Deer Island Dye Plume Tracking Survey Report

by

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TABLE OF CONTENTS

List of Figures

List of Tables

1.0 INTRODUCTION

1.1 Background/Objectives

Contractors working for the Massachusetts Water Resources Authority (MWRA) are in the process of repairing the outfall piping system. During these repairs the outfall flow was diverted through Outfall 005 which is located on the Boston Harbor side of Deer Island (42°20'55"N Latitude by 70°57'41"W Longitude) (See Figure 1). This diversion provided an opportunity to obtain information on the dynamics of the sewage discharge within Boston Harbor. The objective of this study was to conduct a high-resolution field monitoring program to obtain direct observations of the nearfield transport of sewage discharged from the Deer Island outfall 005 into Boston Harbor, using the Battelle Ocean Sampling System (BOSS) to delineate the plume.

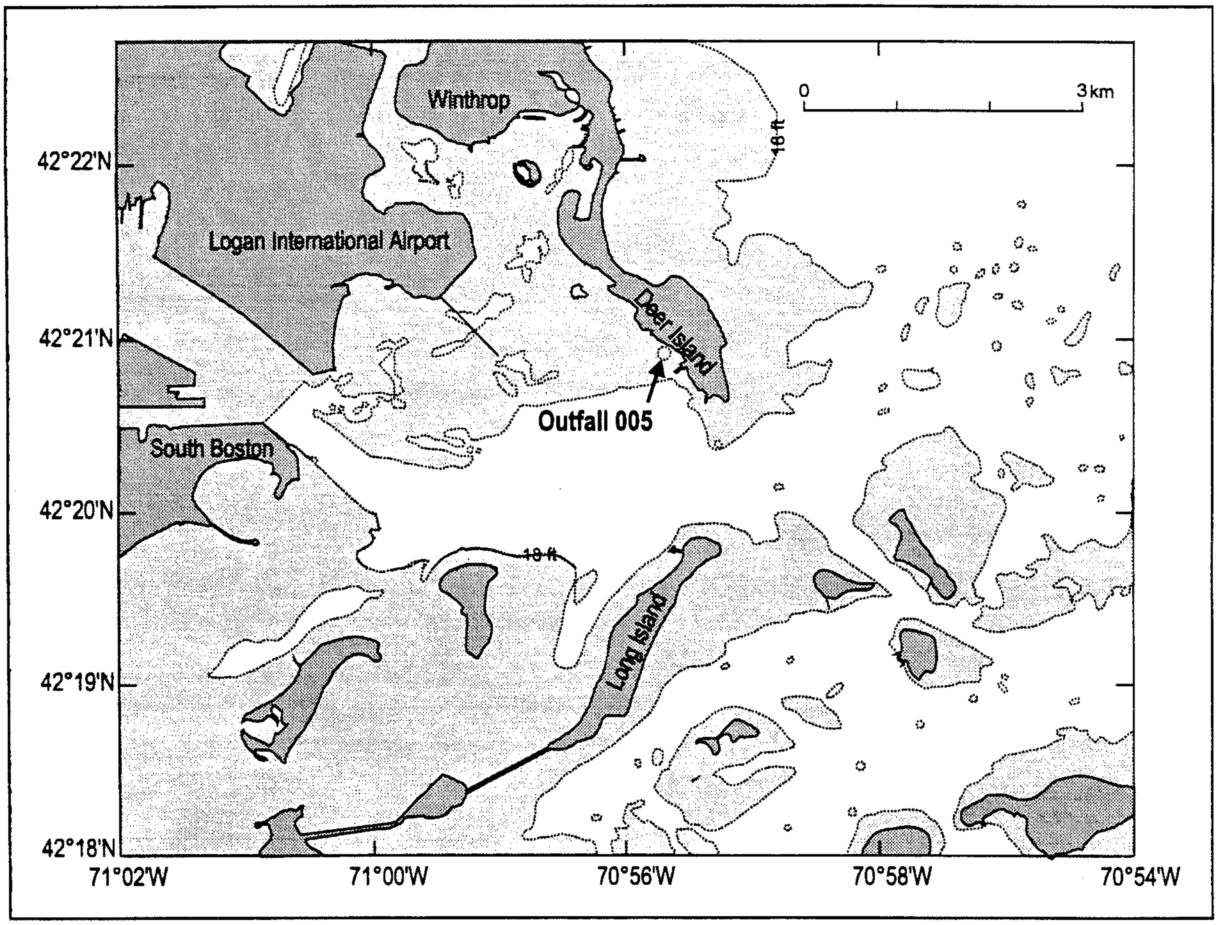


Figure 1. Location of MWRA Effluent Outfall 005 in Boston Harbor

The data obtained from this study will be used by MIT to validate a numeric transport model of the sewage discharge from outfall 005.

1.2 Vessel Operation

The R/V *Una Mas*, owned and operated by TG&B, served as an platform for towing the Battelle Ocean Sampling System during the survey. Mr. Mark Avakian served as captain.

1.3 Personnel

The scientific personnel who participated in the survey are listed in table 1.

Table 1. Scientific Personnel

Name	Organization	Responsibility
Carl Albro	Battelle	Chief Scientist
Jack Bechtold	Battelle	Electronic Technician
Ken Keay	MWRA	Task Manager/Dye Injector
Eric Adams	MIT	Modeler

2.0 METHODS

The CW/QAPP for Deer Island Dye Plume Tracking Study (Albro, 1994) contains details on the survey/sampling methods. Relevant summary information is presented below.

2.1 Field Procedures

Battelle conducted two days of plume tracking around the Deer Island Outfall 005 and Boston Harbor on February 16-17, 1994. The tracking was conducted during daylight hours. Depending on conditions and requirements of MIT's lead modeler, the BOSS was (1) oscillated between 0.5 m below the surface to within 2-3 m of bottom at a speed of 3-4 knots, or (2) towed within 0.5 meter of the surface on a series of horizontal tows. In the latter mode, a rapid vertical profile was conducted approximately every 1000 m while under way. The BOSS *in situ* sensor suite included depth, temperature, conductivity (salinity), dissolved oxygen, and transmissometry. In addition, an *in situ* fluorometer was configured for Rhodamine. The fluorometer was calibrated using Rhodamine in Boston Harbor seawater. During the tow-yo operations, water samples for analysis of bacteria were obtained with bottles provided by MWRA, but the samples were not analyzed due to holding time issues.

2.2 Data Analyses

Calibrating the fluorometer for Rhodamine dye was a two-staged operation. The first stage was to obtain fluorometer readings with varying concentrations of dye in Boston Harbor water. The second stage was to determine whether or not turbidity could cause a false positive dye reading, and if so, to quantify the effect.

To determine the relationship between fluorometer readings and dye concentration, a test tank holding 15 L of Boston Harbor water was prepared. The voltage readings from the fluorometer and transmissometer were obtained. A stock solution of Rhodamine WT dye was prepared by adding 50 μL of a 20% dye stock to 1.0 L of Boston Harbor seawater which resulted in a dye concentration of 10,000 μg/L. Known small volumes of this mixture was added to the water in the test tank giving a dye concentration based on the following:

$$\text{Dye Concentration} = \frac{10000\ \mu g/L * \text{Total Dye Mixture Volume Added}}{\text{Initial Tank Volume+Total Dye Mixture Volume Added}}$$

After each interval of dye addition, the tank was mixed thoroughly and the fluorometer voltage reading recorded. The experimental concentration ranged from 0.013 μg/L to 79.365 μg/L. Transmissometer-meter readings were obtained several times during the experiment. Table 2 shows results of the Rhodamine calibration experiment.

Table 2. Results of Rhodamine Calibration Experiment

Total Dye Volume add to 15 L (L)	Dye Volume added (L)	True Dye Concentration (ug/L)	Transmisso-meter Reading (volts)	Transmisso-meter Value (1/m)	Effect on Fluoro-meter	Fluoro-meter Reading (Volts)	10^v	Corrected Fluorometer Reading	Predicted Concentration (ug/L)
.000000	0.00000	0.000	3.434	1.502	6.7	1.02	10.5	3.8	0.036
0.000020	0.00002	0.013				1.06	11.5	4.8	0.046
0.000040	0.00002	0.027				1.06	11.5	4.8	0.046
0.000080	0.00004	0.053				1.16	14.5	7.8	0.074
0.000150	0.00007	0.100				1.31	20.4	13.8	0.130
0.000300	0.00015	0.200				1.48	30.2	23.5	0.222
0.000450	0.00015	0.300				1.61	39.8	33.1	0.313
0.000600	0.00015	0.400				1.71	51.3	44.6	0.422
0.000750	0.00015	0.500				1.79	61.7	55.0	0.520
0.000900	0.00015	0.600				1.86	72.4	65.8	0.622
0.001200	0.00030	0.800				1.98	95.5	88.8	0.840
0.001500	0.00030	1.000				2.09	123.0	116.4	1.100
0.002000	0.00050	1.333				2.19	154.9	148.2	1.401
0.002500	0.00050	1.666				2.33	213.8	207.1	1.958
0.003000	0.00050	2.000				2.42	263.0	256.4	2.423
0.004500	0.00150	2.999				2.57	371.5	364.9	3.448
0.006000	0.00150	3.998	3.293	1.670	7.5	2.68	478.6	471.1	4.453
0.007500	0.00150	4.998				2.78	602.6	595.1	5.624
0.009000	0.00150	5.996				2.85	707.9	700.5	6.620
0.010500	0.00150	6.995				2.9	794.3	786.8	7.436
0.012000	0.00150	7.994				2.96	912.0	904.5	8.548
0.013500	0.00150	8.992				3.00	1000.0	992.5	9.380
0.015000	0.00150	9.990	3.27	1.698	7.6	3.05	1122.0	1114.4	10.532
0.030000	0.01500	19.960				3.35	2238.7	2231.1	21.086
0.060000	0.03000	39.841	3.26	1.710	7.7	3.63	4265.8	4258.1	40.242
0.090000	0.03000	59.642				3.80	6309.6	6301.9	59.557
0.120000	0.03000	79.365	3.23	1.747	7.9	3.92	8317.6	8309.8	78.533

The BOSS underwater unit was towed in and out of the sewage discharge plume several times before the dye was injected into the effluent. This was done to determine the relationship of fluorometer readings to turbidity (Figure 2). An equation relating the fluorometer reading to beam attenuation was determined using linear regression. This relationship is:

$F_t = A_{ba} + B_{ba}$ * Beam Attenuation Reading
where A_{ba} and B_{ba} are constants determined by linear regression, and
F_t is fluorometer reading due to turbidity

Table 3 shows the regression results for beam attenuation effect on dye reading. The turbidity was found to effect Rhodamine signal at a ratio of 4.88 to 1.

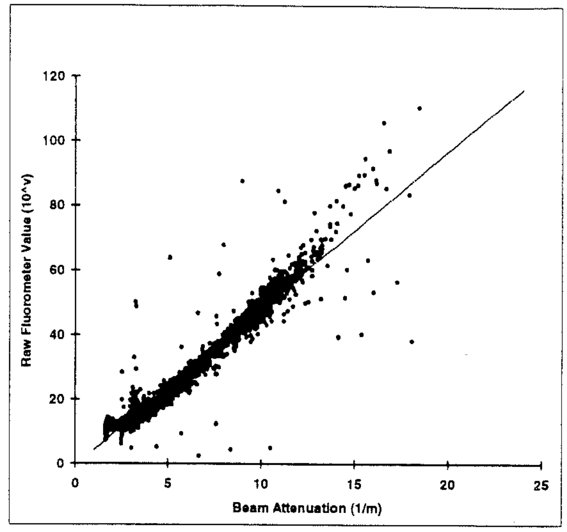


Figure 2. Beam attenuation versus fluorometer reading. Solid line is regression between these variables.

Table 3. Regression Results for Beam Attenuation Effect on Dye Reading

Regression Statistics						
Multiple R	0.9654					
R Square	0.9320					
Adjusted R Square	0.9320					
Standard Error	4.4338					
Observations	2472					
	Analysis of Variance					
	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*	
Regression	1	665359.44	665359.44	33846.20	0	
Residual	2470	48556.06	19.6583			
Total	2471	713915.50				
	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
A_{ba}	-0.6659	0.1793	-3.7140	0.000209	-1.0175	-0.3143
Slope (B_{ba})	4.8775	0.0265	183.9734	0	4.8255	4.9295

Based on the beam attenuation effect, the fluorometer readings from the dye experiment were corrected for turbidity interference. These corrected fluorometer readings were compared to the true dye concentration to develop an equation that related the dye concentrations to be fluorometer and transmissometer readings. The equation was determined using the linear regression function in Excel® spreadsheet program:

Dye Concentration = $B_f * (F_u - F_t)$

where F_u is uncorrected fluorometer reading

B_f is a constant determined by linear regression using dye concentration versus turbidity corrected fluorometry.

Table 4 shows the regression results from Rhodamine dye calibration.

Table 4. Regression Results from Rhodomine Dye Calibration

Regression Statistics						
Multiple R	0.9997					
R Square	0.9995					
Adjusted R Square	0.9611					
Standard Error	0.4182					
Observations	27					
	Analysis of Variance					
	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*	
Regression	1	9728.5113	9728.51	55603.95	2.27E-43	
Residual	26	4.54898	0.1749608			
Total	27	9733.0602				
	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Slope (B_f)	0.0094507	3.5749E-05	264.3632	1.27E-47	0.00938	0.00952

Following the survey, all raw *in situ* instrument measurement data was transformed into engineering units. This transformation involved several operations using the BOSS software. The direct conversion of raw data to engineering data involved the use of calibration coefficients as described in Section 14 of the CW/QAPP for Deer Island Dye Plume Tracking Study (Albro, 1994). To convert oxygen current and membrane temperature to DO, the method developed by Owens and Millard (1985) was used. To calculate salinity and density from conductivity, temperature, and pressure, the algorithms developed by Fofonoff and Millard (1983) was used. To determine the percent saturation of oxygen, the calculated DO was divided by the solubility of oxygen based on an algorithm developed by Weiss (1970). Each parameter was plotted in high-resolution *xy* graphic form for visual inspection of data quality by an oceanographer to determine the representativeness of the data. The vessel position was plotted on map form. These plots are stored in physical oceanography group files, under the supervision of Mr. Albro, to allow inspection by QA staff or MWRA staff. The final plots and maps are shown in the appendix.

3.0 SURVEY SUMMARY

The survey was conducted February 16 and 17, 1994. A summary of the survey operations is given below.
Note: All times are Eastern Standard Time

Tuesday, February 15

1500: Arrived at Norwood Marine to launch the boat, but due to thick ice was not able to launch. We determined that we could launch at Cashman Marine in East Boston, but it was too late to launch on Tuesday.

Wednesday, February 16

0730: Launched the boat at Cashman Marine.

0905: Conducted navigation calibration and depth offset of OS100 CTD.

0930: Boat engine was running hot. Upon inspection, the cooling pump impeller was damaged from ice.

1200: Boat repairs completed and Eric Adams of MIT arrived.

1212: Depart dock for Deer Island Flats.

1249: Started BOSS towing operations around Outfall 005 to obtain background information before dye tracking operations.

1400: Ken Keay of MWRA started dye injection through grating in effluent conduit near diffuser #6. Estimated flow rate of the dye was in the 250 to 360 mL/min range.

1416: Observed dye in the discharge and started dye tracking operations.

1507: High tide at Deer Island Light.

1600: Dye injection stopped.

1743: Stopped tracking operations. Figure 3 shows the tracklines during the day.

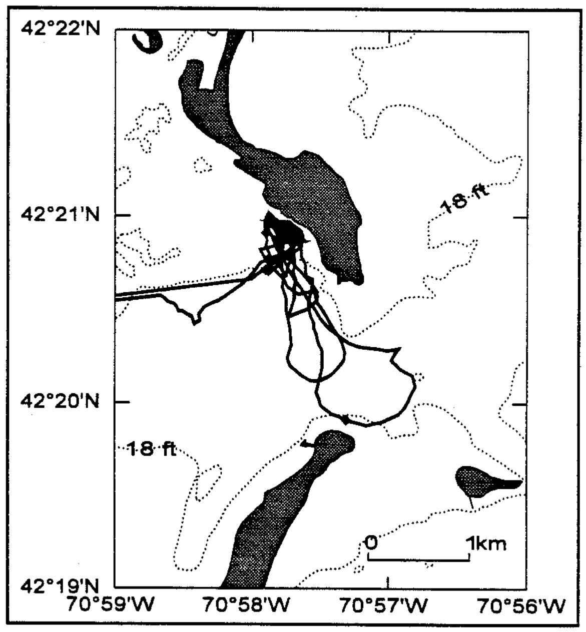


Figure 3. Vessel Tracklines on February 16, 1994.

Thursday, February 17

0825: Arrived at Cashman Marine dock, conducted navigation calibration, and left for Long Island to conduct bay wide towing operations (Figure 4).

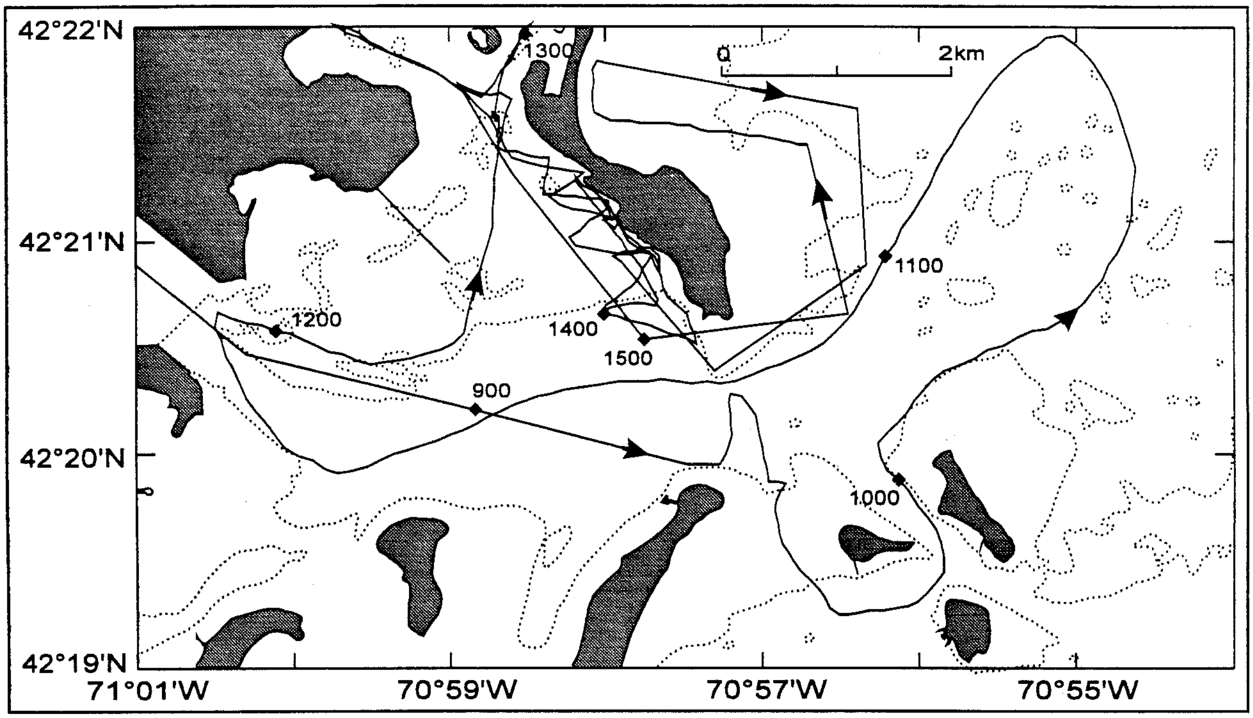


Figure 4. Vessel Tracklines on February 17, 1994.

0903: Started towing operations.

0943: Low tide at Deer Island.

1218: Based on beam attenuation, we entered the outfall plume between Logan airport and Snake Island. The plume was tracked back to the outfall (see section 4.0 for contour maps of plume).

1504: At Ken Keay's request we conducted towing operations off Point Shirley beach on the Board Sound side.

1555: High tide at Deer Island.

1603: Resumed towing operations around Outfall 005.

1644: Stopped towing operations.

1710: Arrived at dock.

4.0 SURVEY RESULTS

Figures 5 - 8 shows contour plots of data obtained from 14:17 to 16:17 on February 16, 1994 in the upper 2 m of the water column. Figures 9 - 11 shows contour plots of data obtained from 12:11 to 14:41 on February 17, 1994 in the upper 2 m of the water column. Rhodamine plot for February 17, 1994 was not included due to low values (< 0.3 µg/L).

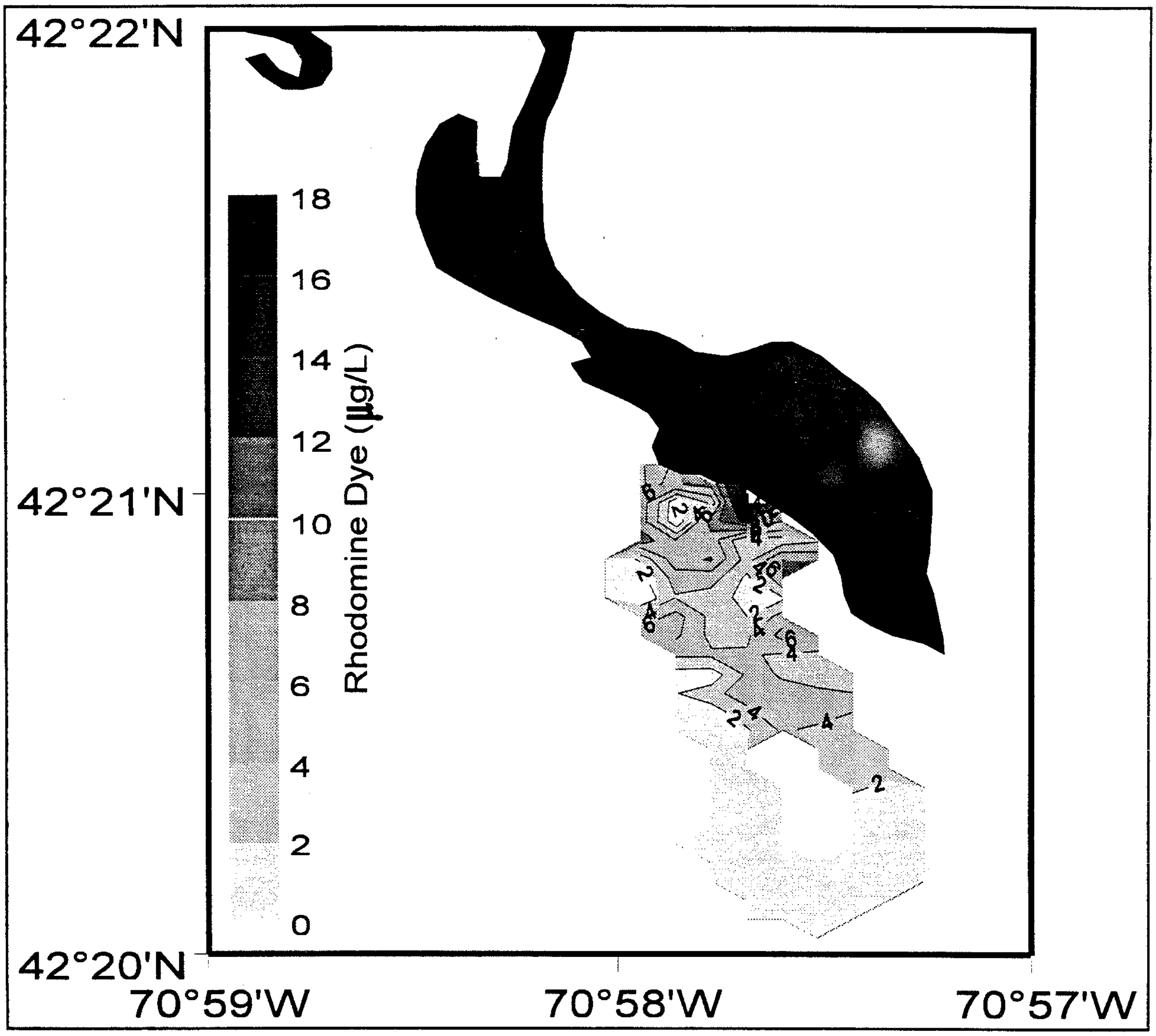


Figure 5. Rhodamine contour plot of data obtained in the upper 2 m of water column on February 16, 1994.

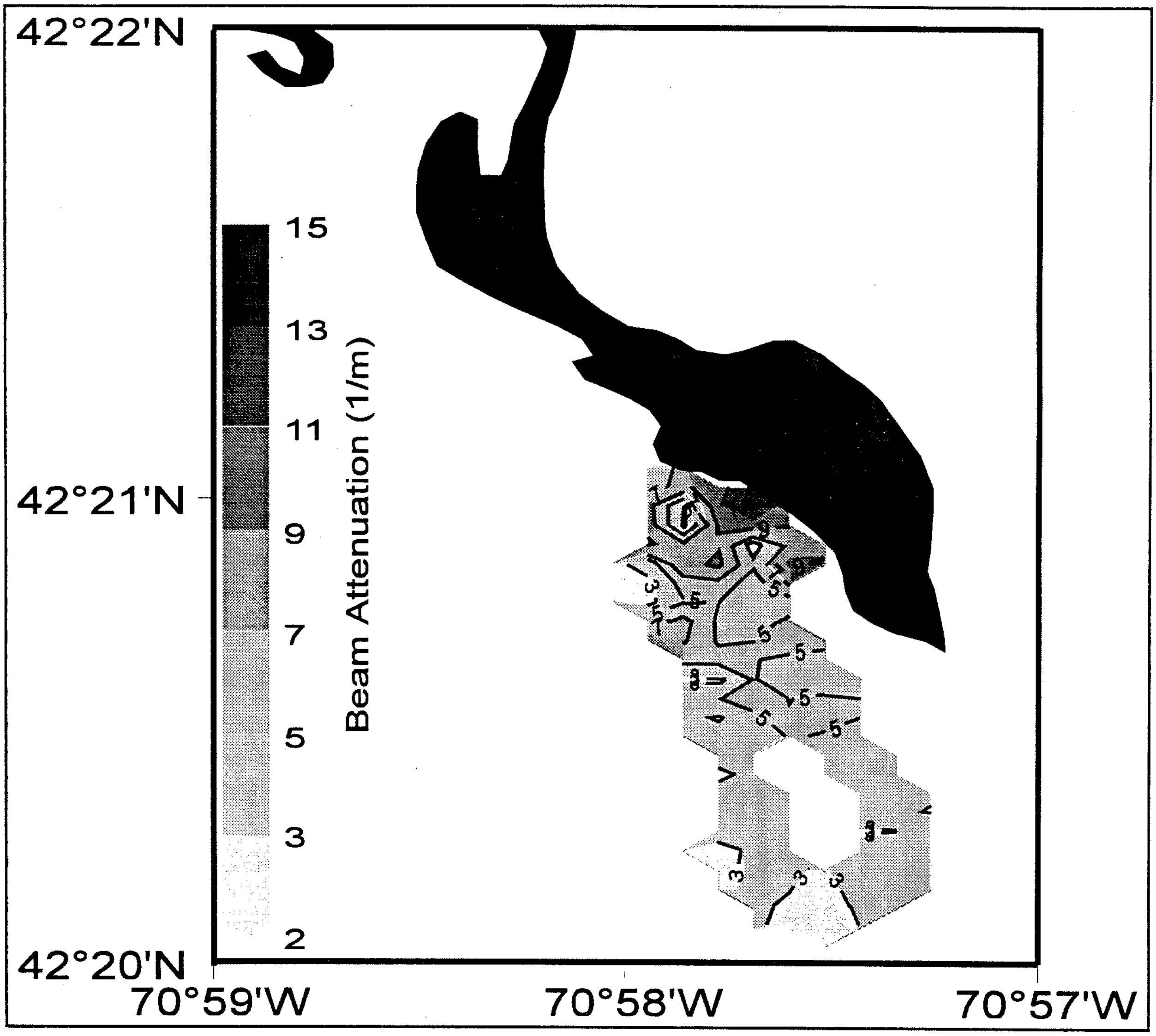


Figure 6. Beam attenuation contour plot of data obtained in the upper 2 m water column on February 16, 1994.

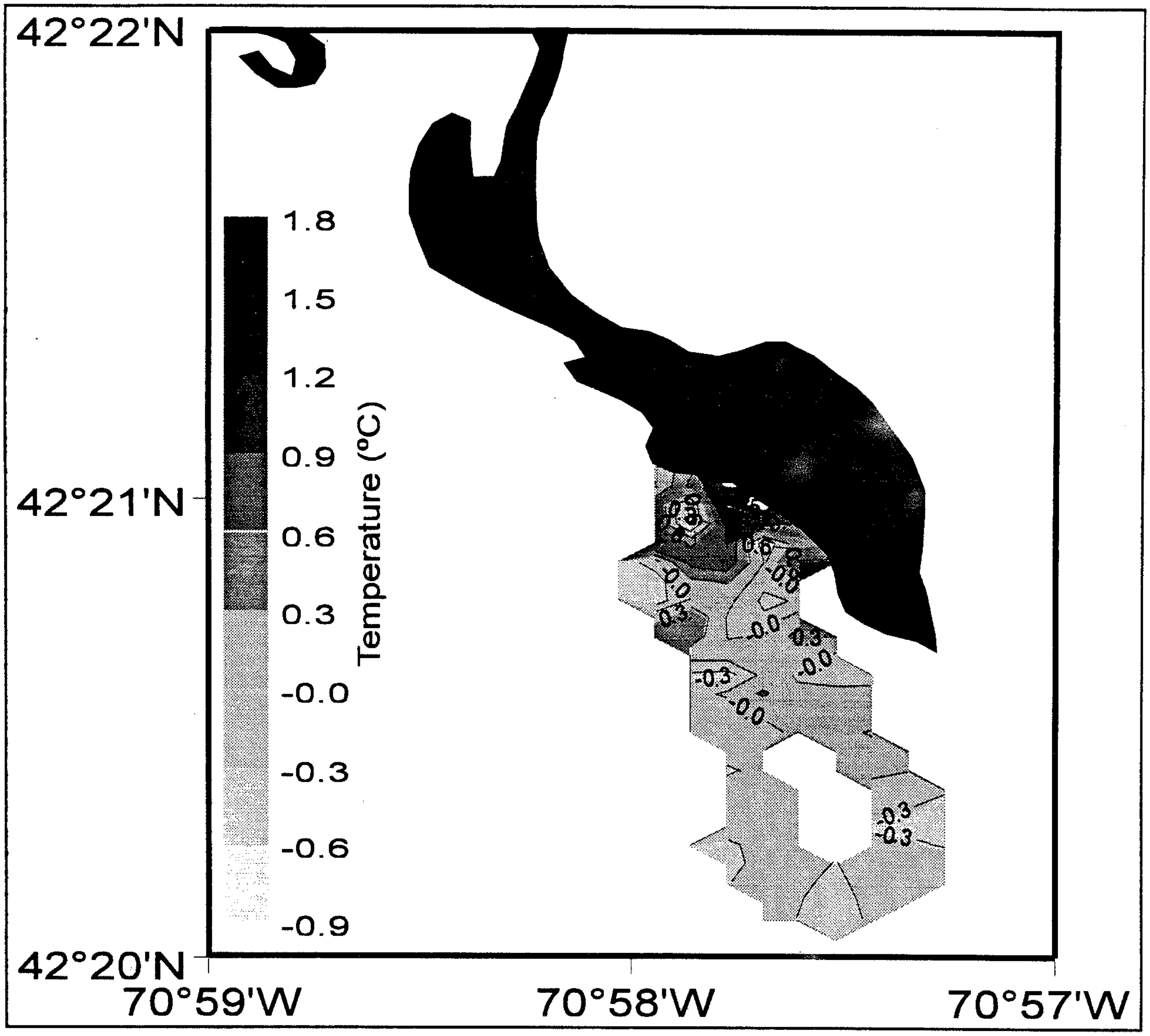


Figure 7. Temperature contour plot of data obtained in the upper 2 m water column on February 16, 1994.

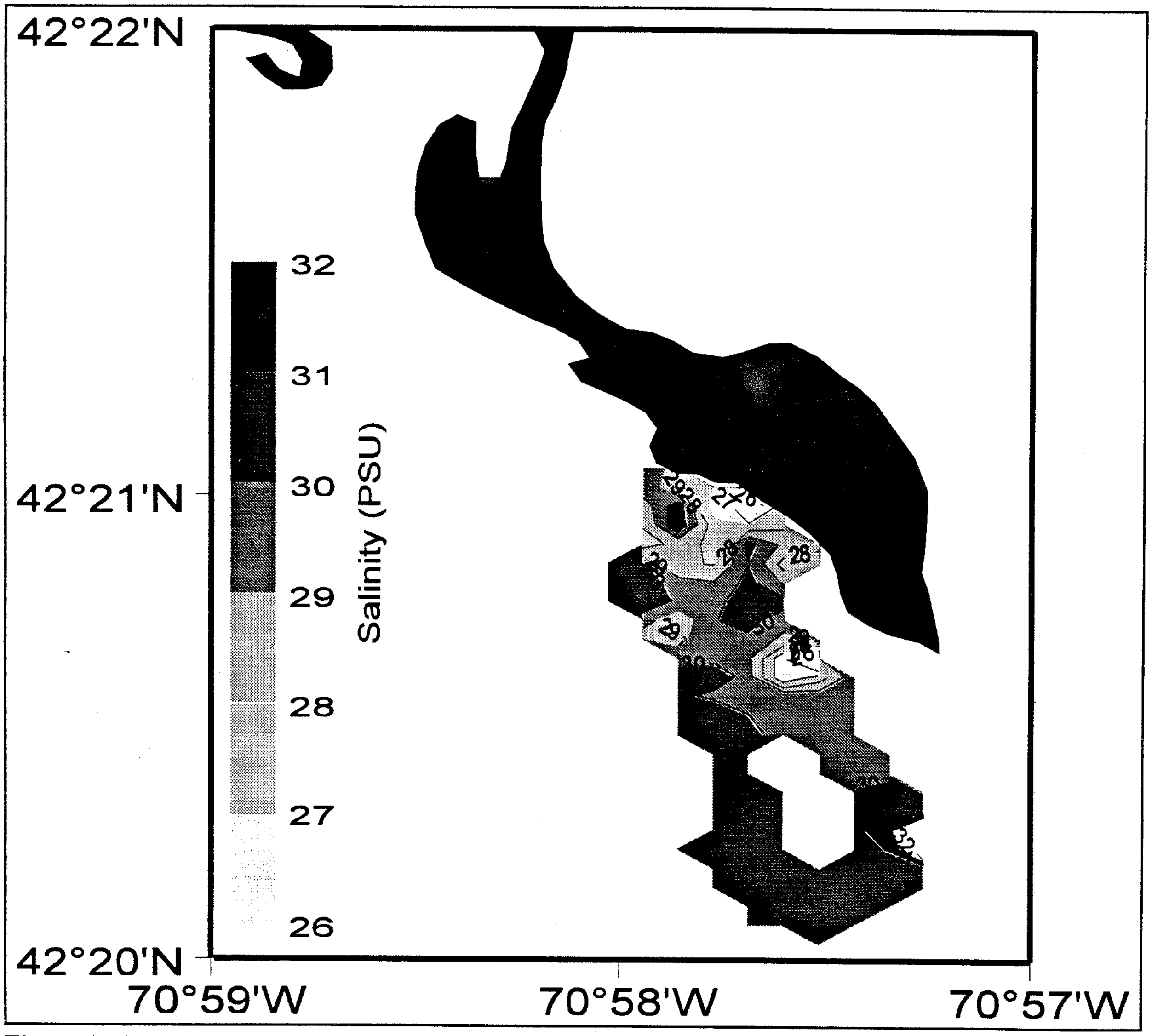


Figure 8. Salinity contour plot of data obtained in the upper 2 m of water column in February 16, 1994.

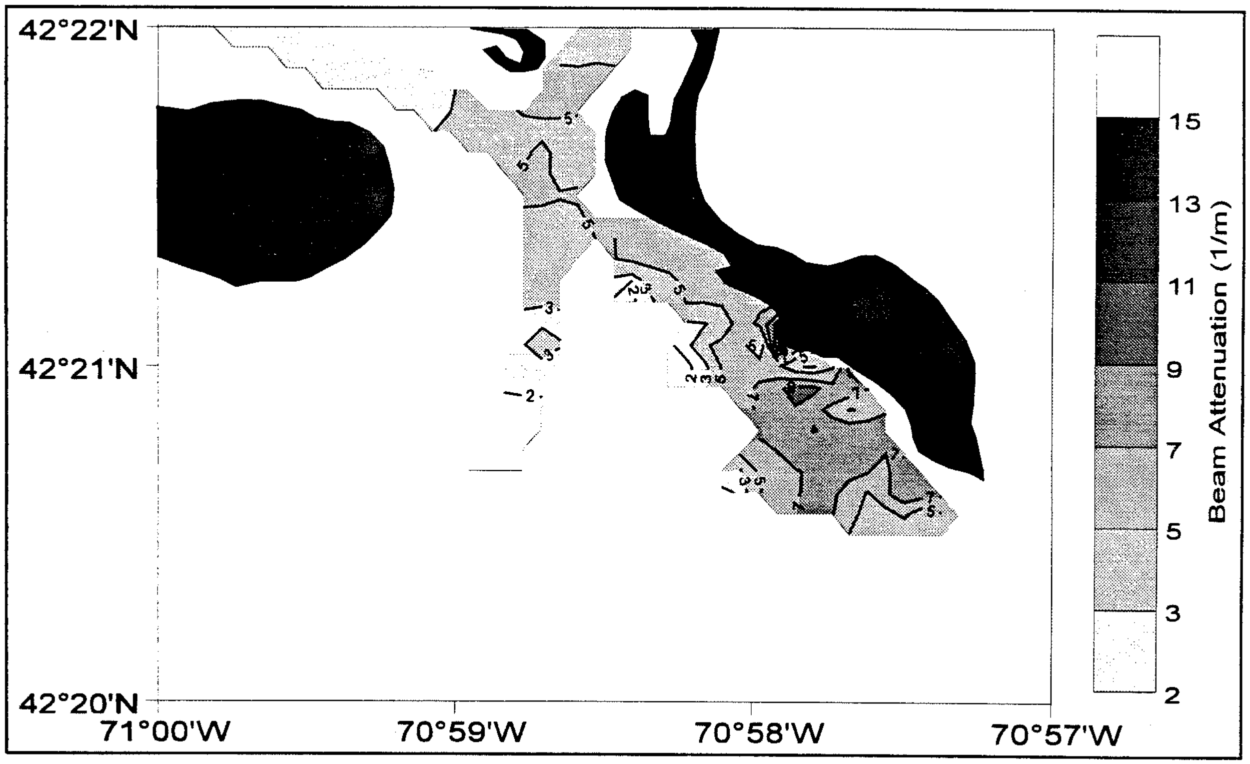


Figure 9. Beam attenuation contour plot of data obtained in the upper 2 m water column on February 17, 1994.

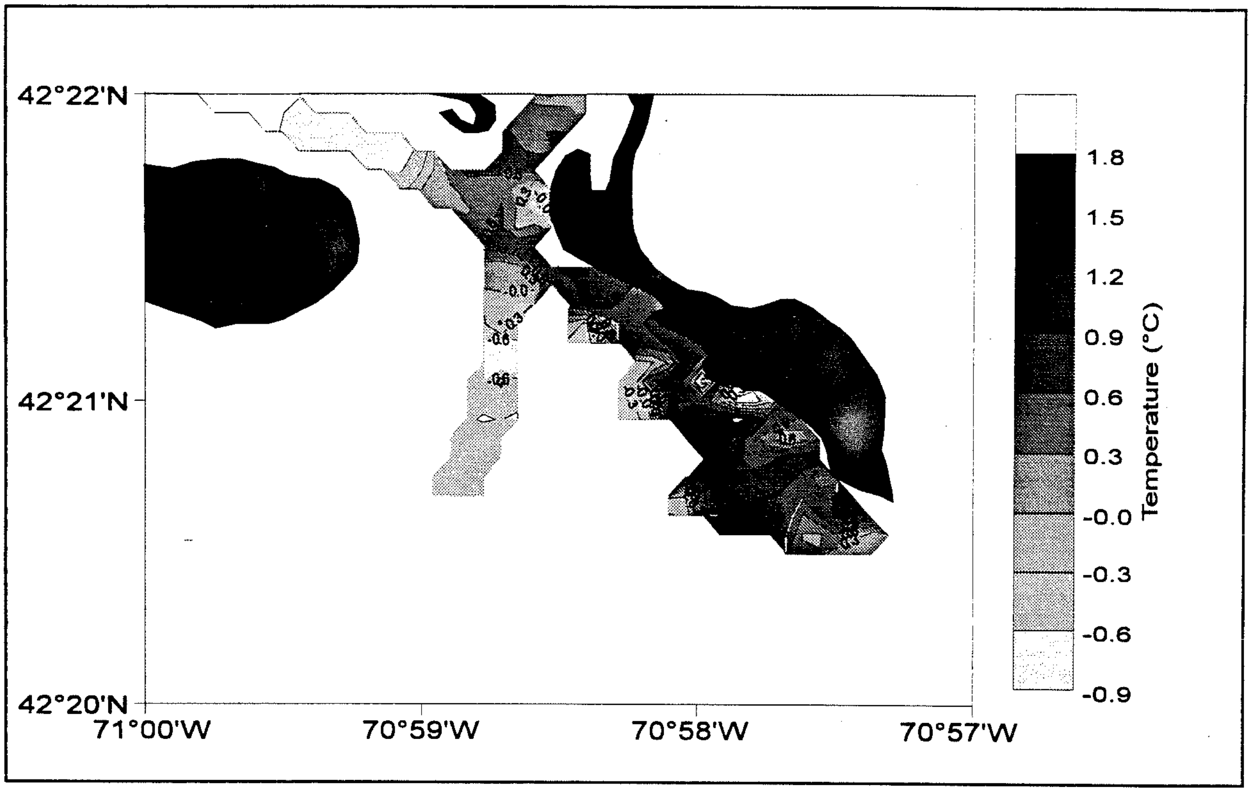


Figure 10. Temperature contour plot of data obtained in the upper 2 m water column on February 17, 1994.

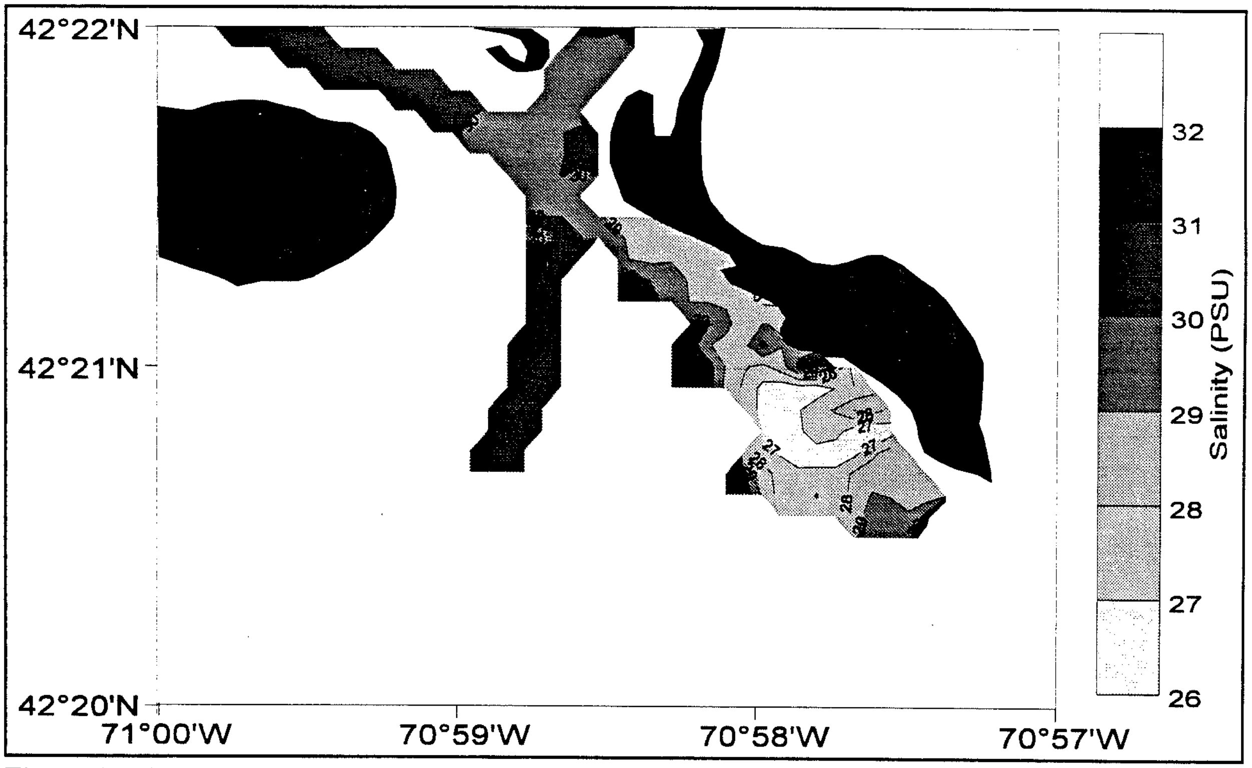


Figure 11. Salinity contour plot of data obtained in the upper 2 m of water column on February 17, 1994.

5.0 REFERENCES

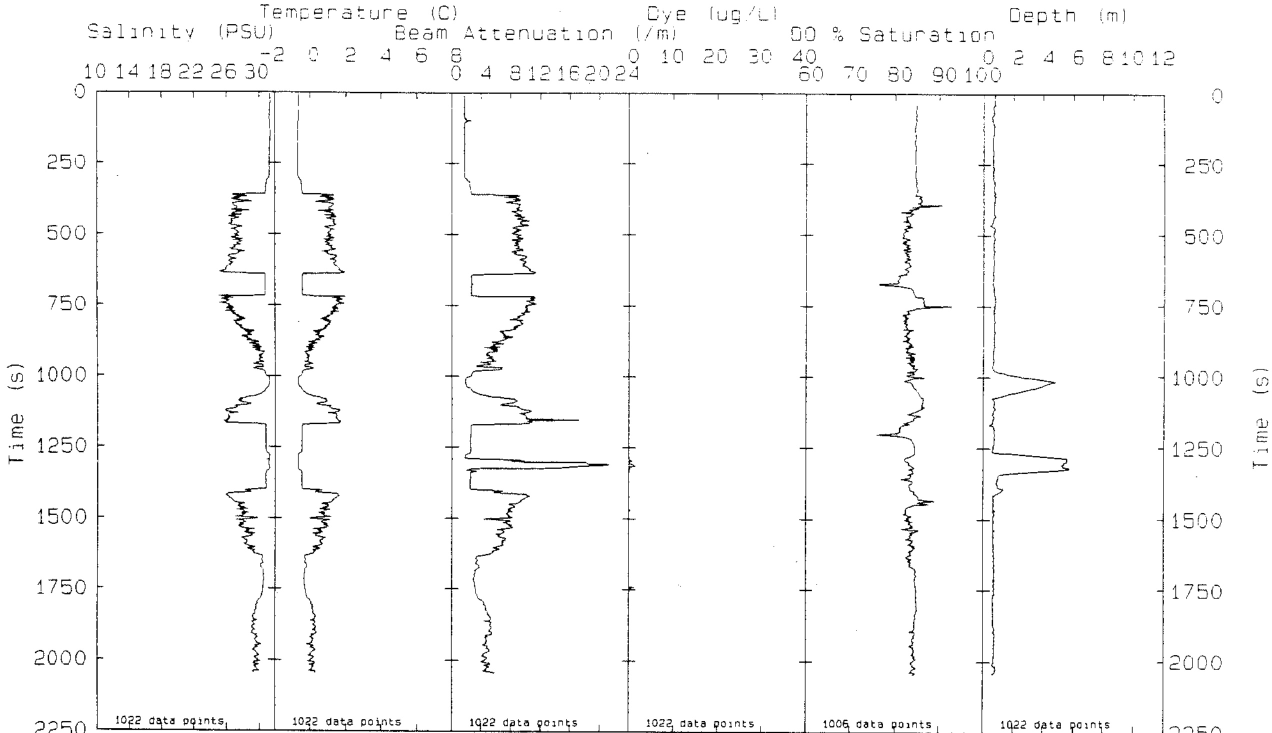
Fofonoff, N.P. and R.C. Millard, Jr. 1983. Algorithms for computation of fundamental properties of seawater. *UNESCO Technical Papers in Mar. Sci.* 44.

Albro, C. 1994. Combined Work/Quality Assurance Project Plan for Deer Island Dye Plume Tracking Study. Prepared for the Massachusetts Water Resources Authority, Boston, MA. 20 pp.

Owens, W.B. and R.C. Millard, Jr. 1985. A new algorithm for CTD oxygen calibration. *J. Phys. Oceanogr.* 15:621-631.

Weiss, R.F. 1970. The solubility of nitrogen, oxygen, and argon in water and seawater. *Deep-Sea Res.* 17:721-735.

Appendix - Graphic plots of data obtained on February 16-17, 1994.



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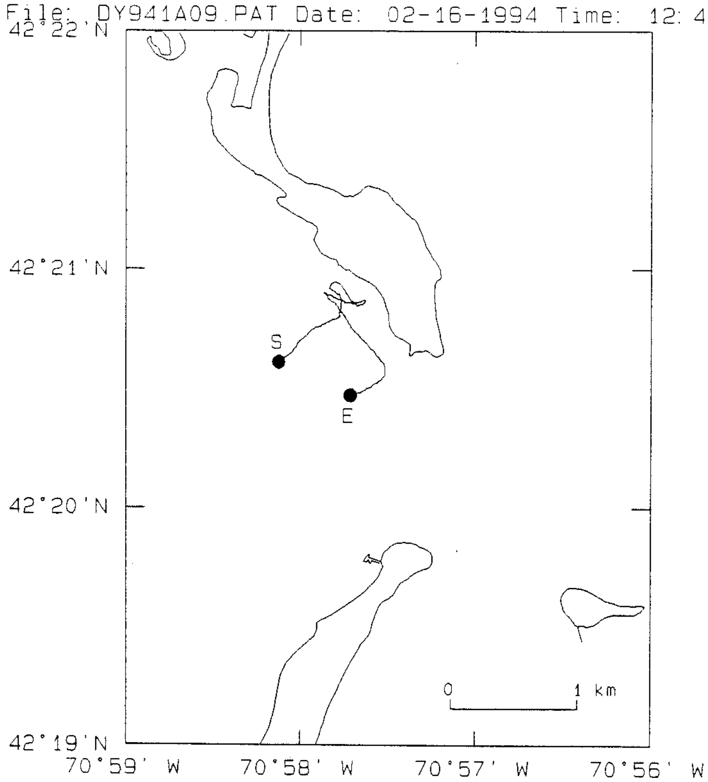
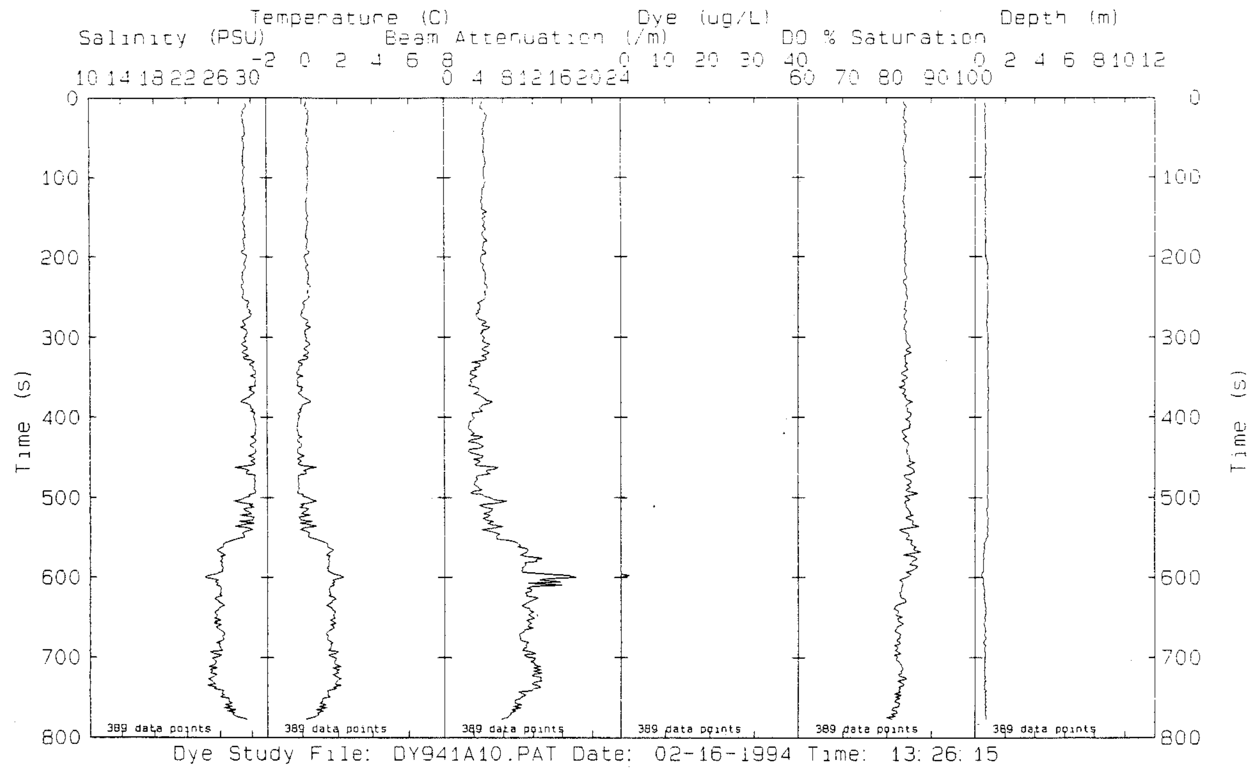


06-28-1994 15:40:56 Battelle



Temperature (C)
Salinity (PSU)
-2 0 2 4 6 8
10 14 18 22 26 30
Beam Attenuation (/m)
0 4 8 12 16 20 24
Dye (ug/L)
0 10 20 30 40
DO % Saturation
60 70 80 90 100
Depth (m)
0 2 4 6 8 10 12
Time (s)
0
100
200
300
400
500
600
700
800
389 data points
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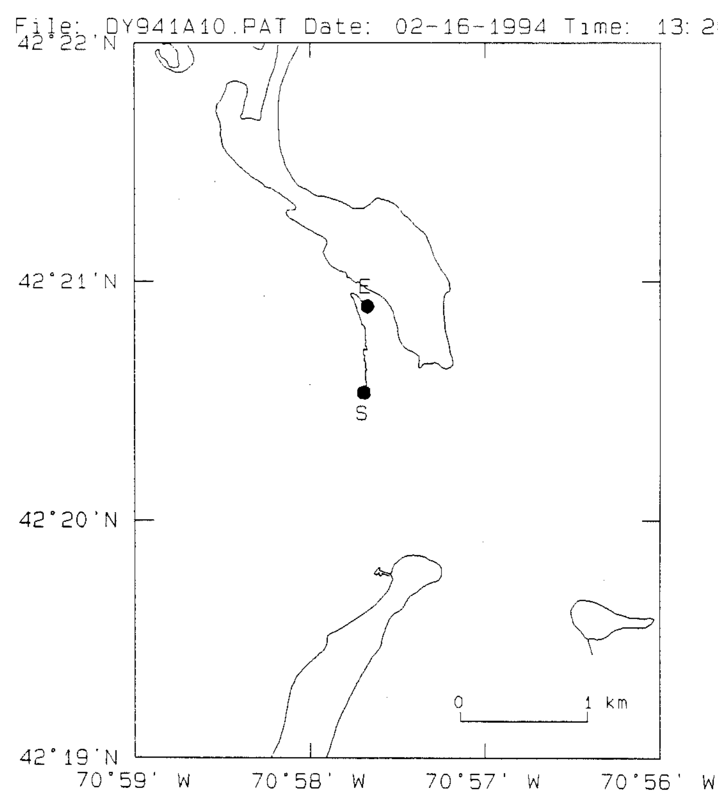

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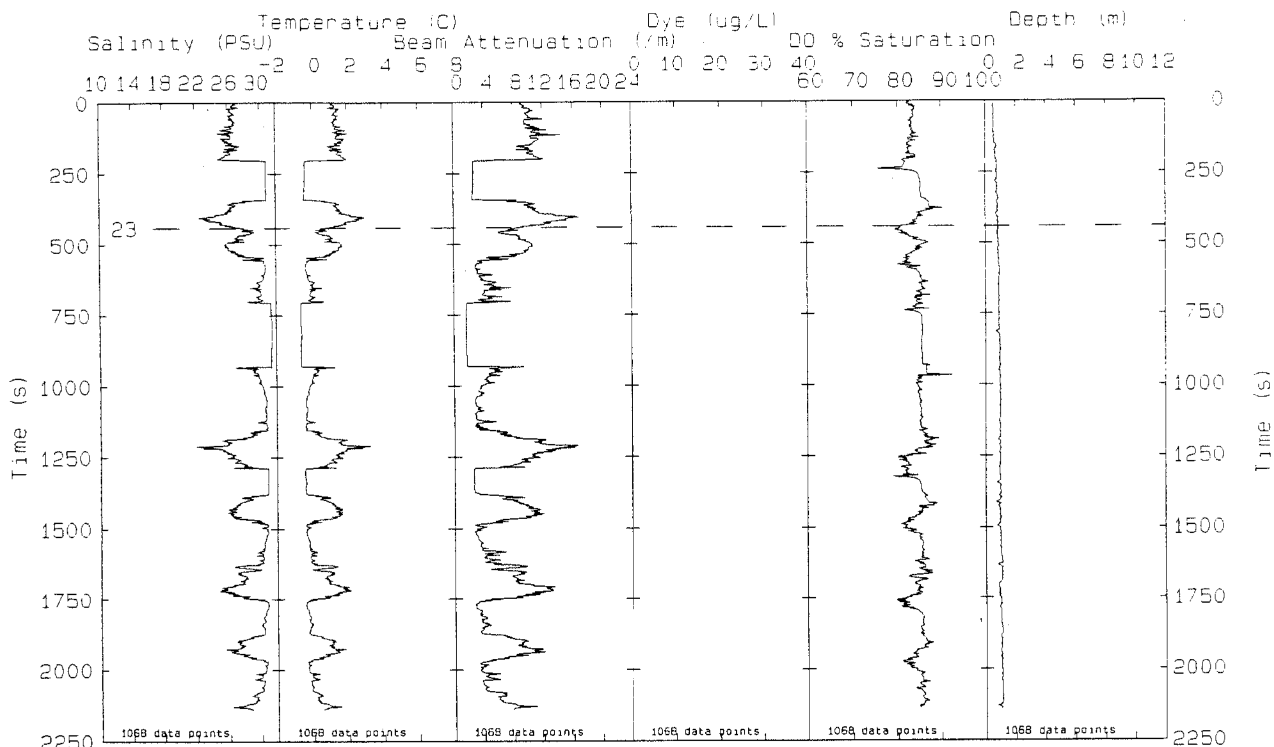
42°19'N
70°59' W
70°58' W
70°57' W
70°56' W
E
S
0
1 km



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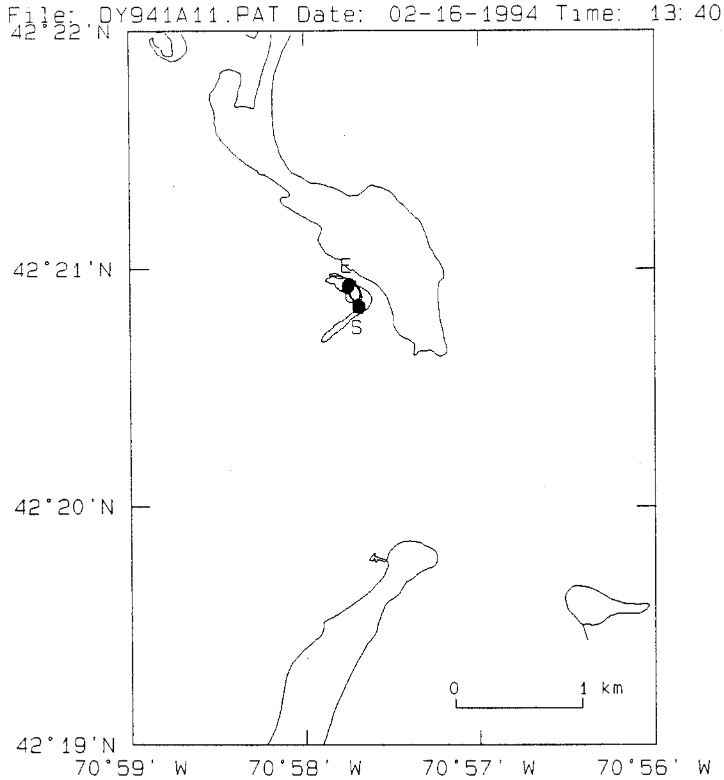

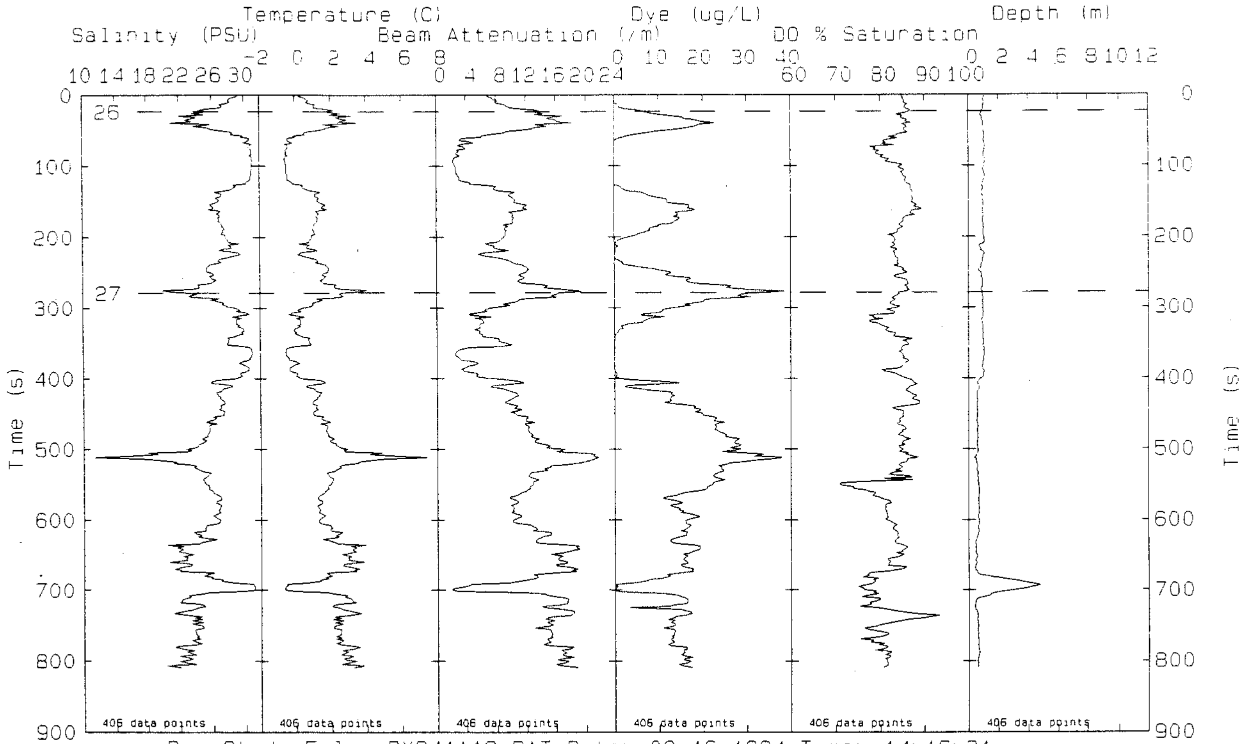

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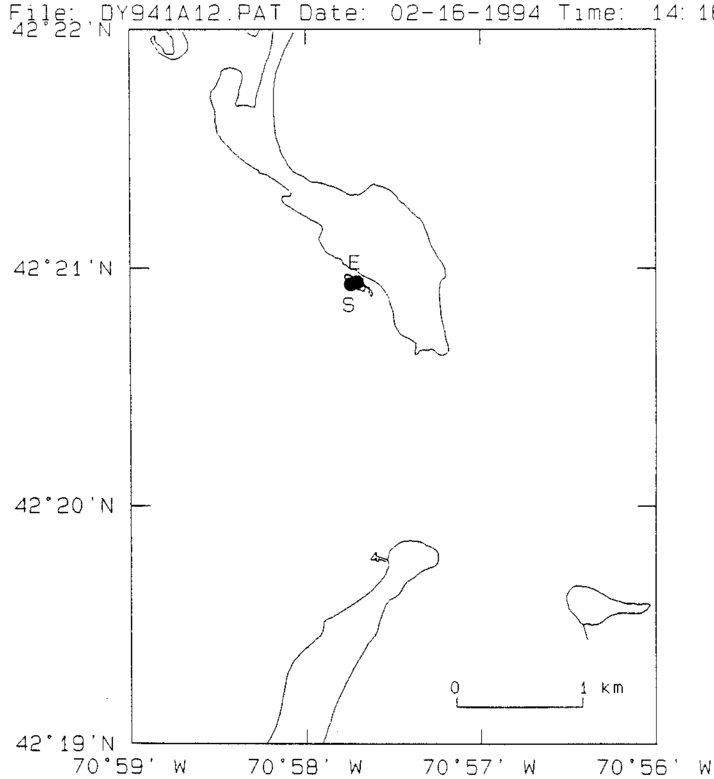

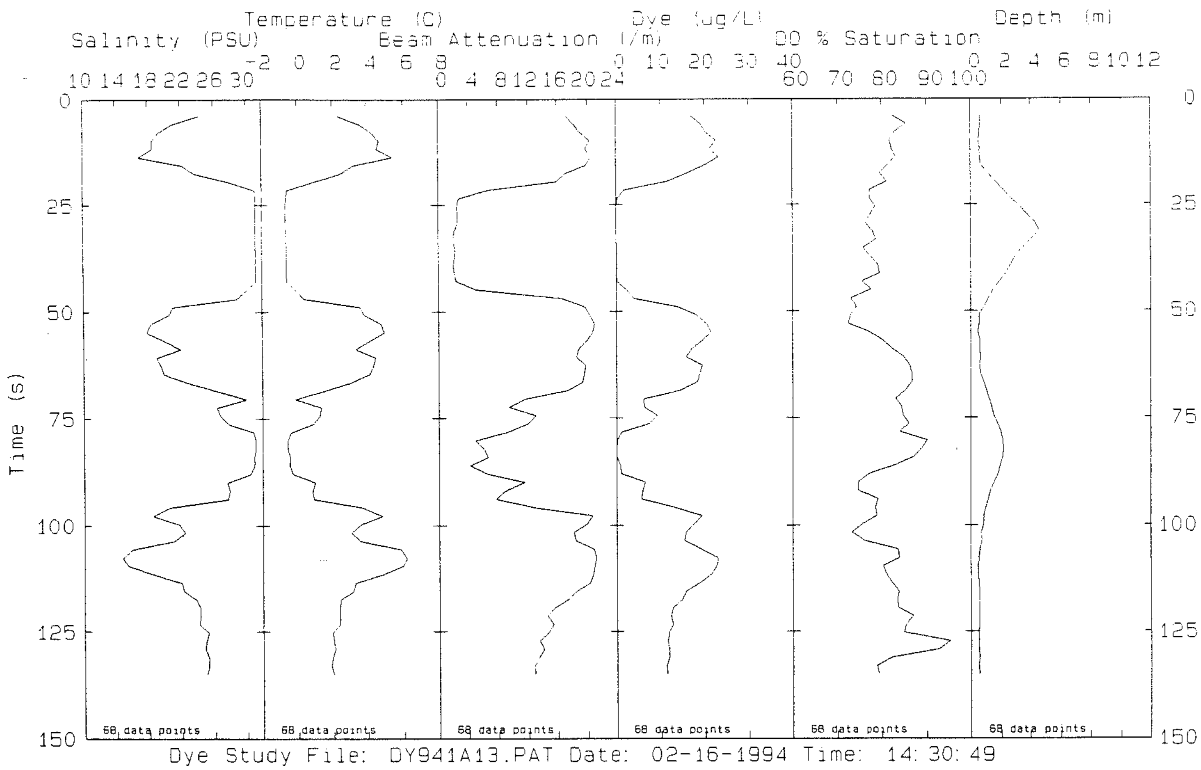
Temperature (C)
Salinity (PSU)
Beam Attenuation (/m)
Dye (ug/L)
DO % Saturation
Depth (m)
Time (s)
68 data points
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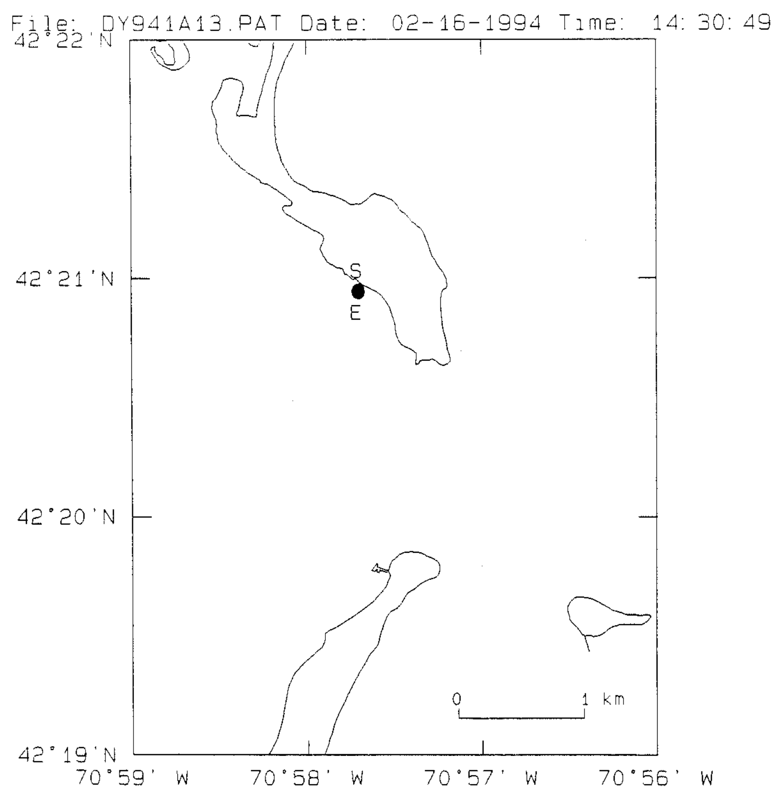
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42°20'N
42°19'N
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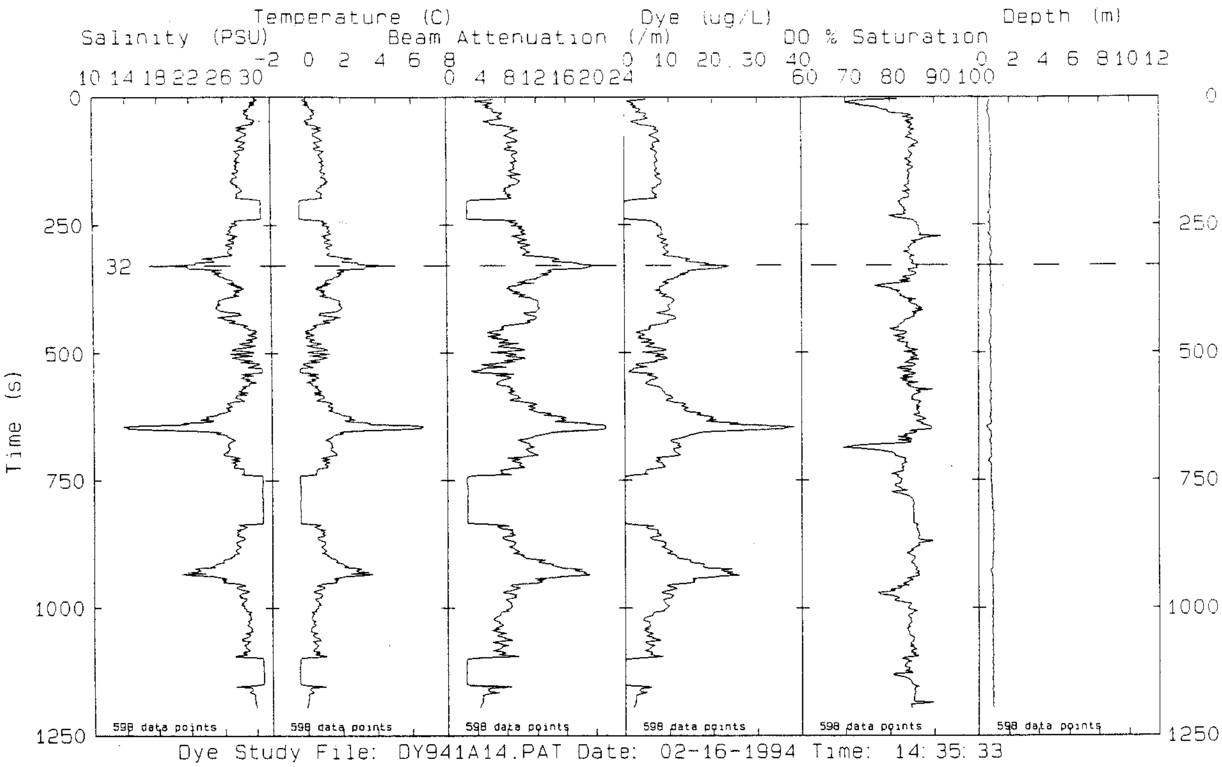
70°58' W
70°57' W
70°56' W
S
E
0
1 km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Dye (ug/L)
DO % Saturation
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Time (s)
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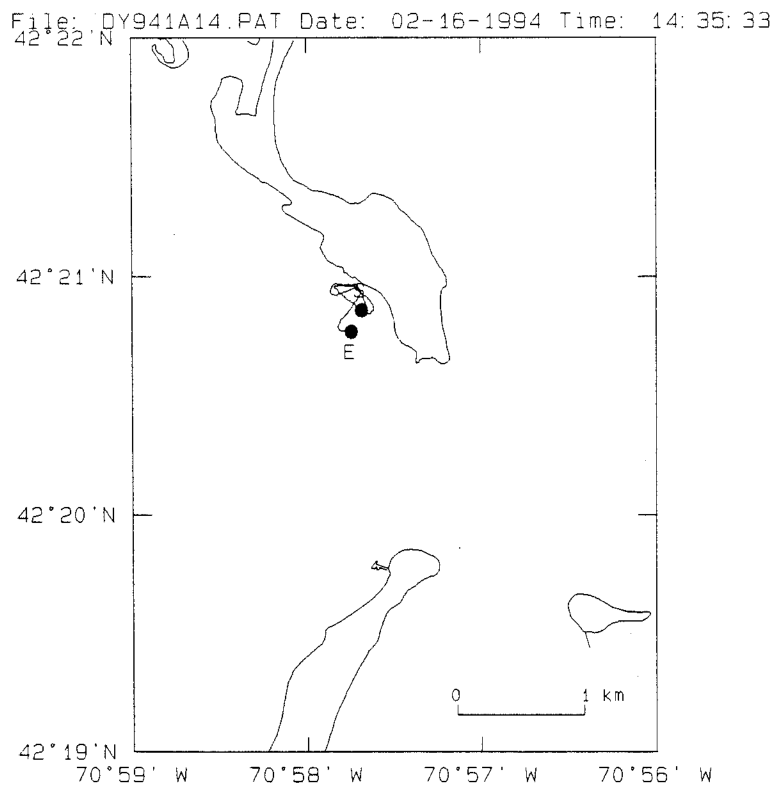
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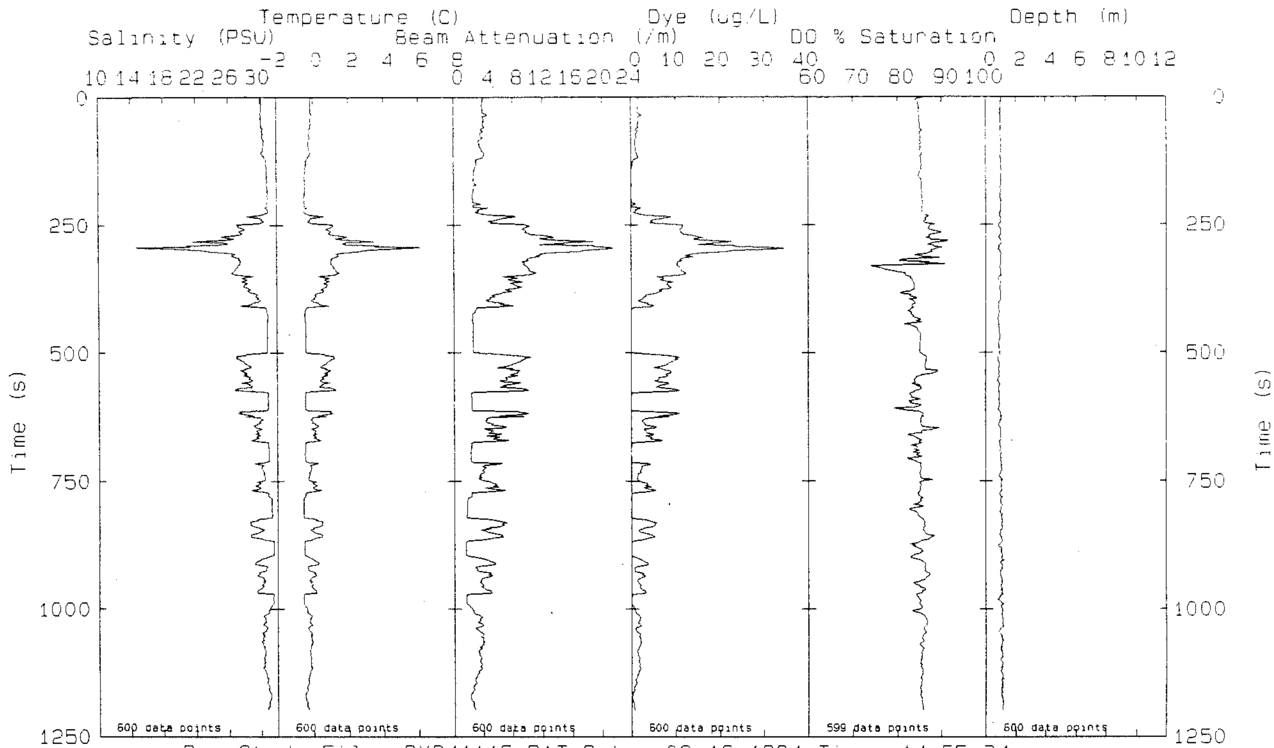
70°56' W
E
0
1 km



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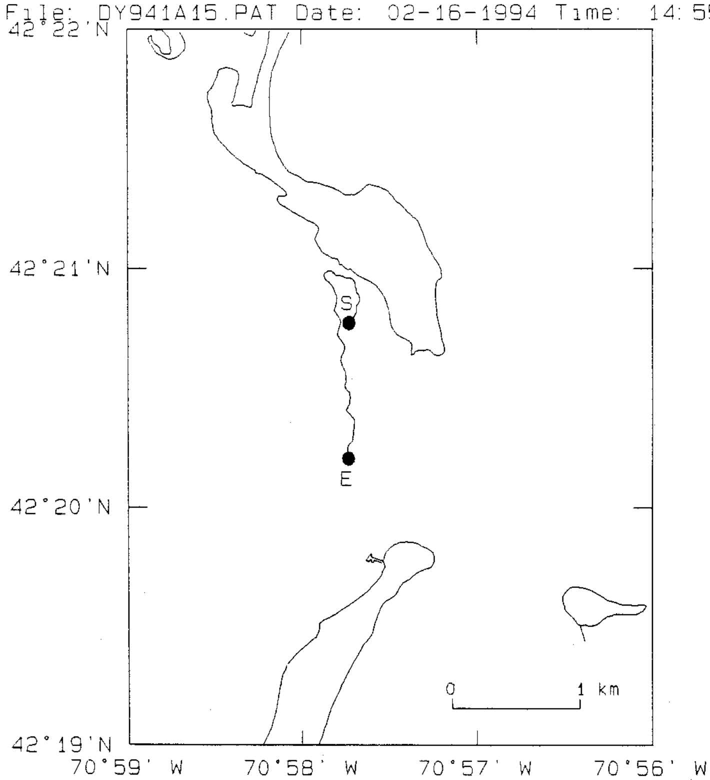

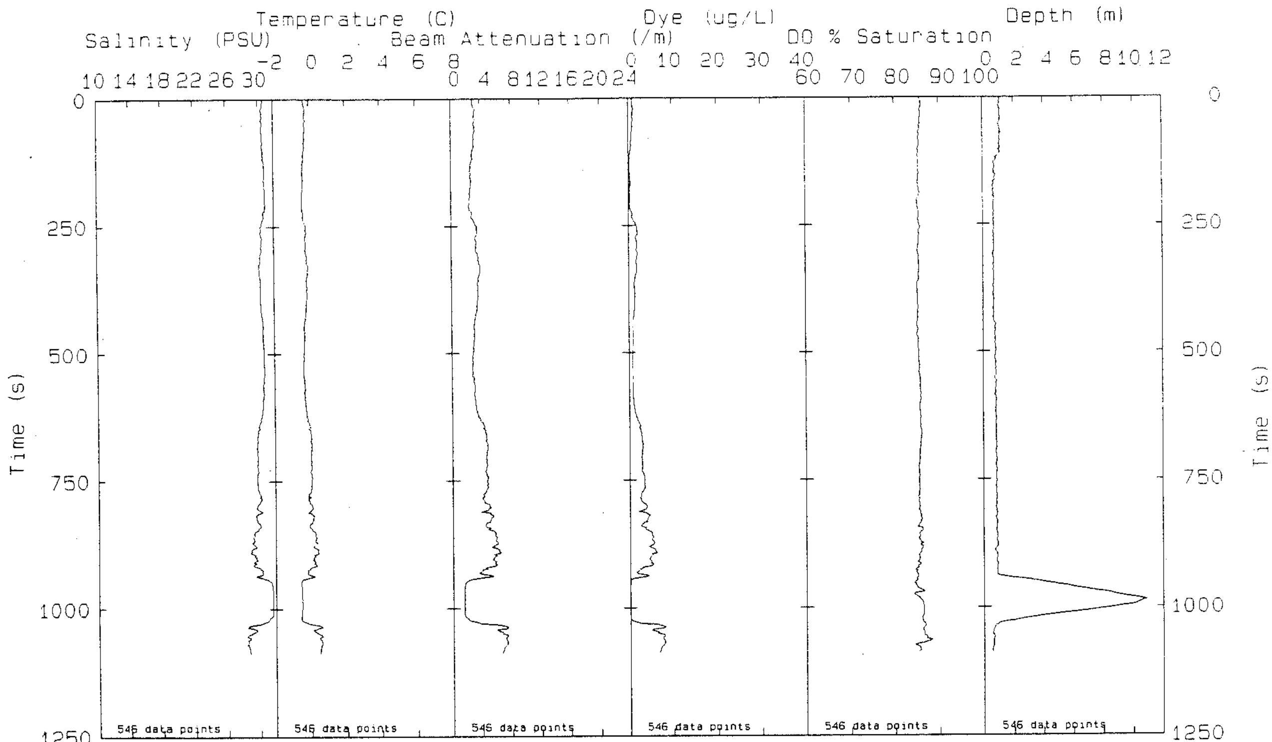

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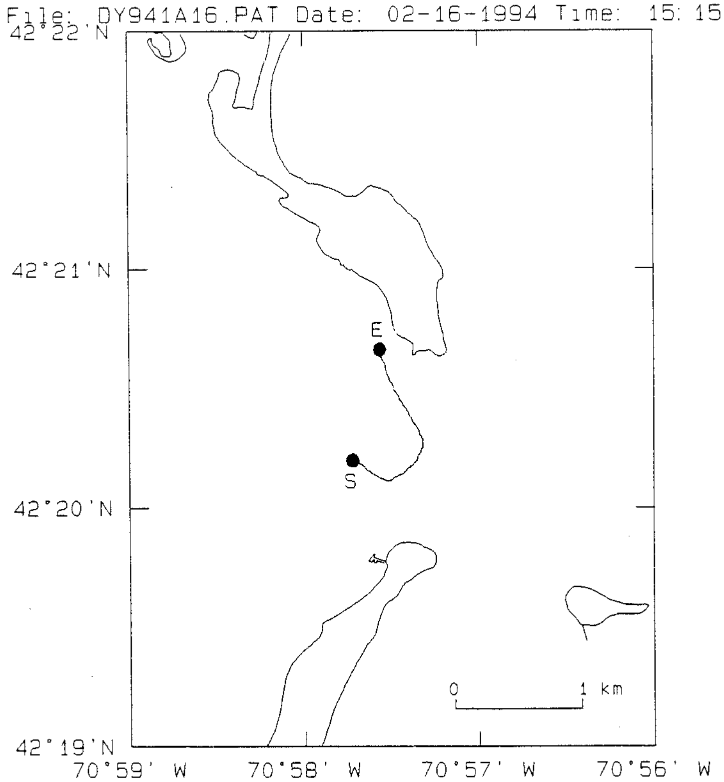

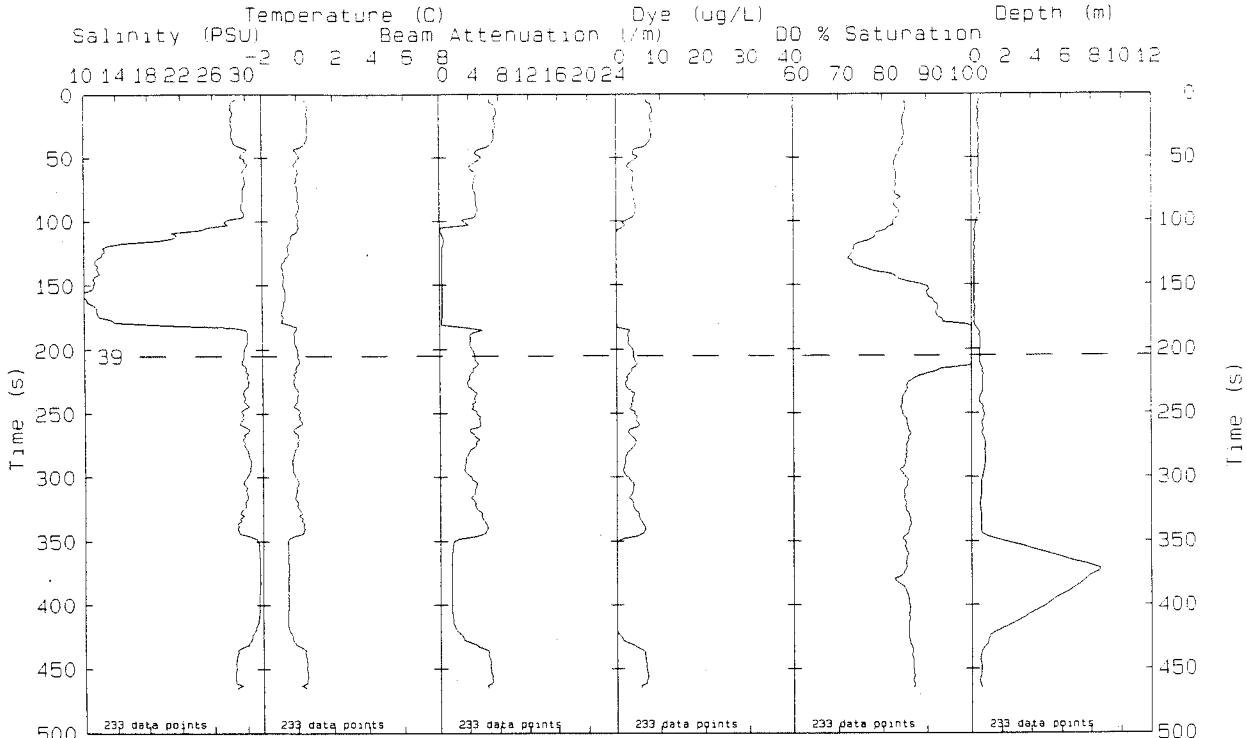

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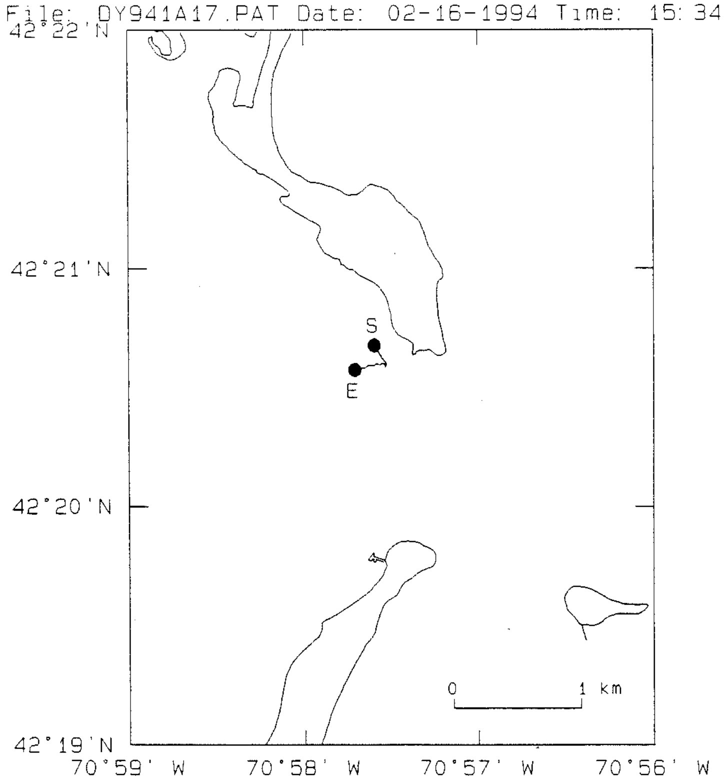
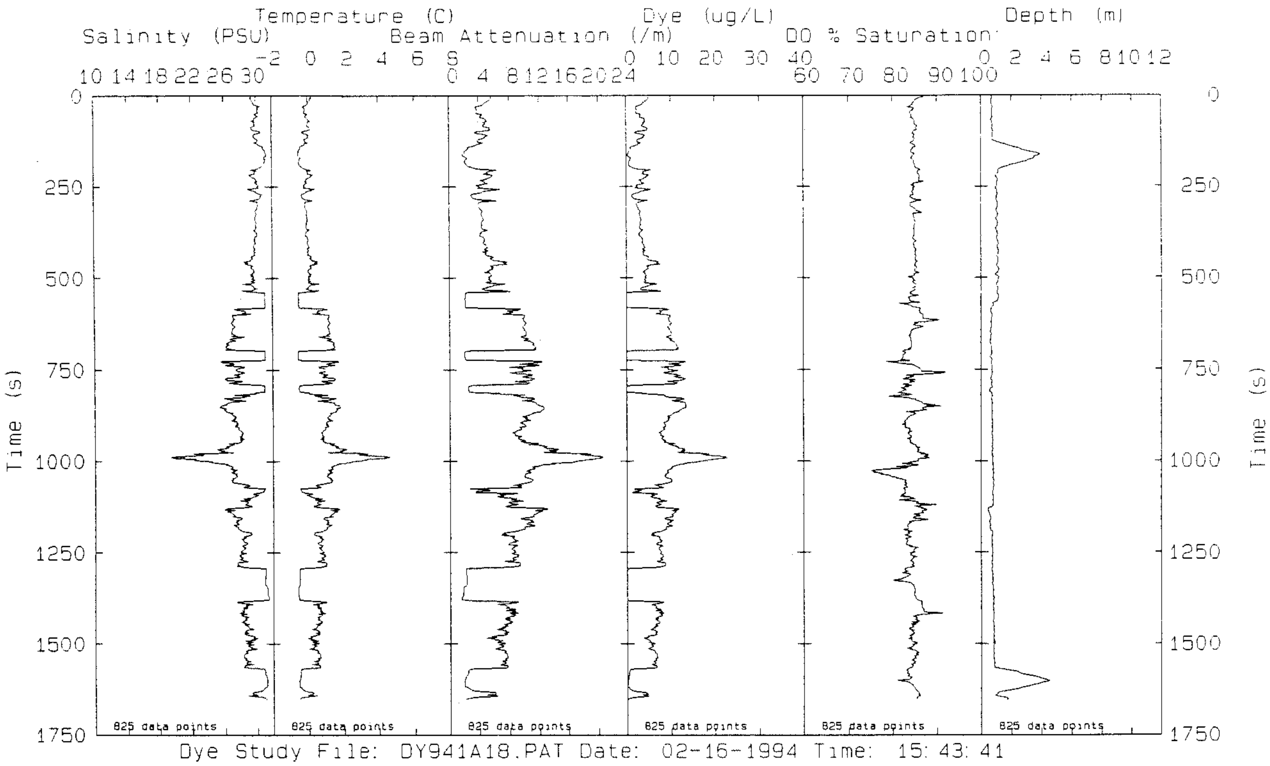
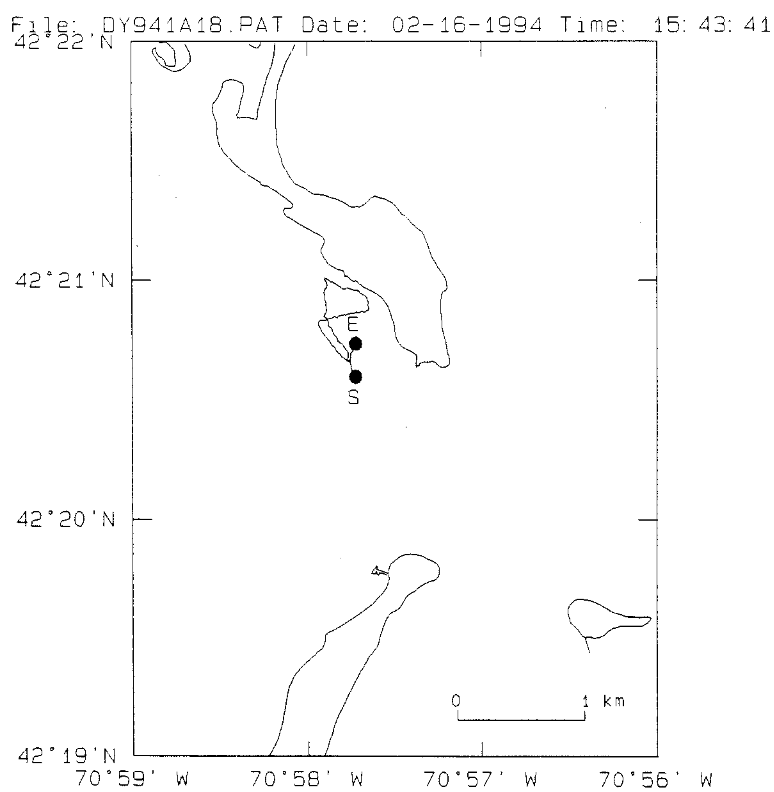
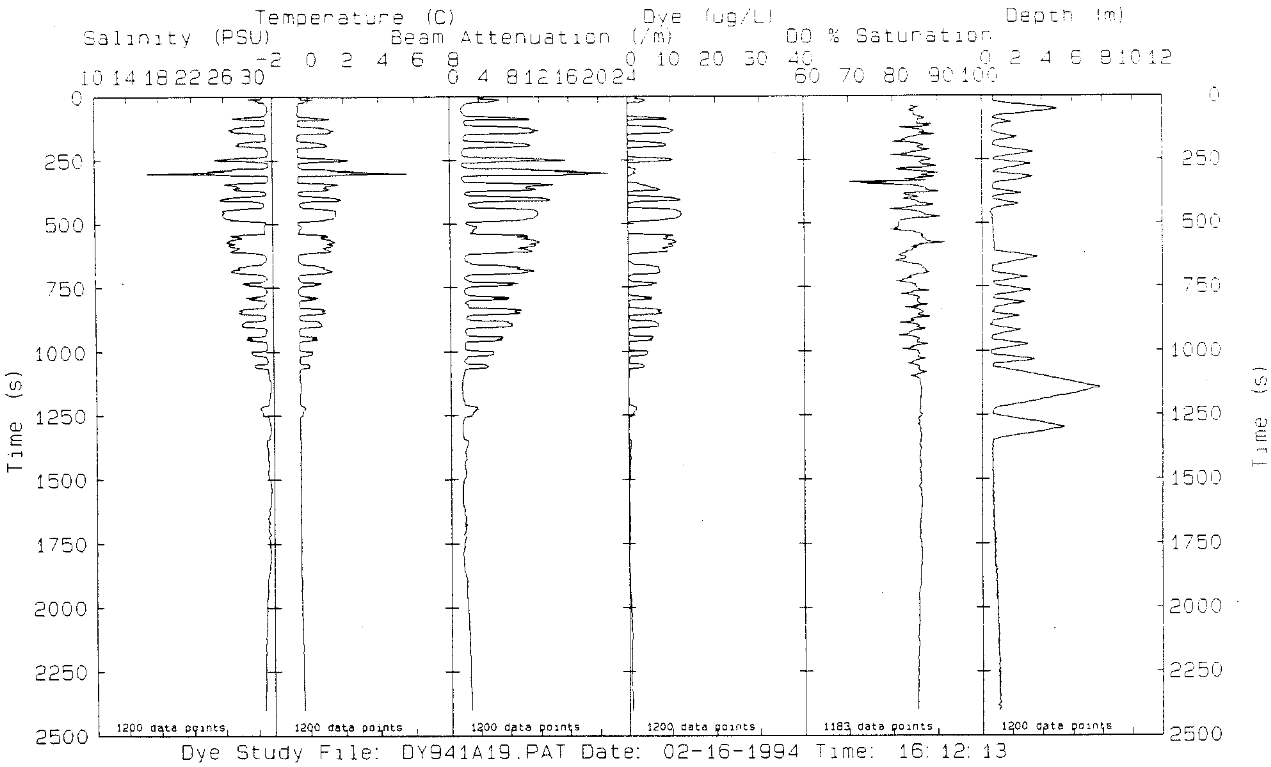


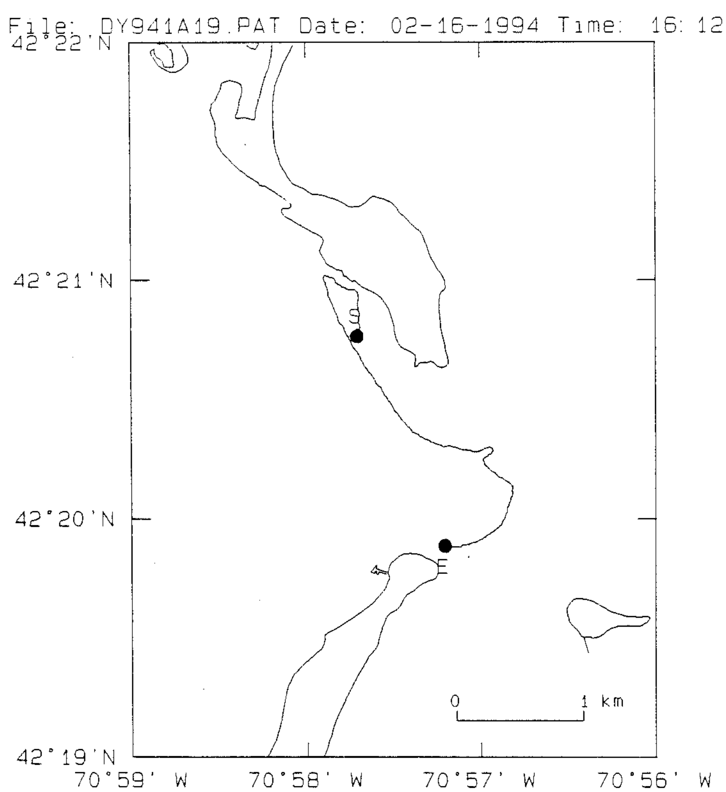
06-28-1994 15: 43: 00 Battelle


Temperature (C)
Salinity (PSU)
Beam Attenuation (/m)
Dye (ug/L)
DO % Saturation
Depth (m)
Time (s)
825 data points
Dye Study File: DY941A18.PAT Date: 02-16-1994 Time: 15:43:41

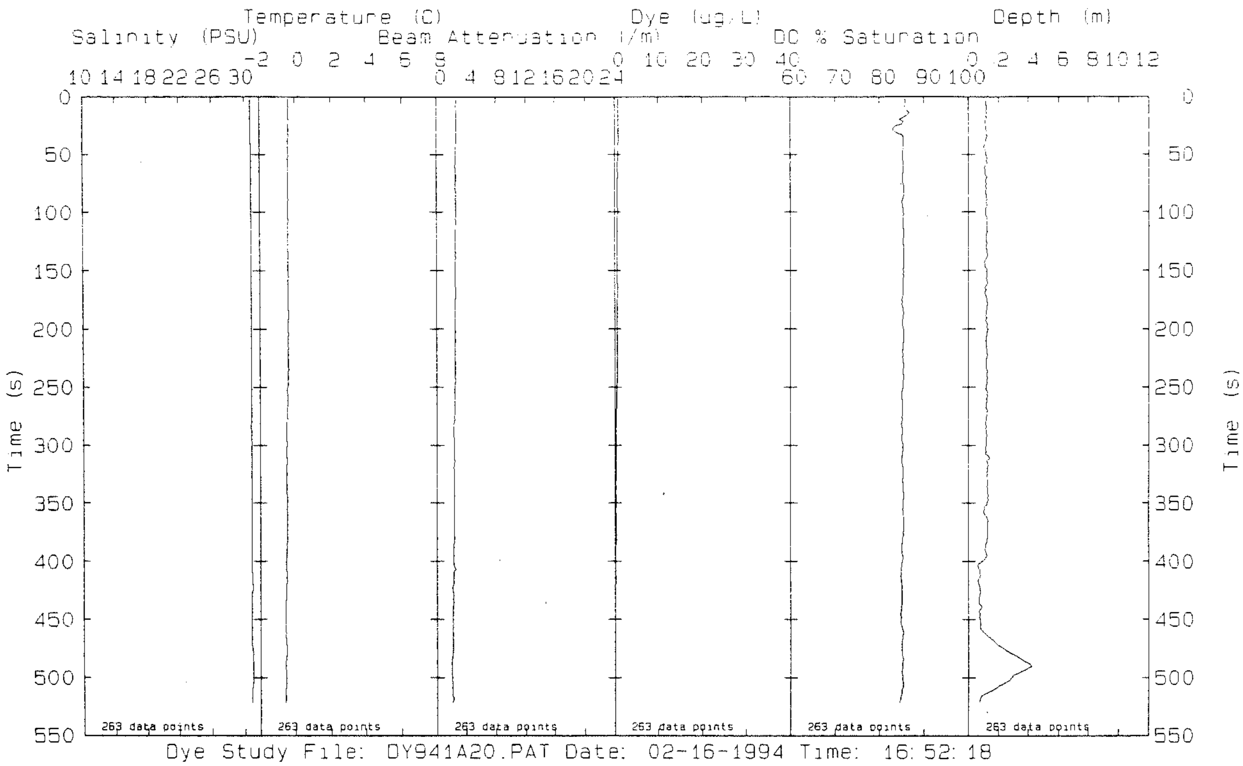

File: DY941A18.PAT Date: 02-16-1994 Time: 15:43:41
42°22'N
42°21'N
42°20'N
42°19'N
70°59' W
70°58' W
70°57' W
70°56' W
E
S
0
1 km



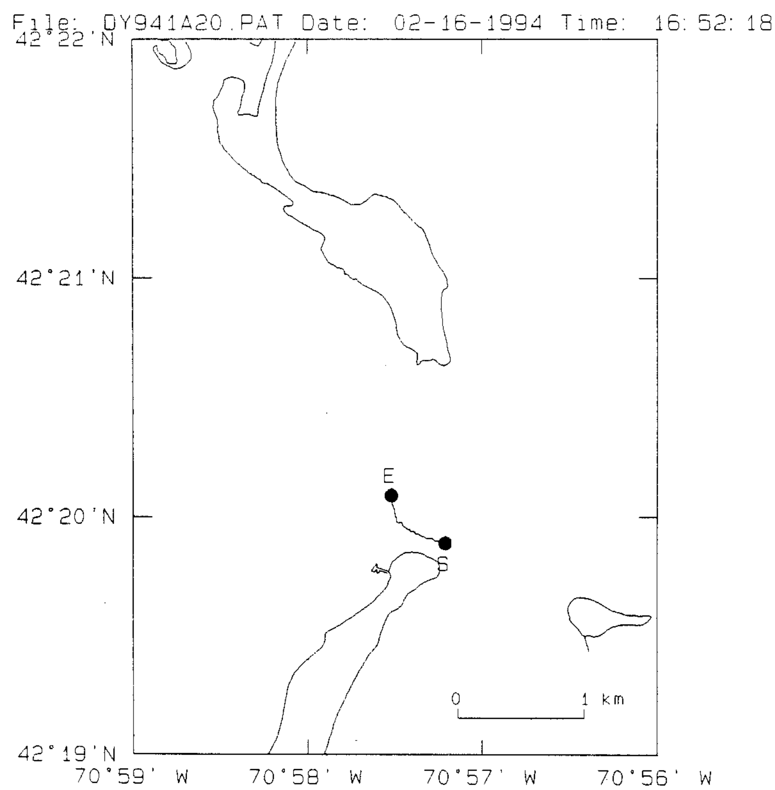
Temperature (C)
Salinity (PSU)
Beam Attenuation (/m)
Dye (ug/L)
DO % Saturation
Depth (m)
Time (s)
1200 data points
1183 data points
Dye Study File: DY941A19.PAT Date: 02-16-1994 Time: 16:12:13



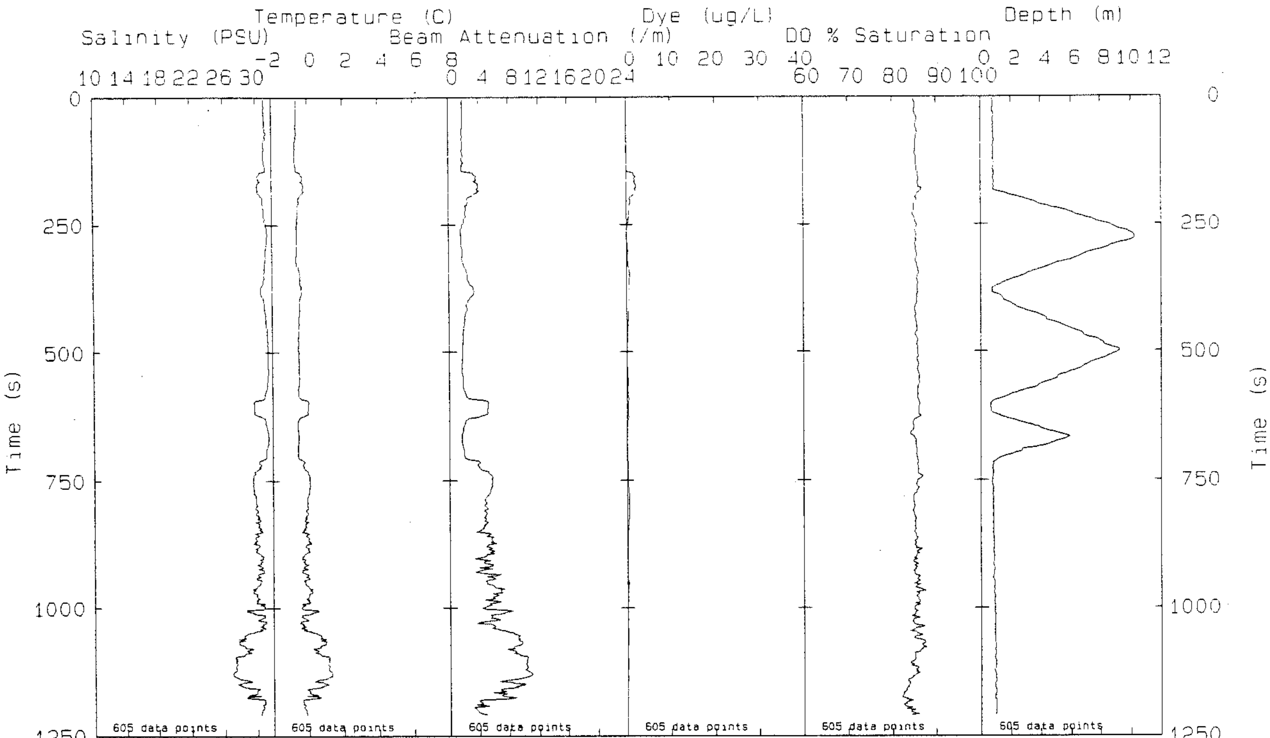
File: DY941A19.PAT Date: 02-16-1994 Time: 16:12:13
42°22'N
42°21'N
42°20'N
42°19'N
70°59' W
70°58' W
70°57' W
70°56' W
S
E
0
1 km



Temperature (C)
Salinity (PSU)
Beam Attenuation (/m)
Dye (ug/L)
DO % Saturation
Depth (m)
-2 0 2 4 6 8
10 14 18 22 26 30
0 4 8 12 16 20 24
0 10 20 30 40
60 70 80 90 100
0 2 4 6 8 10 12
Time (s)
0
50
100
150
200
250
300
350
400
450
500
550
263 data points
Dye Study File: DY941A20.PAT Date: 02-16-1994 Time: 16:52:18

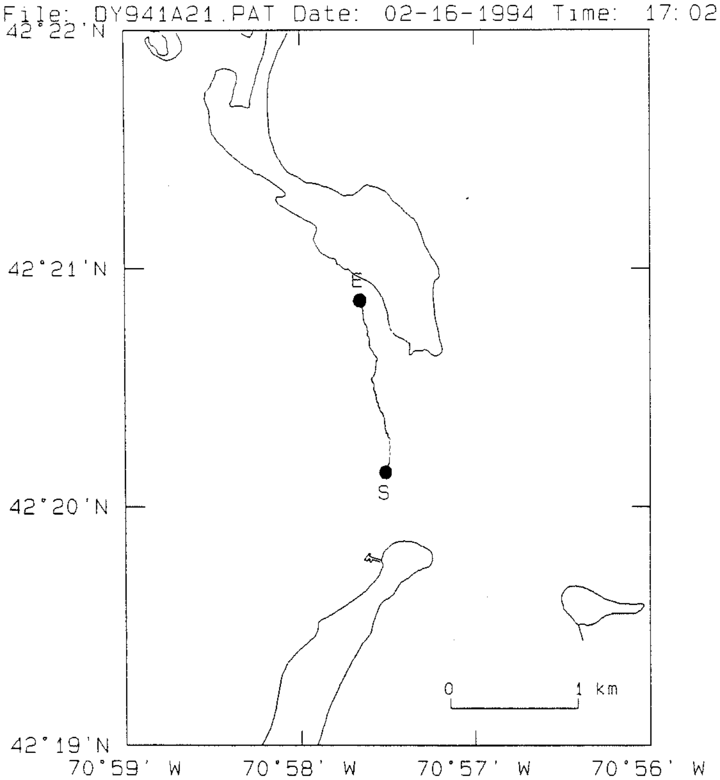


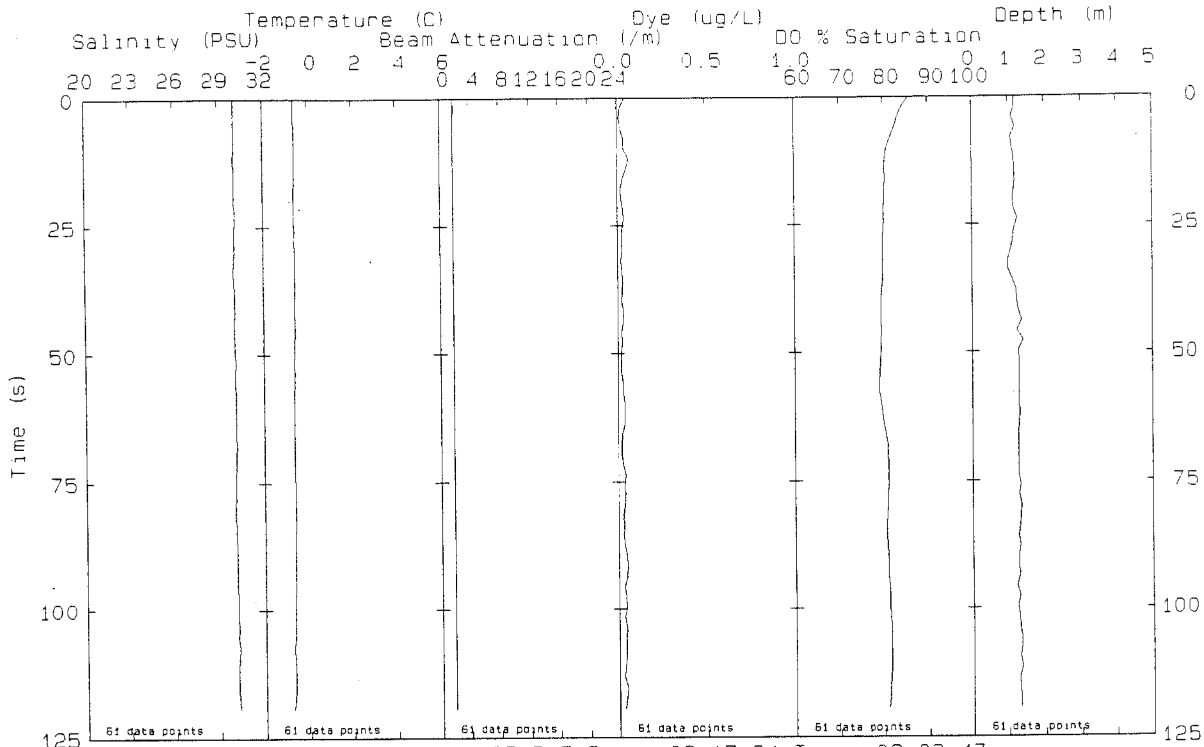
File: DY941A20.PAT Date: 02-16-1994 Time: 16:52:18
42°22'N
42°21'N
42°20'N
42°19'N
70°59' W
70°58' W
70°57' W
70°56' W
E
S
0
1 km



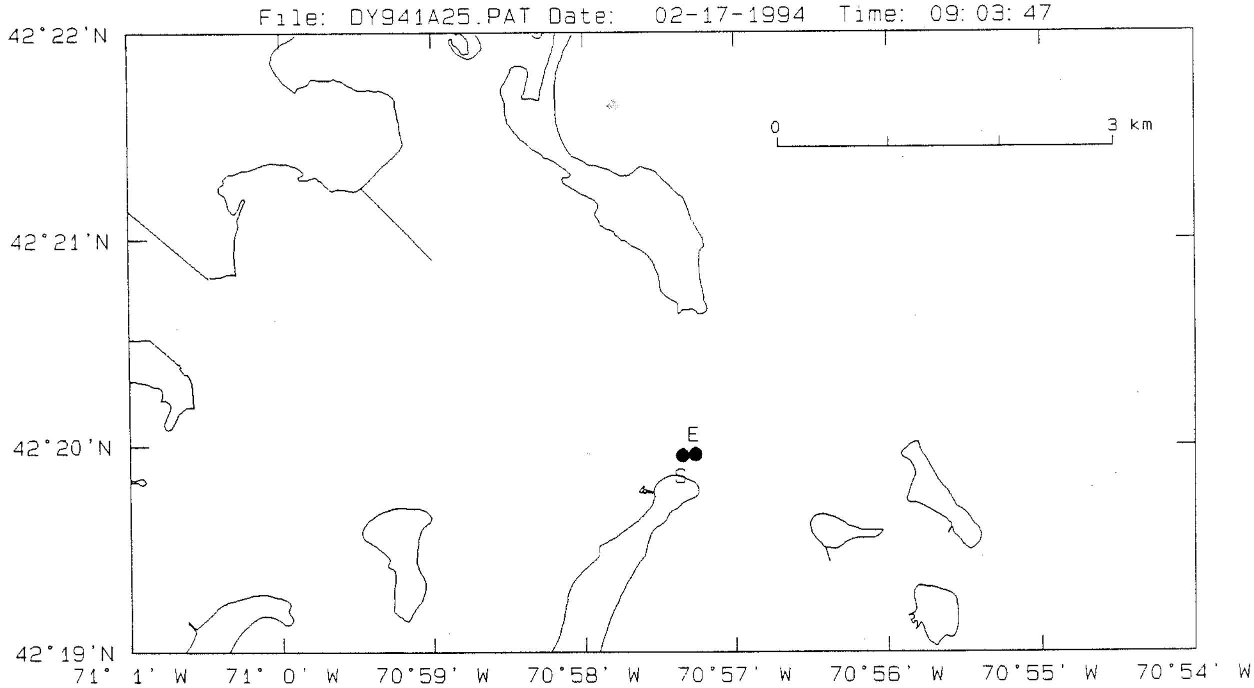
Dye Study File: DY941A21.PAT Date: 02-16-1994 Time: 17:02:09

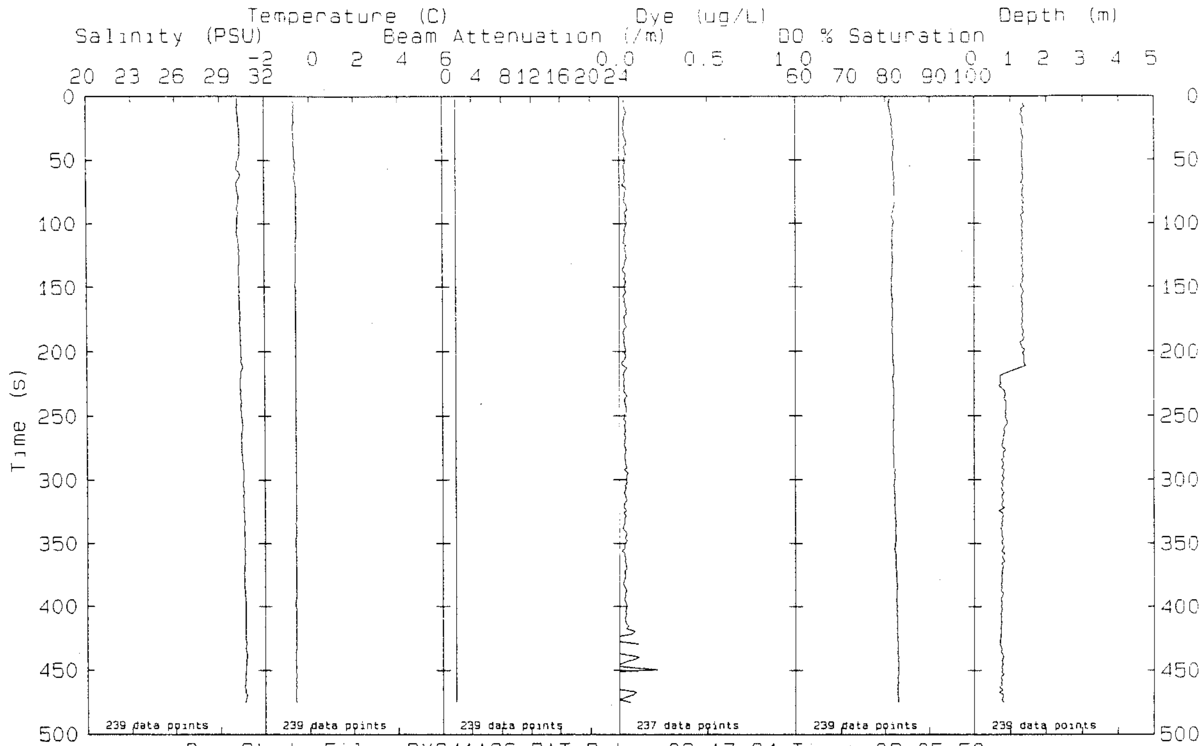
File: DY941A21.PAT Date: 02-16-1994 Time: 17:02:09





Dye Study File: DY941A25.PAT Date: 02-17-94 Time: 09:03:47





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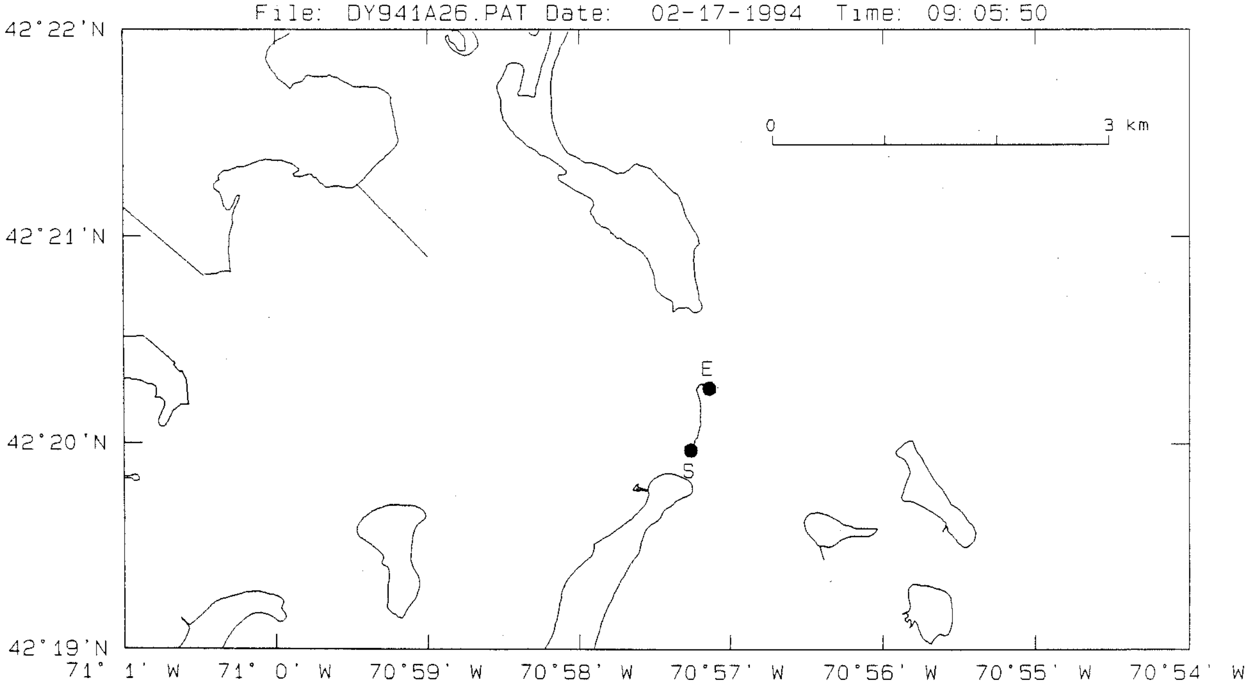
File: DY941A26.PAT Date: 02-17-1994 Time: 09:05:50



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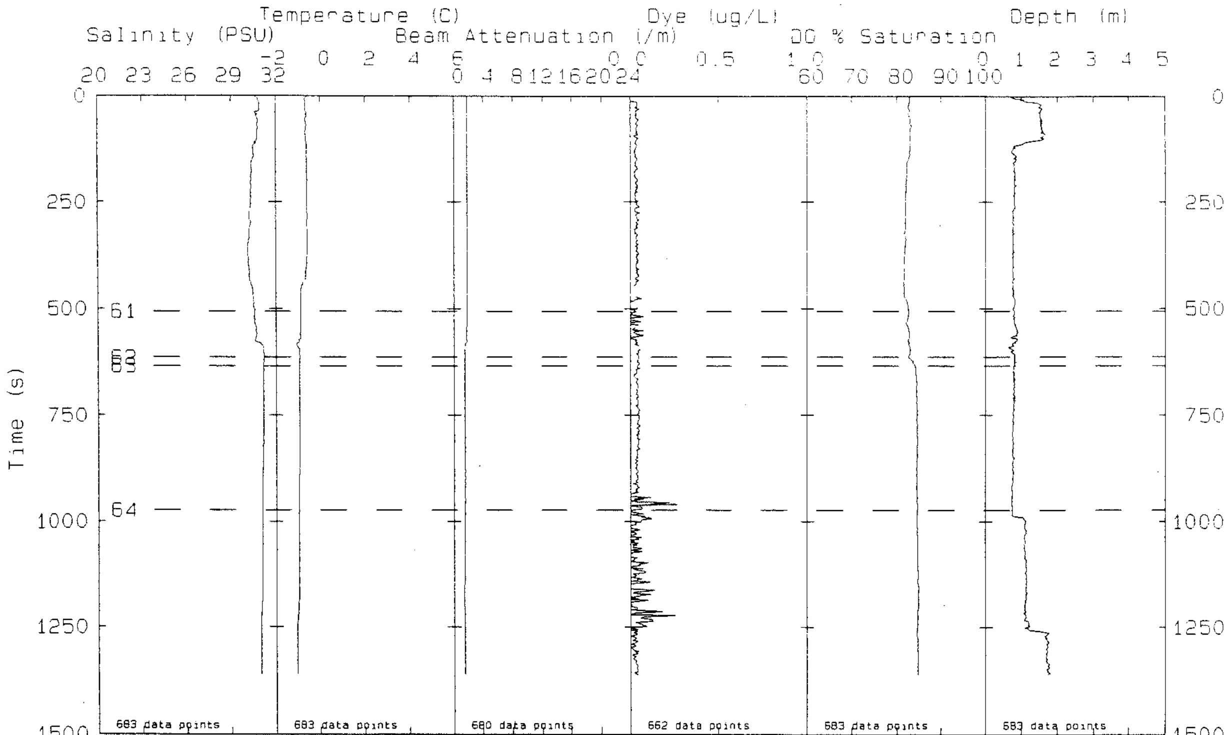

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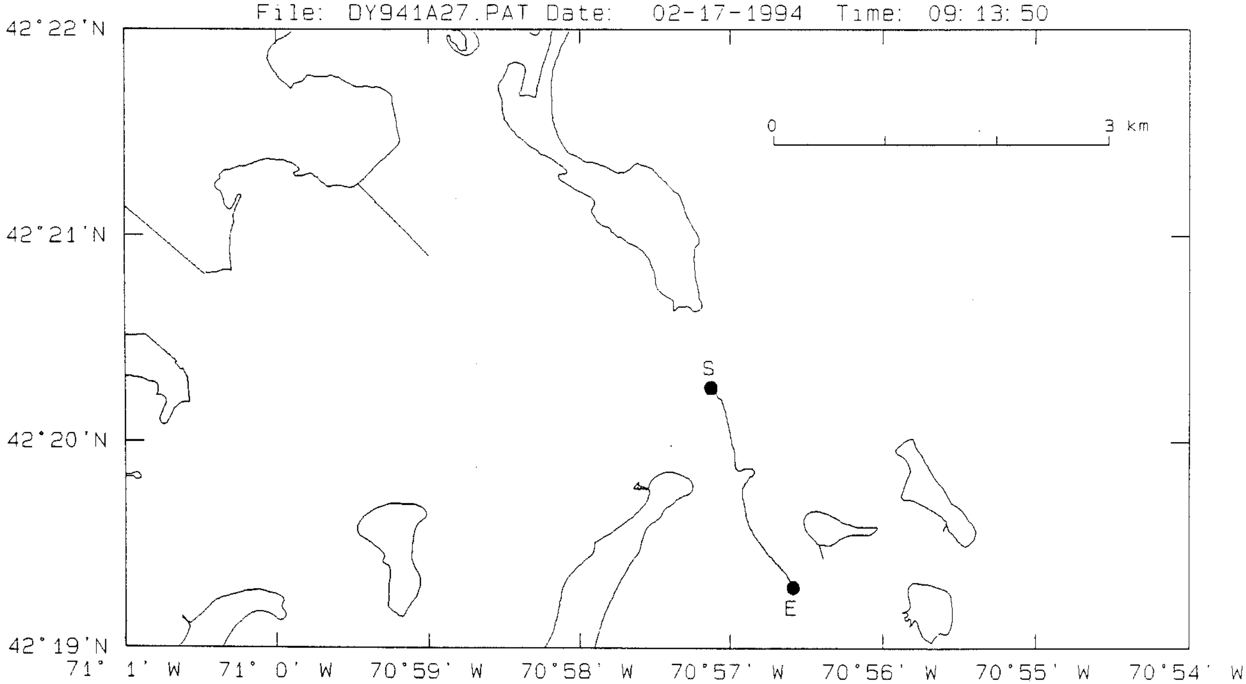
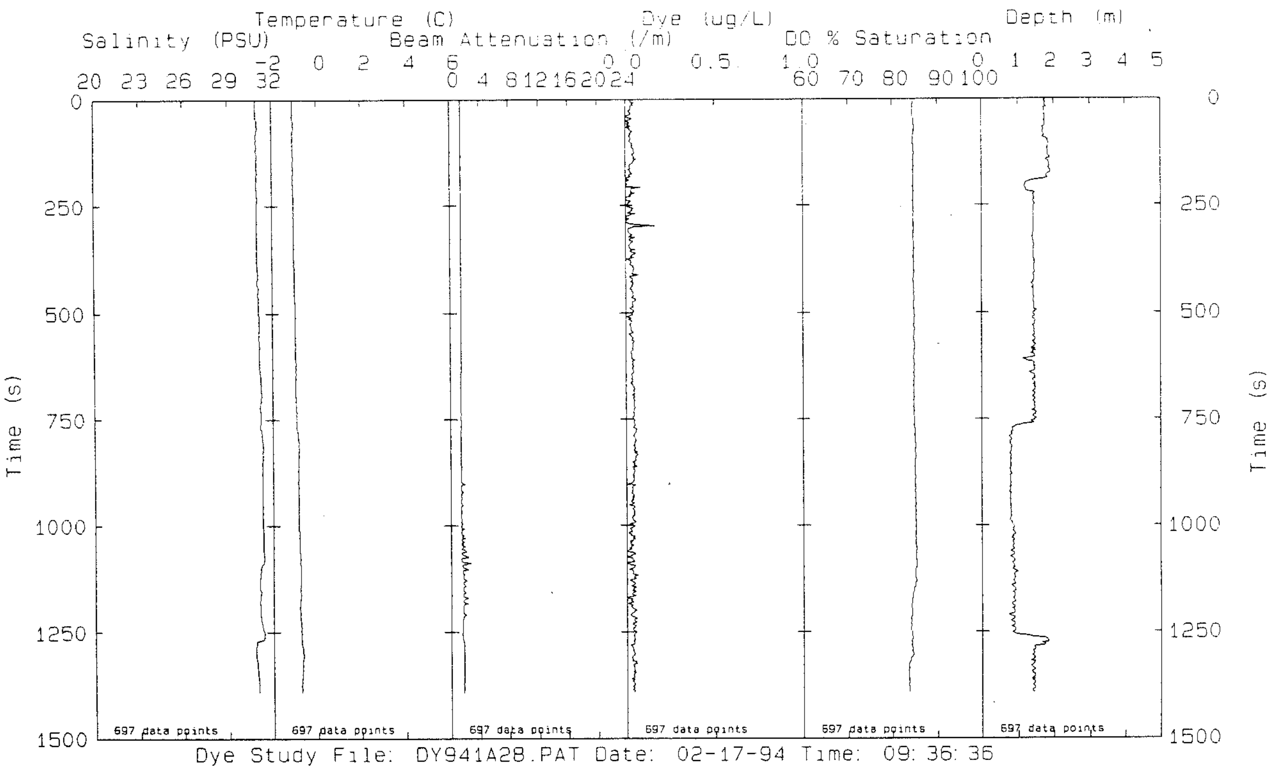
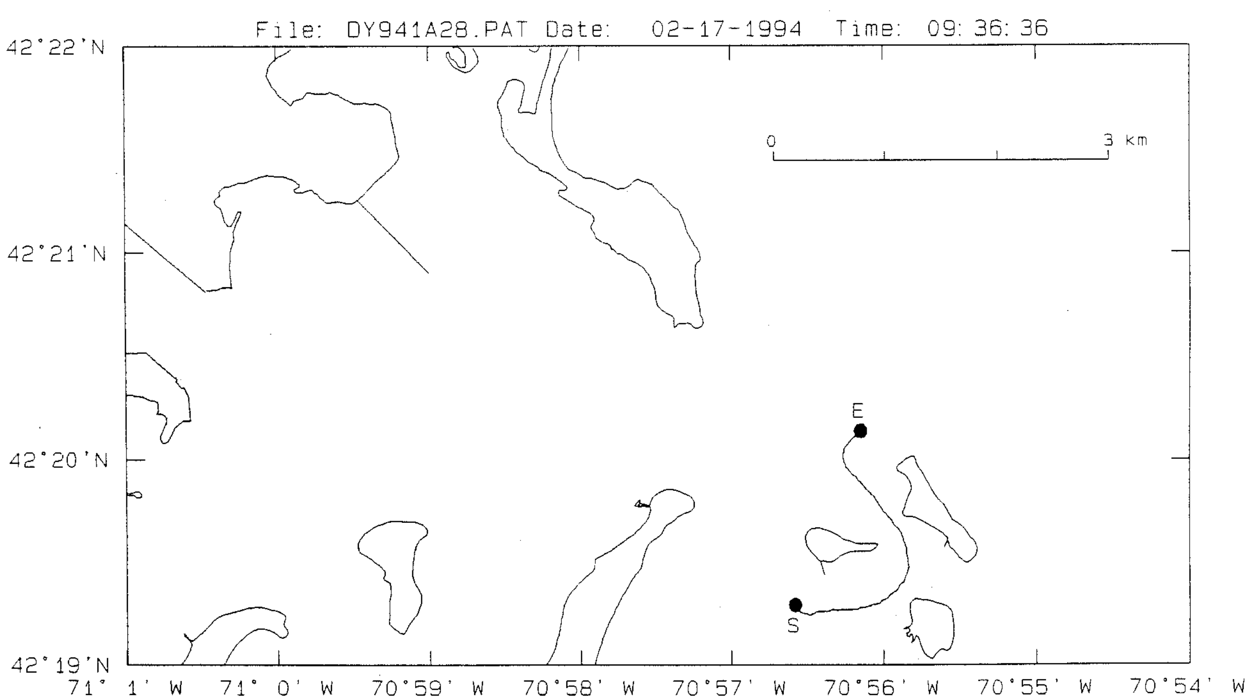
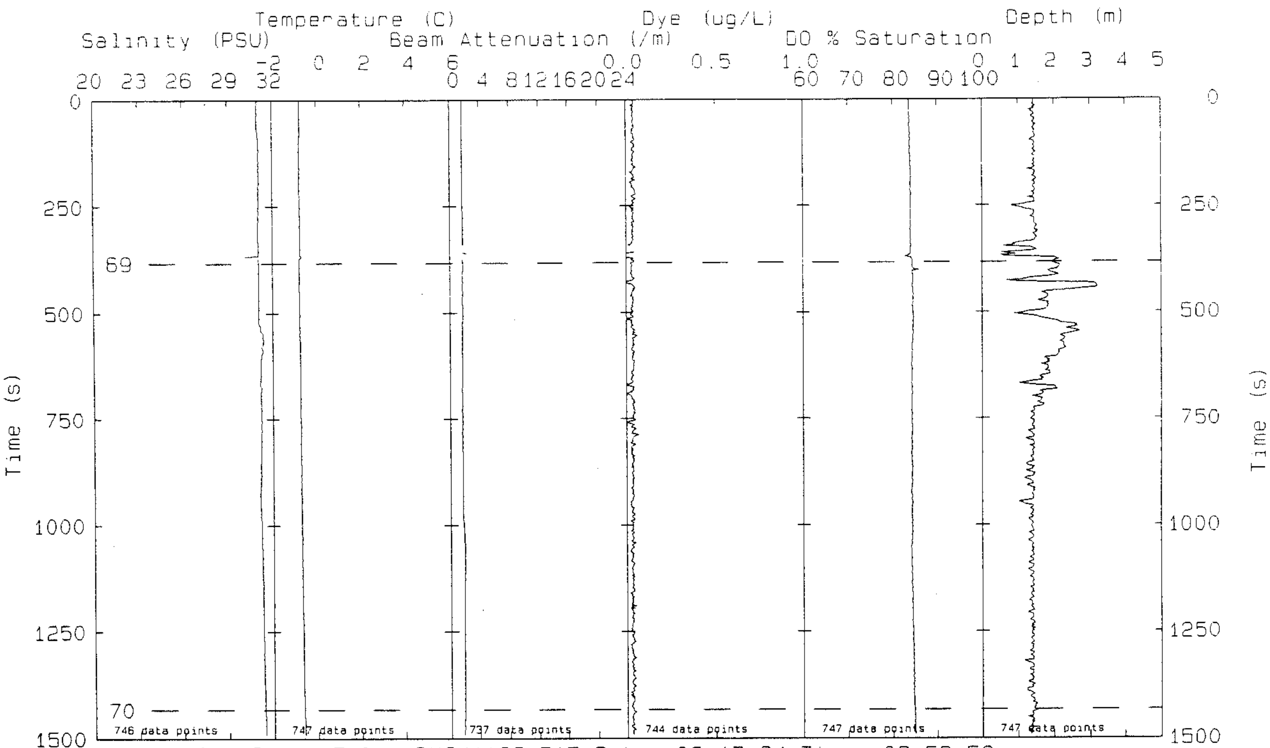
File: DY941A27.PAT Date: 02-17-1994 Time: 09:13:50







06-28-1994 16 20:33 Battelle



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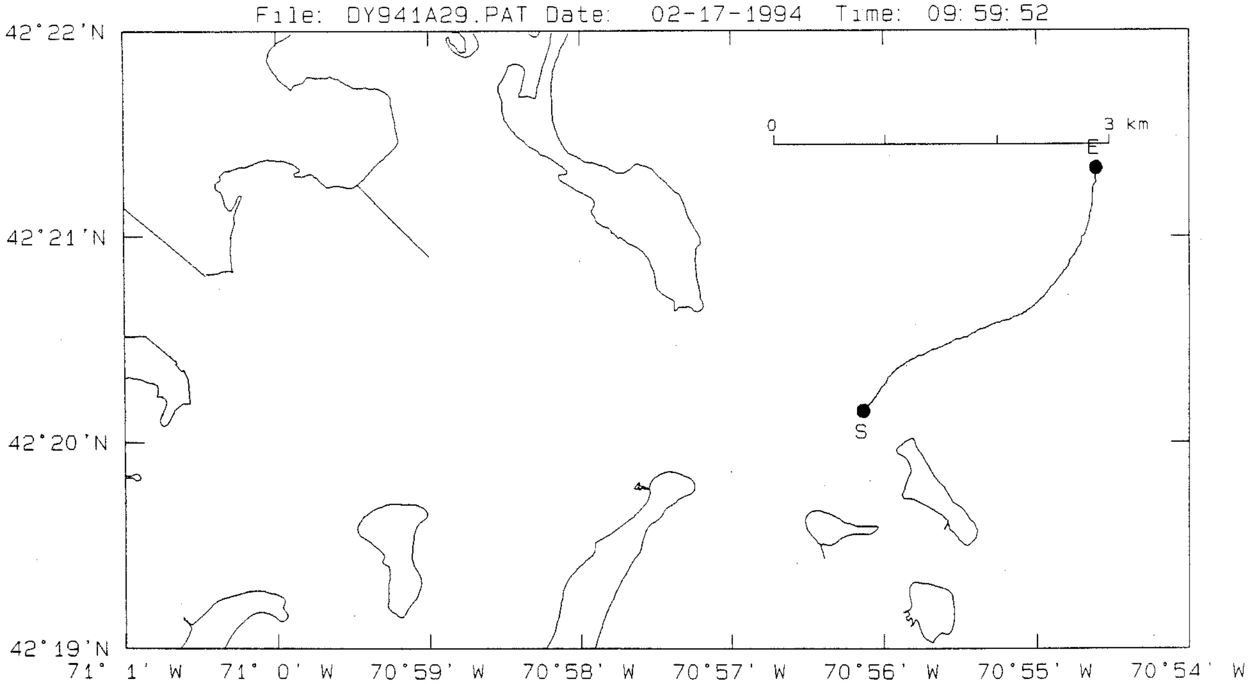
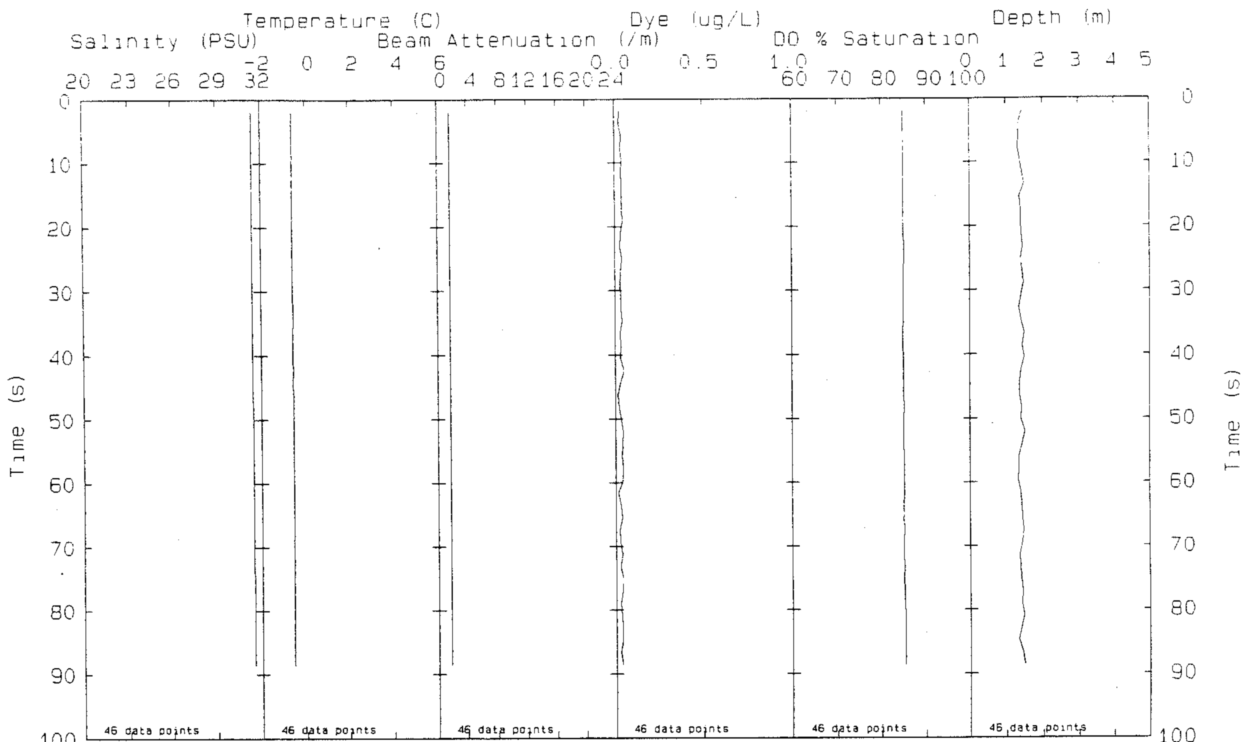
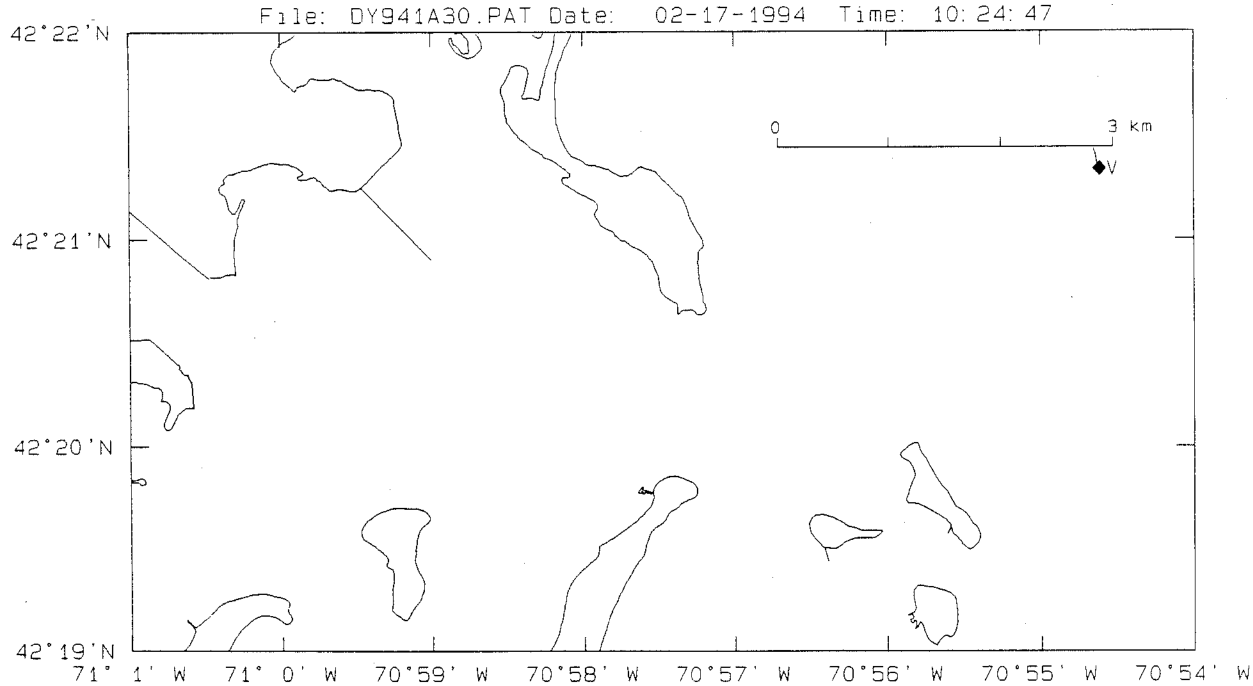
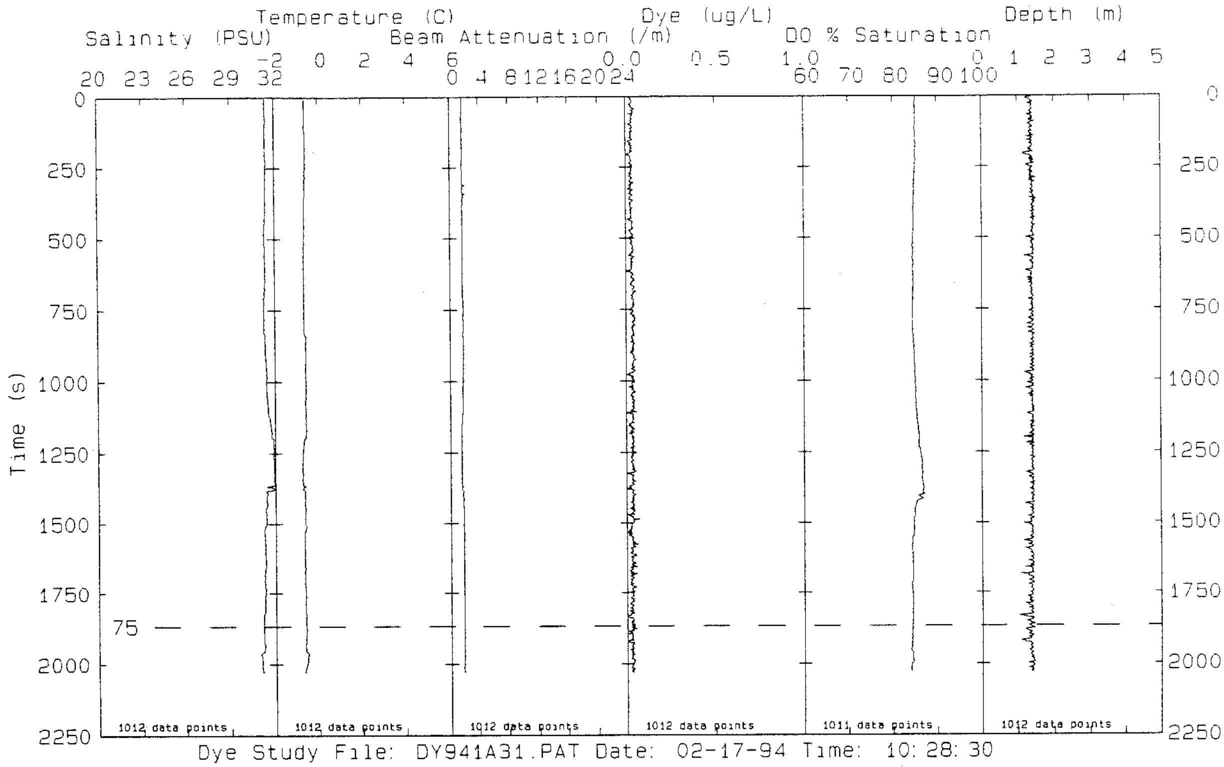


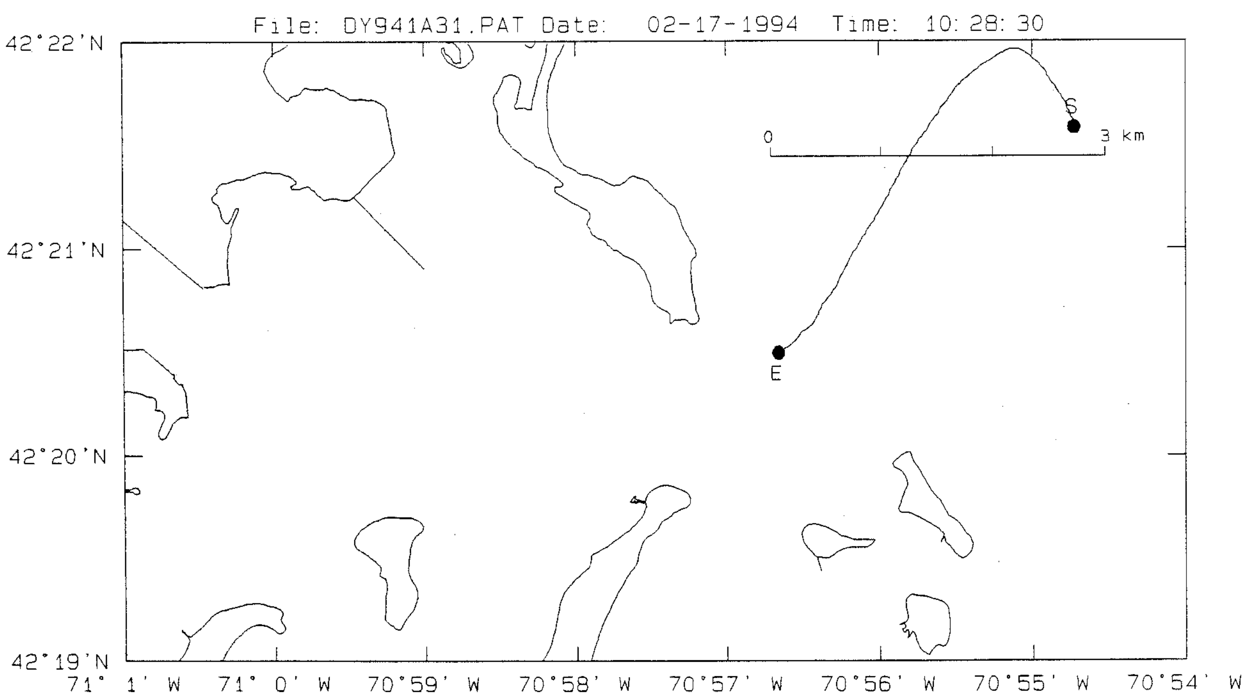


Dye Study File: DY941A30.PAT Date: 02-17-94 Time: 10:24:47

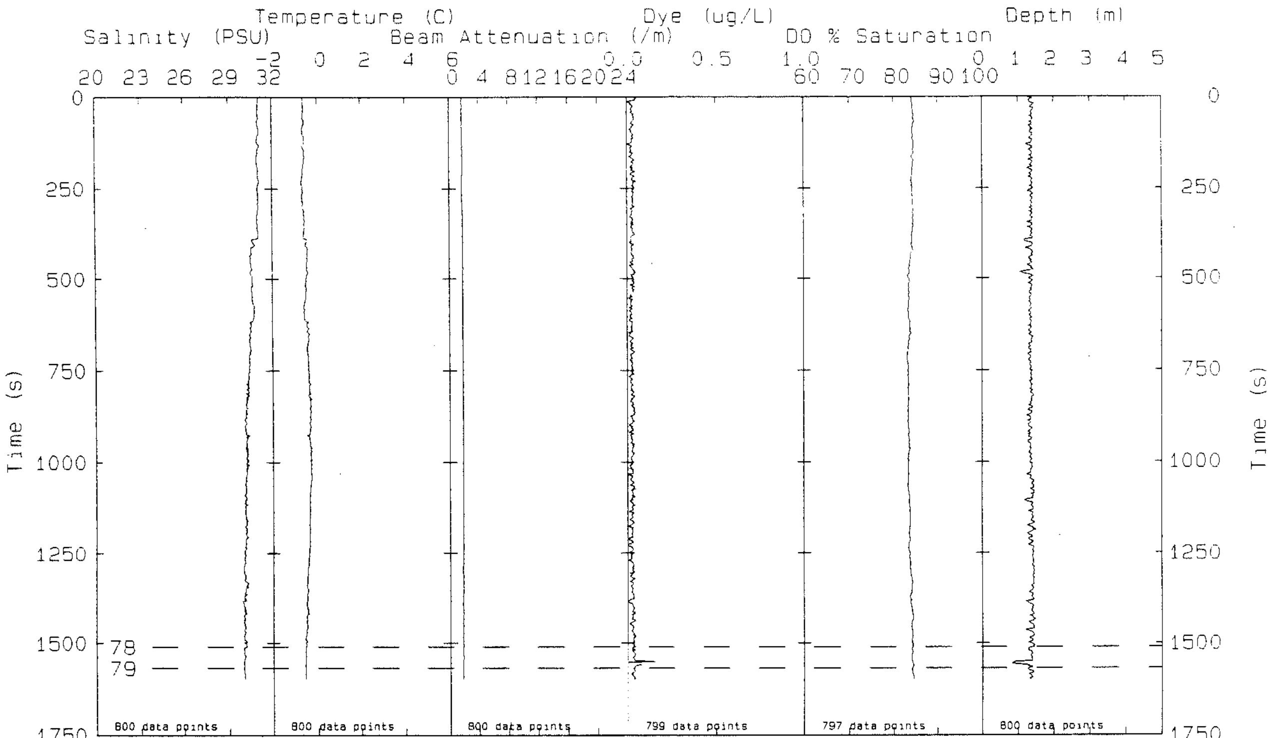




Temperature (C)
Dye (ug/L)
Depth (m)
Salinity (PSU)
Beam Attenuation (/m)
DO % Saturation
-2 0 2 4 6
0.0 0.5 1.0
0 1 2 3 4 5
20 23 26 29 32
0 4 8 12 16 20 24
60 70 80 90 100
Time (s)
0 250 500 750 1000 1250 1500 1750 2000 2250
75
1012 data points
1011 data points
Dye Study File: DY941A31.PAT Date: 02-17-94 Time: 10:28:30



File: DY941A31.PAT Date: 02-17-1994 Time: 10:28:30
42°22'N
42°21'N
42°20'N
42°19'N
S
E
0
3 km
71° 1' W
71° 0' W
70°59' W
70°58' W
70°57' W
70°56' W
70°55' W
70°54' W



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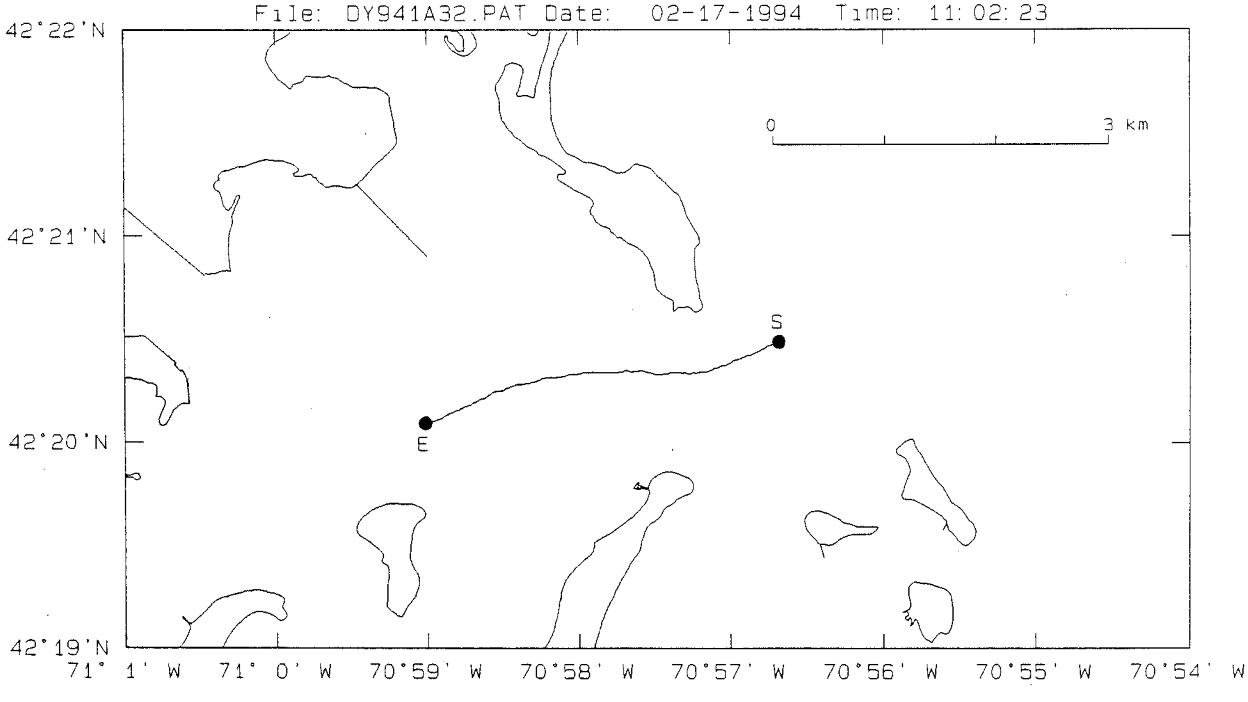
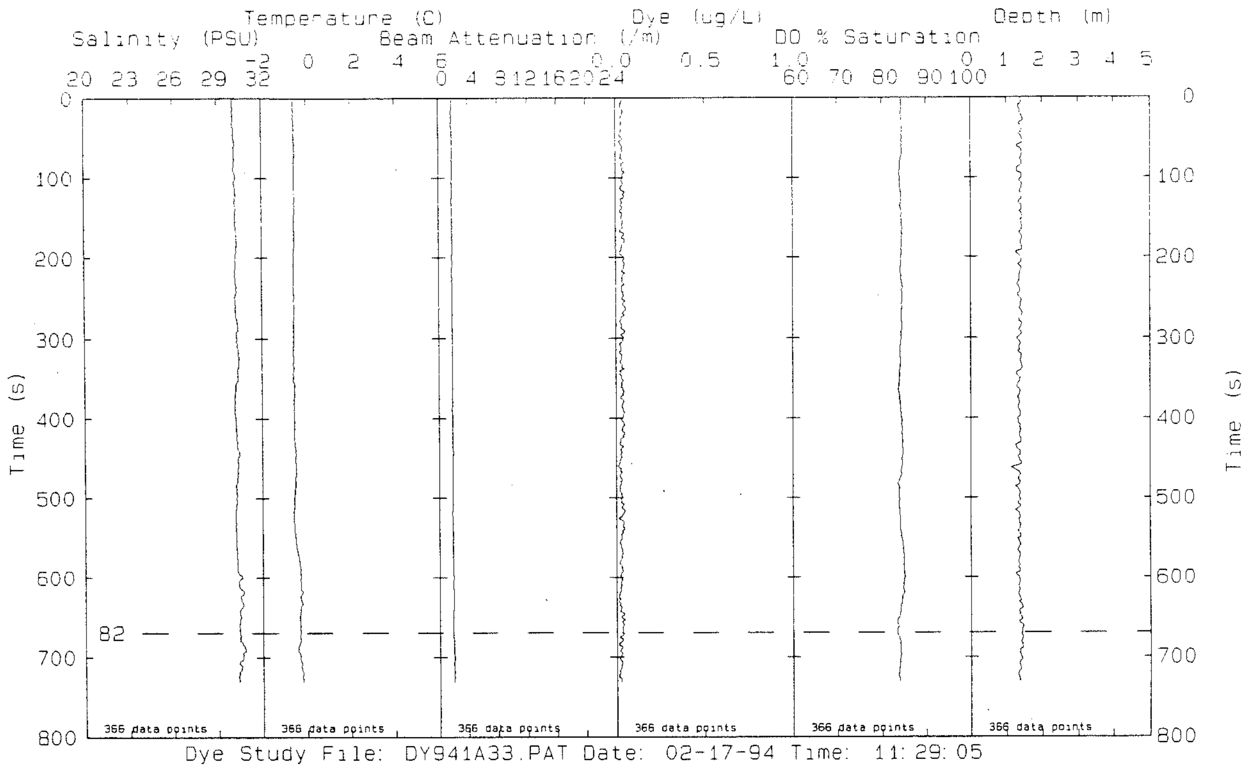
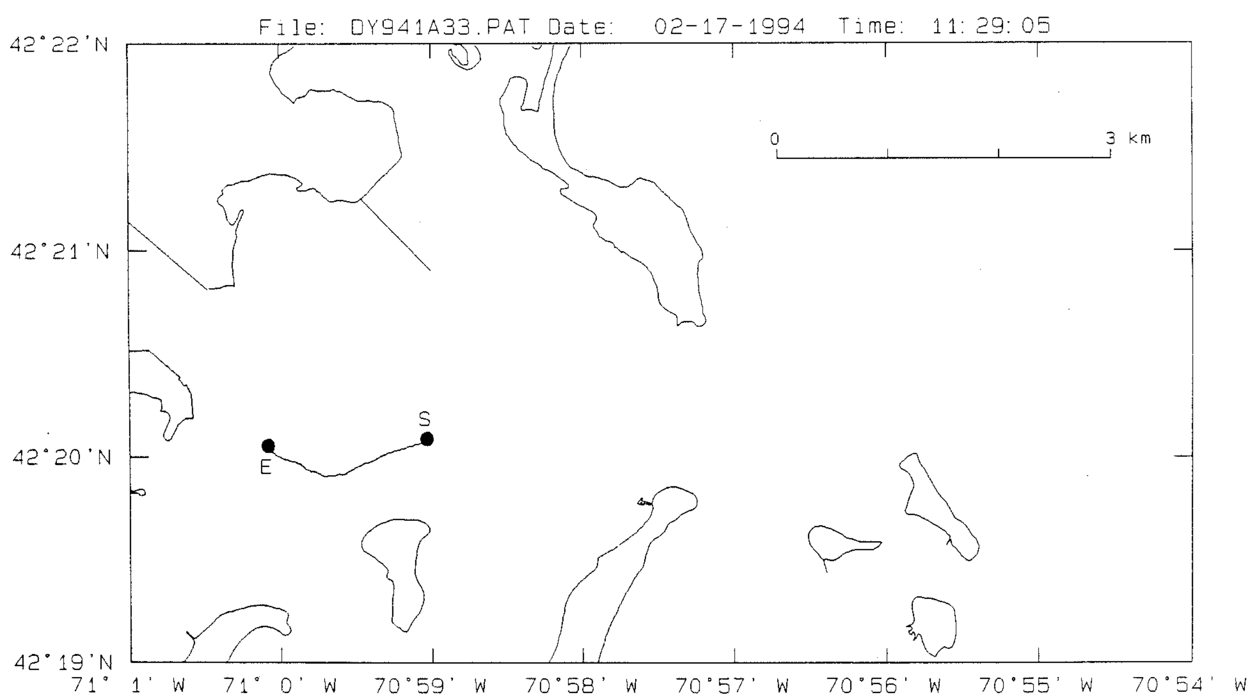
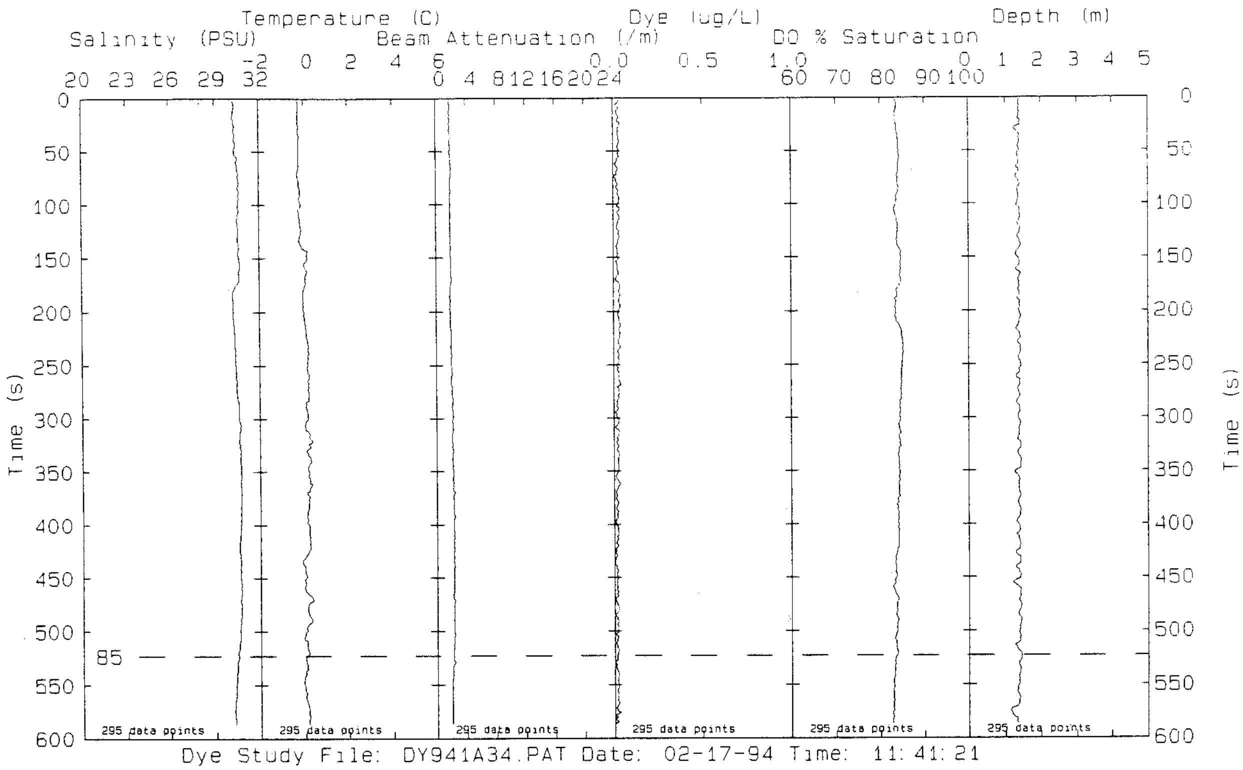


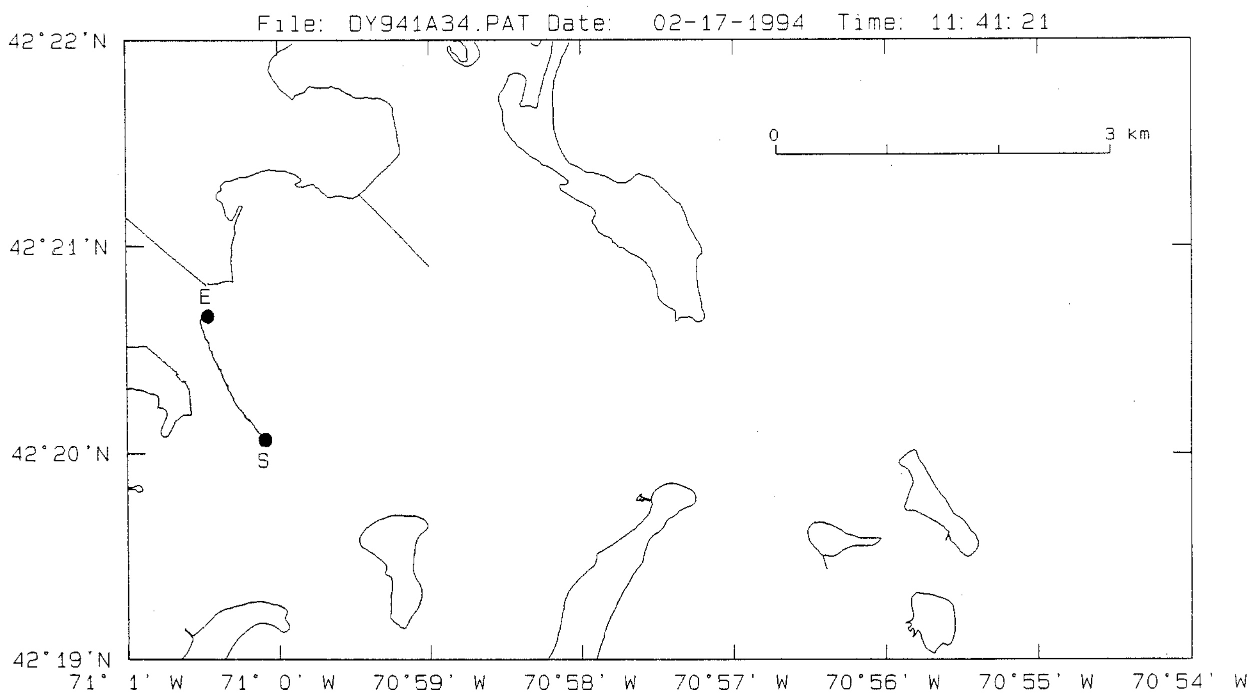




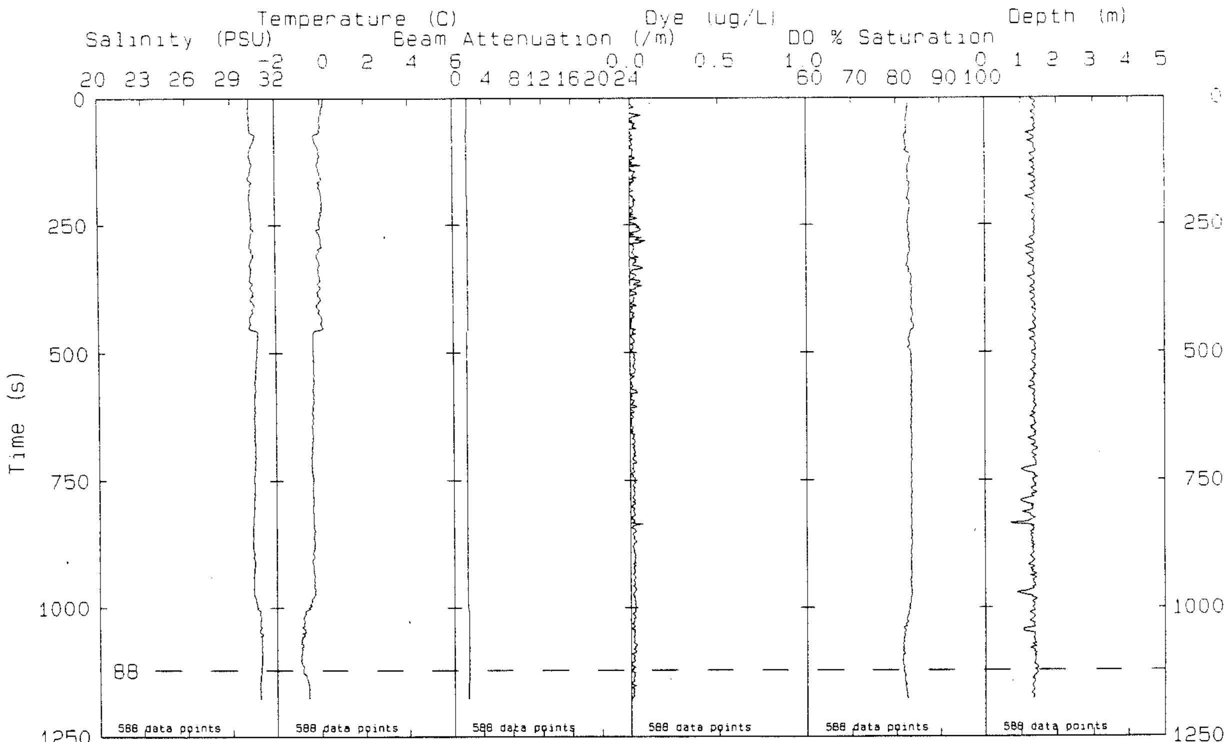
06-28-1994 16:22:12 Battelle



Temperature (C)
Salinity (PSU)
Beam Attenuation (/m)
Dye (ug/L)
DO % Saturation
Depth (m)
Time (s)
85
295 data points
Dye Study File: DY941A34.PAT Date: 02-17-94 Time: 11:41:21



File: DY941A34.PAT Date: 02-17-1994 Time: 11:41:21
42°22'N
42°21'N
42°20'N
42°19'N
71° 1' W
71° 0' W
70°59' W
70°58' W
70°57' W
70°56' W
70°55' W
70°54' W
0
3 km
E
S



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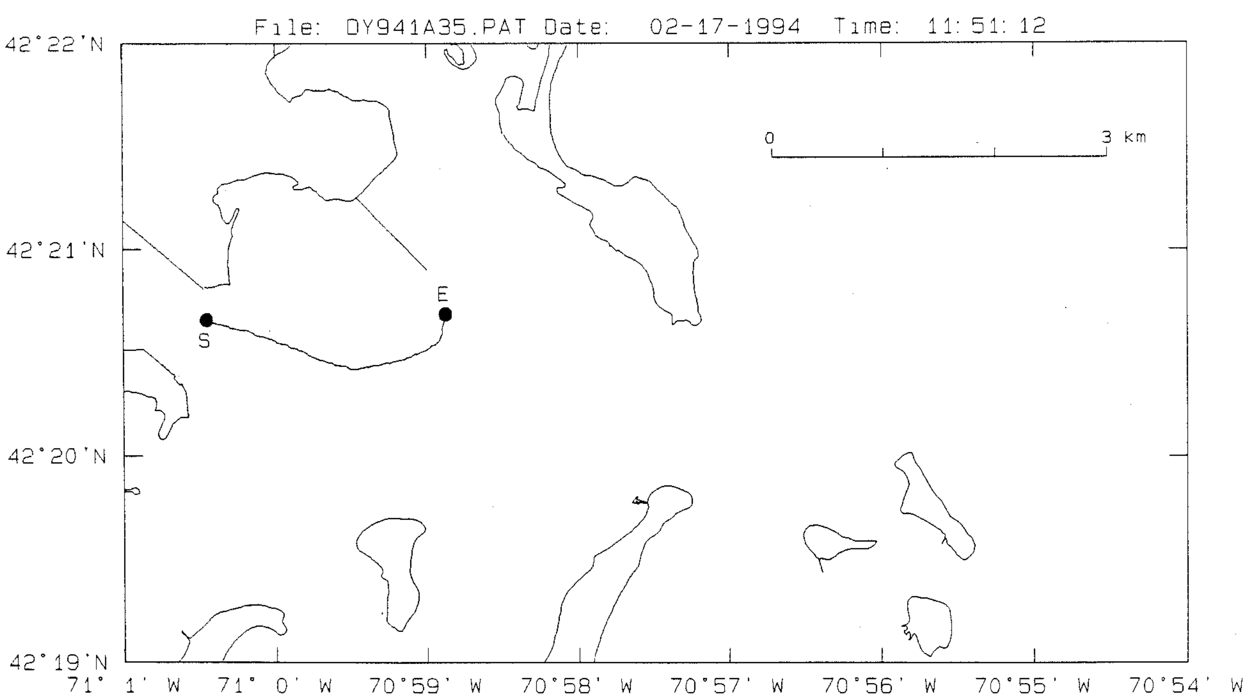
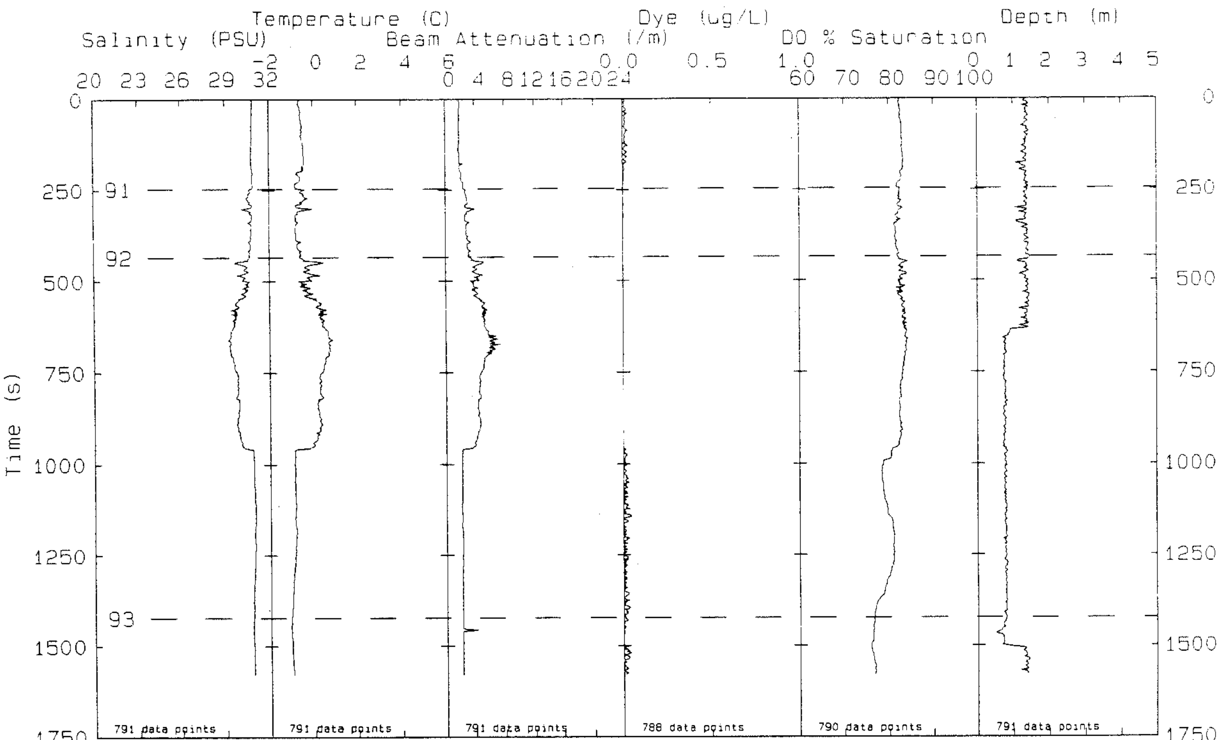
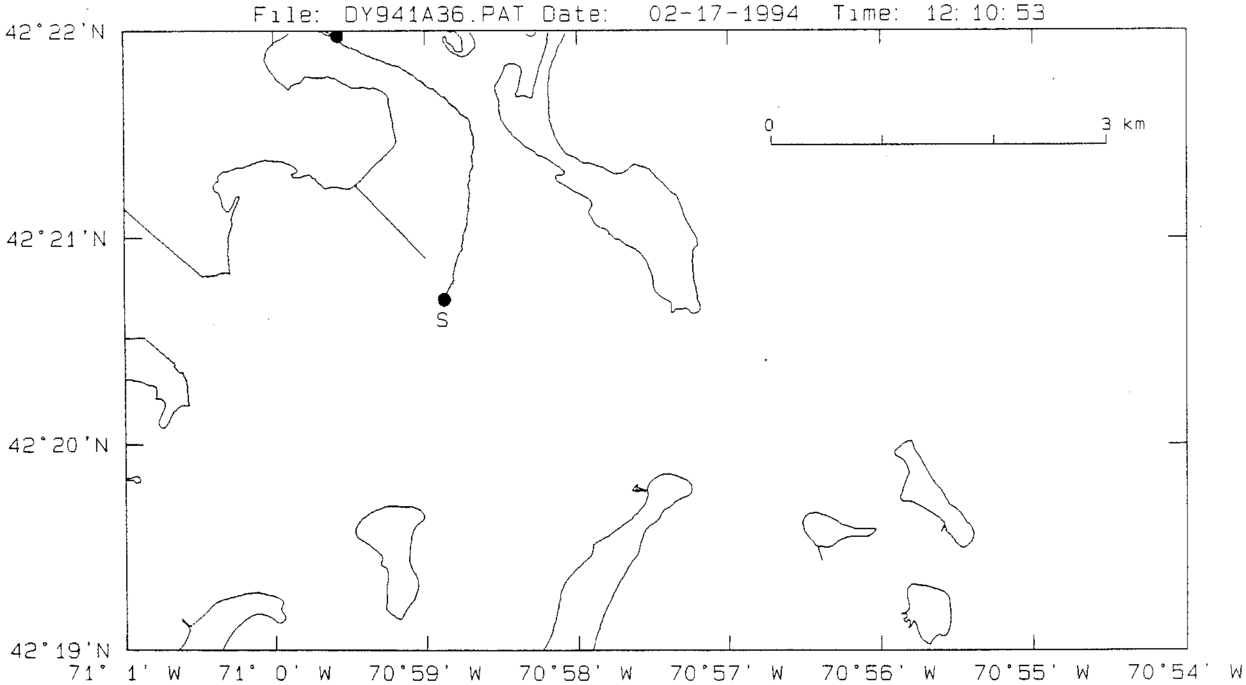


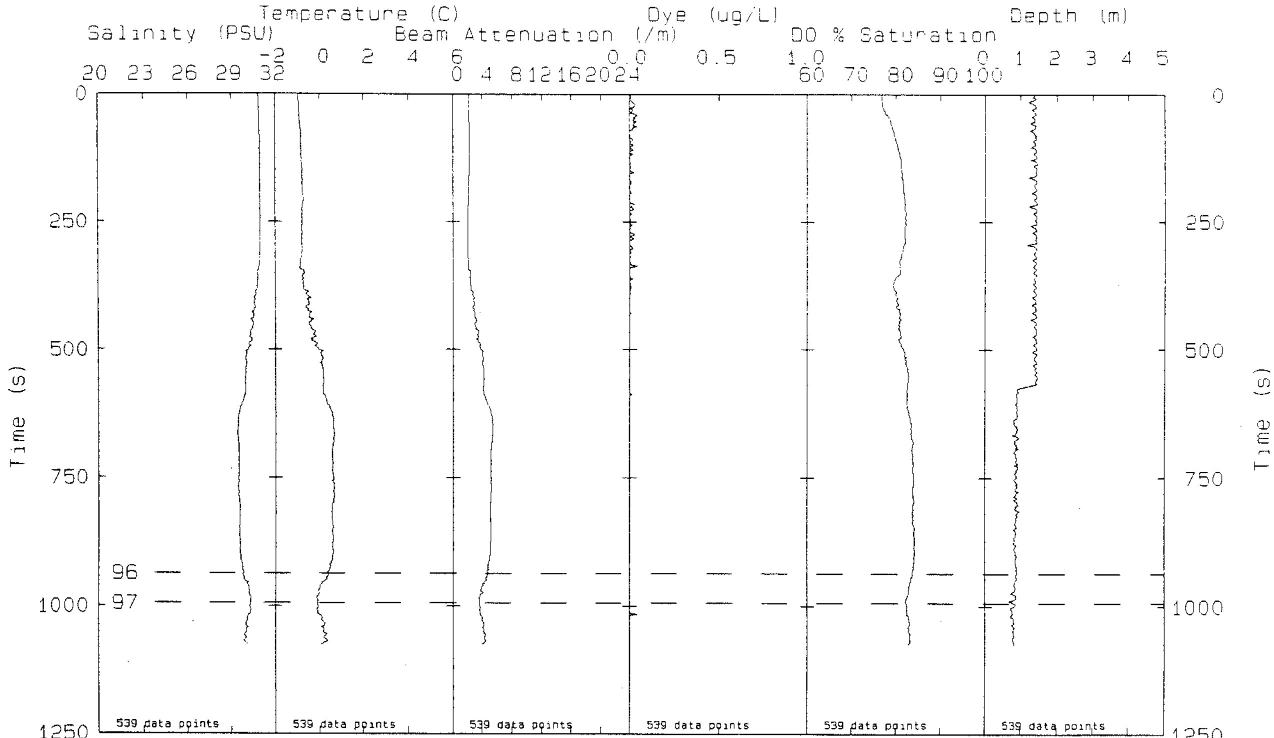
06-28-1994 16:22:41 Battelle



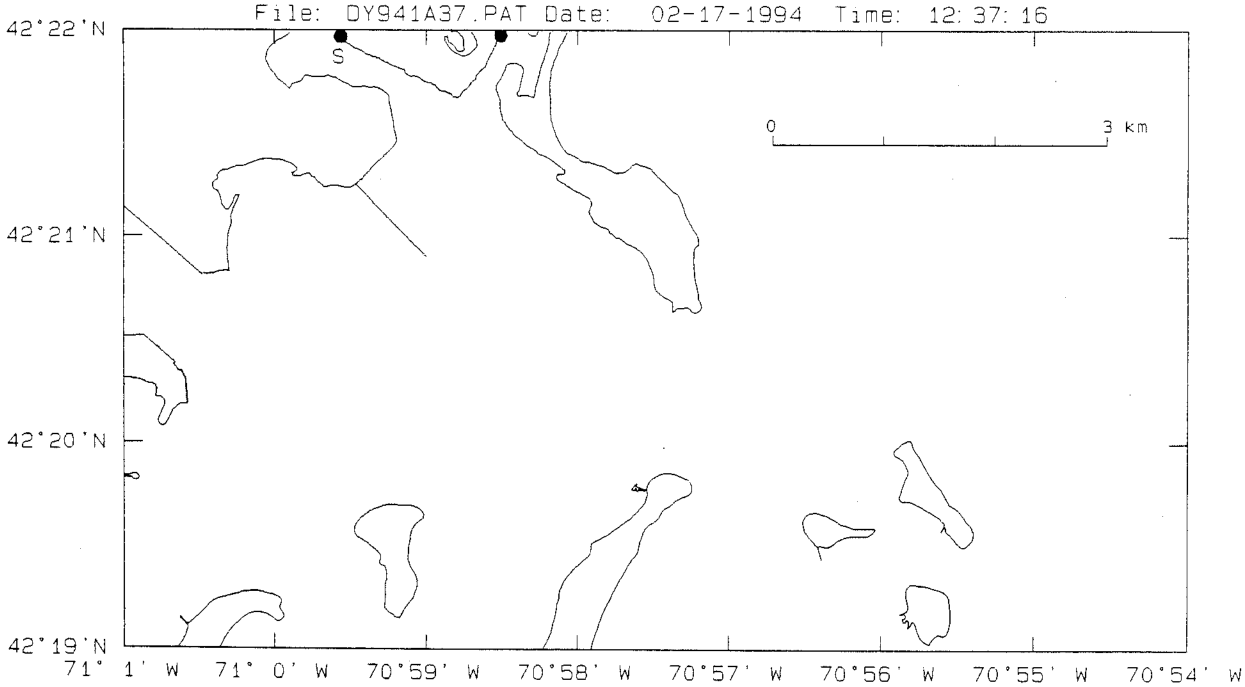
Dye Study File: DY941A36.PAT Date: 02-17-94 Time: 12:10:53

File: DY941A36.PAT Date: 02-17-1994 Time: 12:10:53





Dye Study File: DY941A37.PAT Date: 02-17-94 Time: 12:37:16



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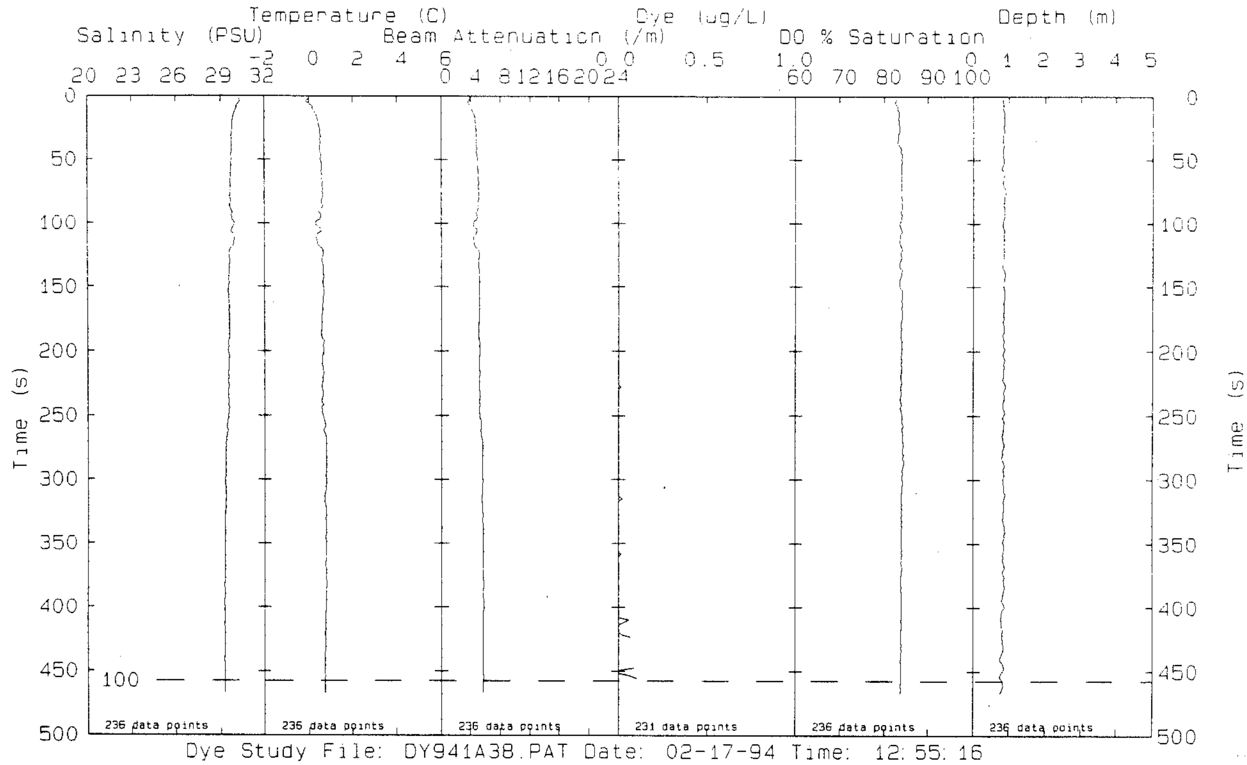
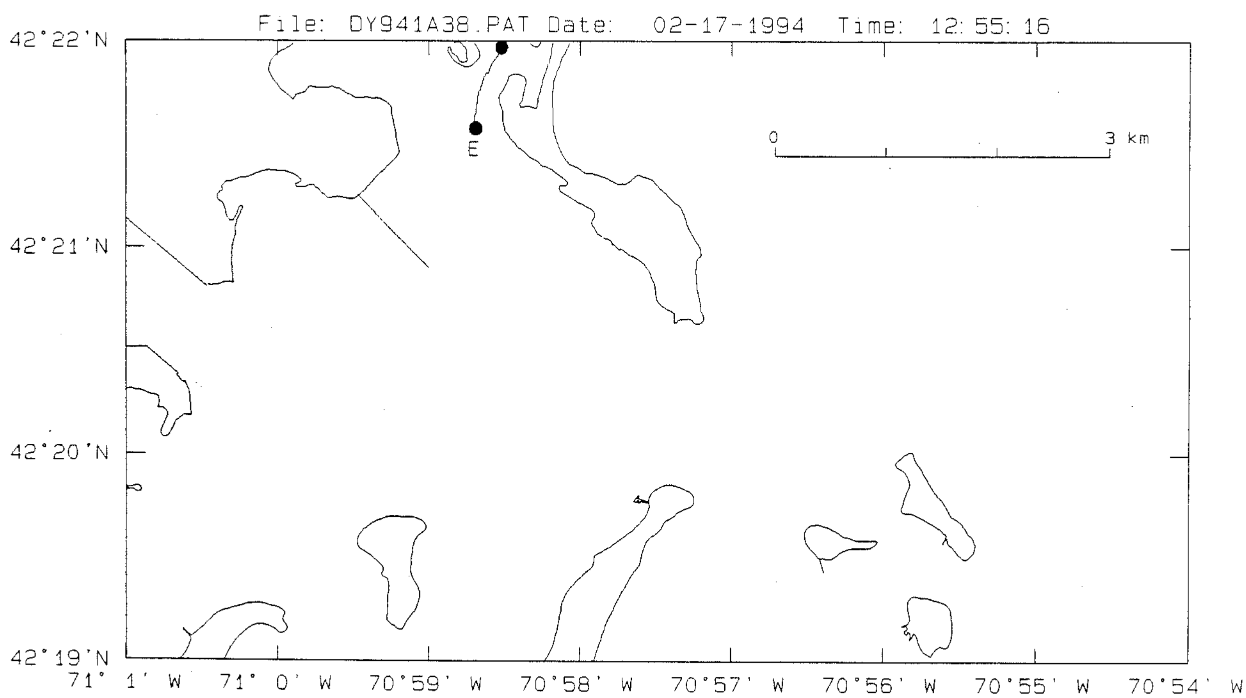
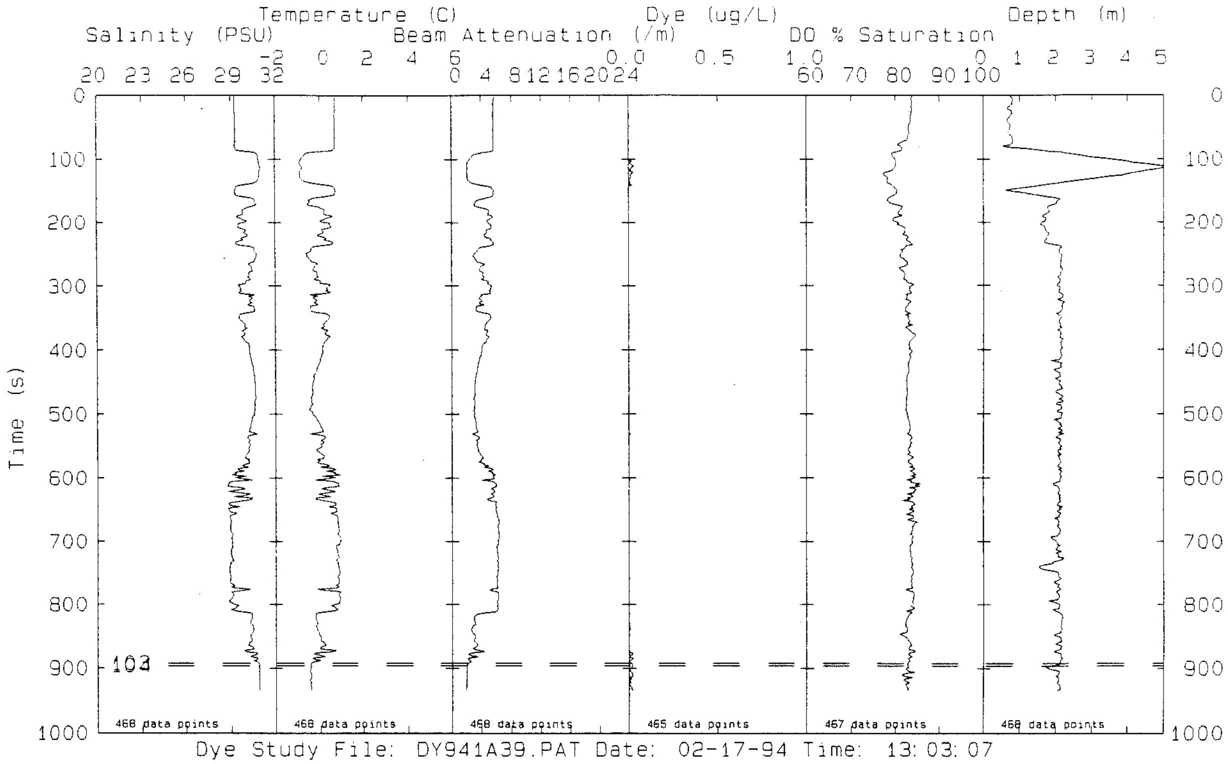
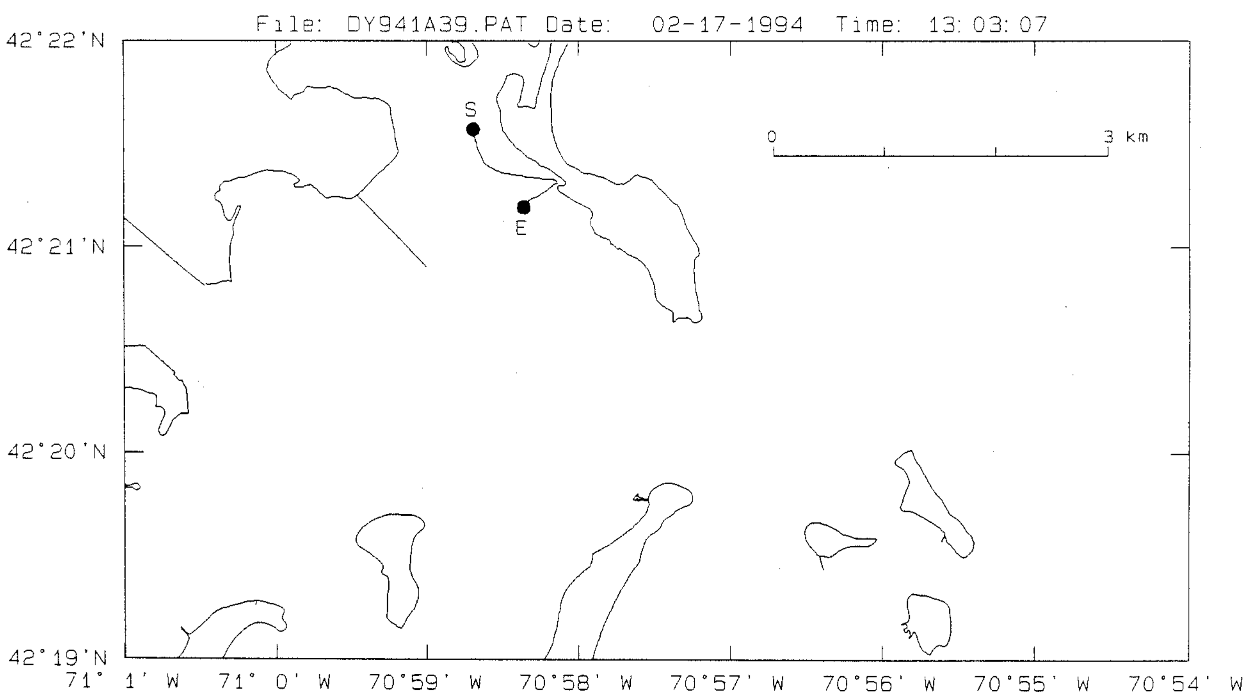
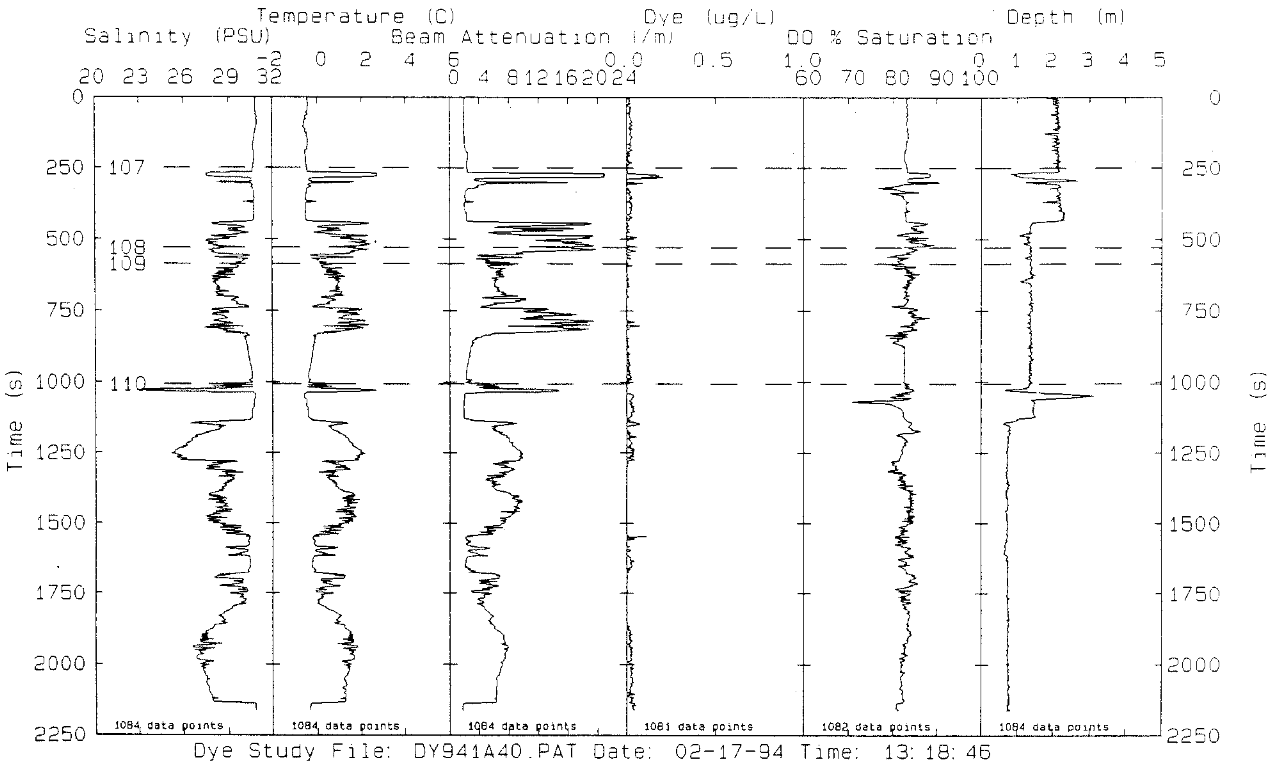

Temperature (C)
Salinity (PSU)
Beam Attenuation (/m)
Dye (ug/L)
DO % Saturation
Depth (m)
Time (s)
100
236 data points
231 data points
Dye Study File: DY941A38.PAT Date: 02-17-94 Time: 12:55:16


File: DY941A38.PAT Date: 02-17-1994 Time: 12:55:16
42°22'N
42°21'N
42°20'N
42°19'N
71° 1' W
71° 0' W
70°59' W
70°58' W
70°57' W
70°56' W
70°55' W
70°54' W
E
0
3 km

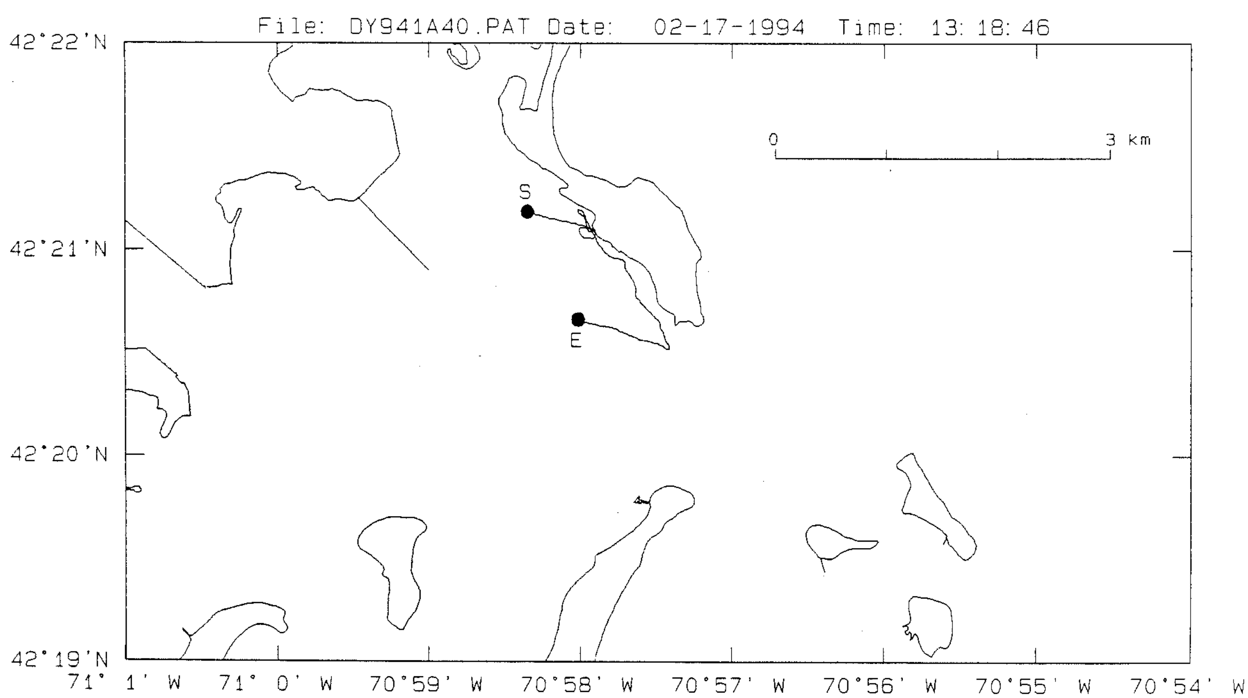




06-28-1994 16 23: 49 Battelle



Temperature (C)
Salinity (PSU)
Beam Attenuation (/m)
Dye (ug/L)
DO % Saturation
Depth (m)
Time (s)
107
108
109
110
1084 data points
1081 data points
1082 data points
Dye Study File: DY941A40.PAT Date: 02-17-94 Time: 13: 18: 46



File: DY941A40.PAT Date: 02-17-1994 Time: 13: 18: 46
42°22'N
42°21'N
42°20'N
42°19'N
71° 1' W
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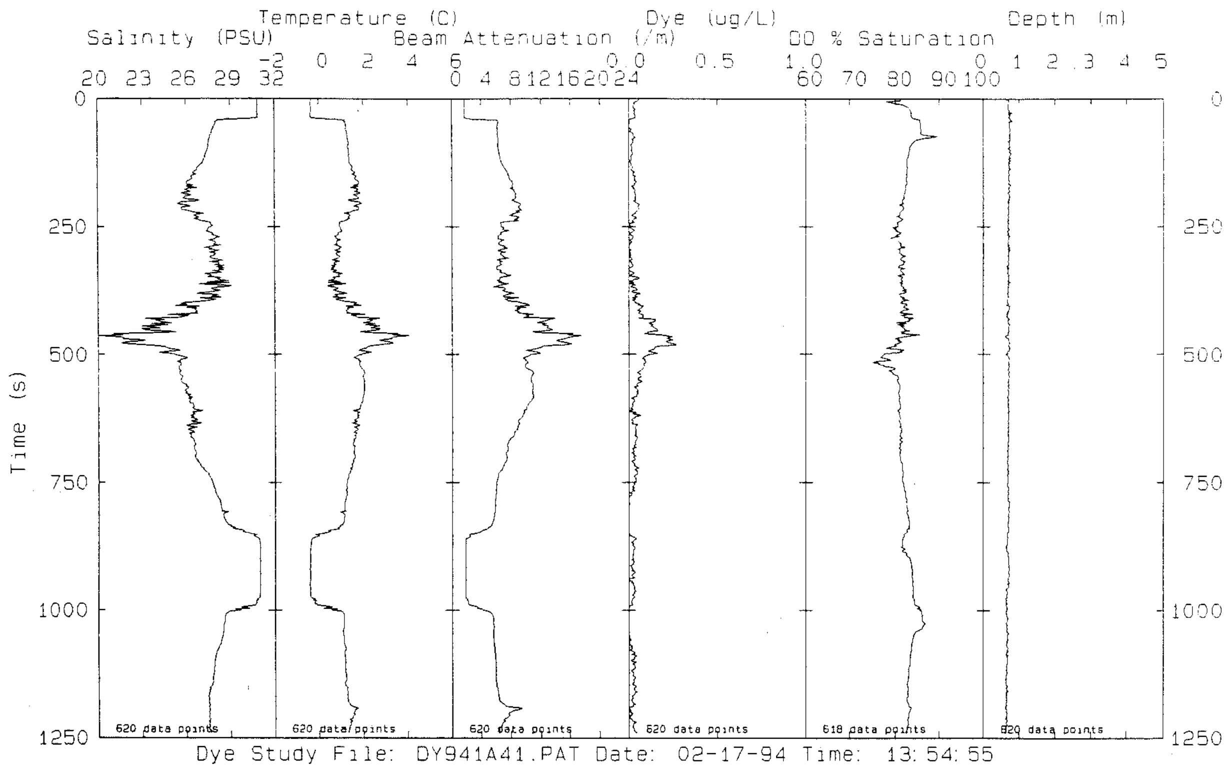
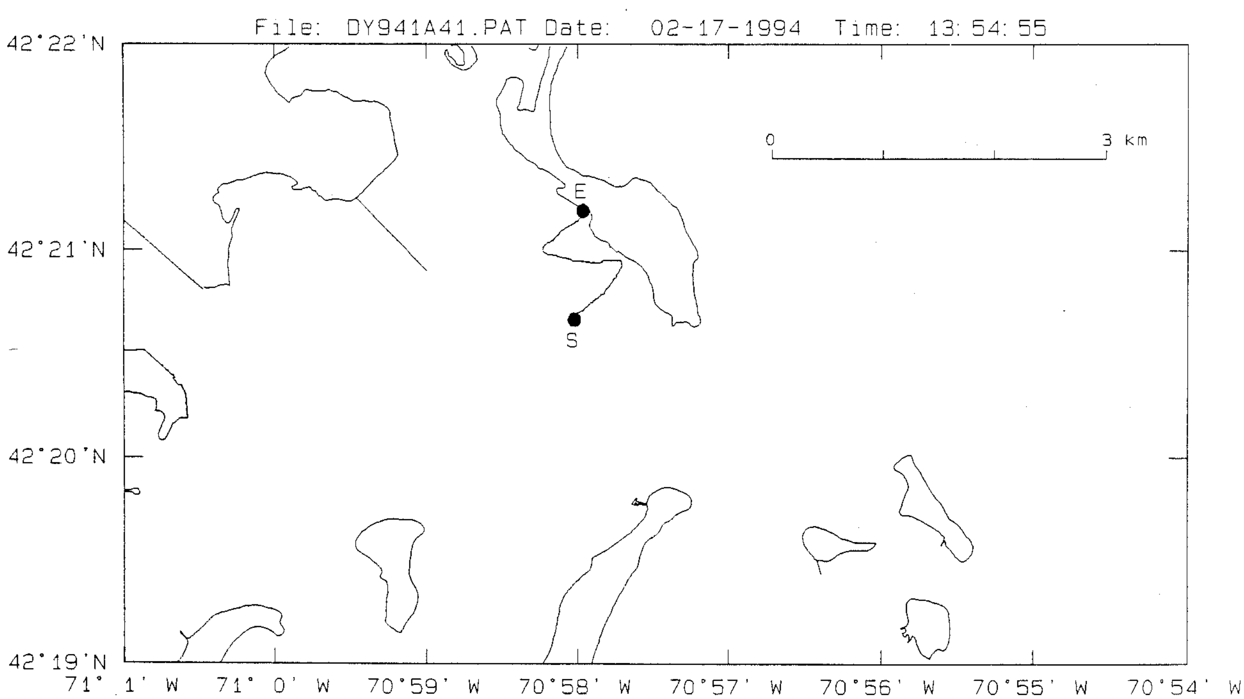
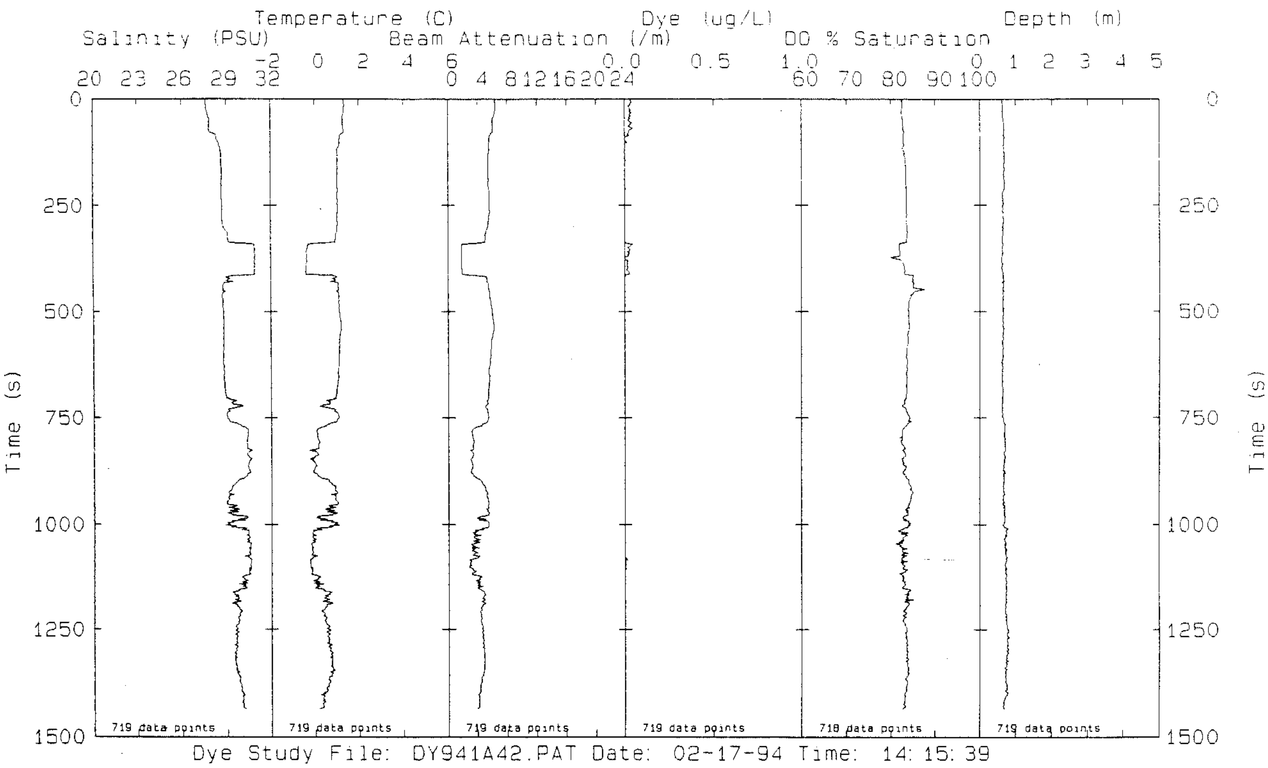
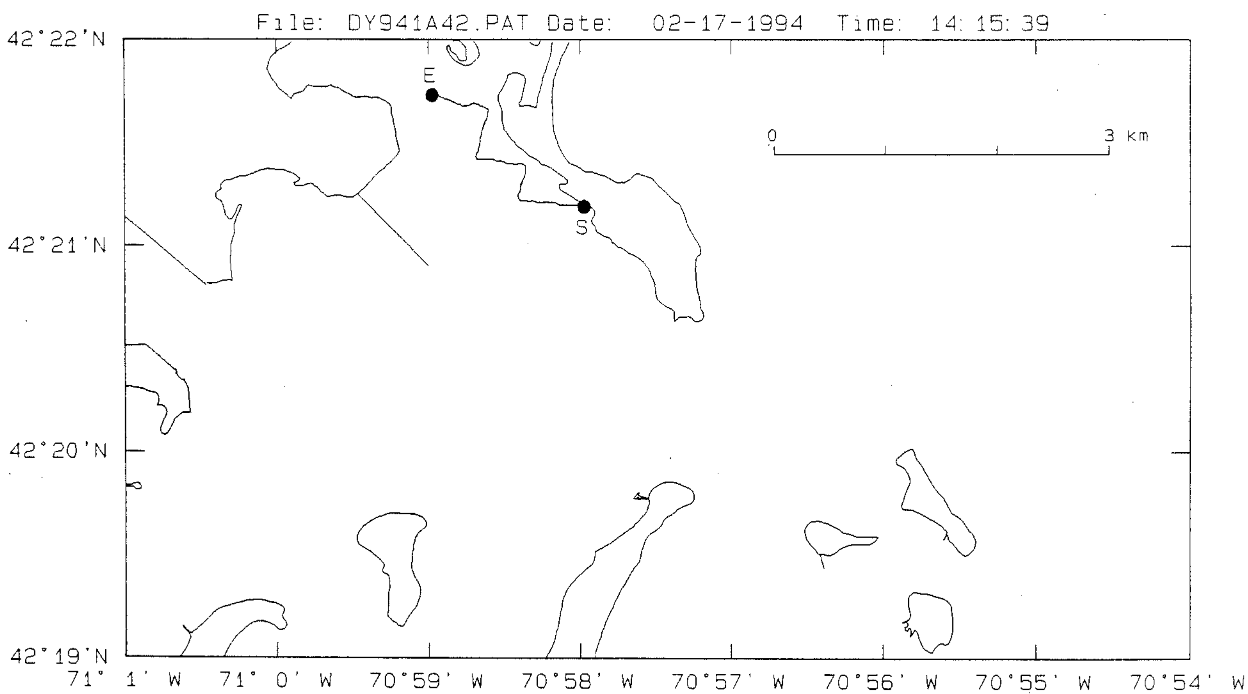
70°56' W
70°55' W
70°54' W
0
3 km
S
E

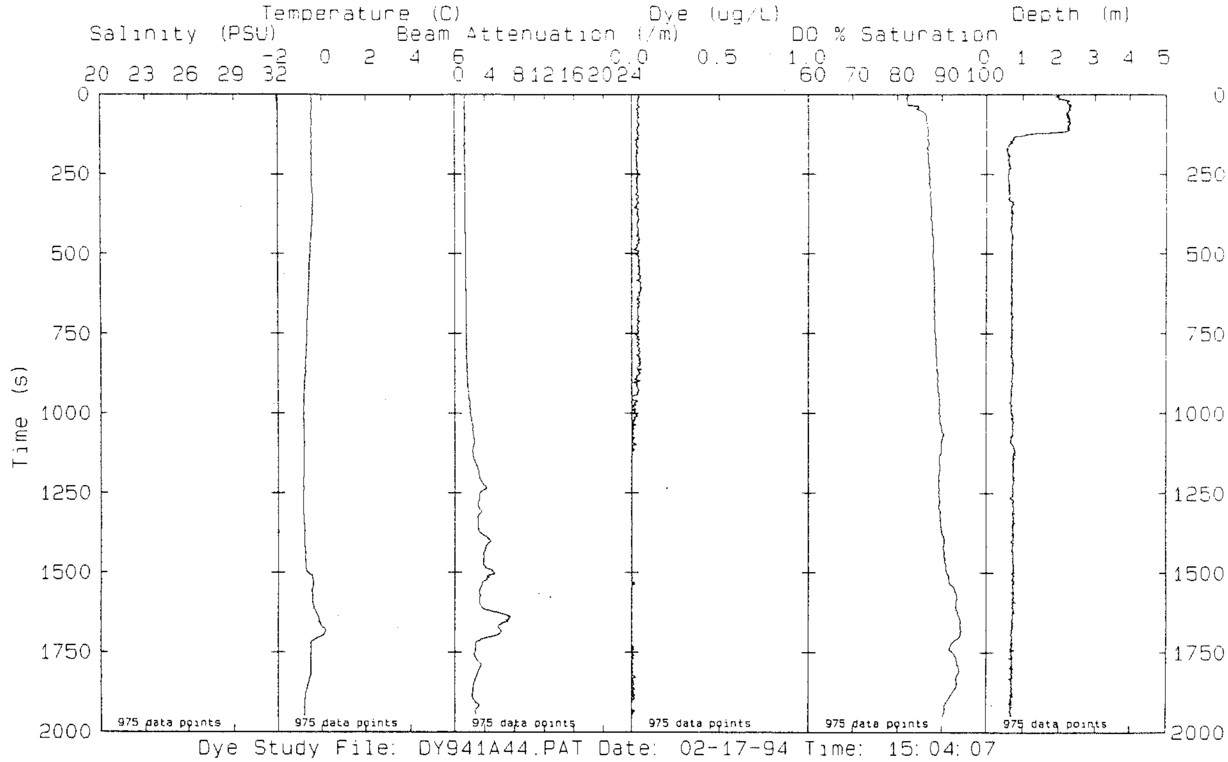


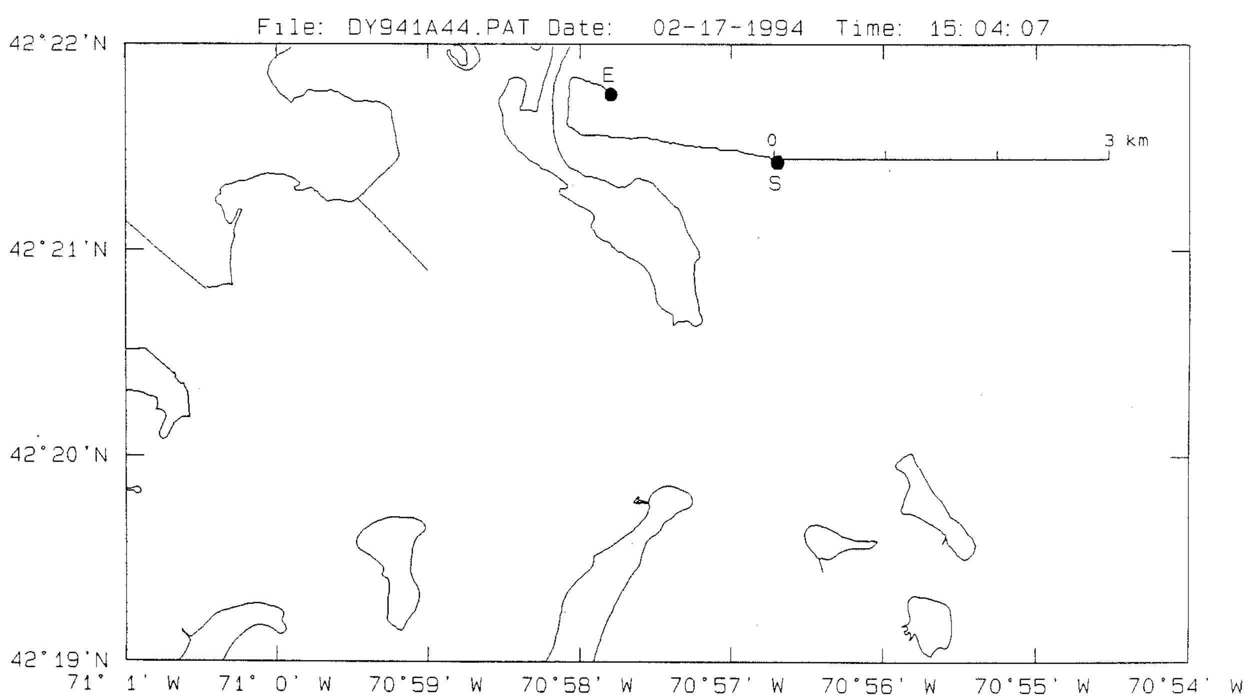


06-28-1994 16:24:46 Battelle


Temperature (C)
Salinity (PSU)
Beam Attenuation (/m)
Dye (ug/L)
DO % Saturation
Depth (m)
-2 0 2 4 6
20 23 26 29 32
0 4 8 12 16 20 24
0.0 0.5 1.0
60 70 80 90 100
0 1 2 3 4 5
0
250
500
750
1000
1250
1500
Time (s)
719 data points
718 data points
Dye Study File: DY941A42.PAT Date: 02-17-94 Time: 14:15:39


File: DY941A42.PAT Date: 02-17-1994 Time: 14:15:39
42°22'N
42°21'N
42°20'N
42°19'N
E
S
0
3 km
71° 1' W
71° 0' W
70°59' W
70°58' W
70°57' W
70°56' W
70°55' W
70°54' W





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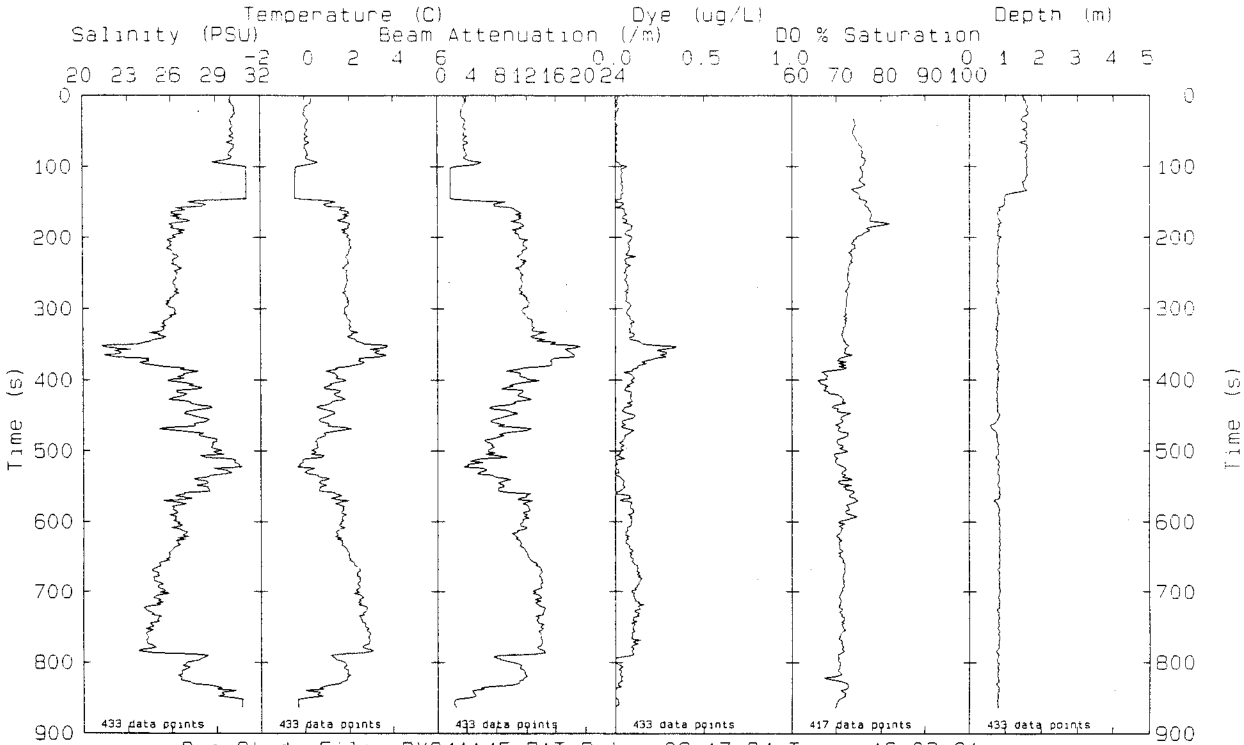
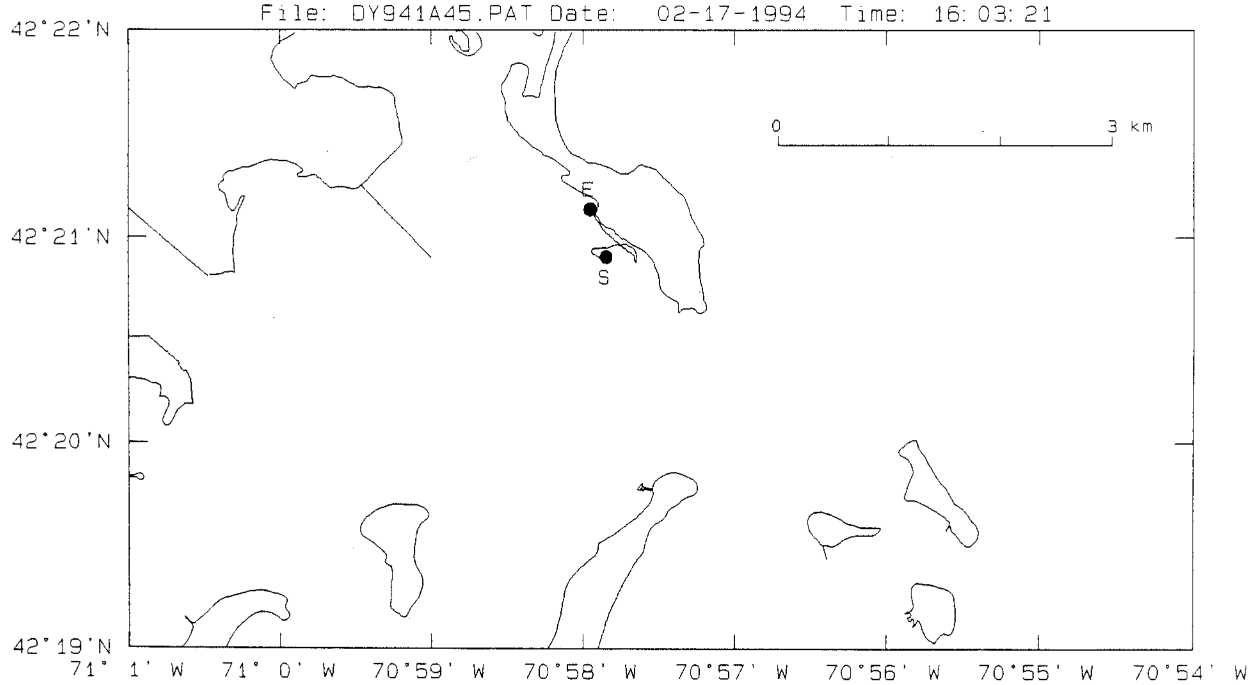
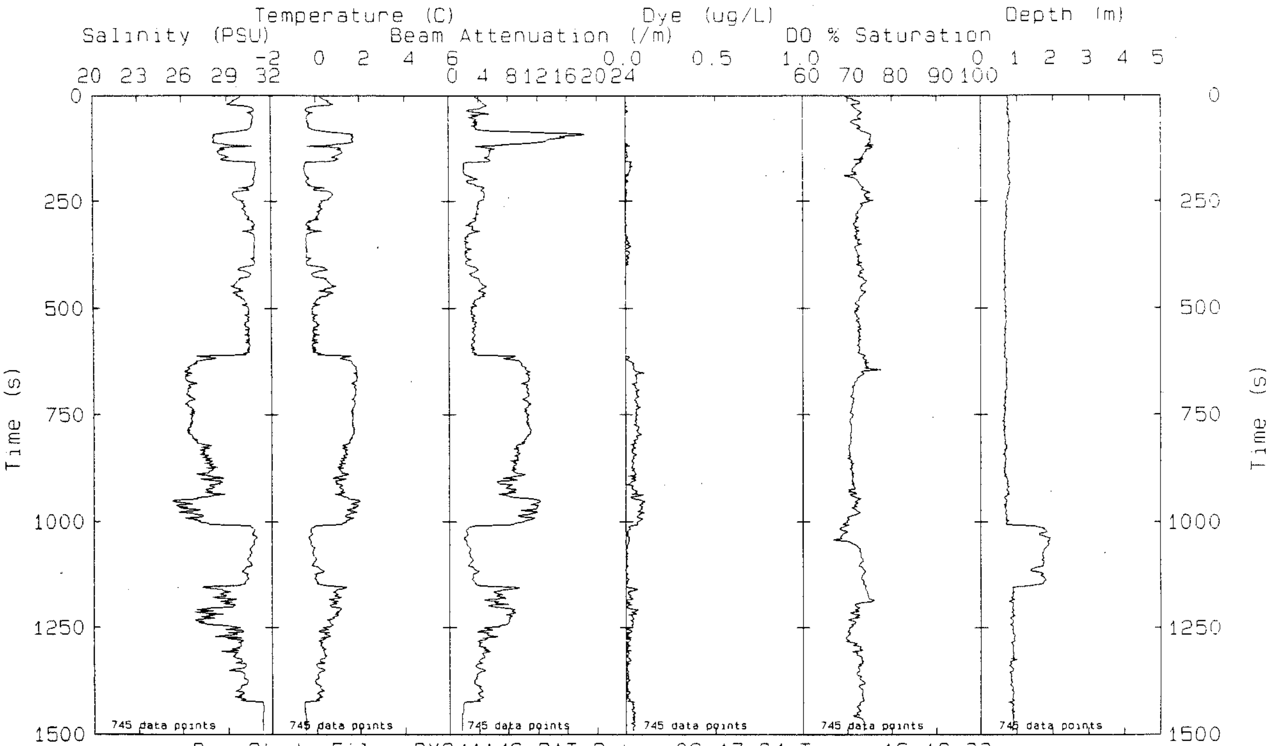


Dye Study File: DY941A45.PAT Date: 02-17-94 Time: 16:03:21

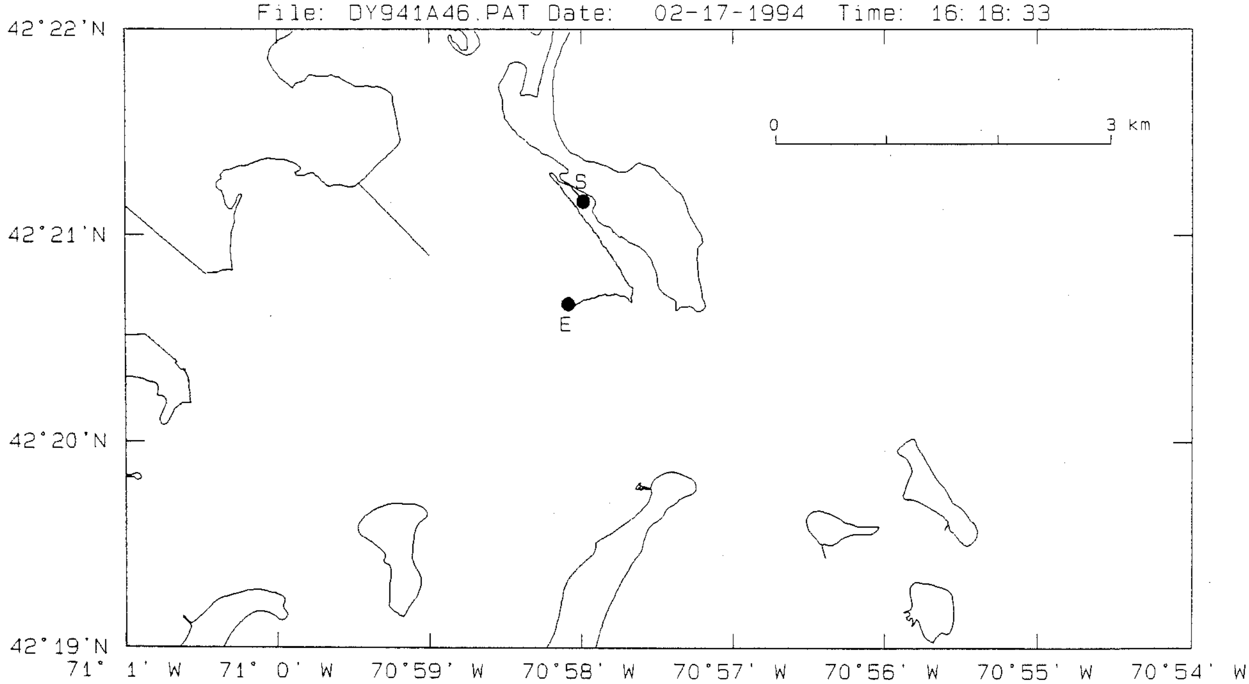
File: DY941A45.PAT Date: 02-17-1994 Time: 16:03:21





Dye Study File: DY941A46.PAT Date: 02-17-94 Time: 16:18:33

File: DY941A46.PAT Date: 02-17-1994 Time: 16:18:33



06-28-1994 16.26:21 Battelle