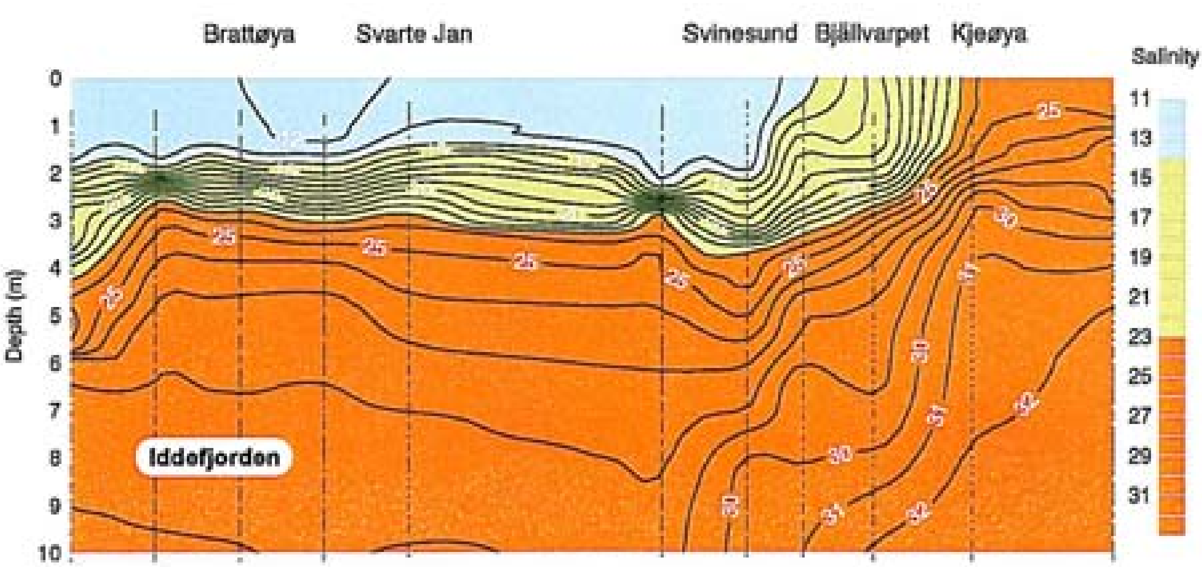
REPORT SNO 3951-98

Hydrophysical observations in the Frierfjord, the Drammensfjord and the Iddefjord

June - December 1997

Transport and mineralisation of nutrients and organic matter in fjords and estuaries

Transfjo



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TRANSFJO

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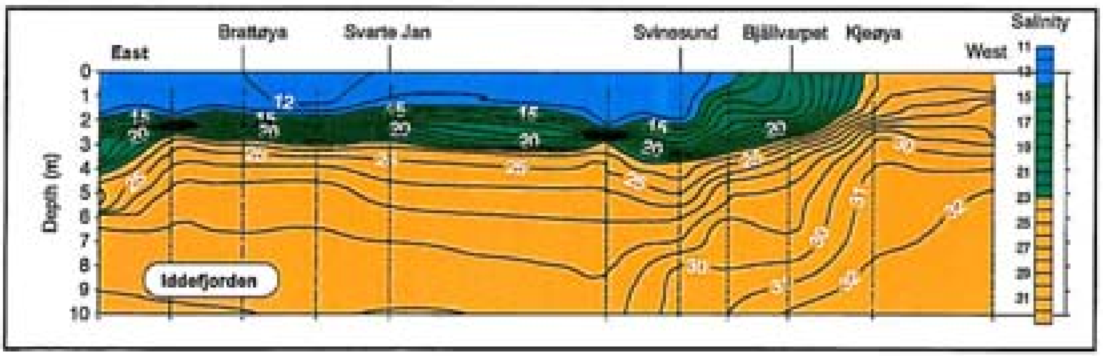
Data report



Norwegian Institute for Water Research

REPORT

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Abstract

The strategic institute programme, TRANSFJO, relies heavily on a fjord model developed at NIVA. To validate and further develop the physical part of the model, extensive measurements of the basic hydrophysical and meteorological parameters in the Frierfjord, the Drammensfjord and the Iddefjord were carried out in July-December 1997. This opportunity was also used to check out instruments and methods to be used in later stages of the program. In technical terms the field studies were a success. With few exceptions the instruments functioned properly, and the malfunctions should be eliminated through better pre-use checking and better deployment procedures. The general impression is that the field studies have produced the kind of data sets which are needed for further development of the model. Furthermore, the data seem to contain new knowledge of hydrophysical processes in fjords in southern Norway. This element will be looked into in 1999.

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4. TRANSFJO	4. TRANSFJO

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Preface

In 1997 the Norwegian Research Council and the Norwegian Institute for Water Research (NIVA) founded a strategic institute program on *"Transport and turnover of nutrients and organic compounds in fjords and estuaries" (TRANSJO). The overall purpose of the research program is to further develop the tools that shall form the basis for better assessments of the benefits in fjords and inshore areas from reducing the local load of nutrients and organic matter.*

The program relies heavily on a fjord model developed at NIVA. The model will be validated and further developed by field observations to estimate transport of nutrients and organic matter in and out of fjords as well as internal processes, especially retention and mineralisation.

The physical part of the model forms the basis for the following calculations of concentrations and transports in the hydrochemical and biological parts of the model. To validate and further develop the physical component of the model, extensive measurements of the basic hydrophysical and meteorological parameters in the Frierfjord, the Drammensfjord and the Iddefjord in southern Norway were carried out in July-December 1997. The opportunity was also used to check out instruments and methods to be used in later stages of the program. This report is a first comprehensive presentation of the field data from the three fjords, primarily for use in the following work on the model.

Oslo, May 1999

Jan Magnusson

Contents

Summary

In 1997 the Strategic Institute Programme (SIP) TRANSFJO concentrated on collecting observations from different fjords to establish a set of data for validating and further develop the physical part of the fjord model. Extensive measurements of basic hydrophysical and meteorological parameters in the Frierfjord, the Drammensfjord and the Iddefjord in southern Norway was carried out in July-December 1997. This opportunity was also used to check out instruments and methods to be used in later stages of the program. The report is a first comprehensive presentation of the field data from the three fjords, primarily for use in the following work on the model.

In technical terms the field studies were a success. With few exceptions the instruments functioned properly, and the malfunctions should be eliminated through better pre-use checking and better deployment procedures.

A thorough study of the data has not been performed yet, but the general impression is that the field studies have produced the kind of data sets, which are needed for further development of the model. Furthermore, the data seems to contain new knowledge of hydrophysical processes in fjords in southern Norway. This element will be looked into in 1999.

1. Introduction.

In 1997 the Norwegian Research Council decided to found a program concerning the transportation and mineralisation of nutrients and organic matter in fjords and estuaries as a strategic institute program at NIVA. In brief the program is called **TRANSFJO**.

The main program elements are quantification of :
- retention of nutrients in order to calculate more relevant nutrient budgets and to have a better understanding of eutrophication effects in fjords and estuaries.
- transport of nutrients and organic matter through fjords and estuaries to the coastal water, in order to have better estimates of eutrophication effects there.
- benefits from reduced inputs of nutrients.

The program relies heavily on a fjord model developed at NIVA (Bjerkeng 1994a-d, Bjerkeng 1995, Kirkerud and Bjerkeng 1994). The first phase in the program is to collect field data to look at some crucial parts of the fjord circulation and how well the model resolves the most important physical processes as tidal transport, estuarine circulation etc. As this model was developed for the inner Oslofjord - a sill fjord with relatively small fresh water discharge, the first step was to collect physical data from sill fjords with varying topography and larger fresh water discharges. The field program was also used to check out instruments and new methods to be used in later stages of the program.

Three fjords in the south-eastern part of Norway were selected for this purpose. They were chosen because they have the general topographical, hydrographical and hydrological characteristics we are looking for and partly because they are relatively close to NIVA, but also as eutrophication problems are most evident in this part of Norway. The field observations started in July and ended in December 1997. All data are stored in NIVAs database, and this report is written to give a first comprehensive presentation of the data for use in the development of the hydrophysical part of the model and to obtain an improve the physical water exchange processes in fjords.

2. Topography, hydrophysical settings and measurements.

2.1 Topography.

The fjords are located on the Norwegian south-coast (**Figure 1** and **Figure 2**). They are sill fjords and some typical topographical and hydrophysical numbers are listed in Table 1.

Table 1. Basic topographical and hydrophysical data for the Frierfjord, Drammensfjord and Iddefjord.

	Frierfjord	Drammensfjord	Iddefjord
Area inside the outer sill (km^2)	17.5	45.1	20.5
Sill depth (m)	23	10	9
Sill width (m)	220	170	80
Max. basin depth (m)	98	124	48
Average fresh water discharge (m^3/s)	270	250	30
Tidal amplitude (m) (M_2+S_2)	0.13	0.13	0.12
Surface salinity	0.5 - 10	1 - 10	1 - 18
Surface layer depth (m)	3 - 6	5 - 10	1 - 5

While the Frierfjord and the Drammensfjord have one main sill, the Iddefjord has two main sills at the entrance and two more sills inside the entrance. The main fresh water discharge differs as the first two fjords receive the river water in the inner part, while the Iddefjord receives fresh water from two rivers situated in the innermost part of the fjord and half way to the mouth.

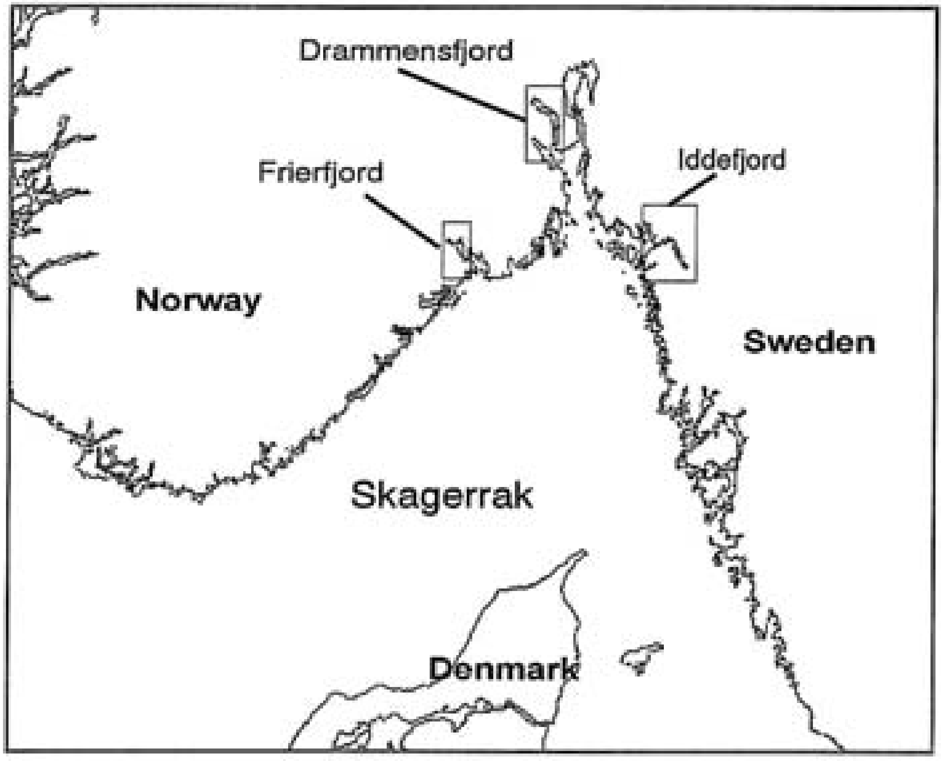

Figure 1. Map of the Skagerrak and the three fjords.

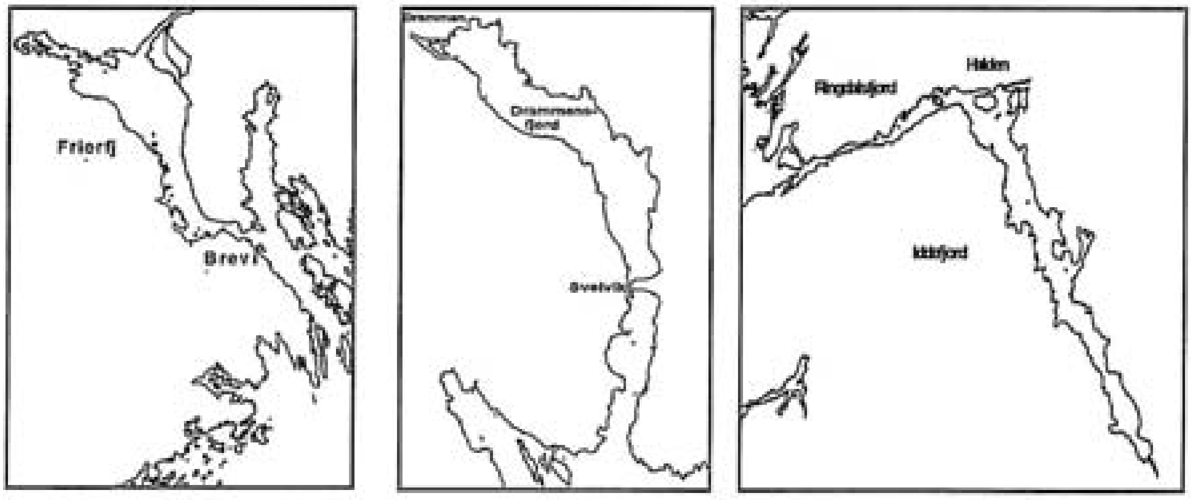

Figure 2. The Frierfjord (left), the Drammensfjord (center) and the Iddefjord (right).

2.2 Measurements.

In the three fjords the following basis observations were planned:

- Current measurements at the main sill,
- water level measurements inside and outside the sill,
- semi-continuos measurement of temperature and salinity from temperature/salinity-strings (T/S-strings) inside and outside the sill, as well as

- hydrographic observations (CTD) on a number of stations about once a week.
- Wind observations in the Drammensfjord and the Iddefjord, where local wind measurements lacked.

In the Iddefjord this basis program was extended by several more current meters inside the sills (Figure 23).

The measurement period for each fjord was about one month. Information of the fresh water discharge and general wind information was collected from the Norwegian Water Resources and Energy Directorate (NVE) and the Norwegian Meteorological Institute (DNMI).

Figure 3 gives a general view of how the instruments were deployed. Figs. 4, 14 and 21 show more exact positions.

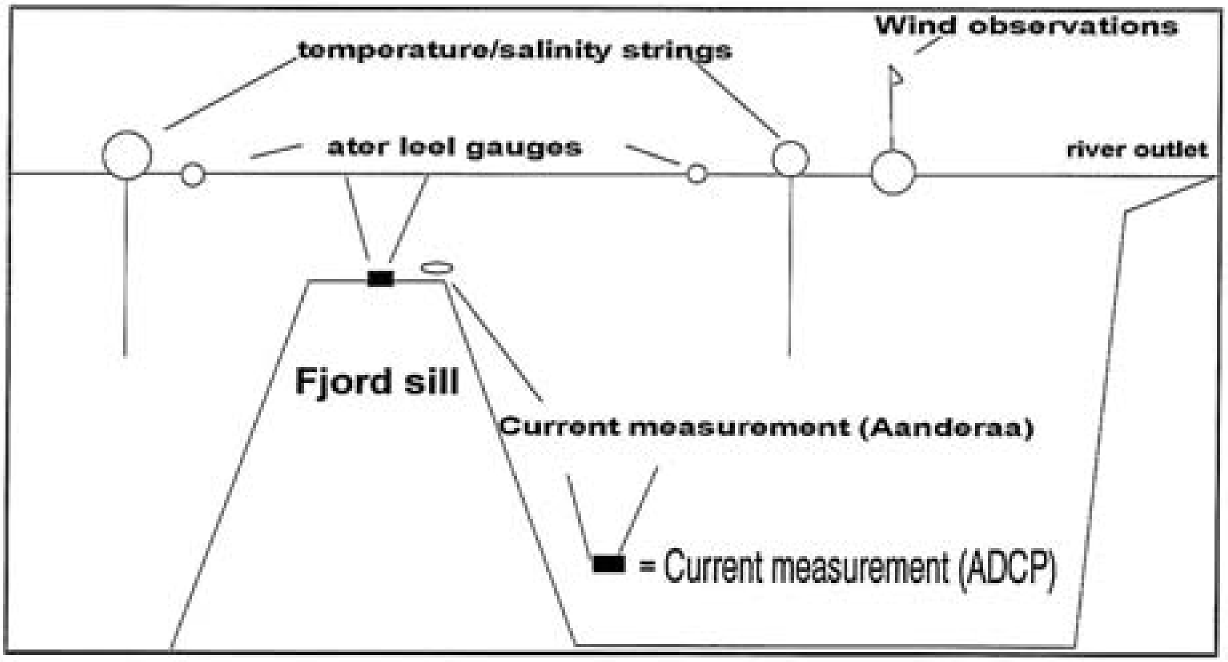

Figure 3. Principal instrument deployment in the fjords.

The following instruments were used:

Current meters:

- Aanderaa current meter with Savonius rotor (RCM-7) or acoustic sensor (RCM-9) equipped with temperature/salinity and pressure sensors. Sampling period: 10 minutes. Two of the instruments were equipped with turbidity sensors (the RCM-9).

- Acoustic Doppler profiler:
-
- 1. ADP, (Nortek), 150 kHz with maximum vertical resolution 1 meter, maximum number of cells 123, maximum measurement range 70 meters.
-

- 2. DCM-12 (Aanderaa), maximum vertical resolution dependent on depth, number of cells 5. Maximum measurement ranges 50 meters.
- SensorData (SD200) current meter, with Savonius rotor and temperature recorder. Sampling period: 10 minutes
- Acoustic current meter (UCM 40) equipped with temperature/salinity sensors. Sampling period: 10 minutes.

Hydrographic observations:

- Temperature/salinity string: Aanderaa-type with sensors at 5 depths and a pressure (depth) sensor at the end of the string. Sampling interval: 10 minutes.
- Profiling temperature and salinity sensor (CTD, Seabird), mainly used in pumped mode. Sampling frequency 2/s.

The observation frequency for CTD-measurements was about once a week, during 4-5 weeks of observation.

In addition

- Water level gauges: Aanderaa type pressure sensor. Sampling interval: 10 minutes.
- Wind instrument: Type Aanderaa. Speed and direction. Sampling interval: 10 minutes.
- High resolution CTD used for profiling the density distribution at the sills (the Drammensfjord and the Iddefjord). The data was collected by visiting scientist Dr. Sherill Lingel, USA.

Observation periods.

Overall observation periods in the three selected fjords were:

The Frierfjord:	21/22.7.97 - 21/22.8.97.
The Drammensfjord	3.9.97 - 6.10.97.
The Iddefjord	21.10.97 - 3.12.97.

3. Preliminary results

3.1 The Frierfjord.

3.1.1 The field study

The measuring period in the fjord was from 21/22.7 1997 to the 21.8 1997 and the instruments were deployed as shown in **Figure 4** (where the hydrographic stations is marked) and in **Figure 3.**

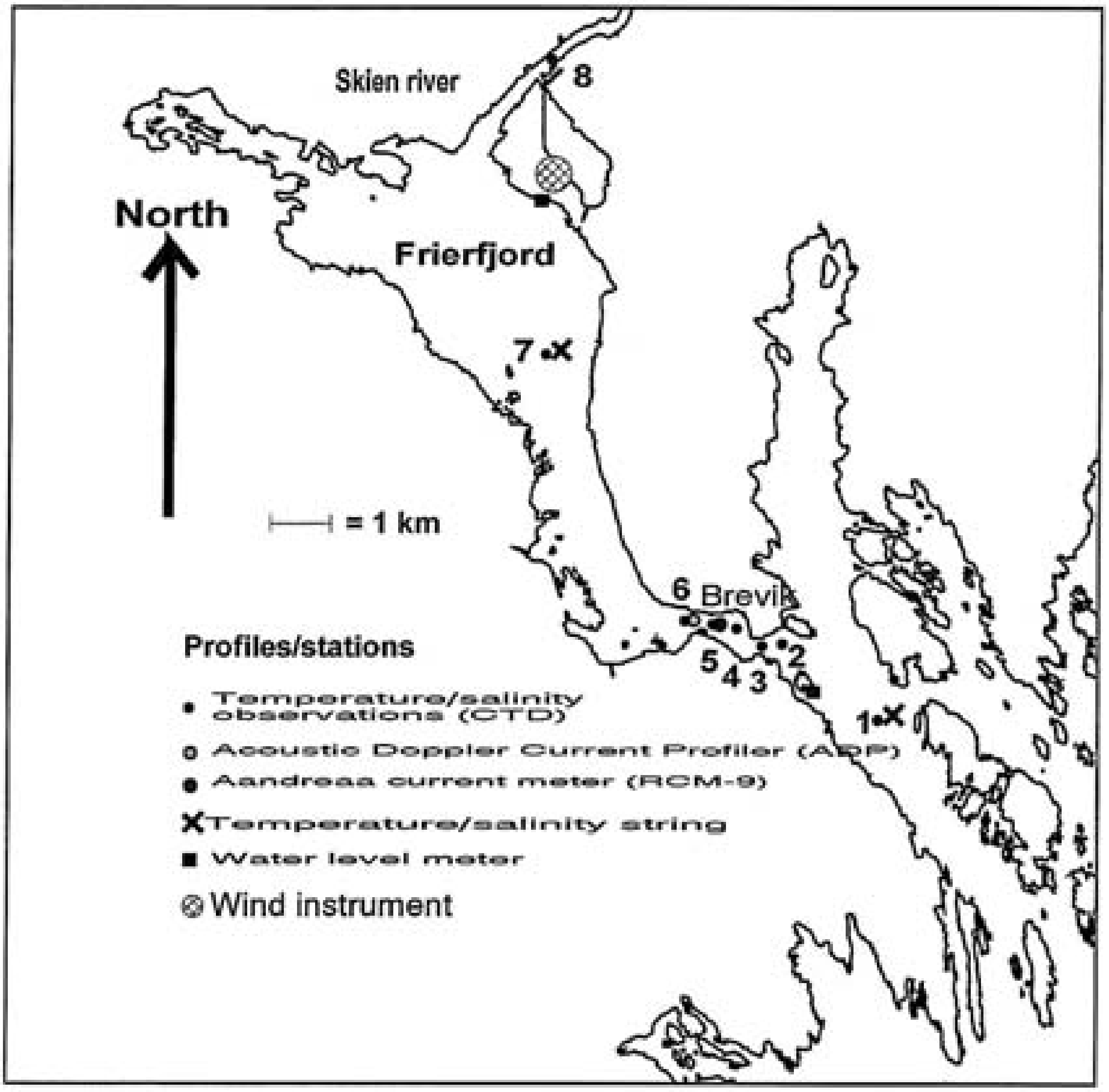

Figure 4. Instrument positions and hydrographic stations in the Frierfjord, July-August 1997.

Table 2. Recording instruments in the Frierfjord July-August 1997. All times are in UTC.

Instrument type	*Inst. no.*	*Sensor no.*	*Start (date)*	*Start (time)*	*Deployed (date)*	*Retrieved (date)*	*Depth of sensor*	*Local name*
T/S-string	1110	49	21.7.97	10:55	22.7.97 ca 09:00	22.8.97	1.6,5,10, 20,30 m	Grava-stranda
T/S-string	1126	34	21.7.97	09:03	21.7.97 ca. 18:13	22.8.97 ca.12:00	1.25,5, 10,20, 30 m	Bjørk-øya
Water level	3110	420	22.7.97	12:44	22.7.97	22.8.97 10:05		Croft-holmen
Water level	3012	147	27.7.97	09:00	27.7.97	23.8.97		Hydro-kaia
Current (ADP)			22.7.97		22.7.97	22.8.97	54 m	Brevik-stranda
Current (RCM-9)	28		21.7.97	09:07	22.7.97 ca. 11:00	22.8.97 10:47	ca. 27 m	Brevik-stranda

Table 3. Hydrographic observations (temperature and salinity) with the Seacat CTD, data file identification and information on the CTD profile mode.

Date	*Stations*	*Observations*	*File*	*Remarks*
22.7.97	1 - 8	$T/S+O_2$	F220797.*	Profile mode, < 0.5 m/s, unpumped
29.7.97	1 - 8	$T/S+O_2$	F290797.*	Profile mode, < 0.5 m/s, pumped
7.8.97	1 - 8	$T/S+O_2$	F070897.*	Profile mode, < 0.5 m/s, pumped
14.8.97	1 - 8	$T/S+O_2$	F140897.*	Profile mode, < 0.5 m/s, pumped
22.8.97	1 - 8	$T/S+O_2$	F220897.*	Profile mode, < 0.5 m/s, pumped

Table 4. Geographic positions of stations in the Frierfjord, July-August 1997.

Instrument	*Station*	*Local name*	*Echodepth (m)*	*North*	*East*
Seacat (CTD)	1	Bjørkøya	102	59°02.28'	09°44.0'
Seacat (CTD)	2	Mølletangen	51	59°03.04'	09°42.02'
Seacat (CTD)	3	Brevik gl. bru	38	59°02.99'	09°41.74'
Seacat (CTD)	4	Trosvik	29	59°03.17'	09°41.32'
Seacat (CTD)	5	Steinholmen	26	59°02.22'	09°40.82'
Seacat (CTD)	6	Blekebakken	57	59°03.24'	09°40.5'
Seacat (CTD)	7	Gravastranda	91	59°05.4'	09°38.2'
Seacat (CTD)	8	Skienselva	11	59°08.22'	09°38.05'
T/S-string no. 1110		Gravastranda	90	59°05.445'	09°38.267
T/S-string no. 1126		Bjørkøya	104	59°02-03'	09°44.0'
Water level no 420		Croftholmen		59°02.06'	09°42.62'
Water level no. 147		Hydrokaia		59°06.94'	09°37.83'
Current (RCM-9)		Brevikstrømmen	27.4	59°03.22'	09°40.87'
Current (ADP)		Brevikstrømmen-north	55.3	59°03.24'	09°40.62'

3.1.2 Results

Wind

During the four weeks of measurements the wind in the Frierfjord was weak and generally blowing from northerly or southerly directions (**Figure 5**).

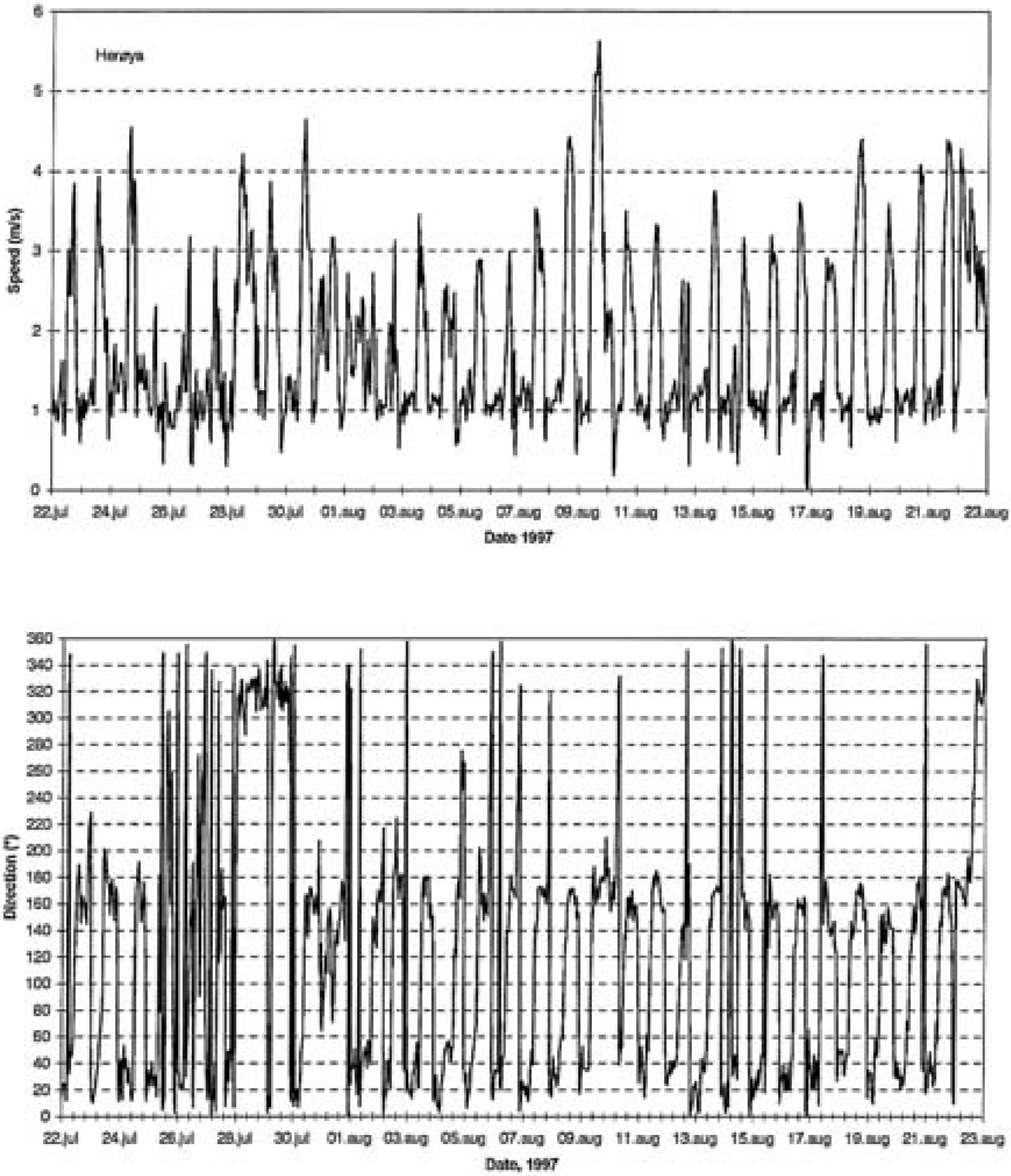

Figure 5. Wind speed and direction at Herøya 22.7-22.8.1997 (data from SFT-Telemark).

Fresh water discharge

The fresh water discharge through the Skien river was low compared to the annual average (270 m^3/s), and for two periods near its minimum of 50 m^3/s (**Figure 6**). From long-term measurements one find that this often can occur in late summer.

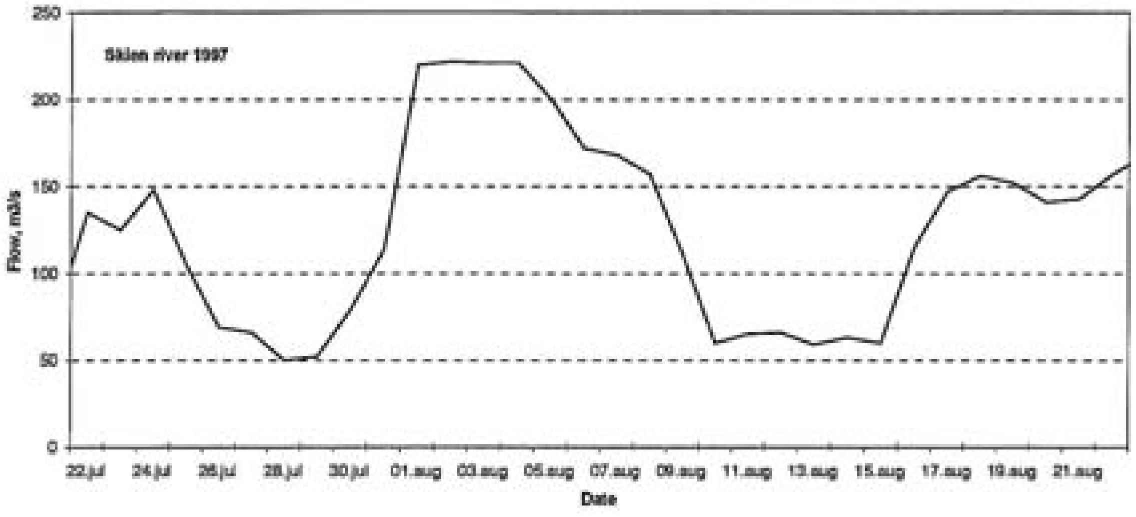

Figure 6. Water discharge from the Skien river July-August 1997.

Water level

The data from water level measurements at Herøya (northern part of Frierfjord) and Croftholmen (outside the sill) is shown in **Figure 7**. The data is not aligned or normalized. As expected the high/low tide at Croftholmen was generally ahead compared to the tide at Herøya.

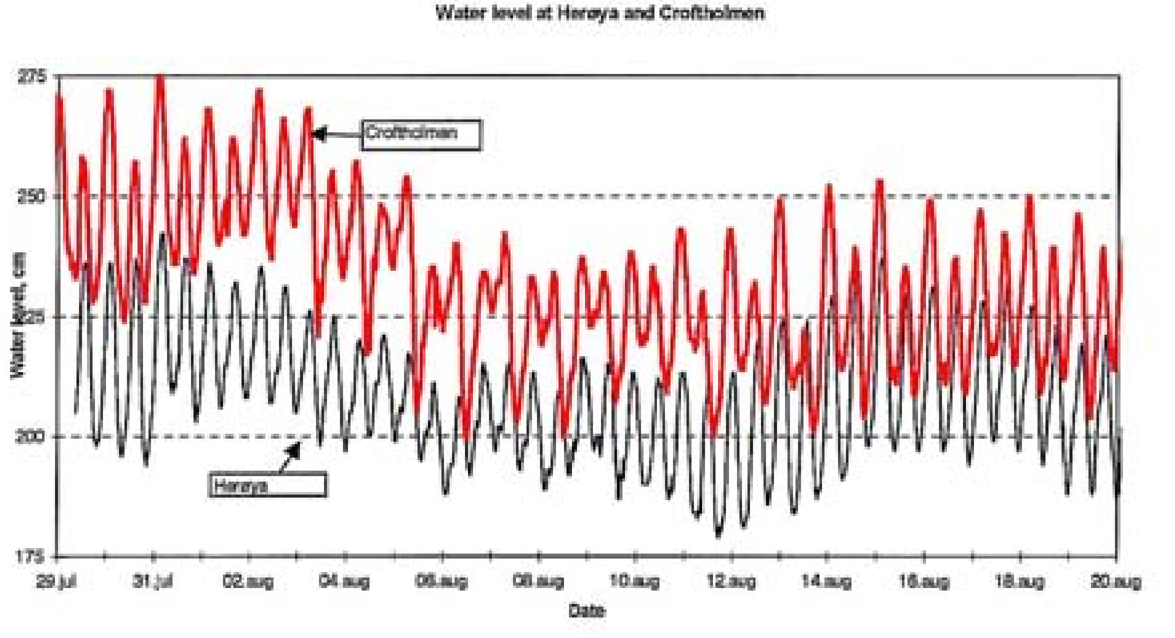

Figure 7. Water level at Croftholmen and Herøya, July-August 1997.

Hydrography and current measurements

A characteristic longitudinal salinity profile of the Frierfjord showing the increasing surface salinity and the hydraulic jump at Brevik is presented in **Figure 8.** Measurements of temperature and salinity by the Aanderaa current meter at 27 m depth inside the sill (23 m) are presented in Figures 9 -10. The dominating feature is decreasing salinity accompanied by decreasing temperature, and vice versa. This is especially evident after August 12.

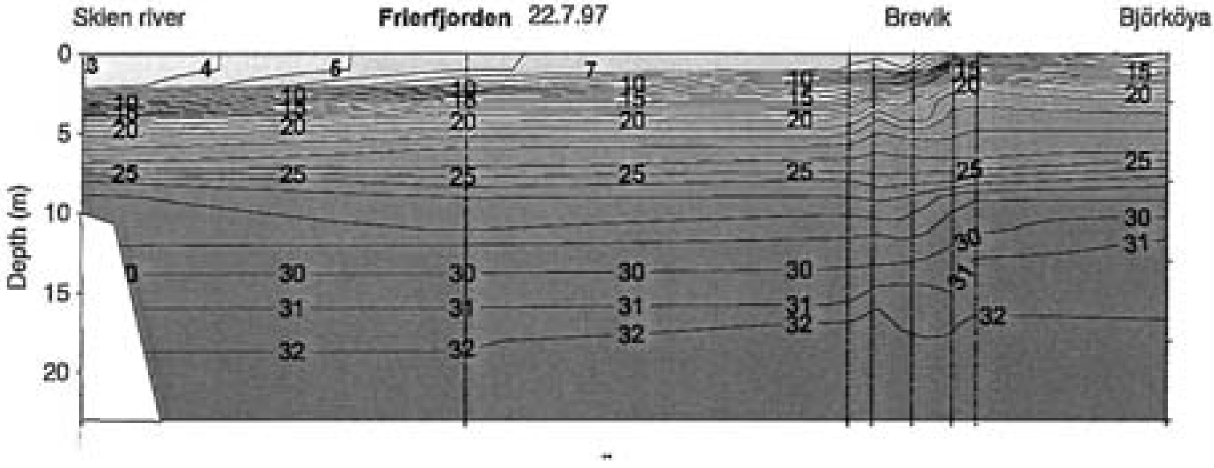

Figure 8. Salinity distribution in the Frierfjord, 22.7.97. Upper and intermediate level above sill depth.

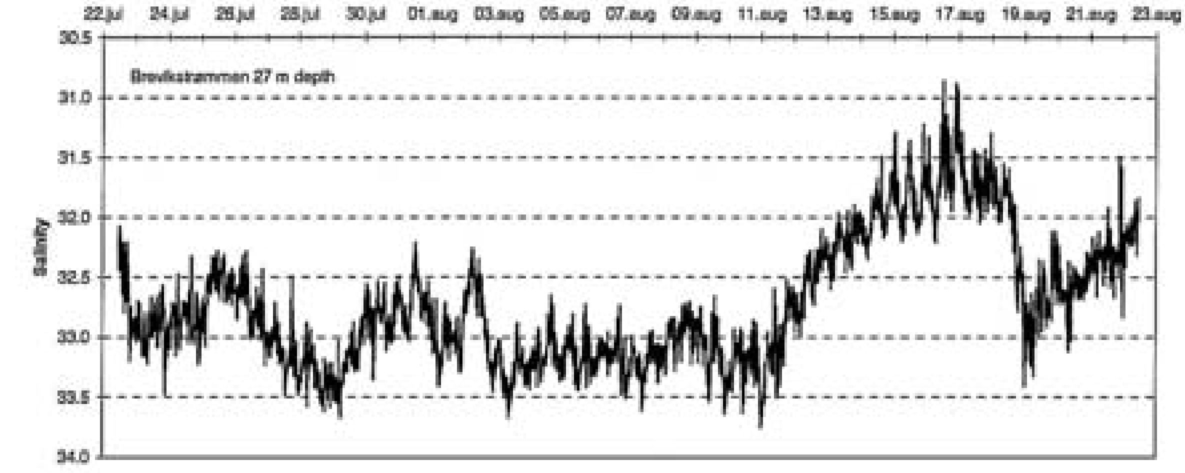

Figure 9. Salinity in the Brevikstrøm July-August 1997 at 27 m, in the sill area.

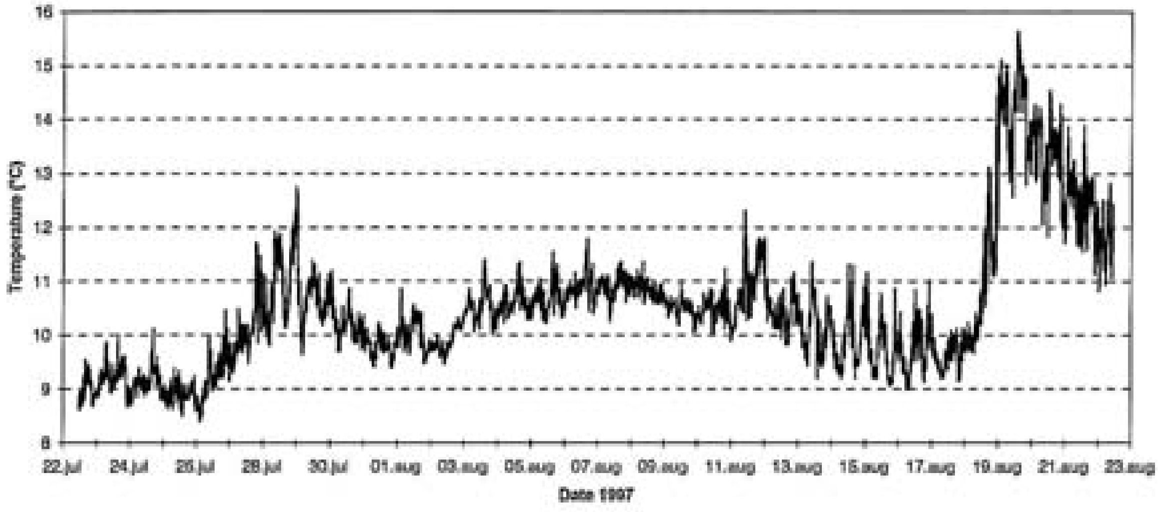

Figure 10. Temperature (°C) at 27 m depth in the Brevikstrøm, July-August 1997, in the sill area.

Figure 11 shows current measurement at 27 m depth inside the sill (the same instrument which figures 9-10 refer to) and **Figure 12** shows the ADP measurements (ca. 55 m depth) inside the sill. Both figures show the east-west component, with current flowing towards east (into the fjord) as positive. **Figure 11** also includes the 25-hour sliding mean, where the semidiurnal tidal component is eliminated.

Considering that the current meter at 27 m depth was situated 6 m below sill depth, the current speed was remarkably high. Compared to Figures 9-10 water masses flowing out of the Frierfjord are relatively cold and with low salinity compared to water entering the fjord.

The ADP shows some of the same features, but does not include 27 m. Considering the low current speeds at 25 m one should not expect speeds that are comparable to those recorded at the other location closer to the sill. Assuming the recordings are correct, different topographic features at the two locations may partly cause the difference: flow through a narrow passage at 27 m versus flow into a relatively wide basin where the ADP was situated.

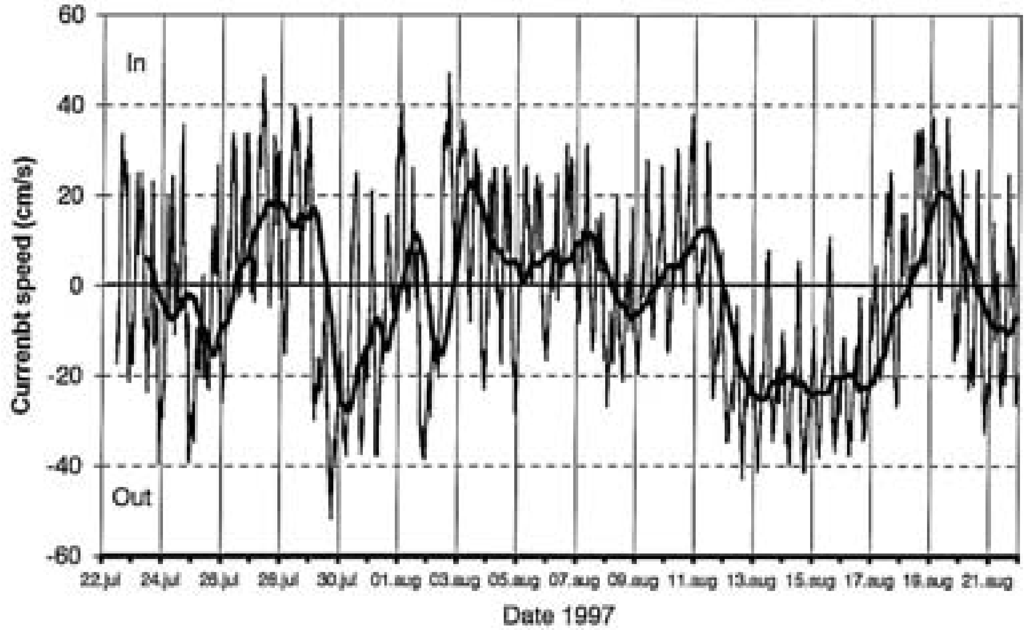

Figure 11. Current speed (cm/s) at 27 m depth in the Brevikstrømmen, projected on a 280 (positive) - 100 degree axis. The figure also includes the 25-hours sliding mean.

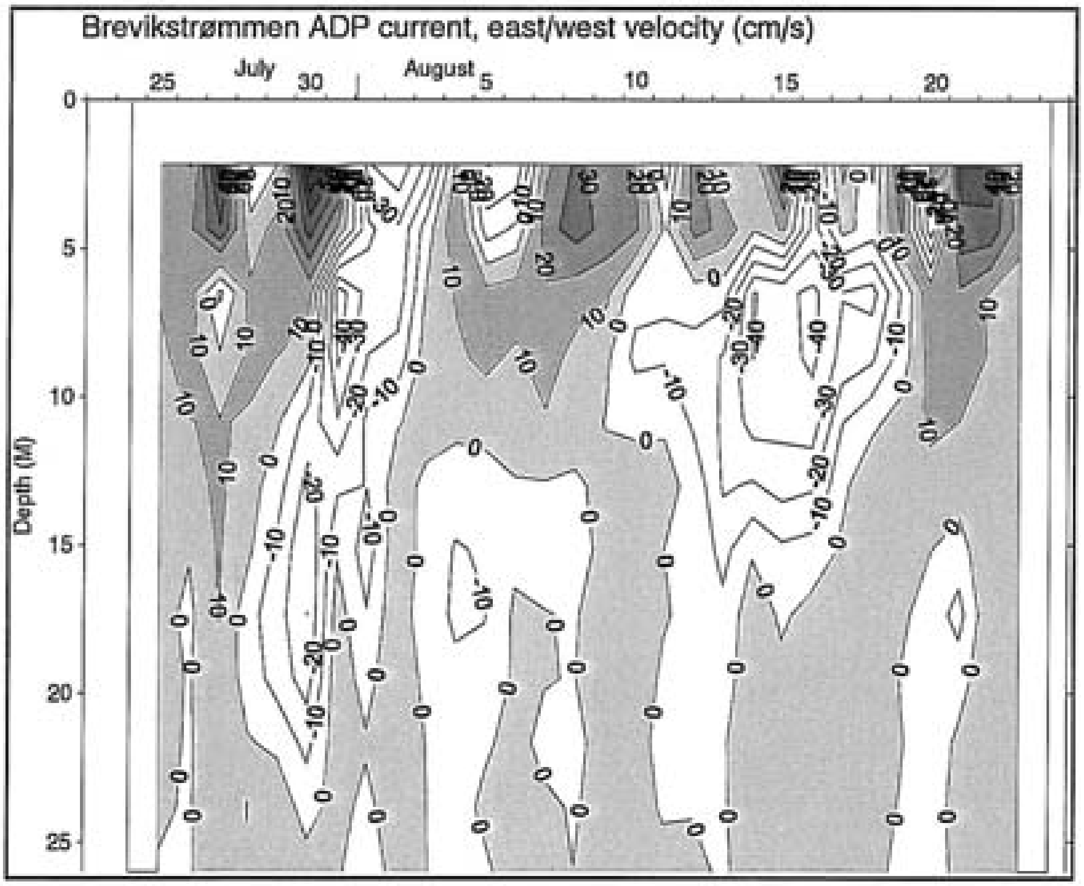

Figure 12. ADP measurements of the east/west component (cm/s) of the current through Brevikstrømmen in July-August 1997. (East =positive).

3.2 The Drammensfjord.

3.2.1 The field study

The measuring period in the fjord was from 3.9 1997 to 6.10 1997. The instruments were deployed as shown in **Figure 3** (principal deployment) and **Figure 13-14** (where the hydrographic stations also are marked).

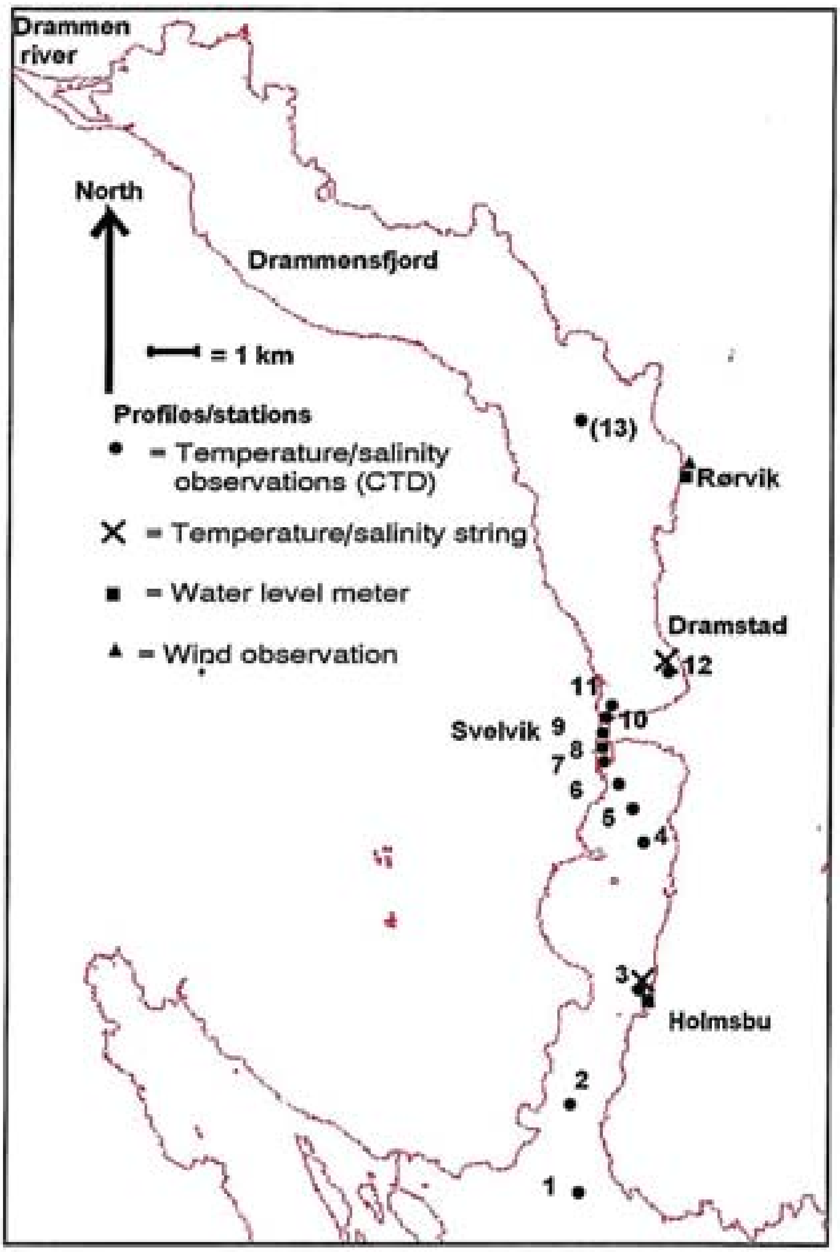

Figure 13. The Drammensfjord. Hydrographic stations, temperature/salinity strings, measurement of water level and wind, September-October 1997.

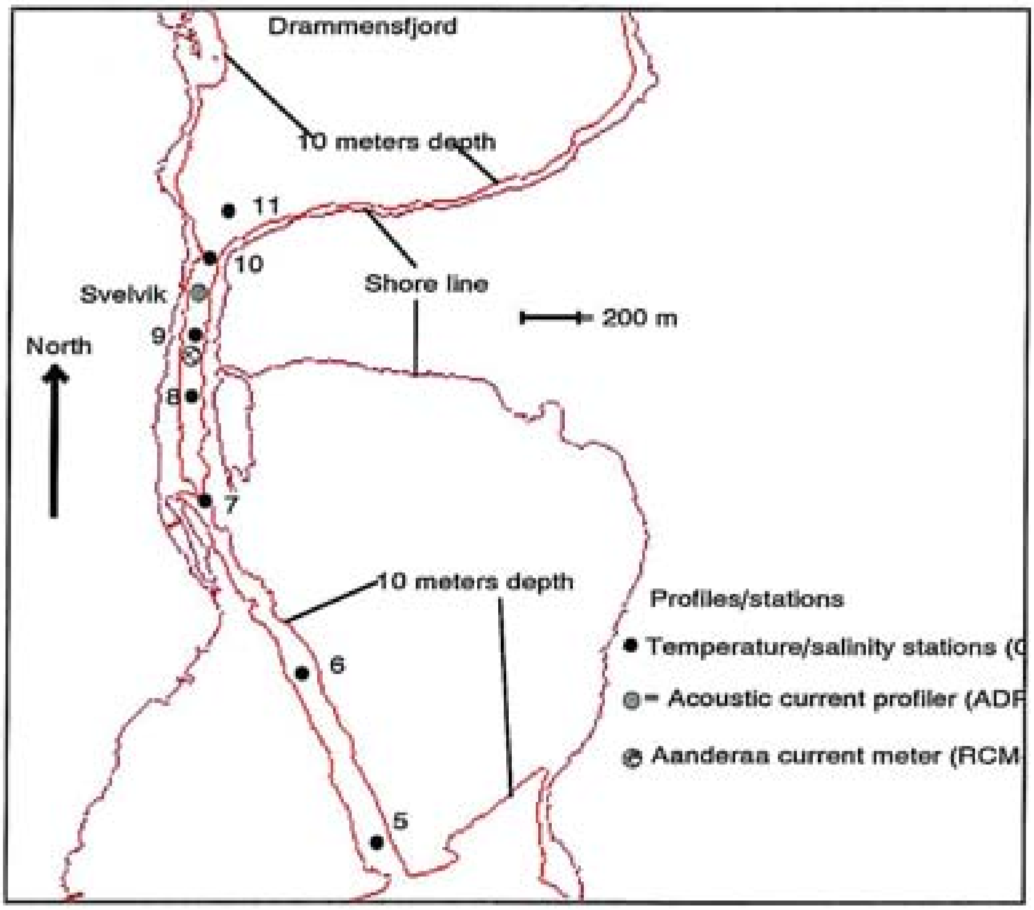

Figure 14. Hydrographic stations and current measurement stations in the Svelvik area in the southern part of Drammensfjord, September-October1997.

Table 5. Recording instruments in the Drammensfjord, September-October 1997. The time is UTC.

Instrument type	*Inst. no.*	*Sensor no.*	*Start (date)*	*Start (time)*	*Deployed (Date/Time)*	*Retrieved (Date/Time)*	*Sensor depth (m)*	*Local name*
T/S-string	1110	49	3.9.97	06:43	ca 14:30	6.10.97 ca. 12:10	1.6, 5,10,15,2 0	Holms-bu
T/S-string	1126	34	3.9.97	06:43	3.9.97 ca. 17:10	6.10.97 ca. 11:15	1.25,5, 10,20, 30	Dram-stad-bukta
Water level	3110	420	5.9.97		5.9.97	6.10.97		Rørvik
Water level	3012	147	5.9.97		ca. 10:40	6.10.97		Holms-bu
Current (ADP)*			2.9.97		3.9.97	6.10.97	12	Svelvik
Current (RCM-9)	28	456	3.9.97	07:40	3.9.97 13:05	6.10.97	ca. 11	Svelvik
Wind**			3.9.97		ca. 10.40			

* = The ADP was tilted horizontally beyond acceptable limit.

** The instrument was only operative during the first week.

Table 6. Hydrographic observations (temperature and salinity) with Seacat CTD.

Date	*Stations*	*Observations*	*Remarks*
10.9.97	1 - 12	$T/S+O_2$	Profile mode < 0.5 m/s, pumped
17.9.97	2 - 12	$T/S+O_2$	Profile mode, < 0.5 m/s, pumped
24.9.97	1 - 14	$T/S+O_2$	Profile mode, < 0.5 m/s, pumped
3.10.97	1 - 12	$T/S+O_2$	Profile mode, < 0.5 m/s, pumped

Table 7. Geographic positions of stations in the Drammensfjord, 1997.

Instrument	*Station*	*Local name*	*Echodepth (m)*	*N*	*E*
Seacat (CTD)	1	Rødtangen	80 -100	59°31.94'	10°24.4'
Seacat (CTD)	2	Berger	33	59°32.62'	10°24.2'
Seacat (CTD)	3	Holmsbu	27	59°34.01'	10°25.42'
Seacat (CTD)	4	Bokerøya	14	59°35.5'	10°25.6'
Seacat (CTD)	5		11	59°35.83'	10°25.30'
Seacat (CTD)	6	Svelvik renne North	11	59°36.15'	10°25.12'
Seacat (CTD)	7		10	59°36.53'	10°24.48'
Seacat (CTD)	8	Verksøya	11	59°36.73'	10°24.45'
Seacat (CTD)	9		12	59°36.84'	10°24.46'
Seacat (CTD)	10		15	59°37.05'	10°24.48'
Seacat (CTD)	11		27-42	59°37.10'	10°24.52'
Seacat (CTD)	12	Dramsbukta	120	59°37.75'	10°25.78'
Seacat (CTD)	13	Sagbukta	117	59°40.00'	10°23.5'
Seacat (CTD)	14	Selvika	120	59°37.65'	10°25.1'
T/S-string no. 1110		Holmsbu	25	59°34.05'	10°25.50'
T/S-string no. 1126		Dramsbukta	100	59°37.75'	10°25.78'
Water level no 420		Rørvik		59°40.25'	10°26.08'
Water level no. 147		Holmsbu		59°39.62'	10°25.5'
Current (RCM-9)		Svelvik	11	59°36.81'	10°24.75'
Current (ADP)		Svelvik	12	59°36.95'	10°24.78

3.2.2 Results

Wind

There were no local observations due to malfunction of instrument.

Fresh water discharge

The variation in fresh water discharge was less than for Skien river in the Frierfjord, and varied between approx. 130 m^3/s and 310 m^3/s (**Figure 15**).

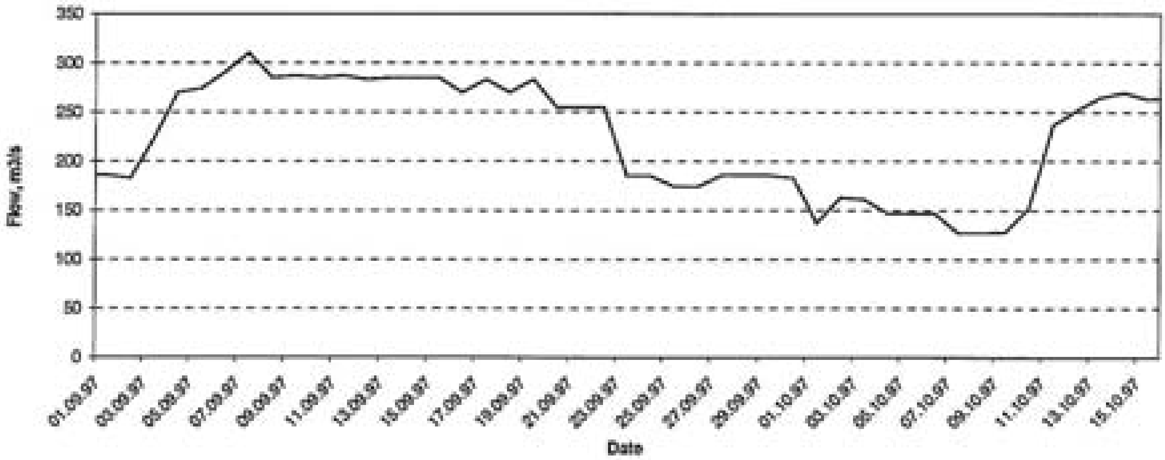

Figure 15. Fresh water discharge, Drammen river. September-October 1997.

Water level

Figure 16 shows simultaneous measurements of water level at Holmsbu (outside the sill) and at Rørvik (inside the sill). The levels are not normalised relative to another, and one may therefore only observe the relative variations.

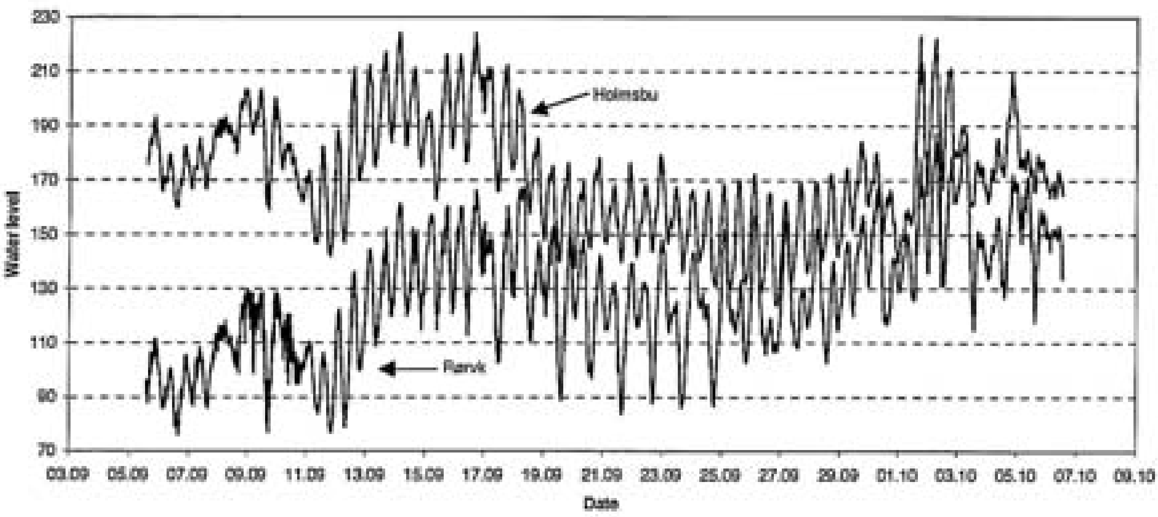

Figure 16. Water levels inside (Rørvik) and outside (Holmsbu) the Drammensfjord sill in September-October 1997.

Hydrography and Current measurements

Due to the high fresh water discharge, the Drammensfjord experiences an estuarine circulation. The water close to the sill bottom was mainly flowing into the fjord, but strongly influenced by the semidiurnal tide (**Figure 17**).

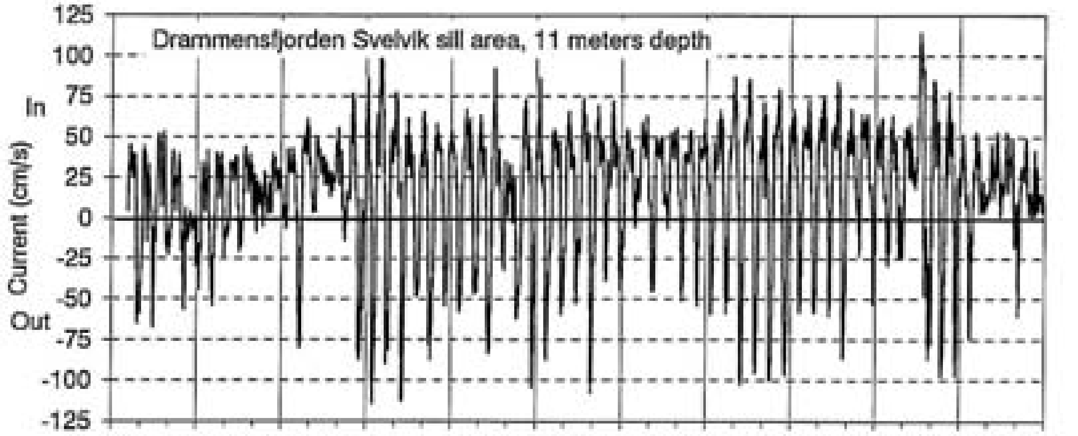

Figure 17. Current speed (cm/s) at the Svelvik sill area, inn/out the fjord (0/180 degrees) at 11m depth (Sill depth).

A characteristic longitudinal salinity profile along the Svelvik sill showing the increasing surface salinity and the hydraulic jump at Svelvik is presented in **Figure 18.** Measurements of temperature and salinity by Aanderaa current meter at the sill bottom are presented in Figures 19-20. The dominating feature is a strong tidal signal of semidiurnal period. **Figure 21** shows a strong connection between high salinity and northerly currents and vice versa, an evidence of the tidal dependent estuarine circulation.

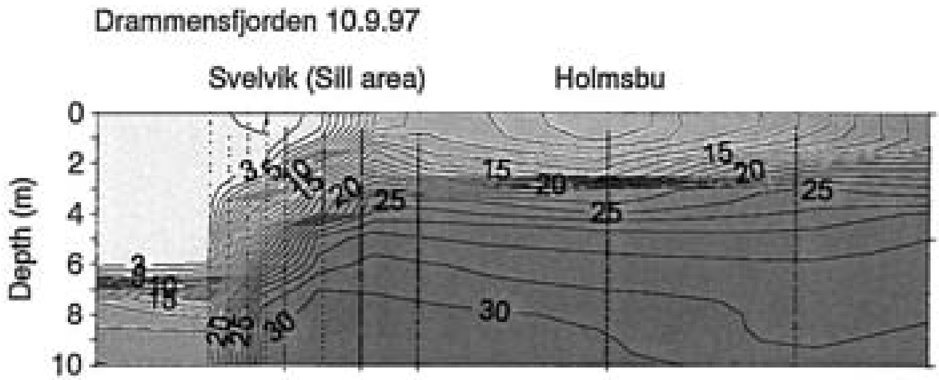

Figure 18. Salinity distribution above sill depth in the Drammensfjorden, 10.9.97.

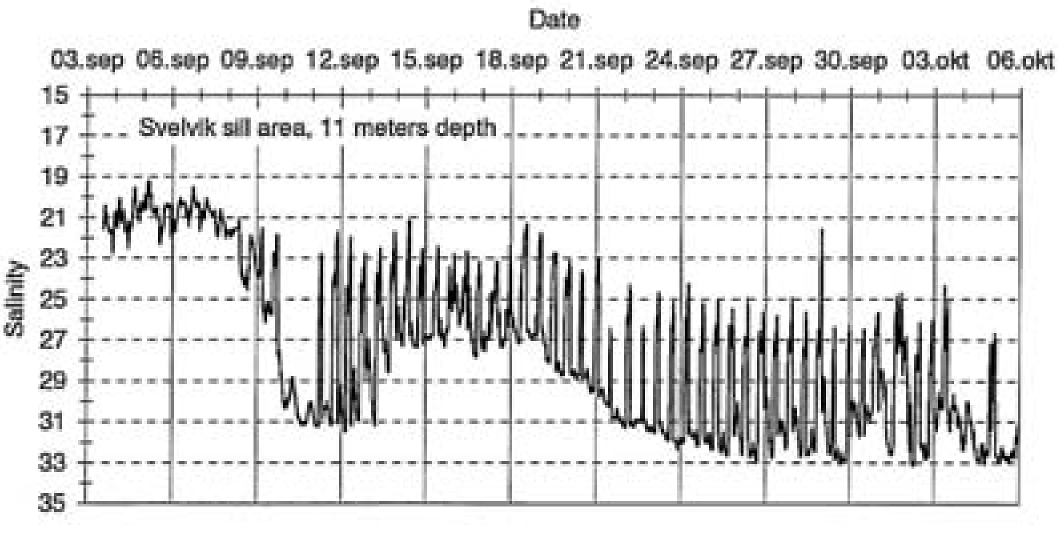

Figure 19. Salinity at 11 meters depth in the Svelvik sill area.

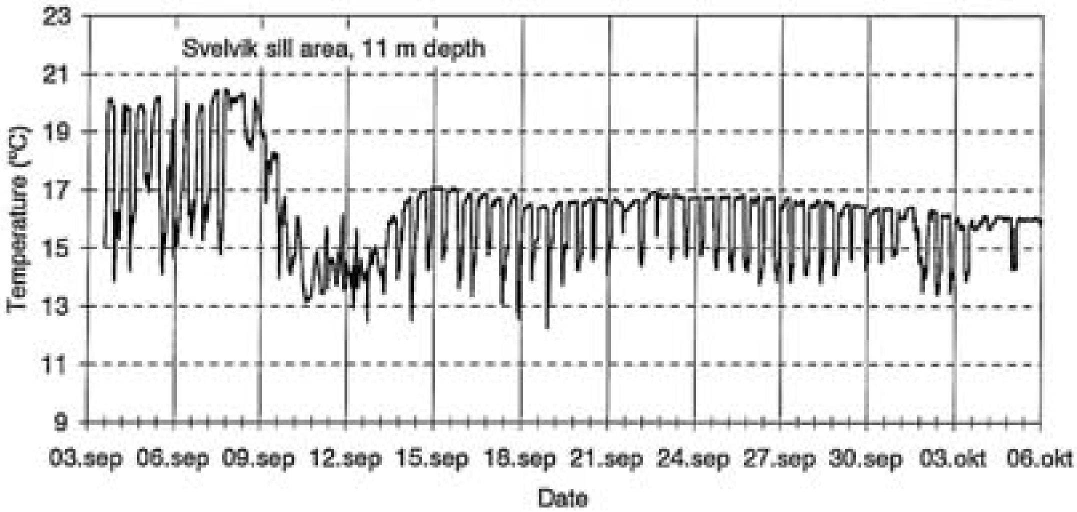

Figure 20. Temperature at 11 meters depth in the Svelvik sill area.

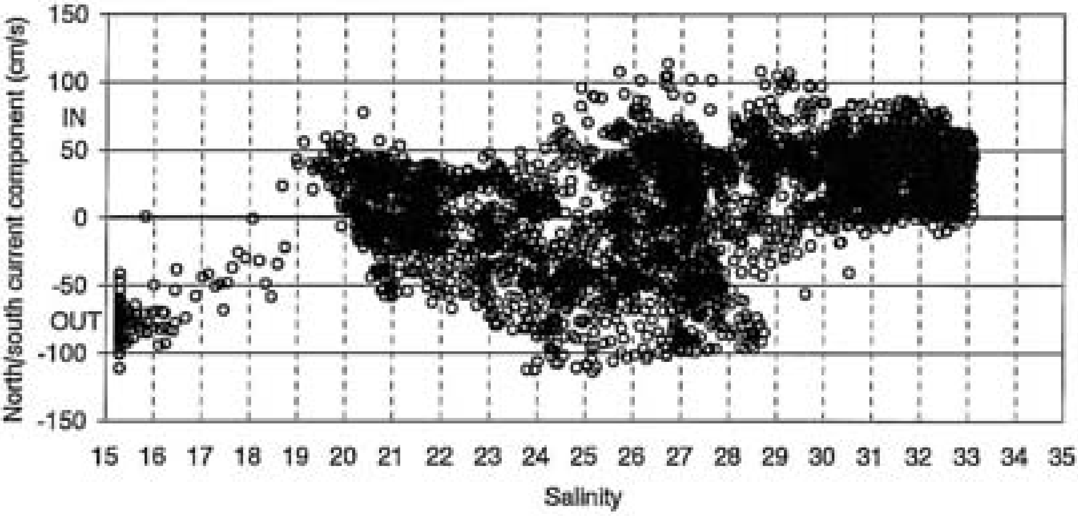

Figure 21. North/south current component (cm/s) and salinity at 11 meters depth in the Svelvik sill area.

3.3 The Iddefjord.

3.3.1 The field study

The measuring period was from 21- 22.10 1997 to 3.12 1997. The hydrographic stations were placed as shown in **Figure 22** and the instruments placed as shown in Figure 23-24.

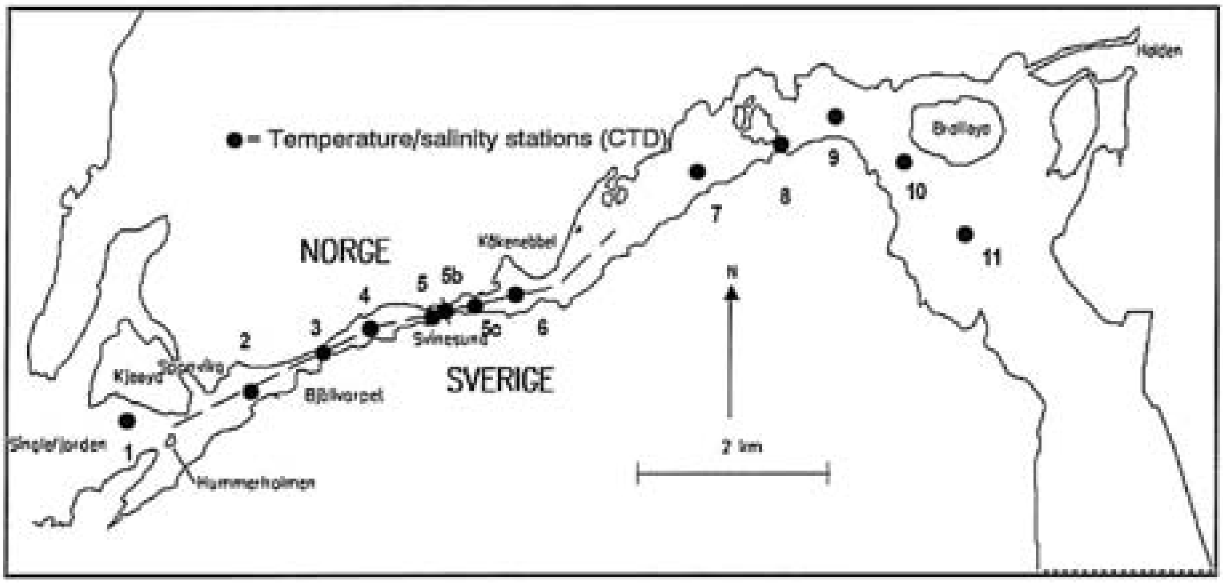

Figure 22. Hydrographic stations in the Iddefjord, October-December 1997.

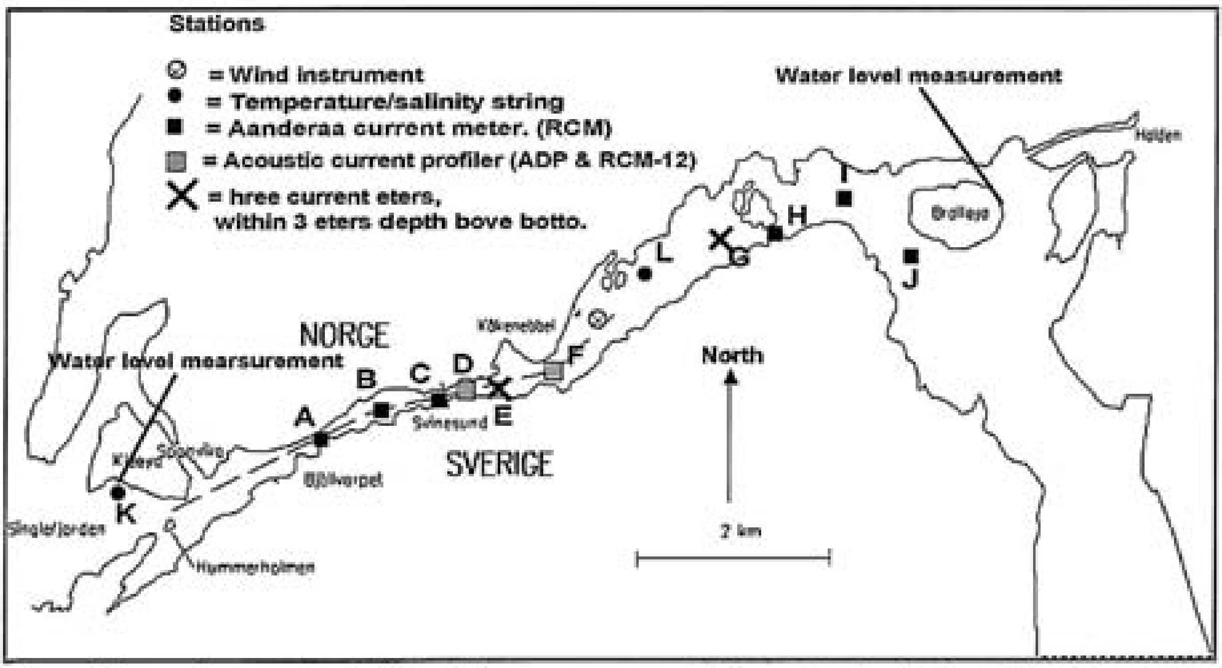

Figure 23. Temperature/salinity strings, measurement of current, water level and wind, October-December 1997.

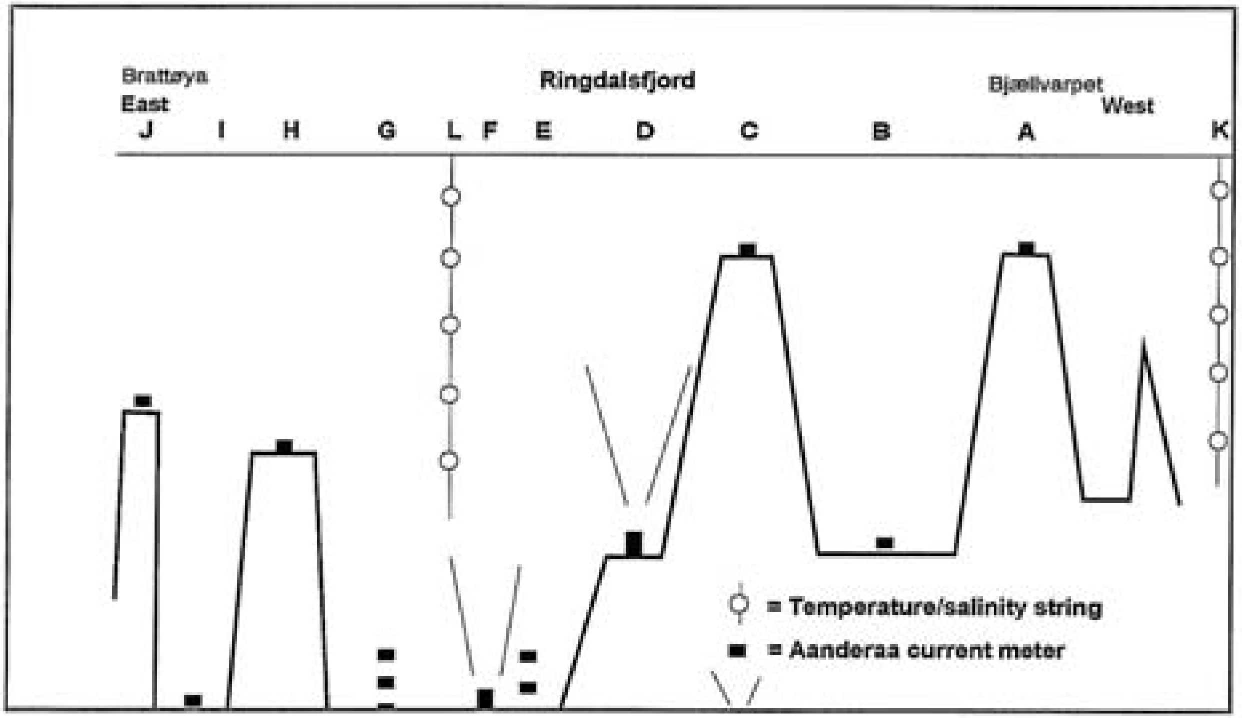

Figure 24. Deployed current meters and T/S-strings in the Iddefjord (Ringdalsfjorden), October-December 1997. Principal positions.

Table 8. Recording instruments in the Iddefjord, October-December 1997. Time is UTC.

Instrument type	*Inst. no.*	*Sensor no.*	*Start*	*Deployed*	*Retrieved*	*Sensor depth (m)*	*Local name*
T/S-string	1110	49	21.10.97	23.10.97	3.12.97	1.6, 5 10,15, 20	Kjeøya
T/S-string	1126	34		22.10.97 ca 16:20	3.12.97	1.25,5, 10,20, 30	Unner-berg
Water level	3110	420	23.10.97	23.10.97	3.12.97		Bratt-øya
Water level		147	23.10.97	23.10.97	3.12.97		Kjeøya
Current	RCM-7	900	21.10.97	23.10.97	3.12.97	10	Bjäll-varpet
Current	RCM-7	269	21.10.97	23.10.97	3.12.97	26	Rør-bekk
Current	RCM-7	8362	21.10.97	23.10.97	3.12.97	10	Svine-sund sill
Current	ADP		21.10.97	23.10.97	3.12.97	24	East Svine-sund sill
Current	UCM	4071	29.10.97		3.12.97	At bottom	Station E
Current	RCM-9	28	29.10.97		3.12.97	Middle	StationE

Table 8, continues

Instrument type	Inst. no.	Sensor no.	Start	Deployed	Retrieved	Sensor depth (m)	Local name
Current	SD200	269	29.10.97		3.12.97	Upper	Station E
Current	ADCP, RCM-12	21	21.10.97	22.10.97	3.12.97	41	Kråke-nebbet
Current	UCM	4009	22.10.97	22.10.97	3.12.97	35, lower	Orr-viken
Current	RCM-9	25	21.10.97 12:10	22.10.97	3.12.97	middle	Orr-viken
Current	RCM-7	276	21.10.97	22.10.97	3.12.97	Upper	Orr-viken
Current	RCM-7	183	21.10.97	22.10.97	3.12.97	22	Svarte Jan
Current	RCM-7	4772	21.10.97	22.10.97	3.12.97	40	Viks-tången
Current	RCM-7	2608	21.10.97	22.10.97	3.12.97	20	Bratt-øya
Wind			23.10.97	23.10.97	3.12.97		Dann-marks-skjæret

Table 9. Hydrographic observations (temperature and salinity) with Seacat CTD, file identification and profiling mode.

Date	*Stations*	*Observations*	*Remarks*
29.10.97	1-11	$T/S+O_2$	Profile mode < 0.5 m/s, pumped
7.11.97	1-11	$T/S+O_2$	Profile mode, < 0.5 m/s, pumped
14.11.97	1-12	$T/S+O_2$	Profile mode, < 0.5 m/s, pumped
3.12.97	1-13	$T/S+O_2$	Profile mode, < 0.5 m/s, pumped

Table 10. Geographic positions of stations and moored instruments in the Iddefjord, October-December 1997.

Instrument	*Station*	*Local name*	*Depth (m)*	*N*	*E*
Seacat (CTD)	1	Kjeøya	64	59°05.3'	11°13.0'
Seacat (CTD)	2	Sponvika	31	59°05.48'	11°14.25'
Seacat (CTD)	3	Bjällvarpsterskelen	10	59°05.67'	11°15.05'
Seacat (CTD)	4	Rørbekk	28	59°05.82'	11°15.70'
Seacat (CTD)	5	Svinesund sill	10	59°05.88'	11°16.25'
Seacat (CTD)	5b	Svinesund bridge	16	59°05.89'	11°16.32'
Seacat (CTD)	5c	Hjelmekollen	24	59°05.93'	11°16.60'
Seacat (CTD)	6	Blåsoppbukta	41	59°06.96'	11°17.00'
Seacat (CTD)	7	Roparhällen	36	59°06.59'	11°18.95'
Seacat (CTD)	8	Svarte Jan	25	59°06.75'	11°19.69'
Seacat (CTD)	9	Vikstången	40	59°06.93'	11°20.46'

Table 10, continues.

Instrument	Station	Local name	Echodepth (m)	N	E
Seacat (CTD)	10	Brattøya	21	59°06.55'	11°23.00'
Seacat (CTD)	11	Kuskjær	26	59°06.28'	11°21.65'
Seacat (CTD)	12	Skysskafaren	33	59°05.90'	11°22.20'
T/S-string no. 1110	K	Kjeøya	60	59°05.39'	11°13.0'
T/S-string no. 1126	L	Unnerberg	36	59°06.50'	11°18.29'
Water level no 420		Brattøya		59°06.87'	11°22.00'
Water level no. 147		Kjeøya		59°05.45'	11°13.00'
RCM-7	A	Bjällvarpet	10	59°05.67'	11°15.05'
RCM-7	B	Rørbekk	26	59°05.81'	11°15.57'
RCM-7	C	Svinesund sill	10	59°05.88'	11°16.25'
ADP	D	Svinesund east	24	59°05.91'	11°16.43'
UCM+RCM-9 +SensorData	E	Hjelmekollen		59°05.95'	11°16.82'
ADCP, RCM-12	F	Kråkenebbet	41	59°06.05'	11°17.44'
UCM+RCM-9 +RCM-7	G	Orrviken	25	59°06.67	11°19.05'
RCM-7	H	Svarte Jan	22	59°06.74'	11°19.65'
RCM-7	I	Vikstången	40	59°06.93'	11°20.46'
RCM-7	J	Brattøya	20	59°06.48'	11°21.4'
Wind instrument		Dannmarksskjæret		59°06.28'	11°17.80'

3.3.2 Results.

Fresh water discharge

Apart from being far smaller than the fresh water discharge to the Frierfjord and the Drammensfjord, the daily discharge to the Iddefjord also showed smaller variations (**Figure 25**).

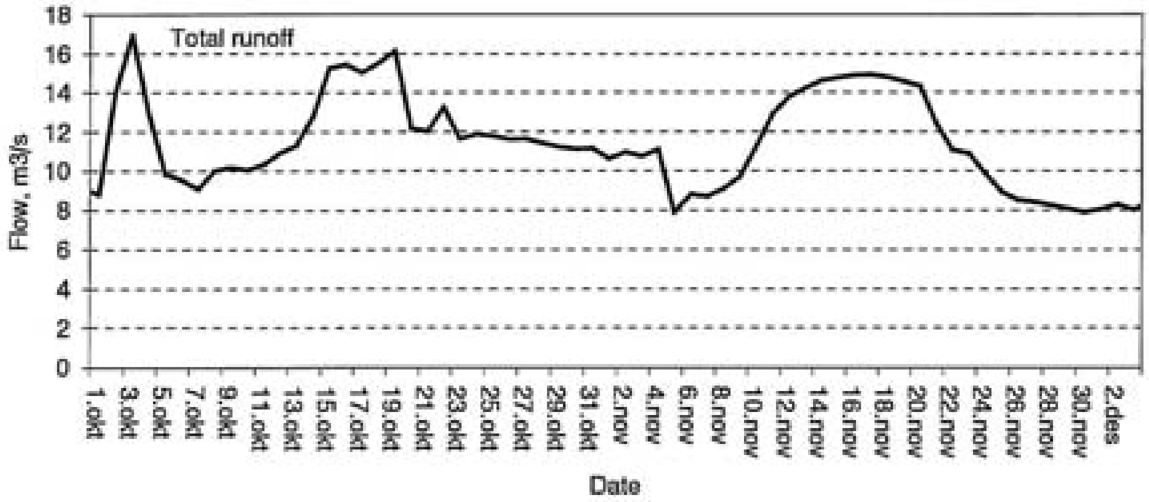

Figure 25. Total runoff from Tista (at Halden) and Enningdal rivers to the Iddefjord in October - December 1997.

Water level

Figure 26 shows simultaneous measurements of water level at Kjeøya (outside the sills) and at Brattøya (inside the sills). The levels are not normalised relative to another, and one may therefore only observe the relative variations. The water level at Brattøya should be treated with care, as the average variations do not follow the Kjeøya instrument. As the pressure sensor on the ADP inside the Svinesund sill was in phase with Kjeøya but slightly behind, the instrument at Brattøya could be malfunctioning.

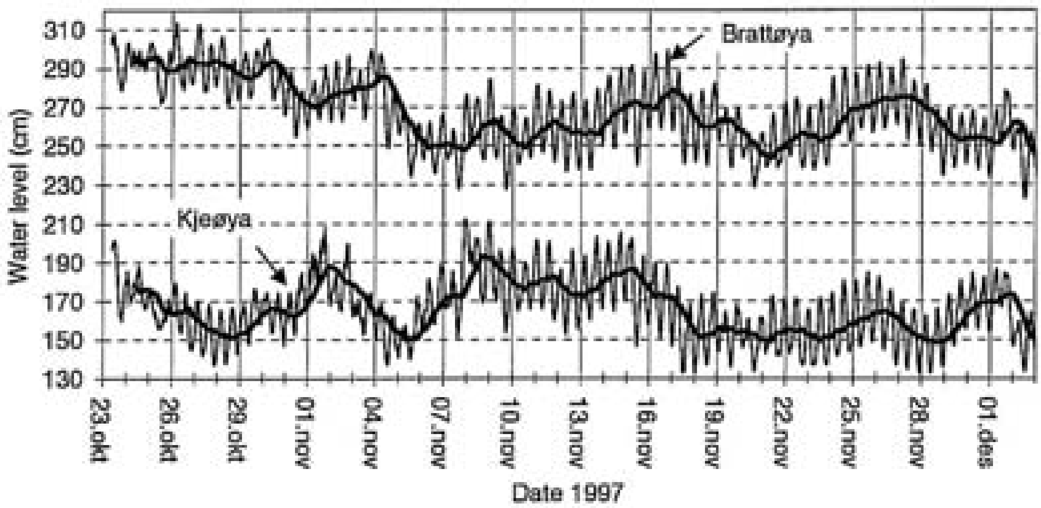

Figure 26. Water level outside (Kjeøya) and inside (Brattøya) the Iddefjord sills. 10 minutes observations and averaged over a tidal cycle.

Hydrography and current measurements.

A characteristic longitudinal salinity profile showing the increasing surface salinity and the hydraulic jump at the Svinesund and Bjällvarpet sills is presented in **Figure 27**.

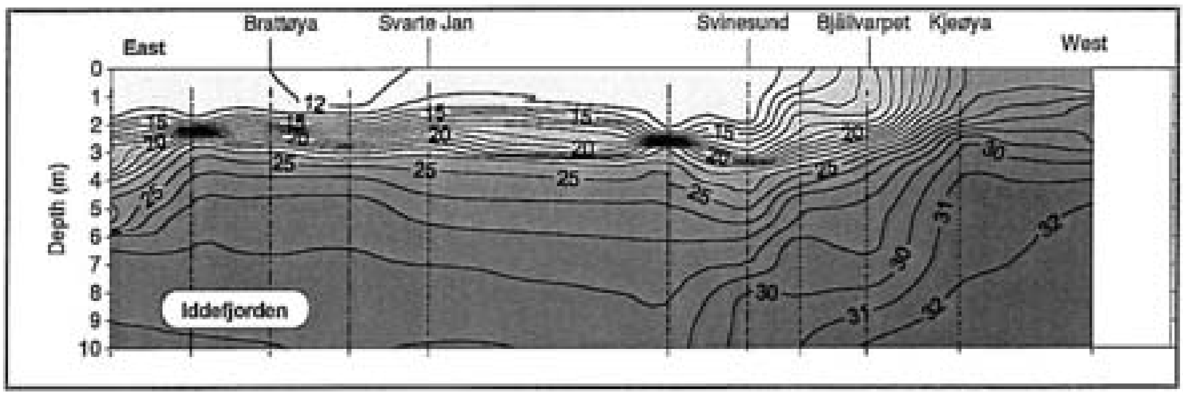

Figure 27. Salinity distribution above sill level in the Iddefjord, 17.11.97.

Figures 28-31 present measurements of current speed and salinity from the Aanderaa current meters on the Svinesund and Bjällvarpet sills. The following Figures 32-48 show corresponding data series from the current meter stations further away from the sills (see Fig. 22 for more details). The dominating feature is a strong tidal signal of semidiurnal period, weakening towards the inner part of the fjord. Superimposed on the series are also signals of longer and more irregular periods, probably of local meteorological origin or caused by variations of the density field in the coastal water.

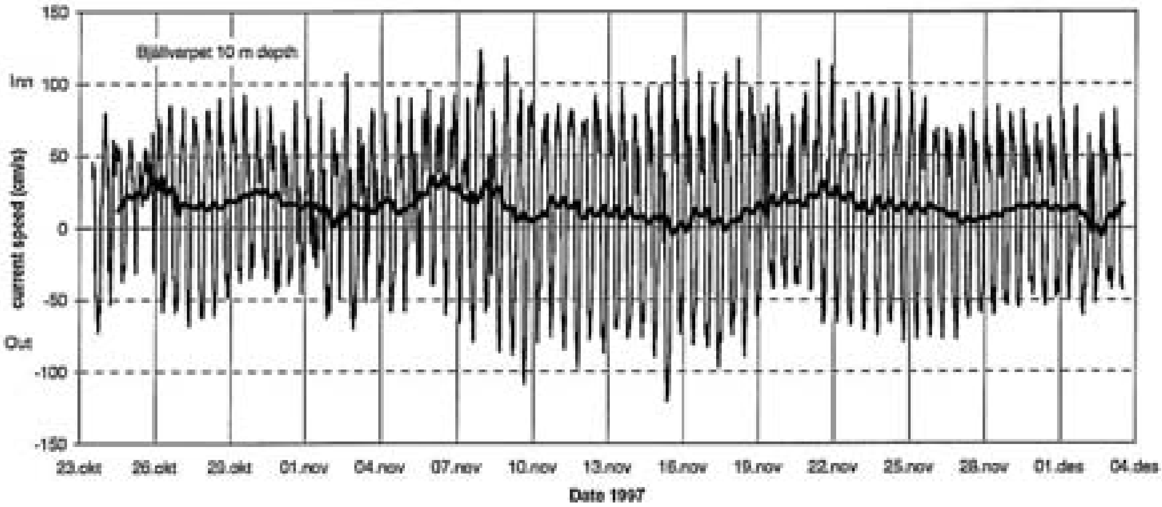

Figure 28. Current (in/out) at 10 m depth, Bjällvarpet (station A).

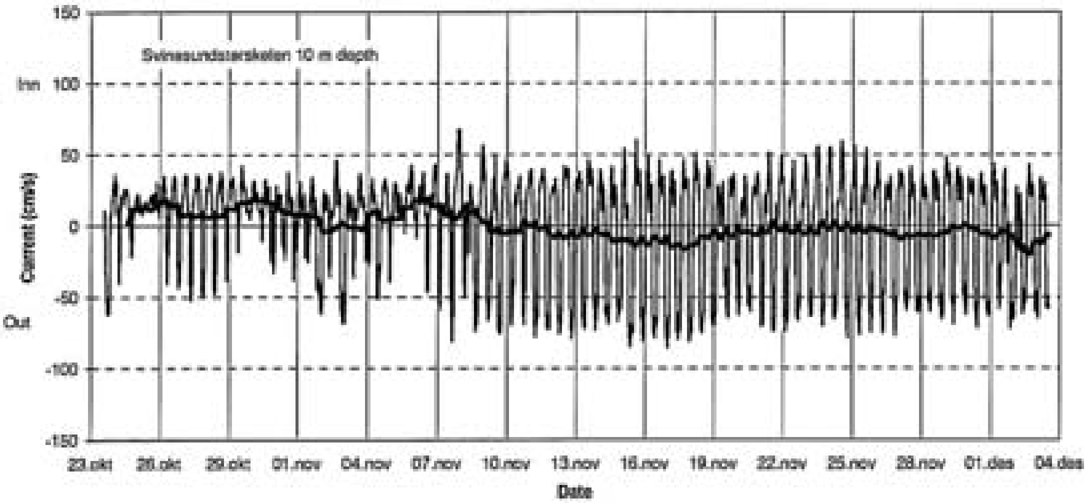

Figure 29. Current (in/out) at 10 m depth, Svinesund (station C).

As an overall average there was a distinct outflow in the upper 5 m during the approx. 6 weeks of measurements (Figure 36). Below 15-20 m depth the current was generally flowing into the fjord, which may be consistent with a gradually increase of salinity in the basin water (Figure 39).

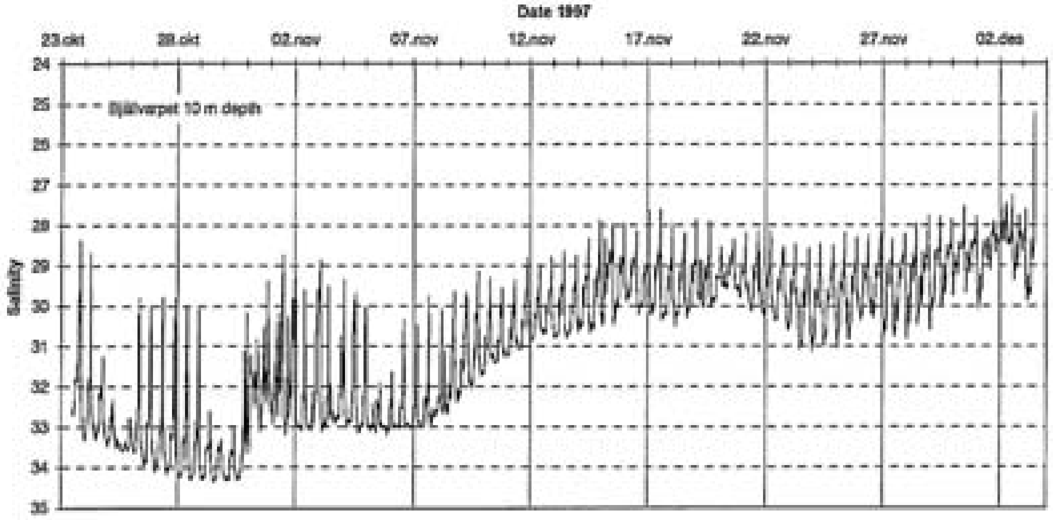

Figure 30. Salinity at 10 m depth, Bjäillvarpet (station A).

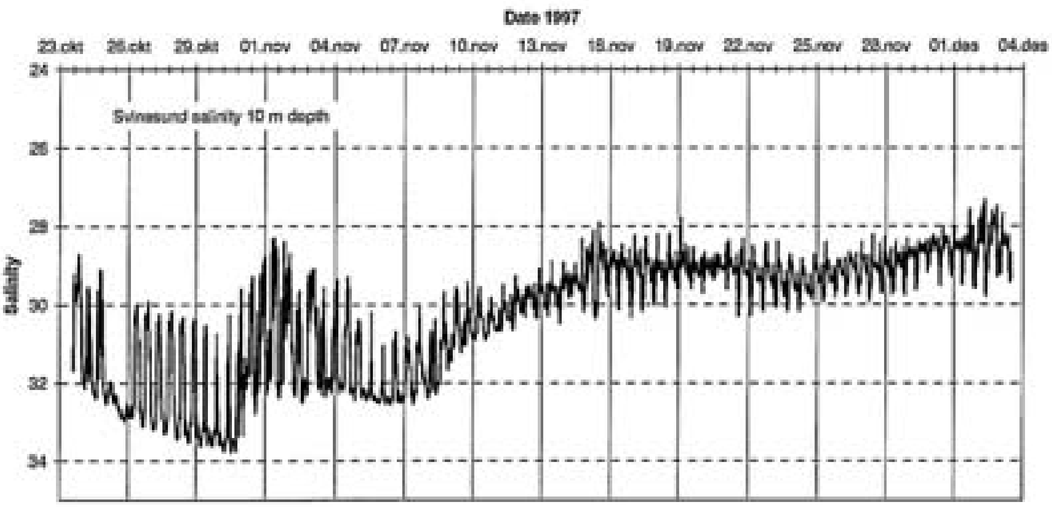

Figure 31. Salinity at 10 m depth, Svinesund (station C).

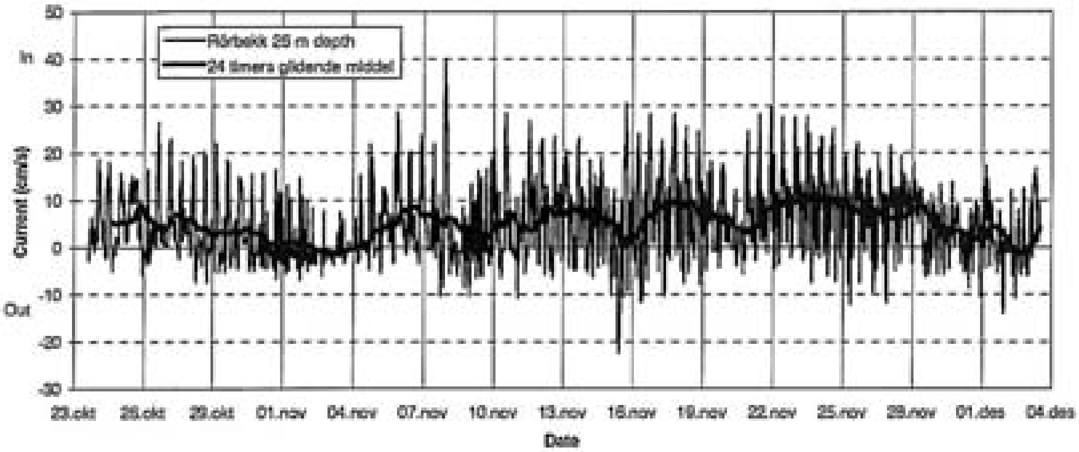

Figure 32. Current (in/out) at 26 m depth, Rørbekk (station B).

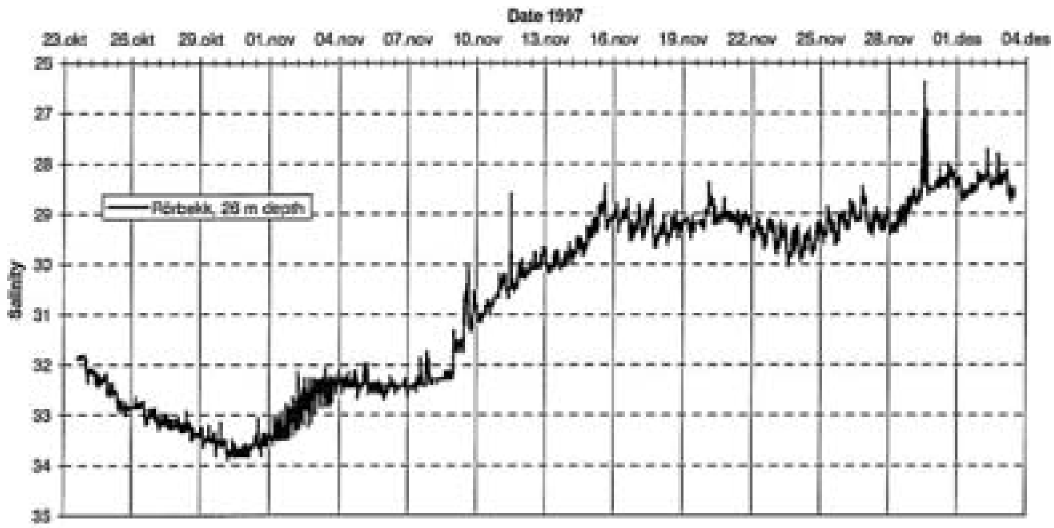

Figure 33. Salinity at 26 m depth, Rørbekk (station B).

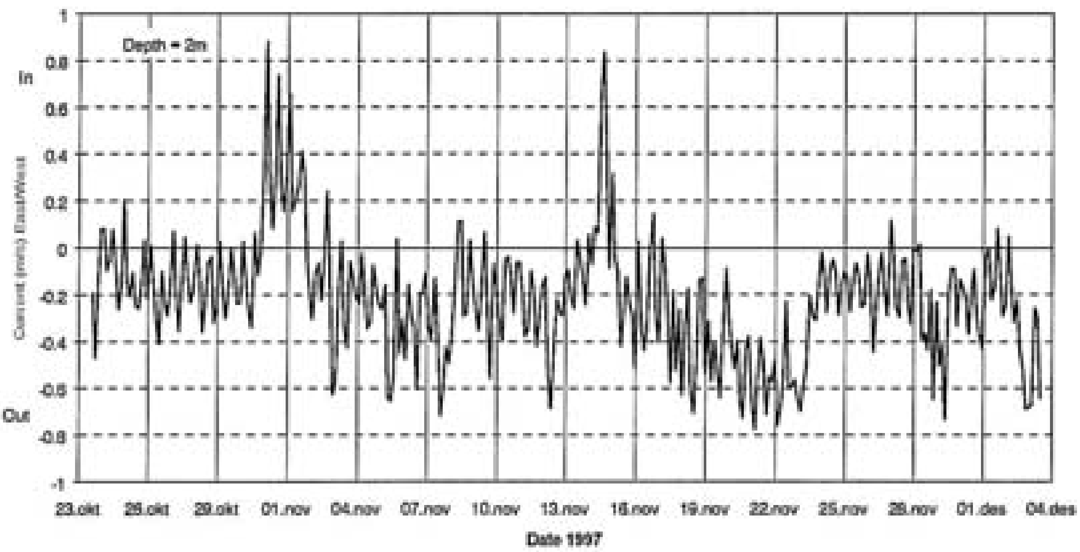

Figure 34. East/West current (m/s) at 2 m depth inside Svinesund (station D), as measured by the ADP.

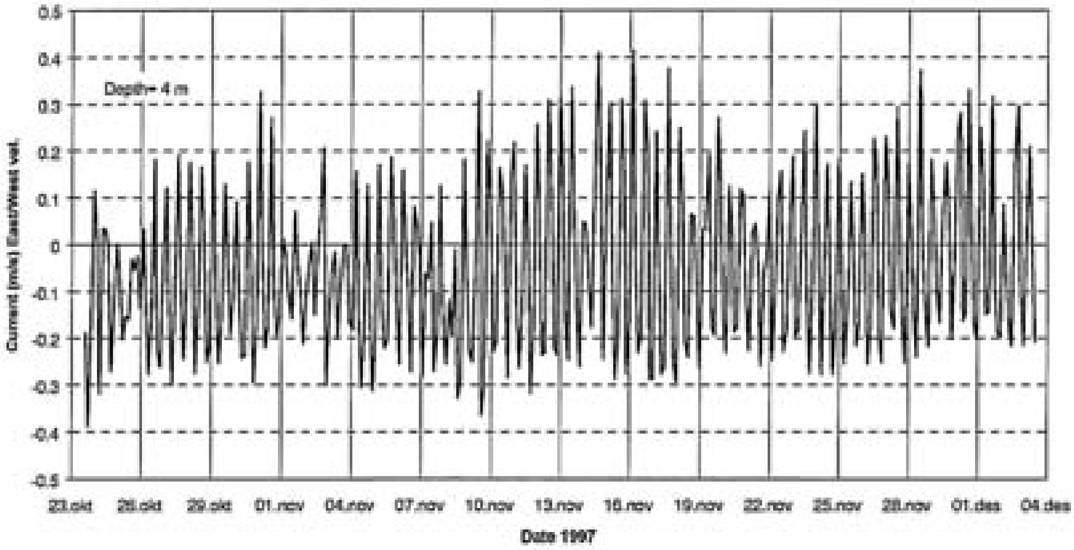

Figure 35. East/West current (m/s) at 4 m depth inside Svinesund (station D), as measured by the ADP.

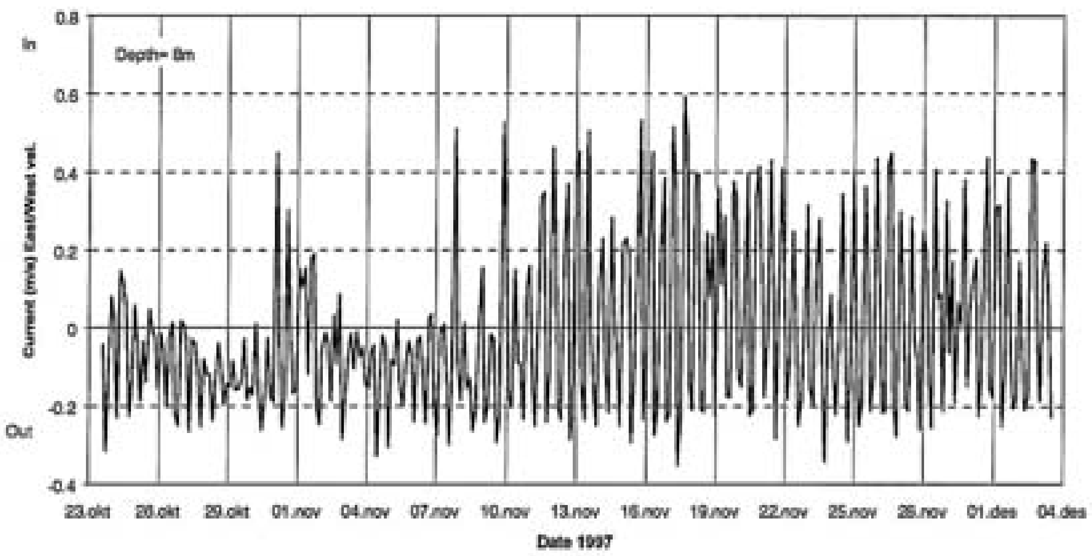

Figure 36. East/West current (m/s) at 8 m depth inside Svinesund (station D), as measured by the ADP.

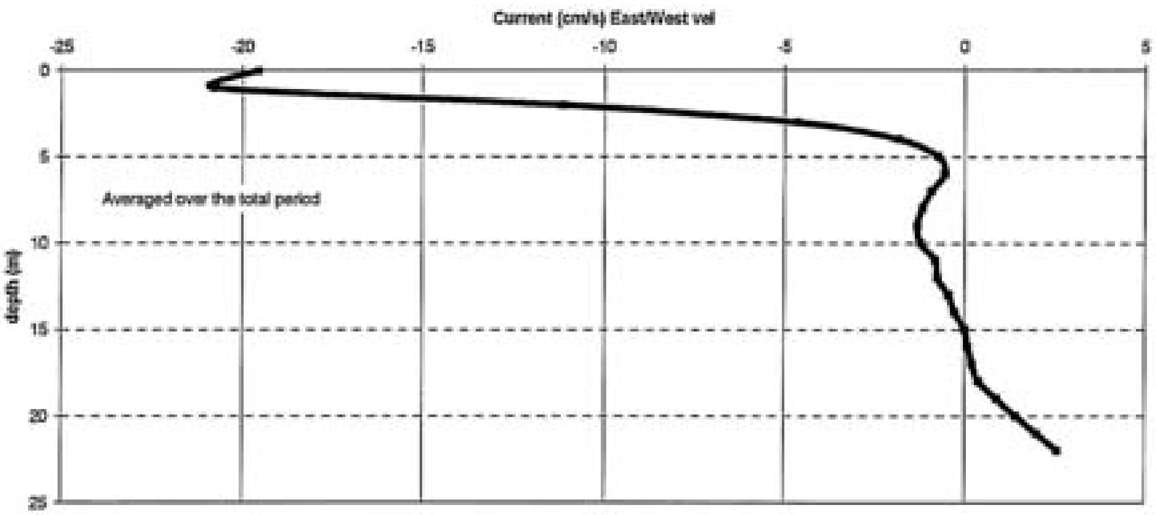

Figure 37. East/West currents (ADP), mean over the period, inside Svinesund (station D).

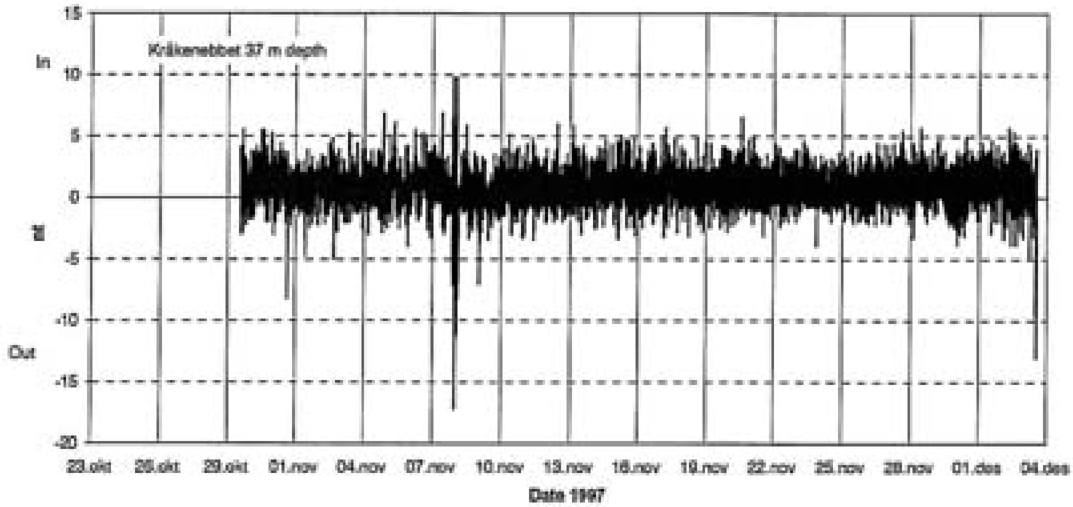

Figure 38. Current (in/out) at 37 m depth, inside Svinesund (station E).

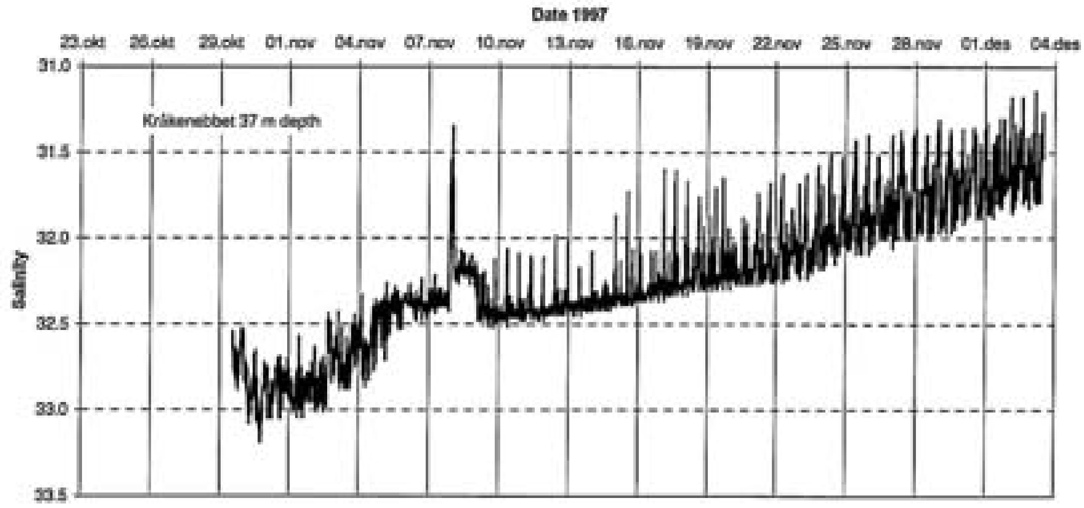

Figure 39. Salinity inside Svinesund at 37 m depth (station E).

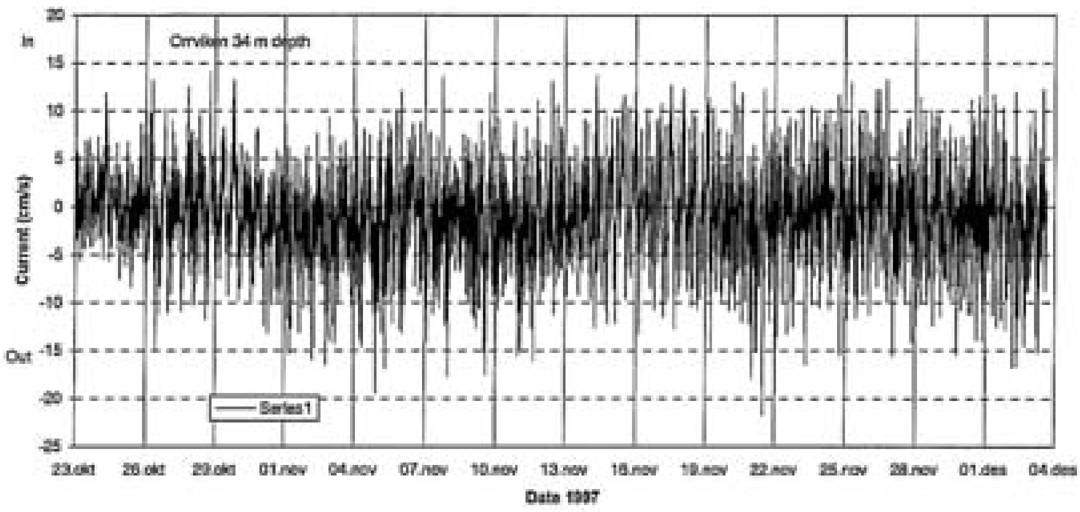

Figure 40. Current (in/out) at 34 m depth, Orrviken (station G).

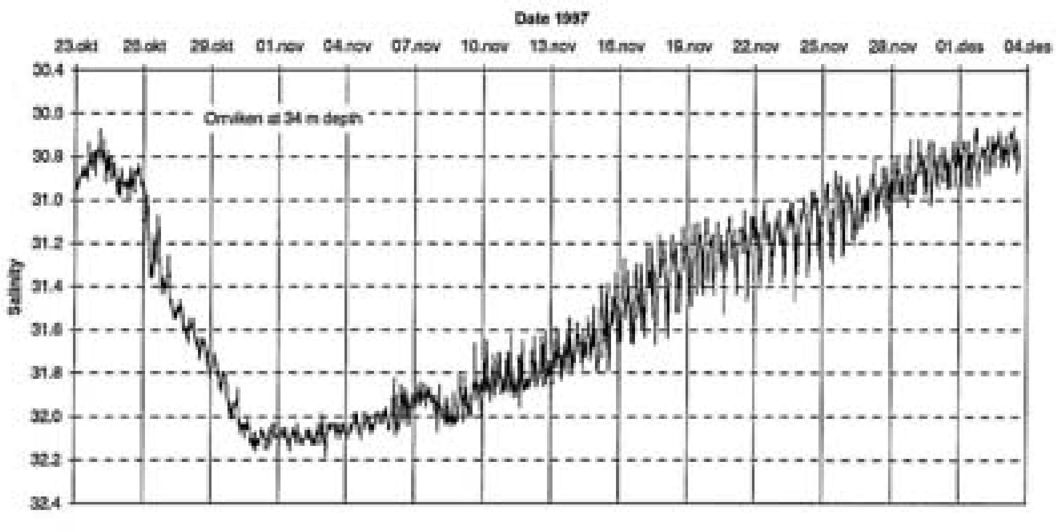

Figure 41. Salinity at 34 m depth, Orrviken (station G).

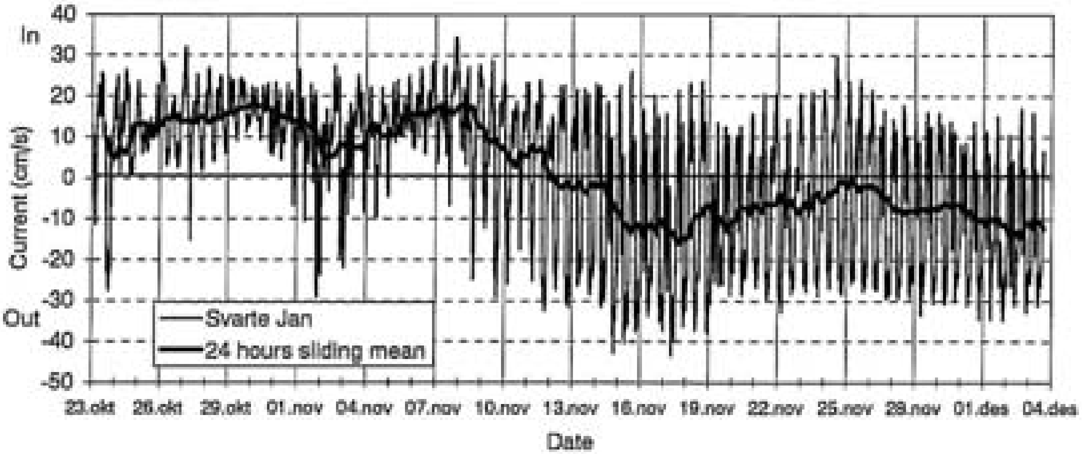

Figure 42. Current (in/out) at 18 m depth, Svarte Jan (station H).

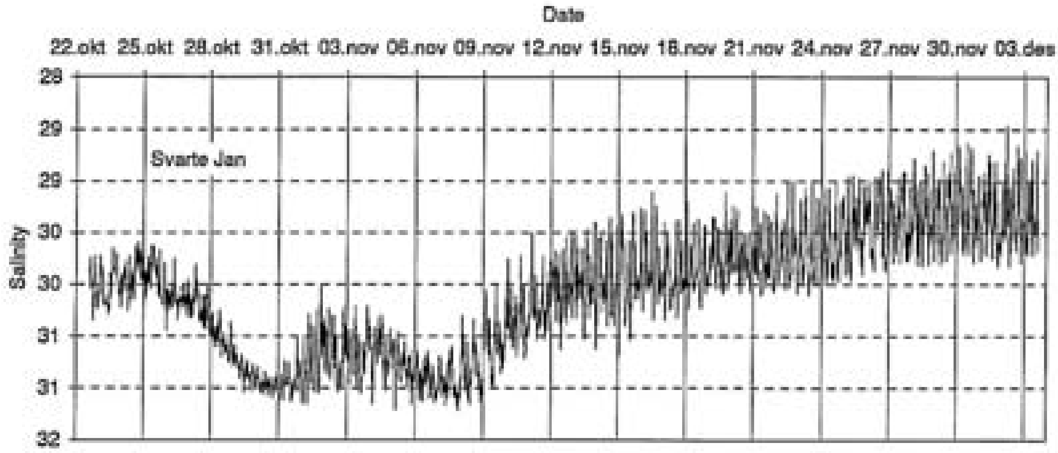

Figure 43. Salinity at 18 m depth at Svarte Jan (station H).

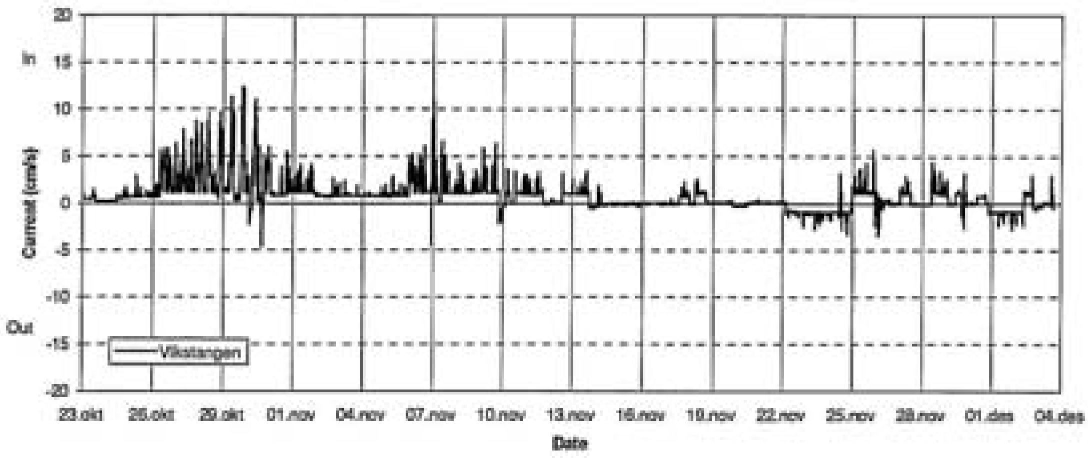

Figure 44. Current (in/out) at 40 m depth, Vikstangen (station I).

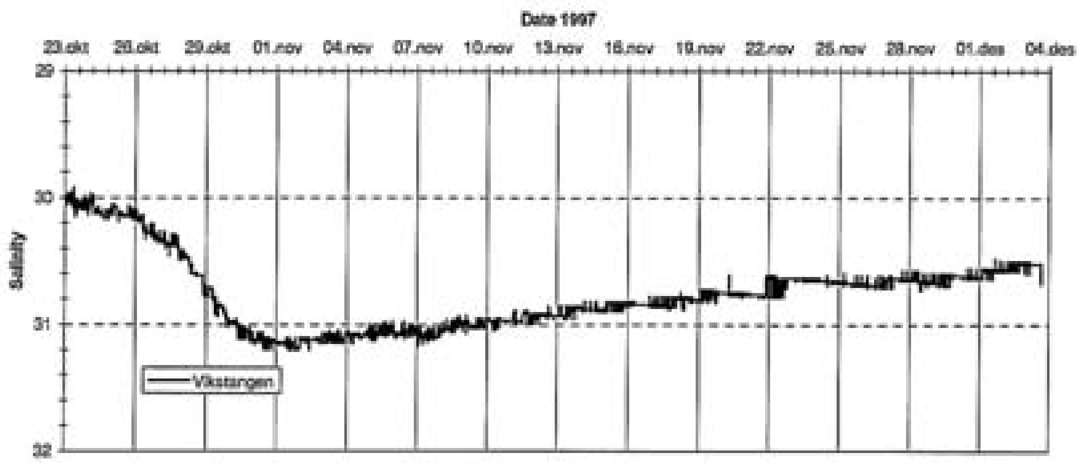

Figure 45. Salinity at 40 meters depth, Vikstangen (station I).

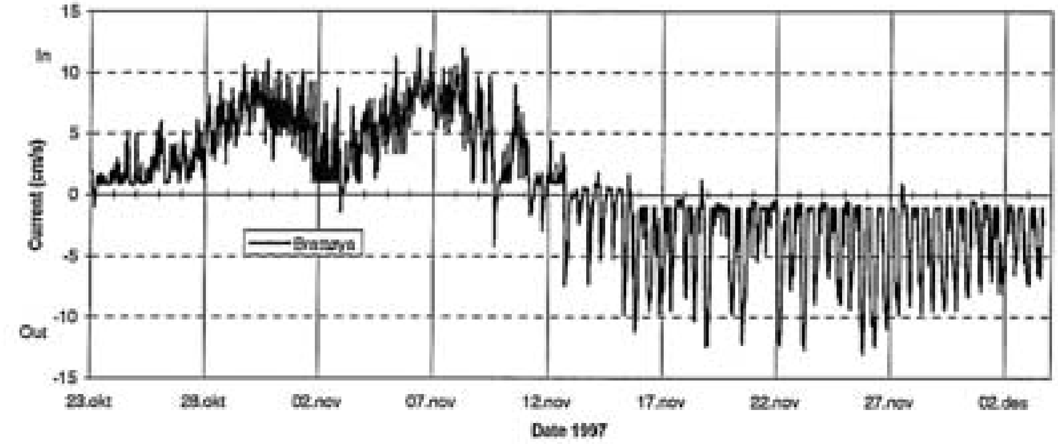

Figure 46. Current at 20 meters depth, Brattøya (station J).

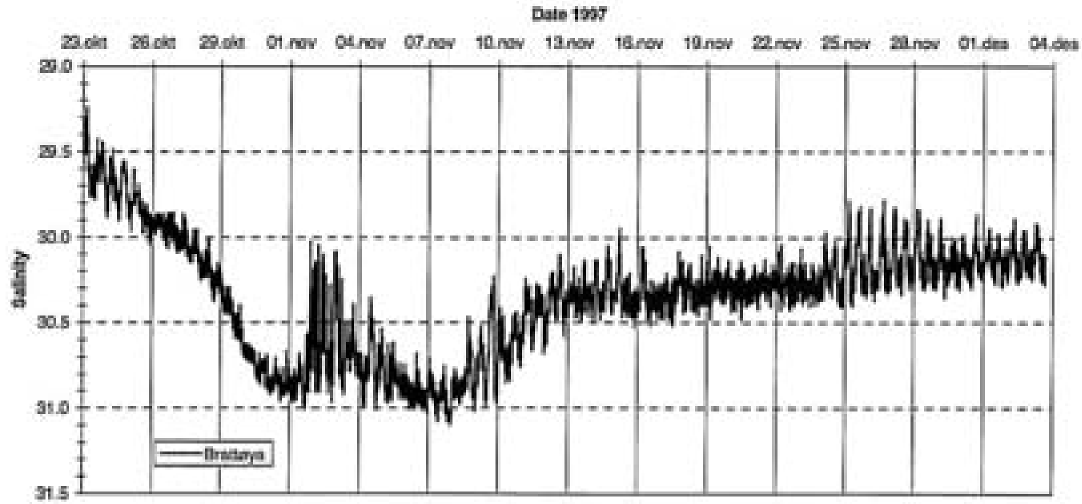

Figure 47. Salinity at 20 m depth, Brattøya (station J).

4. Overall conclusion

In technical terms the field studies were a success. With few exceptions the instruments functioned properly, and the malfunctions should be eliminated through better pre-use checking and better deployment procedures.

A thorough study of the data has not been performed, but the general impression is that the field studies have produced the kind of data sets, which are needed for further analyses, and development of the model. Furthermore, the data seems to contain new knowledge of hydrophysical processes in fjords in southern Norway. This element will be looked into in 1999.

5. Literature

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