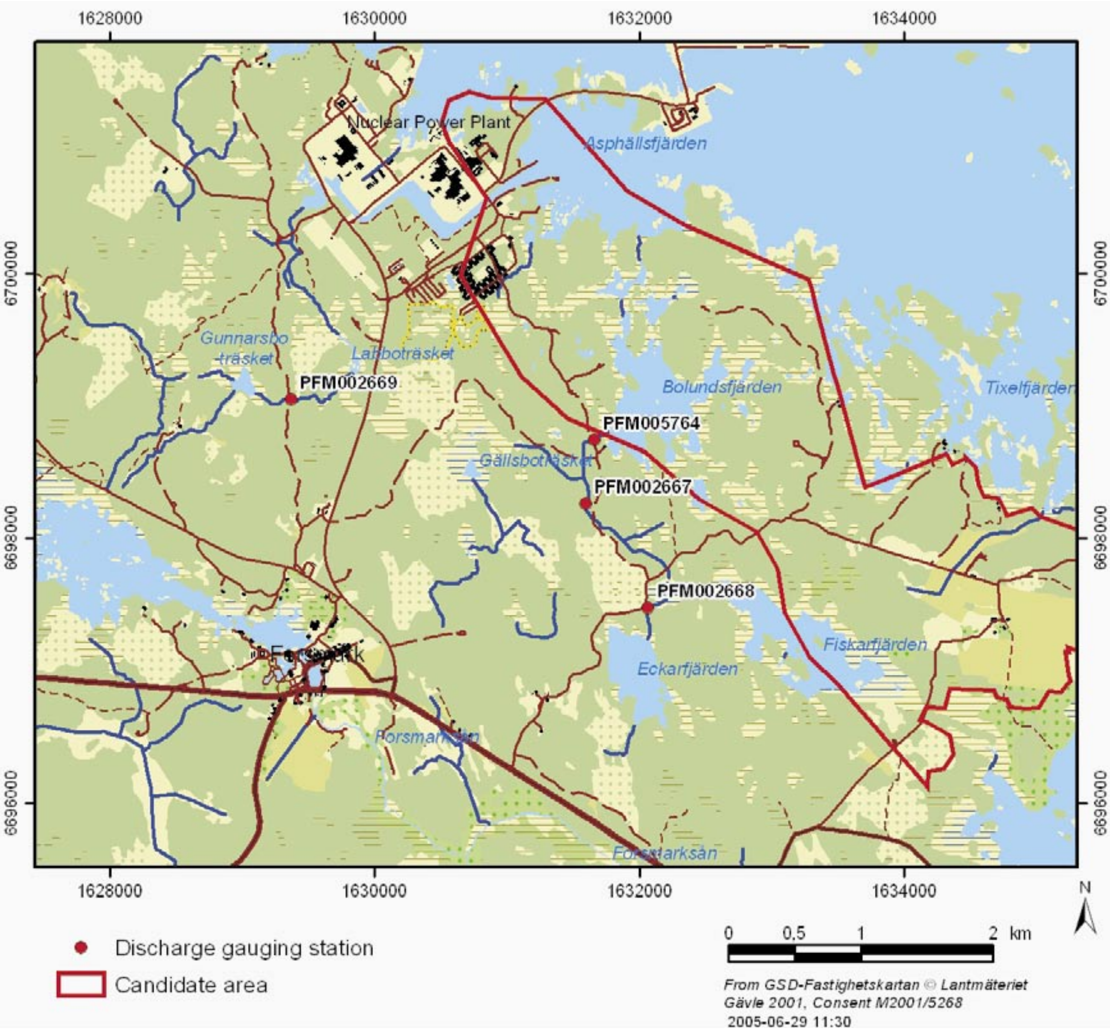

Figure 1-1. *Location of the permanent, automatic brook discharge gauging stations.*

2 Objective and scope

The objectives of the installation of gauging stations for measurement of brook discharge in the central parts of the site investigation area are to provide:

- information on the spatial and temporal variation of brook discharge,
- increased understanding of the water balance 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.

Based on the listed objectives, the limitations set by the flat landscape, the experience from the manual discharge measurements and the desire to avoid migration obstacles for the fish, it was decided to install so-called long-throated flumes at four locations. Two, from a hydrological point of view interesting preliminary selected locations, had to be given up. At the outlet of Lake Bolundsfjärden, the section is well-defined at low water levels, while flow appears over a very wide section at higher water levels. A dam over this wide section should heavily influence the upstream hydrological conditions. The brook from Lake Gällsboträsket has a so low gradient that also the installation of a long-throated flume should influence the level of the lake. However, by the installation of PFM002667 in the brook from Lake Eckarfjärden to Lake Bolundsfjärden, just before the inflow of the brook from Lake Gällsboträsket, the discharge in the latter brook can be approximated as the difference between the discharge at PFM005764 and PFM002667 (see Figure 1-1).

3 Execution

3.1 General

Different methods for discharge measurements are described in SKB's method description for surface hydrology measurements (SKB MD 364.008, version 1.0, "Ythydrologiska mätningar", SKB internal document). Based on the method description, the need for accurate measurement, a literature review and the limitations set by the flat landscape, it was decided that flumes should be used. Contacts were made with the Swedish Meteorological and Hydrological Institute (SMHI) and the Swedish Agricultural Univesity (SLU). The Swedish experience of discharge measurements by flumes in natural environments is very limited. SMHI had no stations with flumes while SLU was using so called H-flumes at two stations. In urban environment, however, the use of different types of flumes for discharge measurements are quite common in Sweden. The company MJK Automation AB, who had delivered the flumes to SLU and has extensive experience of flumes in urban environment, was consulted. Based on the specification presented by SKB, with the flat landscape and the desire to avoid fish migration obstacles as the most critical requirements, MJK recommended the installation of long-throated flumes. Long-throated flumes have several advantages as the cross-sectional design is quite flexible and computational design can be used. Besides, long-throated flumes give accurate measurements over relatively wide flow ranges and work under a high degree of submergence.

Due to the limited experience from discharge measurements by flumes under Swedish natural conditions and the requirements put by the flat landscape, it was decided to start with the installation of one station to gain experience especially from winter conditions with freezing and risk for ice damming.

3.2 Preparations

The planned locations of the gauging stations were visited together with the site ecologist who after an inventory approved the locations from an environmental point of view.

The catchment areas upstream the planned gauging stations were preliminary determined based on the existing "lake-centered" catchment area delineation /Brunberg et al. 2004/. Based on catchment area sizes and regional discharge data the mean discharge (MQ) was estimated for the planned stations. With additional information on the lake percentage, the norms of the Swedish National Road Administration were used to estimate mean high discharge (MHQ) and highest discharge (HHQ). From the manual measurements it was known that the brooks were completely dry at all planned locations during the summer and early autumn of 2003. Based on the gathered information, preliminary flume designs were compared. It was clear that at three of the stations it would be necessary to have two flumes to cover the discharge range with accurate measurements.

The measurements of brook gradients performed during 2004 /Brydsten and Strömgren, 2005/ were used in the design of the stations and also led to a re-location of PFM002667 from the brook from Lake Gällsboträsket to the brook from Lake Eckarfjärden, just upstream the conjunction with the brook from Lake Gällsboträsket, due to the very low gradient. The re-location was approved by the site ecologist.

For the first station (PFM005764) two standard design flumes were used, while the two large flumes at PFM002667 and PFM002669 and the flume at PFM002668 were designed using the flume design software WinFlume.

MJK Automation AB was responsible for the design, manufacturing and delivery of the flumes.

3.3 Execution of field work

The field work included:

- cleaning of approximately 30 m of the brook reach from vegetation and if necessary minor excavations,
- excavation of approximately 0.5 m of the brook sediments at the positions of the flumes (the exact excavation depth was determined based on the type of sediments and underlying Quaternary deposits), where two flumes were installed at the same station the small flume was located 4–5 m upstream the large flume,
- construction of the foundation for the flumes by filling the excavation by crushed stone (thickness depended on excavation depth and the chosen elevation of the flume above the natural bottom of the brook), 0.1 m of gravel and 0.05 m of sand, compaction of the filling by a vibrator,
- installation of rubber liners upstream of the flumes to prevent leakage, coverage of the rubber sheets by coarse gravel,
- installation of a rubber hose in the sand bed for heat circulation below the flume bottom to prevent freezing,
- installation of the flume; levelling, fixation, refilling, and arrangement of a tight connection between the flume and the rubber liner,
- installation of iron bars upstream the flumes to protect from debris disturbing the measurements,
- installation of the service module with the LPG burner, connection of the LPG burner and the rubber hose for the heat circulation, filling of the system by glycol,
- installation of screened tubes for devices for measurement of electrical conductivity and temperature of the water,
- surveying and levelling of the top of the level observation tubes and bottom of the upstream and downstream edges of the flume bottom,
- calibrations by an area-velocity method based on Doppler technology.

The field work was performed by SKB personnel under supervision of MJK Automation AB.

Calibration has been performed at three occasions by an area-velocity measurement instrument based on Doppler technology (Isco 2150); April 24, 2004, for PFM005764 only, and December 14, 2005, and April 7, 2005, for all four stations. The calibration measurements were carried out by MJK Automation AB.

The monitoring equipment installed at the discharge gauging stations; pressure transducers for measuring the water depth in the flume and devices for measurement of electrical conductivity and temperature are described in AP 400-04-31 and /Nyberg et al. 2004/

3.4 Data handling/post processing

The data from the surveying and levelling of the flumes are stored in SKB's SICADA database and are traceable by the number of the activity plan, AP PF 400-02-32. The catchment areas of the gauging stations are stored in SKB GIS.

Discharge equations for the installed flumes have been derived using the flume design software WinFlume (http://www.usbr.gov/pmts/hydraulics_lab/winflume/).

3.5 Nonconformities

The results from PFM005764, which was installed in November 2003, clearly indicated that critical flow was not reached at high discharges, implying that the measurements were influenced by downstream conditions. The flume was installed with its bottom immediately above the natural bottom of the brook to meet the desire to allow fish migration. Based on the experience, measurements of brook gradients downstream the gauging stations and estimates of the Manning number, the flume performance for different bottom elevations was tested by the WinFlume software. It was concluded that the flume bottom elevation had to be raised by approximately 0.3 m to obtain a good performance at high discharges. A reinstallation of the flume was made in October 2004.

4 Results

In Figures 4-1 to 4-3 the different phases of the construction are illustrated with PFM002667 as an example; cleaning of vegetation, excavation of the reach of the brook and the foundation for the flumes (excluding the top sand layer) and ready station with the two flumes and the service module with the LPG burner for heating. Photos from the three other gauging stations are shown in Appendix 1.

Figure 4-1. *Cleaning of vegetation for installation of brook discharge gauging station PFM002667.*

Figure 4-2. *Excavation of the reach of the brook and the foundation for the flumes (excluding the top sand layer) at PFM002667. In the foreground the iron bars installed upstream the flumes to avoid disturbances of debris can be seen.*

Figure 4-3. *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 to the left. The tube in the middle of the brook between the flumes is screened and used for installation of devices for measurement of electrical conductivity and temperature.*

In Table 4-1 the size of the catchment areas and the installation dates for the four gauging stations are given. The flumes at PFM005764 were first installed in November 2003. Due to unsatisfactory functioning at high discharges the flumes were reinstalled in October 2004 with the bottom levels raised by approximately 0.3 m.

The catchment areas of the four gauging stations are shown in Figure 4-4. Separate, detailed maps of the four catchments are presented in Appendix 2.

The positions of the gauging stations including levels for top of casing of the level observation tubes and the bottom of the flumes are given in Table 4-2.

Table 4-1. Catchments areas and installation dates for the discharge gauging stations.

Id code	Catchment are (km^2)	Installation date
PFM005764	5.59	Nov. 2003, reinstalled Oct. 2004
PFM002667	2.26	Oct. 2004
PFM002668	1.31	Oct. 2004
PFM002669	2.83	Oct. 2004

Table 4-2. 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
Flume bottom, downstream edge	6698748.2	1631659.2	0.570
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
Flume bottom, downstream edge	6698755.1	1631667.5	0.600
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
Flume bottom, downstream edge	6698748.1	1631660.2	0.895
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
Flume bottom, downstream edge	6698754.9	1631668.1	0.885
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
Flume bottom, downstream edge	6698265.0	1631594.0	1.501
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
Flume bottom, downstream edge	6698274.6	1631598.7	1.505
PFM002668 (QFM3)			
Obs. tube, top of casing	6697474.9	1632066.9	5.482
Flume bottom, upstream edge	6697475.5	1632065.7	4.287
Flume bottom, downstream edge	6697476.7	1632067.5	4.280
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
Flume bottom, downstream edge	6699046.4	1629372.5	5.849
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
Flume bottom, downstream edge	6699041.8	1629382.7	5.855

***Figure 4-4.** Catchment areas for the brook discharge stations PFM5764, PFM002667, PFM002668 and PFM002669. (Separate, detailed maps of the catchments areas are presented in Appendix 2.)*

The flumes are manufactured in stainless steel. Drawings of the flumes are shown in Appendix 3. The discharge equations for the flumes derived by the WinFlume software and recommended discharge interval for which they should be used are given in Table 4-3.

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 November 2003–October 2004, see Table 4-3) based on expected head measurement errors of ± 2 mm, surveyed bottom gradients and assessed Manning numbers.

The calibration by the area-velocity method 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.

Table 4-3. 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
QFM4 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 flow 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 calibration December 14, 2004, of the large flume at PFM005764, both flumes at PFM002667, PFM002668, and the large flume at PFM002669 showed an agreement between the discharge calculated by the derived equations for the flumes and the area-velocity method within the excepted error of the latter method. For PFM005764, PFM002668 and PFM002669 the expected error of the area-velocity method was ± 5% as an average over the calibration period. However, at PFM002667 the expected error of the area-velocity method was considered to be larger due to disturbances in the velocity profile. However, the discharge was within the interval that could be measured by both the small and the large flumes and these values showed good agreement. The general conclusion of the December calibration was that the derived discharge equations showed a good agreement with the results obtained from the area-velocity method for the discharge varying between approximately 12 and 40 L/s at the different gauging stations.

At the calibration April 7, 2005, the discharges were generally higher, varying between approximately 25 and 75 L/s. This meant that the discharge was outside the range of all small flumes. The calibrations were disturbed by siltation in the road culverts used for the area-velocity measurements at PFM005764, PFM002667 and PFM002669. Estimations of siltation depths were possible at PFM005764 and PFM002669. With compensation for estimated siltation there were agreements within 5% between the discharges calculated by the two methods. At PFM002668 the agreement was within 3% between the two methods. In the road culvert at PFM002667 it was not possible to make measurements with acceptable accuracy by the area-velocity method. A cleaning is needed if the culvert should be used for calibration purposes in the future.

5 Discussion and conclusions

The installed long-throated flumes provide possibilities for accurate discharge measurements in the major brooks within the central part of the site investigation area. However, the accuracy of the discharge measurements is highly dependent on the accuracy of the head measurement devices, and the maintenance and cleaning of the flumes and the downstream brook reaches. Especially during winter frequent inspections are crucial for the operation to avoid disturbances from ice.

The performed calibrations show a good accuracy for the discharges calculated by the equations derived for the flumes by the WinFlume software. However, additional calibrations are desirable for high discharges, especially to verify that the measurements are not disturbed by tailwater conditions.

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Appendix 1

Photos of the gauging stations

PFM005764

Figure A1-1. *Top: Winter conditions in Feb. 2004 before reinstallation. Middle: Reinstallation in Oct. 2004. Bottom: After reinstallation, winter discharge in Jan. 2005 exceeding the capacity of the small flume.*

PFM002668

Figure A1-2. *Top: Before cleaning of vegetation in Sep. 2004. Middle: After excavation and refilling with crushed stone and gravel, Sep. 2004. Bottom: After installation in Jan. 2005, the screened tube with devices for measurement of electrical conductivity and temperature in the foreground.*

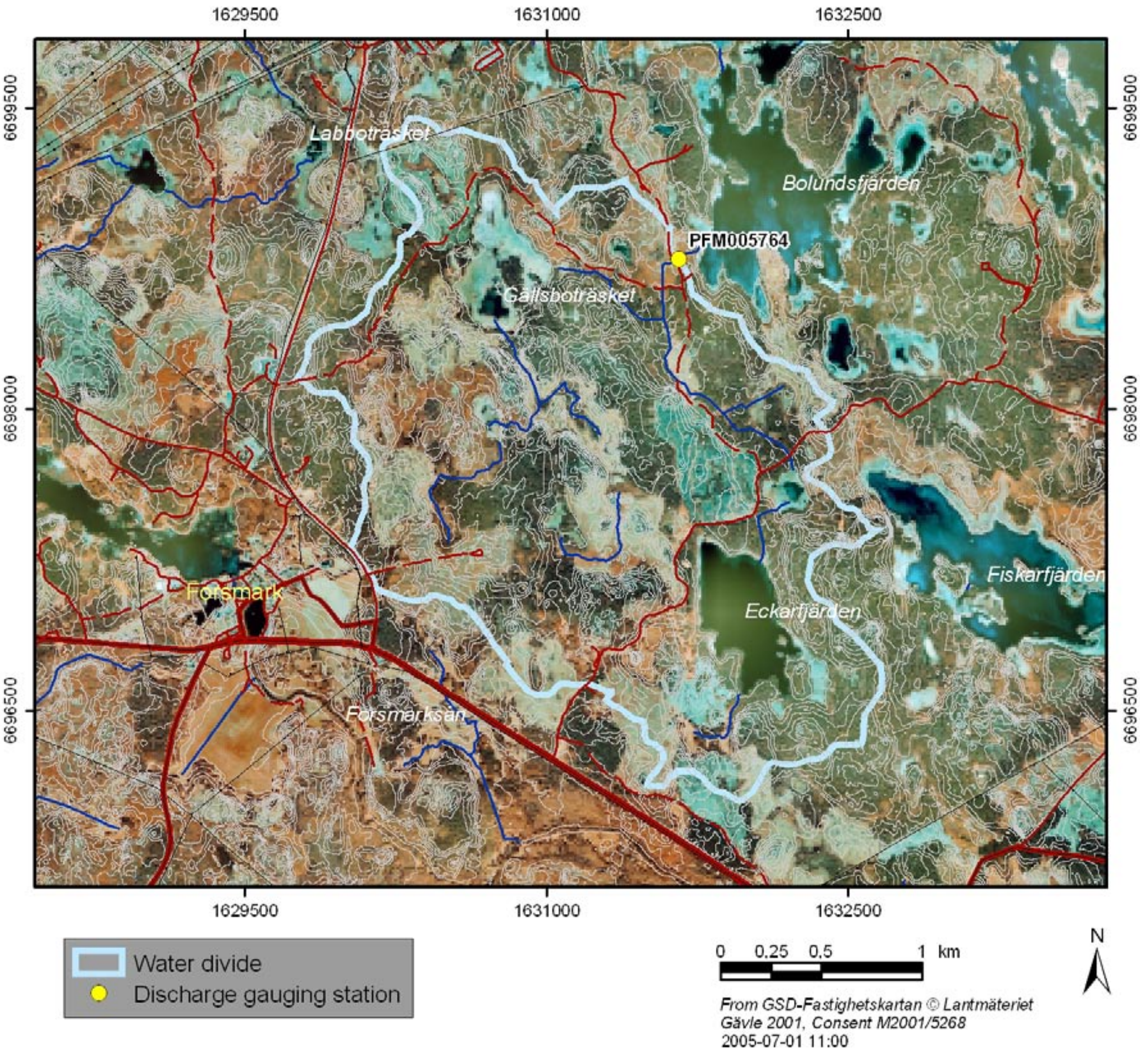
PFM002669

Figure A1-3. *Top: After cleaning of vegetation in Sep. 2004. Middle: After excavation and refilling with crushed stone and gravel, Sep. 2004. Bottom: After installation in May 2005.*

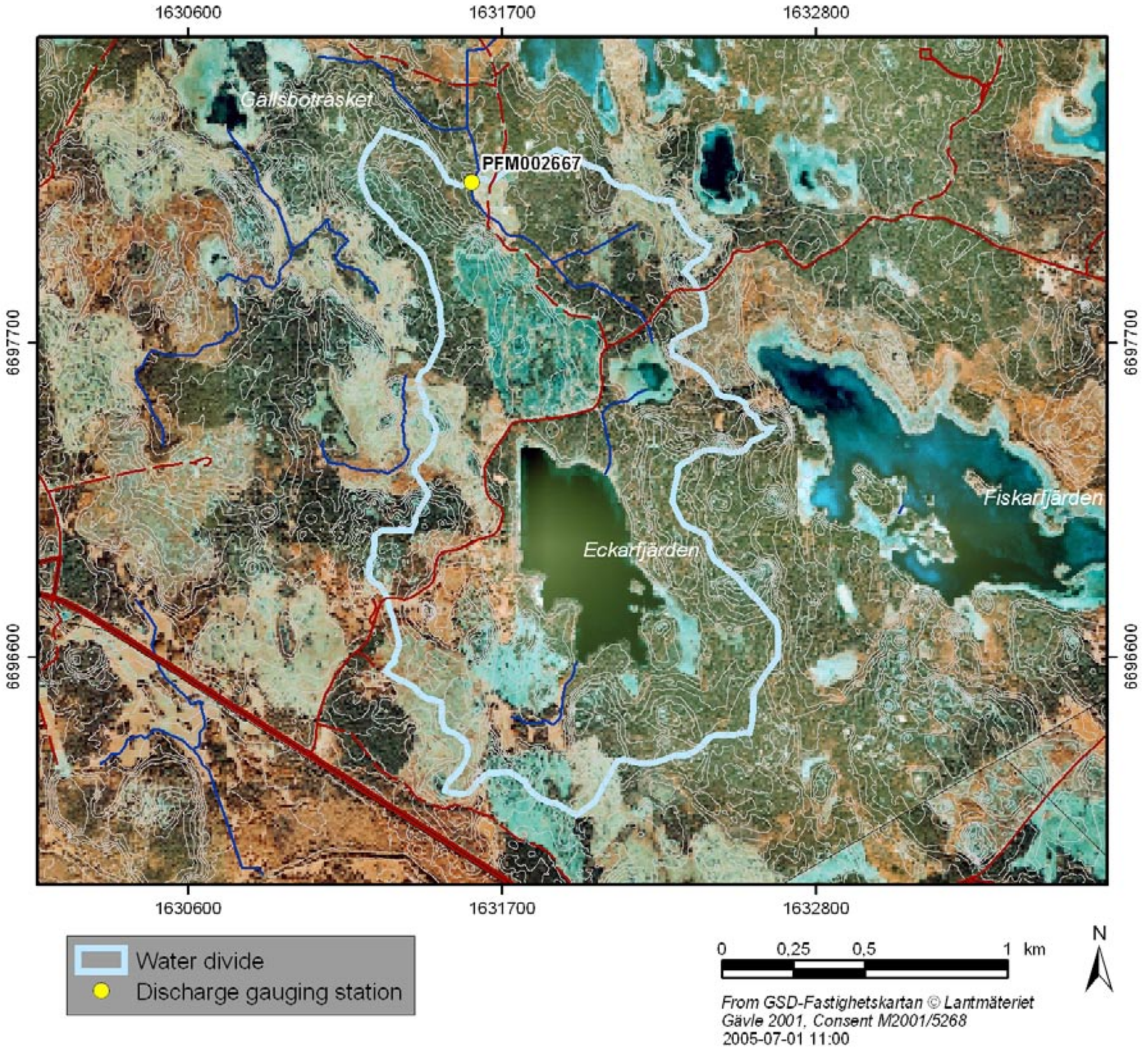
Appendix 2

Maps of the catchment areas of the gauging stations

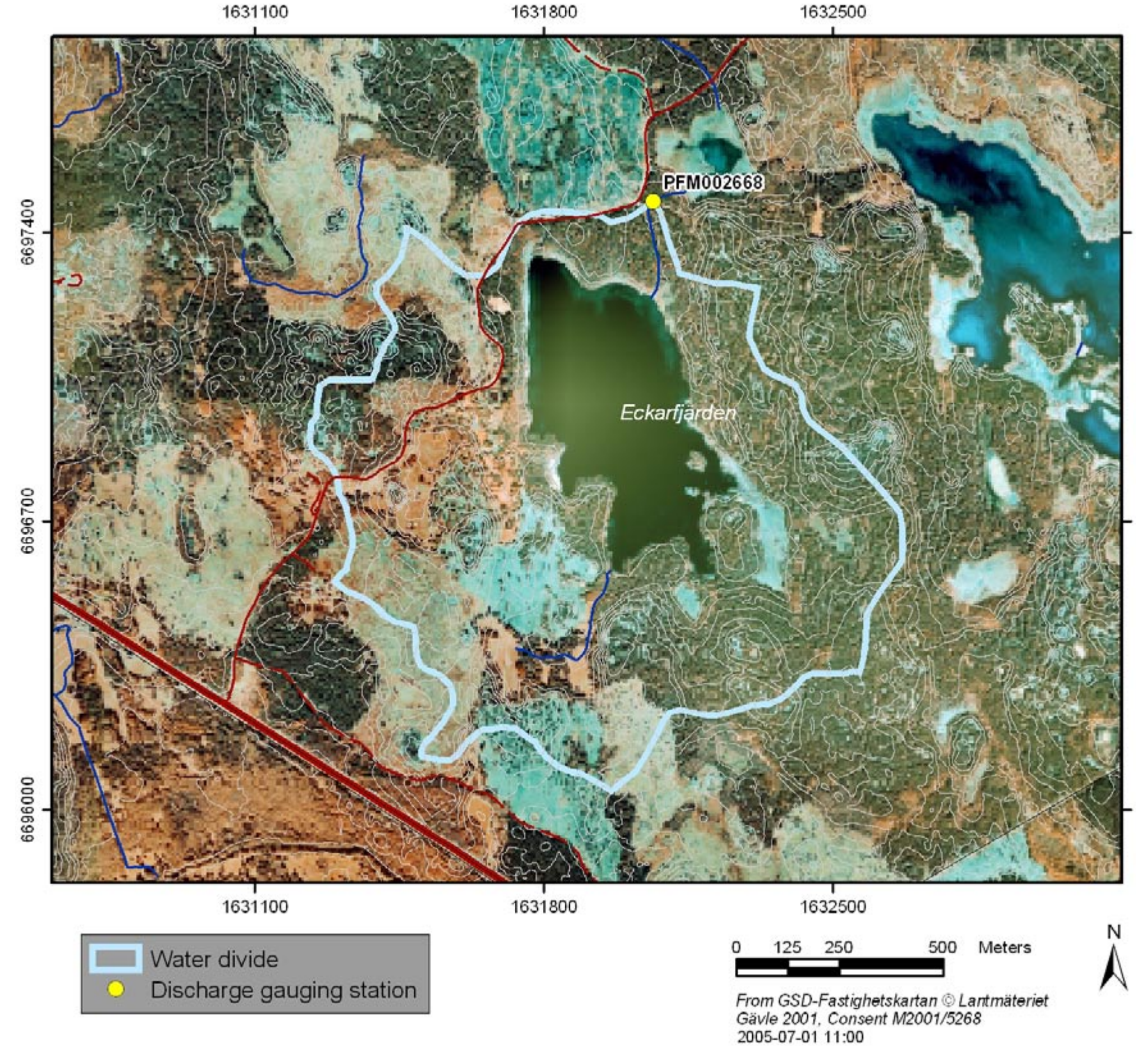
PFM005764



PFM002667


1630600
1631700
1632800
6697700
6696600
Gällsboträsket
PFM002667
Eckarfjärden
Fiskarfjärden
Water divide
Discharge gauging station
0
0,25
0,5
1 km
N
From GSD-Fastighetskartan © Lantmäteriet
Gävle 2001, Consent M2001/5268
2005-07-01 11:00

PFM002668



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1631800
1632500
6697400
6696700
6696000
PFM002668
Eckarfjärden
Water divide
Discharge gauging station
0 125 250 500 Meters
N
From GSD-Fastighetskartan © Lantmäteriet
Gävle 2001, Consent M2001/5268
2005-07-01 11:00

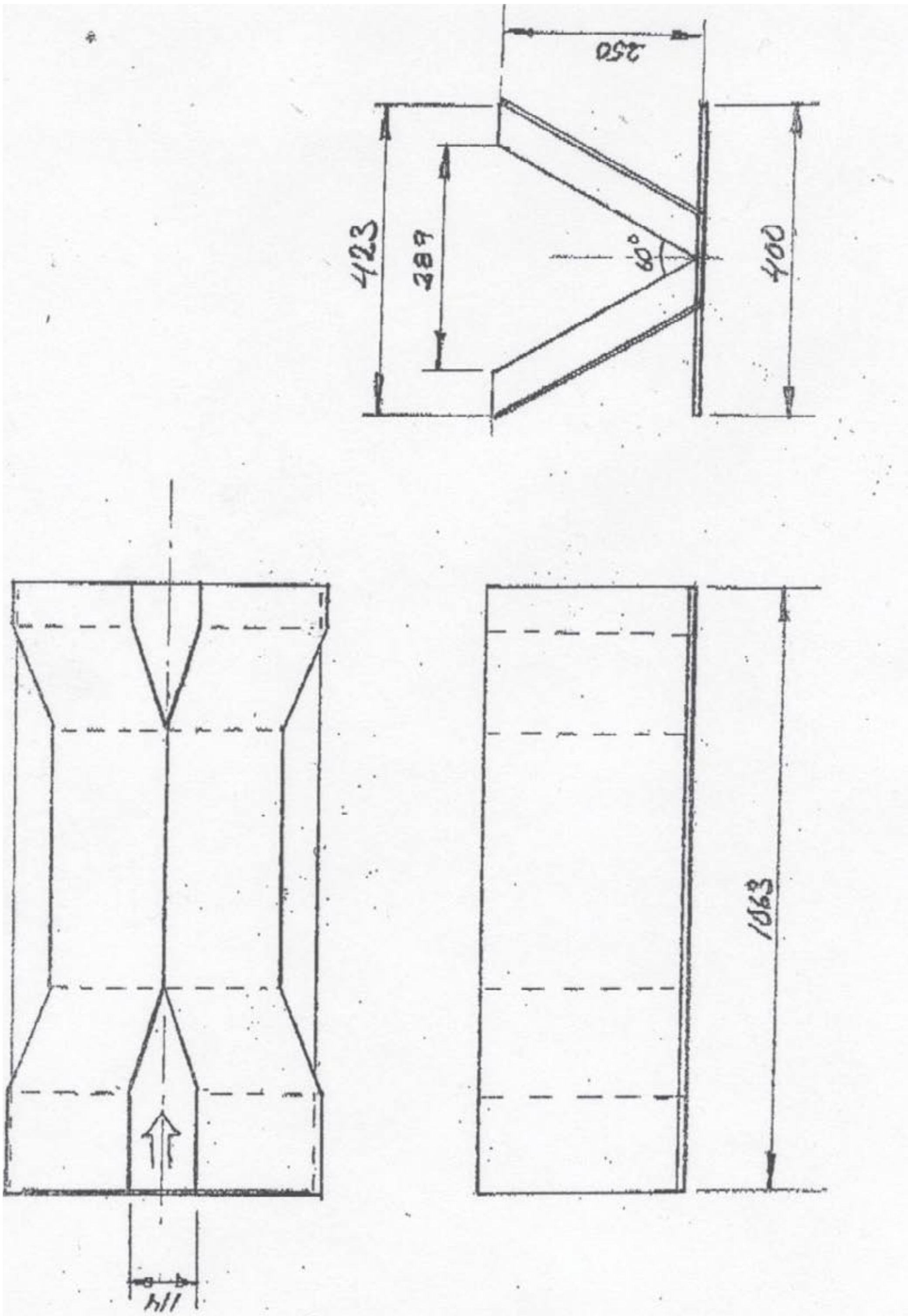
PFM002669

1626900
1627600
1628300
1629000
1629700
6700200
6699500
6698800
6698100
Labbotrasket
PFM002669
Water divide
Discharge gauging station
0 125 250 500 Meters
N
From GSD-Fastighetskartan © Lantmäteriet
Gävle 2001, Consent M2001/5268
2005-07-01 11:00

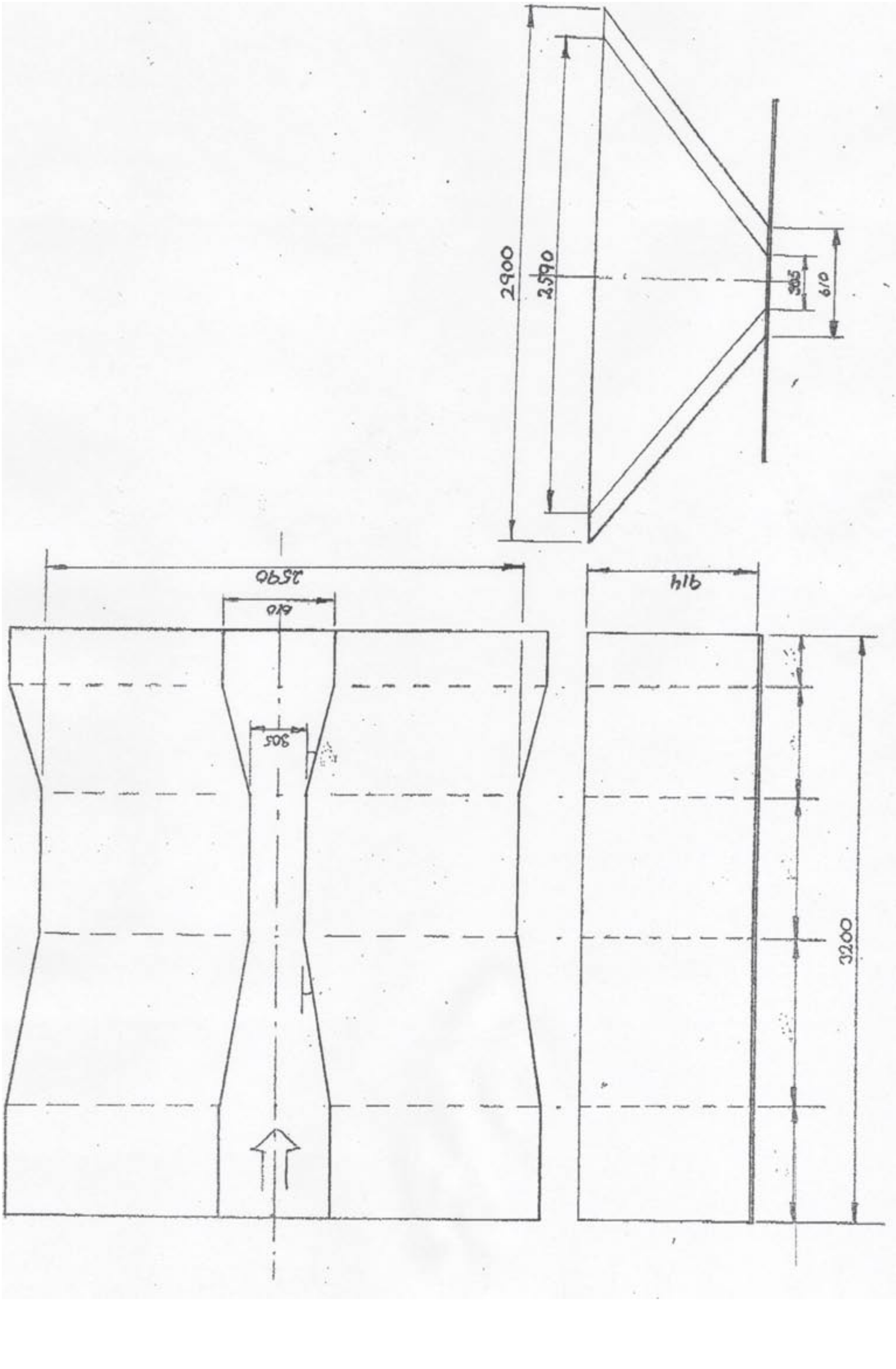
Appendix 3

Drawings of the flumes

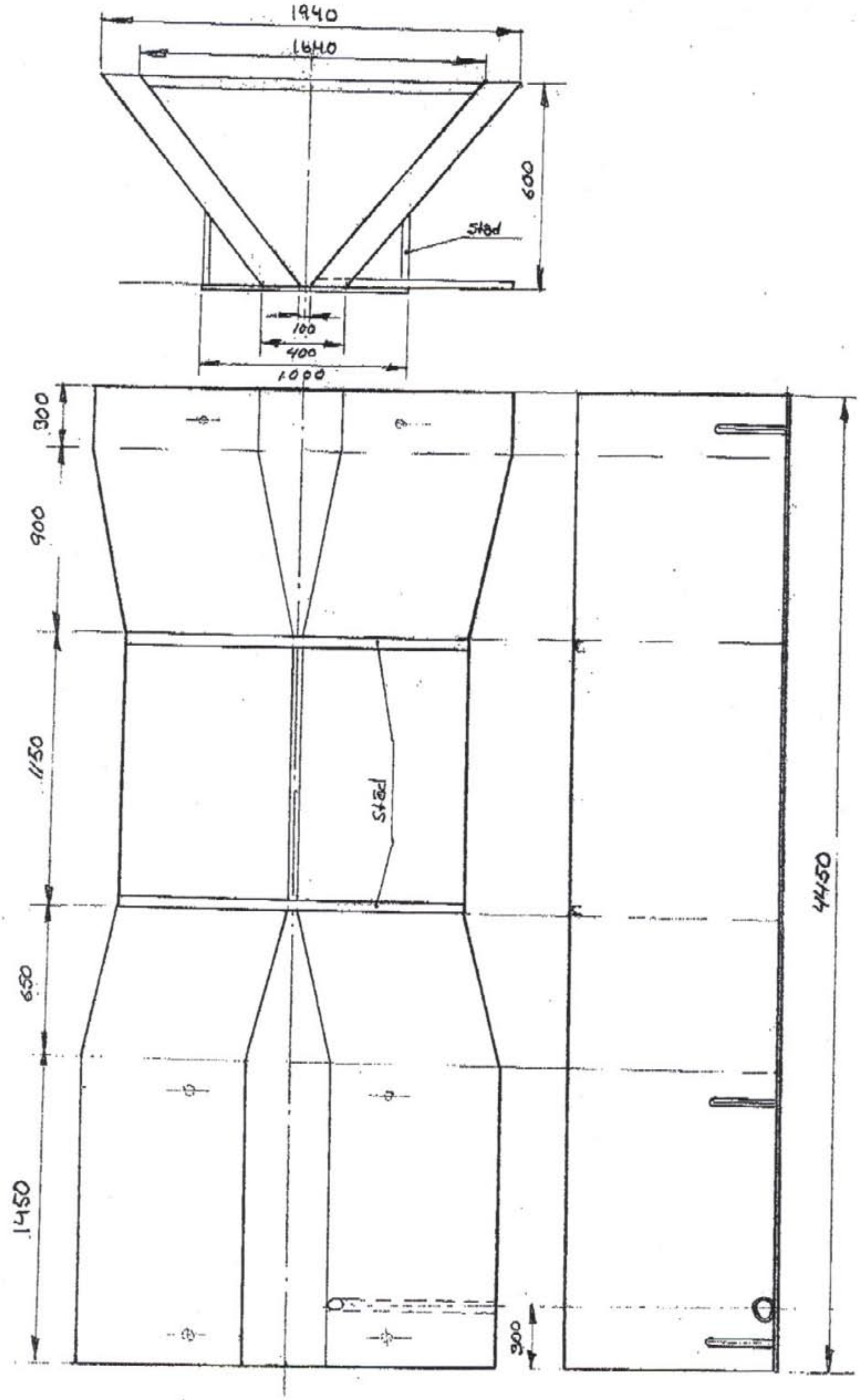
PFM005764, PFM002667 and PFM002669, small flume (recommended discharge interval 0–20 L/s)



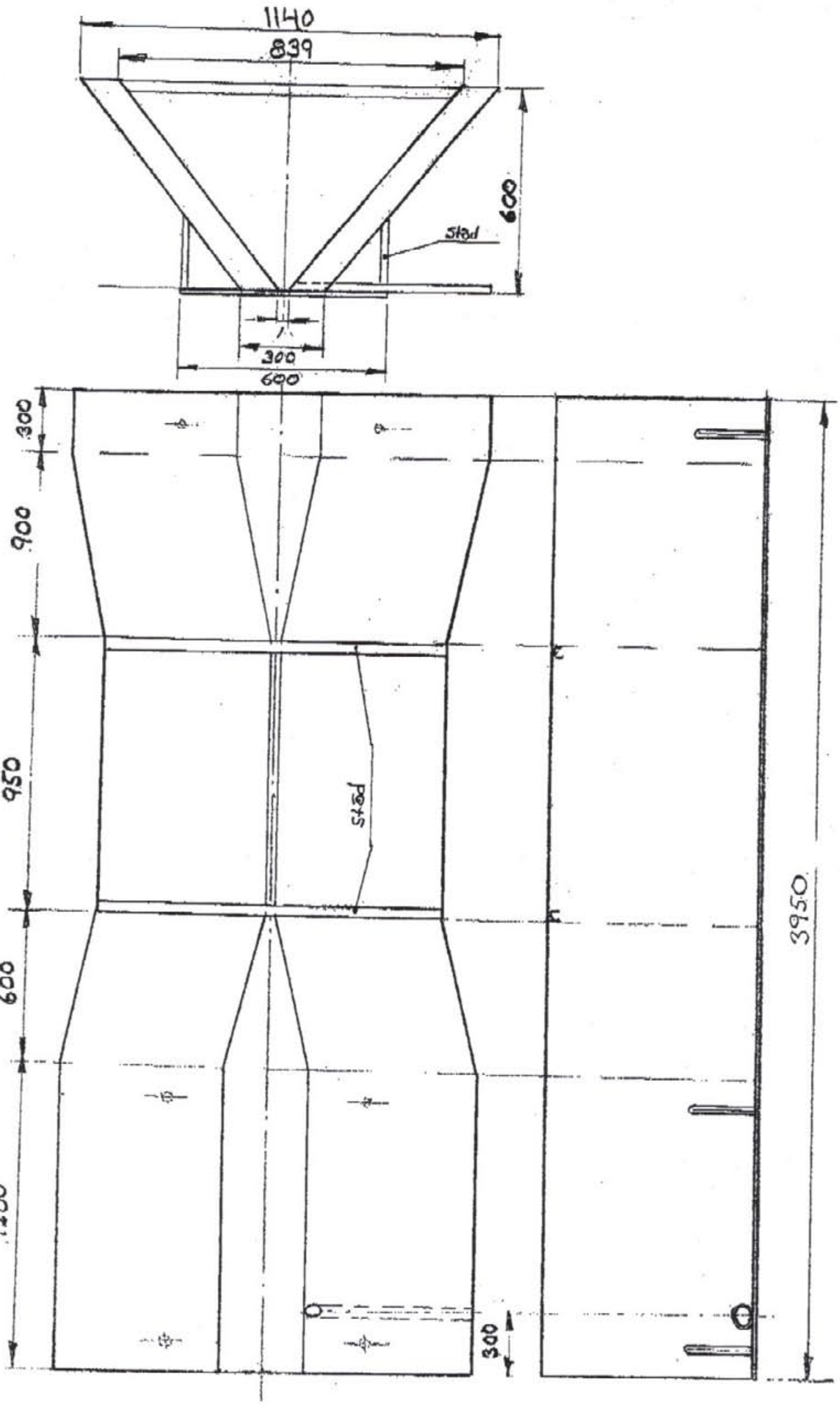
PFM005764, large flume
(2' SRCRC, recommended discharge interval 20–1400 L/s)



PFM002667, large flume
(recommended discharge interval 20–500 L/s)



PFM002668
(recommended discharge interval 0–250 L/s)



PFM002669, large flume
(recommended discharge interval 20–920 L/s)