Oceanographic Measurements—Salinity, Temperature, Suspended Sediment & Turbidity, Minas Passage Study Site

June - August 2009

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EXECUTIVE SUMMARY

Oceanographic measurements in the Minas Passage and Cape Sharp area, which included possible sites for tidal device installations and cable routing, were made in June, July and August, 2009 as part of a survey to provide baseline information for monitoring the tidal power demonstration site in the area. Water column temperature, salinity and turbidity profiling; and water column sampling for suspended sediment, were undertaken at three benchmark stations in the tidal power study area and at five stations in a cross section of Minas Passage extending from Cape Sharp. Salinities and temperatures observed were comparable to literature values for Minas Passage and inner Bay of Fundy, while turbidity and corresponding levels of suspended sediment, among the first to be measured for the Minas Passage, were comparable to or slightly higher than literature values. Suspended sediment measurements showed moderate variability even during a single survey. The water column was vertically homogenous at all sites due to mixing by tidal currents. Small differences in all parameters with tidal stage and location, as well as position across Minas Passage, were observed. Salinity ranged from about 30.1 to 31.0˚/₀₀, temperature from 10.0 to 14.8˚C; turbidity from 0.7 to 4.9 NTU; and suspended sediment from about 3.25 to 14.9 mg/L over the June to August period. The seasonal cycles of salinity, temperature and turbidity at the site show little annual variation of salinity; a pronounced temperature cycle which peaks in August-September and is lowest in February-March; and turbidity which is lowest in June and low in summer, and peaks in February-March.

INTRODUCTION

Nova Scotia's Bay of Fundy has the highest tides in the world and the greatest potential for generation of electricity from the tides. In part to further its commitment to a sustainable energy future for Nova Scotians, the Province of Nova Scotia has undertaken to establish a research and test facility for tidal power technology development, and selected Minas Basin Pulp and Power Limited of Hantsport, Nova Scotia, to develop the necessary infrastructure and coordinate use of the site by interested companies and organizations which produce tidal energy devices (tidal device providers) and which will partner in the project. The project to develop the test facility was inaugurated in January 2008 and includes engineering and environmental components, the latter to provide information on the physical conditions such as currents, relating to the supply of tidal energy as well as for adequate device design; seabed geology and geotechnical information for device installation; and background information on the oceanography, biology, fisheries, and socioeconomic environment, relating to the governmental and public environmental assessment/ regulatory processes under which the project must operate. The environmental approval for the project was awarded in September 2009, but a program to extend baseline monitoring and carry out additional seabed surveys was begun in late June 2009, to meet expected monitoring requirements of the project. Subsequently the legal entity to operate the project—the Fundy Ocean Research Centre for Energy—was established and is currently managing operation and construction of the facilities, and monitoring and environmental programs for the project.

Physical oceanographic measurements of water column temperature, salinity, turbidity and suspended sediment levels were obtained as part of the survey program involving seabed photography and video assessment in both the summer of 2008 and the winter and summer of 2009. The present report covers the results of baseline data collection which took place in June to August, 2009, and provides an overview of all data acquired to date, as part of the baseline information gathering requirements for the project.

METHODS

Field Sampling—Oceanographic measurements were made between camera deployments for the seabed survey, which occupied approximately 1-2 hours during the slack tide period. Cruises on which measurements were taken took place on June 18, July 2-3 and August 4-5, 2009, using the MV *Tide Force*, a 50-foot wide-bodied lobster boat operated by Mark Taylor, Centreville, N.S., out of Hall's Harbour. Scientific crew included Patrick Stewart, M.Sc. (Envirosphere Consultants), Brent Smith (Seaforth Geosurveys, Dartmouth), and Ulrich Lobsiger (Ulrich Lobsiger Consulting, Halifax)(July survey).

Depth profiles of salinity, temperature, and turbidity were measured using a Seabird SBE 19plus V2 SEACAT CTD profiler equipped with a low and high range optical backscatter sensor (OBS) (Campbell Scientific OBS-3+ Suspended Solids and Turbidity Monitor, with low and high-range sensors), although levels were always in the range sampled by the low-range sensor and only this sensor was used for analysis; the CTD was lowered at approximately 1 m/s and sensors were sampled at a frequency of 4/second. Three stations (Stations 3, 9 & 19) sampled on earlier cruises (Envirosphere Consultants Limited, 2009) (Tables 1 and A1) were routinely occupied on flood and ebb tides, and five stations were occupied in a transect across Minas Passage from Cape Sharp to a point midway between Cape Blomidon and Cape Split during the June and July surveys (Figure 1)[1] to provide additional background information of potential relevance to other studies of oceanography and sediment transport in relation to tidal power impacts. In July, ten shallow water stations (TU1 to TU10) were also occupied in shallow water near the location of the shore facilities to obtain additional water samples and, it was hoped, a range of suspended sediment levels, for OBS sensor calibration (Table 1, Figure 2).

Table 1. Locations of CTD stations, Minas Passage, June – August, 2009.

Station	Latitude[1]	Longitude[1]	Depth (m)[2]
3	45° 22.074’ N	64° 26.176’ W	46.4
9	45° 21.765’ N	64° 26. 211’ W	31.5
19	45° 22.098’ N	64° 25.679’ W	43.2
OC1	45° 21.687’ N	64° 23.642’ W	34.5
OC2	45° 21.125’ N	64° 23.748’ W	69.0
OC3	45° 20.621’ N	64° 23.849’ W	94.6
OC4	45° 20.118’ N	64° 23.957’ W	89.1
OC5	45° 19.576’ N	64° 24.058’ W	31.6
TU1	45° 22.217’ N	64° 24.503’ W	0.0
TU2	45° 22.204’ N	64° 24.662’ W	3.7
TU3	45° 22.205’ N	64° 24.711’ W	5.4
TU4	45° 22.196’ N	64° 24.975’ W	7.3
TU5	45° 22.245’ N	64° 24.858’ W	2.8
TU6	45° 22.281’ N	64° 25.199’ W	4.1
TU7	45° 22.181’ N	64° 24.470’ W	0.4
TU8	45° 22.225’ N	64° 24.639’ W	1.5
TU9	45° 22.166’ N	64° 24.431’ W	3.0
TU10	45° 22.158’ N	64° 24.406’ W	2.9

1. Nominal Positions are presented for all but “TU” stations—Actual positions are presented in Appendix D. 2. Depths below MLW from digital elevation model or CHS charts.

Routine stations were chosen to represent major bottom types over which different conditions of re-suspension might occur: sedimentary bedrock outcrops (Station 3), cobble and boulder bottom (Station 19); and basalt bedrock platform (Station 9). Water samples at routine stations were taken to calibrate the CTD using a 5-L Niskin water sampler attached so it’s mid-point was 2 m above the OBS sensor on the CTD; samples were taken at 1 m below surface, estimated mid-depth, and from the deepest depth reached by the CTD to obtain information on suspended sediment levels and composition concurrent with the CTD record. For the ten-nearshore calibration stations occupied in July, the sampler was placed with the mid-point 1 m above the OBS sensor; the CTD and sampler was lowered to the maximum depth and a water sample was taken immediately. Samples were collected in 500 mL polyethylene bottles in June and subsequently in 1 L bottles. At all regular stations the CTD was lowered into the water at about 0.5 m depth and allowed to stabilize for about 1 minute before lowering to the greatest depth available, the Niskin was triggered, and the sample returned to the surface. The sample was removed while the CTD remained submerged, and a second cast to mid-depth was undertaken. A final, 1 m sample was taken with the CTD off. The CTD output files in text format are contained in a CD attached to this report.

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[1] In June, the transect across Minas Passage was sampled only on the ebb tide because the cruise was cut short due to camera equipment failure.

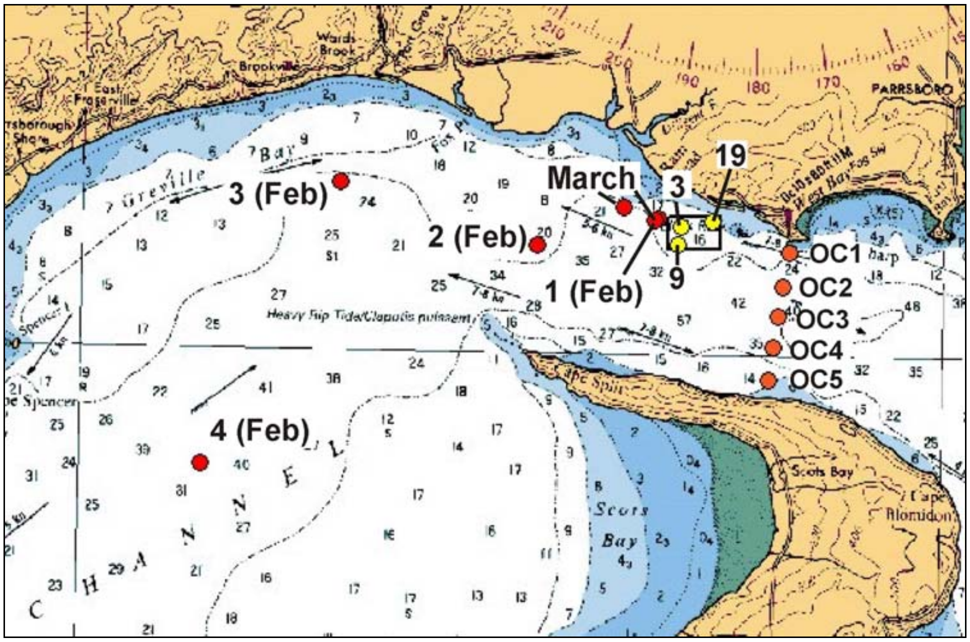

Figure 1. Stations for CTD and TSS measurements, 2009. Box indicates area designated for tidal device deployments.

All sampling was done while the tide was running, and the high tidal currents made logistics for sampling difficult. We elected to sample while drifting with the current, and so to represent the water mass (i.e. Lagrangian frame of reference), presuming that suspended sediment potentially re-suspended by the tidal currents would reach a steady state in the water column associated with the water mass. Holding station while sampling would also have resulted in problems with the sampling array trailing out on an angle from the vessel, making it difficult to trigger the water sampler and to estimate the position of the CTD and water samples in the water column. As a consequence of sampling while drifting, however, we could not lower the CTD or sample close to the bottom[2]. The vessel also moved a significant distance during each sampling event; motoring back to sites against the current was time-consuming and often impractical. Sampling at slack tide was not possible as the video and photographic survey for the project, which required low current conditions, was carried out at that time.

In addition to the CTD measurements, a standard secchi disk (22 cm diameter) was lowered on the ebb tide during the June 18, 2010 cruise only, at one of the main stations (Station 19) and at the five cross-sectional stations (OC1 to OC5) off Cape Sharp.

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[2] The maximum depth sampled by the CTD which is presented in this report can be compared to the depth below MLW for the site estimated from the digital elevation model, if this is required.

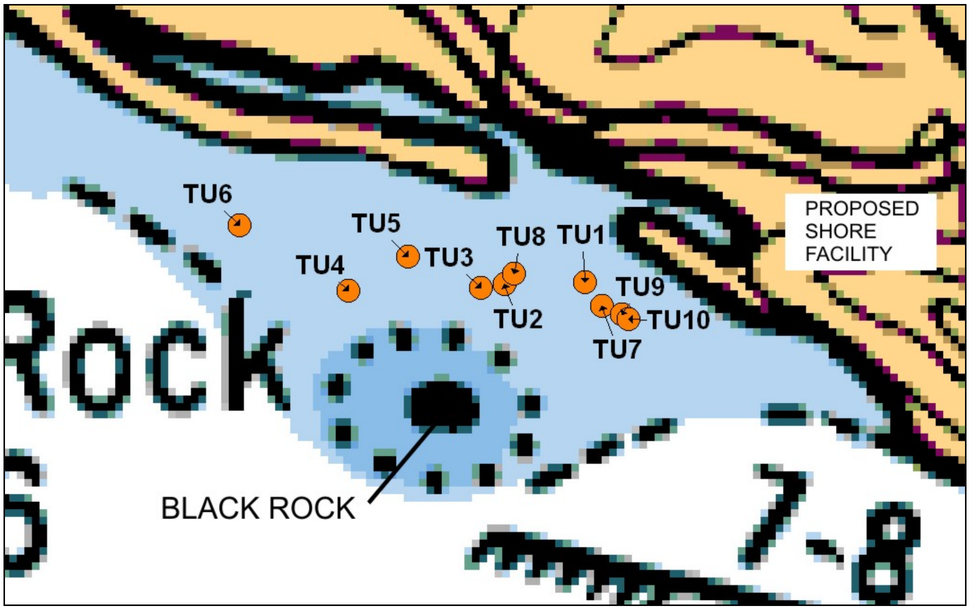

Figure 2. Additional sampling locations for turbidity calibration, July 2009.

Laboratory Measurement of TSS—Levels of total suspended solids in water samples were determined gravimetrically by filtering measured volumes of samples onto pre-weighed 47 mm, 0.45 µm pore size, Millipore membrane filters, subsequently rinsed with deionized water to remove salts, and dried at 60˚ C. for one hour. A Mettler AB104S balance accurate to 0.1 mg checked regularly against traceable standard weights was used for measurements and all analyses were conducted at Envirosphere Consultants Limited lab in Windsor, N.S. Due to the low levels of SPM encountered, the methodology was modified during the summer to filter larger volumes of water[3], allowing greater precision in measurements at the low levels of SPM involved. The analysis was carried out using a standard method based on Standard Methods (2005), Method 2540D, Total Suspended Solids, by an experienced technician. Filters were stored frozen after analysis.

Data Analysis—CTD records were examined to provide: 1) depth plots of temperature, salinity and turbidity; and 2) point turbidity data to correspond to water samples taken to calibrate the instrument. For each cast in which a water sample was taken, the instrument depth at the time of sampling was determined, the depth of the sampler estimated (instrument depth minus 2 m) and ten measurements surrounding the sample depth from the down- and upcast traces were extracted and averaged. The surface value of turbidity was estimated from the first ten measurements on the down and last ten measurements upcast record; only measurements before 0.5 m were used. In July, for the ten additional stations occupied for instrument calibration, turbidity values estimated for the position of the sampler were used and ten measurements before and after the sample was taken were averaged to give a value to correspond to the calibration sample.

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[3] 2 x 100 mL aliquots from a Class "A", wide mouth, volumetric pipettes were filtered for June & July samples (consistent with the approach used earlier in the program) and approximately 950 mL was filtered in August using a combination of volumetric pipettes and graduated cylinders, due to the low concentrations of suspended matter observed.

RESULTS AND DISCUSSION

General—Depth profiles of temperature, salinity and turbidity obtained in the surveys are presented in Appendices C to E for the June, July and August cruises respectively, separated into downcast and upcast (data recorded as the instrument was lowered to the greatest depth, and raised, respectively)(data outputs of the CTD data are contained in an attached CD). All the profiles of temperature, salinity, and turbidity showed the vertically homogenous water column, with some microstructure, including occasional turbidity spikes, but no analysis was conducted to summarize the variability.

Transparency—Secchi depth (a measure of water transparency) was only measured during the June survey. Secchi depths[4] during the survey ranged from 5.3 to 6.1 m, indicating moderately high transparency, corroborating the generally low turbidity values observed (see below)(Table 2). These are higher than levels of 3.00 to 3.75 m noted to characterize Minas Channel and more in line with levels for outer Bay of Fundy (5.75 to 10.25 m) (Huntsman (1952) from Bousfield and Leim 1959). Underwater video recorded on the same cruise interpreted by the author also showed high water transparency and absence of particulate matter.

Table 2. Secchi depth measurements, June 18, 2009.

Station	Secchi Depth (m)
19	5.8
OC1	5.3
OC2	5.3
OC3	6.1
OC4	5.3
OC5	5.5

Local Variations of Temperature, Salinity and Turbidity—The water column was well mixed on all occasions, with a small range of salinity, temperature and turbidity observed (Appendix B, Table B-1, Appendix C-E). Differences between surface and bottom temperature and salinity were not examined in detail, but they were small, based on the range of temperatures and salinity observed (Appendix B, Table B-1). The average difference between maximum and minimum temperatures on a CTD cast were less than 1% (maximum 3.7%) and for salinity less than 0.2% (maximum ~0.6%). Turbidity appeared to be routinely slightly higher in the bottom measurements than at the surface although corresponding measurements for total suspended solids showed greater variation and did not demonstrate differences between surface and bottom water (Figure 3). Variability of salinity, temperature and turbidity through the water column based on all data points in CTD casts as shown by standard deviations was small and similar between surveys, with no obvious patterns related to tide stage or location (Table B-1, Figure B1). Variability relative to the mean was small for salinity and temperature (less than 0.2 and 0.8% respectively), but from about 7 to 28% for turbidity (Figure B2), highest in June when turbidity was lowest. This ‘noise’ in the turbidity signal may be due to larger particles which occur in the water column [seen in underwater video] passing the OBS sensor.

Differences between tide stage in salinity, temperature and turbidity, were small. At the study site, average temperature increased slightly as the ebb tide progressed in July, and was highest in the early flood stage, but no difference was observed between early ebb and early flood in August (Figure 4). Salinity decreased as the ebb progressed at Stations 3 and 9 in July and was lowest in early flood;

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[4] Secchi disk value is the average of the depth where the disk disappears on lowering and where it reappears on raising.

average salinities in August were similar between ebb and flood tide (Figure 5). Turbidity decreased from early ebb to early flood tide in July at two of the stations, and between ebb and flood in August (Figure 6).

Differences in temperature, salinity and turbidity were observed between stations in the cross section of Minas Passage at Cape Sharp (Figure 7-9). Temperature on the ebb tide was highest near Cape Sharp and lowest in the center of Minas Passage; on the flood tide, higher temperatures remain on the Cape Sharp side of Minas Passage but are not elevated on the south side (Figure 7). Lowest salinities were found on the ebb tide near Cape Sharp, intermediate levels in the center of the Passage and lower levels on the south side (Figure 8). On the incoming tide, lowest salinities occur along the Cape Sharp side and salinities on the south side are similar to those in the middle of Minas Passage. Turbidities appear to be lower on the Cape Sharp side for both ebb and flood tides, and highest on the south side of the Passage (Figure 9). No differences in salinity, temperature, or turbidity between ebb and flood tide were observed at stations located in the cross section of Minas Passage (Figures 7-9) in the June and July surveys.

Table 3. Suspended sediment and turbidity measurements, Minas Passage, June 18 – August 4, 2009.

	Bottom 2 m			**Mid-Water**			**Surface 1m**		
Station	**Depth (m)**	**Turbidity (NTU)(range)**	**TSS (mg/L)**	**Depth (m)**	**Turbidity (NTU)(range)**	**TSS (mg/L)**	**Depth (m)**	**Turbidity (NTU)(range)**	**TSS (mg/L)**
June 18, 2009									
19 ebb	24.7	0.39 (0.29-0.57)	13.75	20.5	0.38 (0.19-0.78)	8.00	0.9	0.21 (0.05-0.32)	7.50
July 2, 2009									
3 ebb	31.3	1.39 (1.20-1.58)	7.25	12.0	1.81 (1.31-3.71)	7.25	1.0	1.51 (1.34-1.79)	7.50
9 ebb	28.2	1.51 (1.34-1.77)	6.25	17.0	1.37 (1.15-1.54)	4.75	1.0	1.37 (1.20-1.55)	7.00
19 ebb	24.8	1.25 (1.05-1.39)	9.5	12.1	1.28 (1.14-1.42)	8.5	1.0	1.32 (1.03-1.75)	13.5
19 flood	37.0	1.26 (1.12-1.40)	6.25	23.7	1.27 (1.15-1.52)	5.0	1.0	1.32 (0.94-2.06)	8.0
July 3, 2009									
3 ebb+1	46.7	1.35 (1.23-1.51)	13.00	15.5	1.23 (1.09-1.39)	4.75	1.0	1.13 (0.94-1.26)	10.25
9 ebb+1	31.0	1.36 (1.21-1.60)	8.50	19.5	1.34 (1.10-1.48)	4.75	1.0	1.23 (1.09-1.34)	4.75
3 flood	41.1	0.99 (0.75-1.14)	–	–	–	–	1.0	0.94 (0.75-0.06)	–
9 flood	33.5	1.12 (0.94-1.24)	–	–	–	–	1.1	0.83 (0.78-1.00)	–
19 ebb	42.1	1.33 (1.18-1.58)	–	–	–	–	1.0	1.11 (0.66-1.30)	–
TU1 ebb	4.6	1.27 (1.05-1.67)	12.25	–	–	–	1.1	0.85 (0.71-0.94)	–
TU2 ebb	6.3	1.28 (1.02-1.48)	10.25	–	–	–	1.0	1.05 (0.93-1.21)	–
TU3 ebb	9.8	1.25 (1.00-1.54)	8.75	–	–	–	1.1	1.18 (1.02-1.39)	–
TU4 ebb	21.8	1.25 (0.96-1.57)	3.25	–	–	–	1.1	1.32 (1.05-1.57)	–
TU5 ebb	9.0	1.34 (1.10-1.54)	9.00	–	–	–	1.0	1.22 (1.08-1.42)	–
TU6 ebb	10.0	1.29 (1.03-1.58)	9.25	–	–	–	1.0	1.16 (1.00-1.26)	–
TU7 ebb	5.5	1.20 (1.03-1.45)	4.5	–	–	–	1.0	1.02 (0.81-1.26)	–
TU8 ebb	4.0	1.32 (1.19-1.69)	11.25	–	–	–	1.0	1.18 (1.05-1.28)	–
TU9 ebb	5.6	1.62 (1.26-2.37)	10.25	–	–	–	1.0	1.39 (1.24-1.60)	–
TU10 ebb	7.4	1.41 (1.25-1.69)	6.25	–	–	–	1.0	1.23 (1.11-1.30)	–
August 4, 2009									
3 ebb	44.1	1.66 (1.48-1.80)	10.21	24.5	1.66 (1.31-3.19)	8.34	1.0	1.48 (1.39-1.64)	9.78
3 flood	34.5	1.42 (1.18-1.75)	5.40	19.5	1.30 (1.06-1.45)	6.60	1.0	1.21 (1.03-1.39)	4.04
9 ebb	28.2	1.42 (1.28-1.55)	7.10	25.0	1.39 (1.24-1.7)	5.43	1.0	1.32 (1.23-1.39)	9.36
9 flood	48.2	1.44 (1.18-1.60)	5.47	38.0	1.31 (1.23-1.45)	3.40	1.0	1.30 (1.05-1.51)	5.26
19 ebb	38.7	1.65 (1.33-1.79)	6.52	23.8	1.60 (1.33-1.73)	6.28	1.1	1.31 (1.09-1.54)	14.90
19 flood	37.2	1.66 (1.43-1.92)	5.76	16.5	1.45 (1.28-1.75)	5.65	1.1	1.32 (1.21-1.48)	5.13

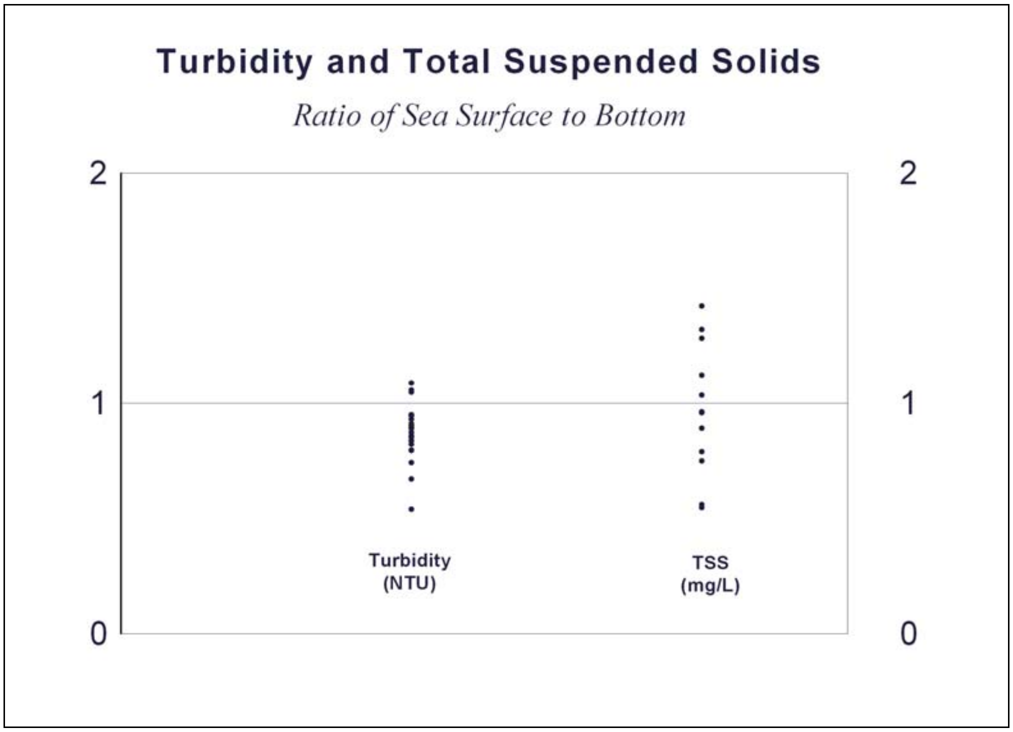

Figure 3. Comparison of variation in turbidity between surface and bottom measurements of turbidity (NTU) and total suspended solids observed in study area during June to August, 2009.

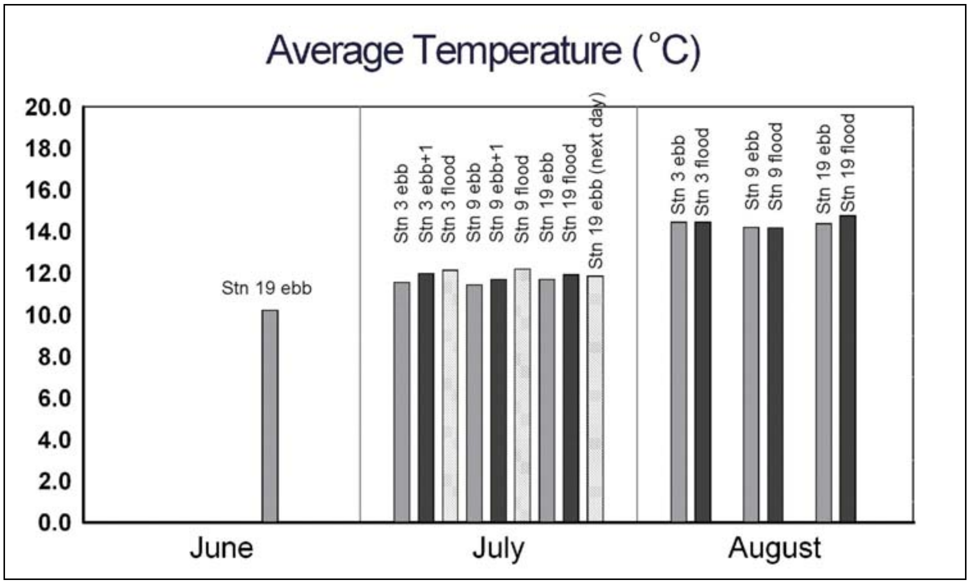

Figure 4. Average temperature of the water column at different tide stages at monitoring stations at the Bay of Fundy tidal power demonstration site, Minas Passage.

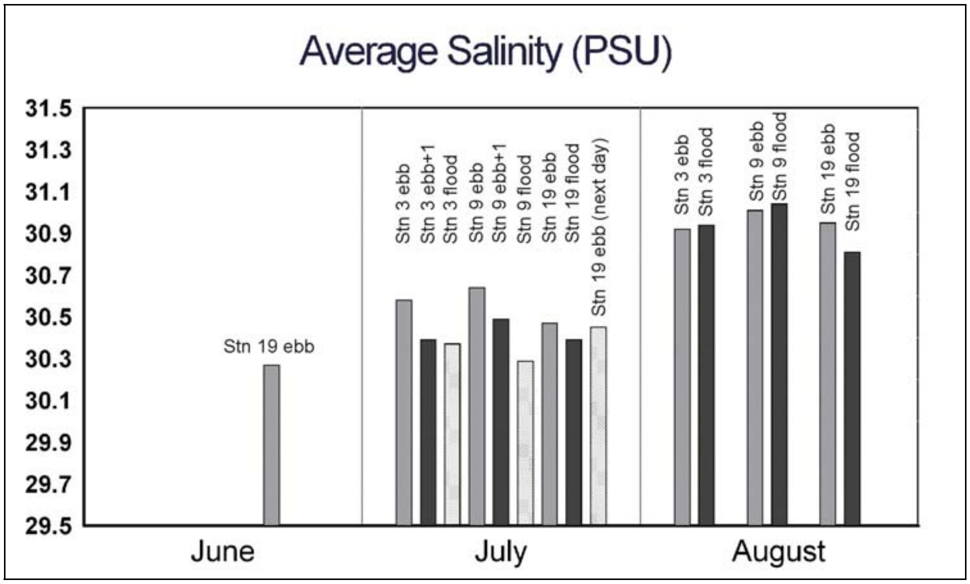

Figure 5. Average salinity of the water column at different tide stages at monitoring stations at the Bay of Fundy tidal power demonstration site, Minas Passage.

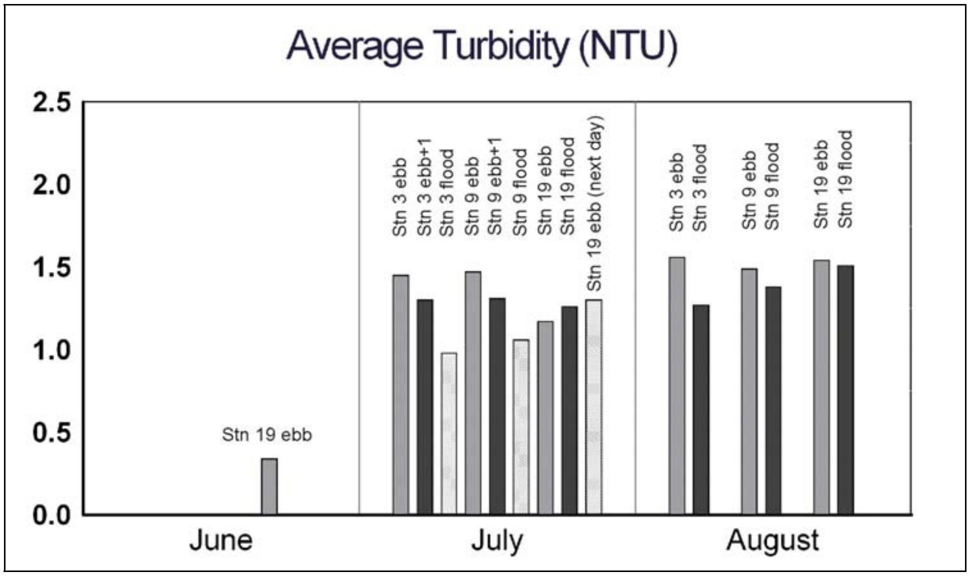

Figure 6. Average turbidity of the water column at different tide stages at monitoring stations at the Bay of Fundy tidal power demonstration site, Minas Passage.

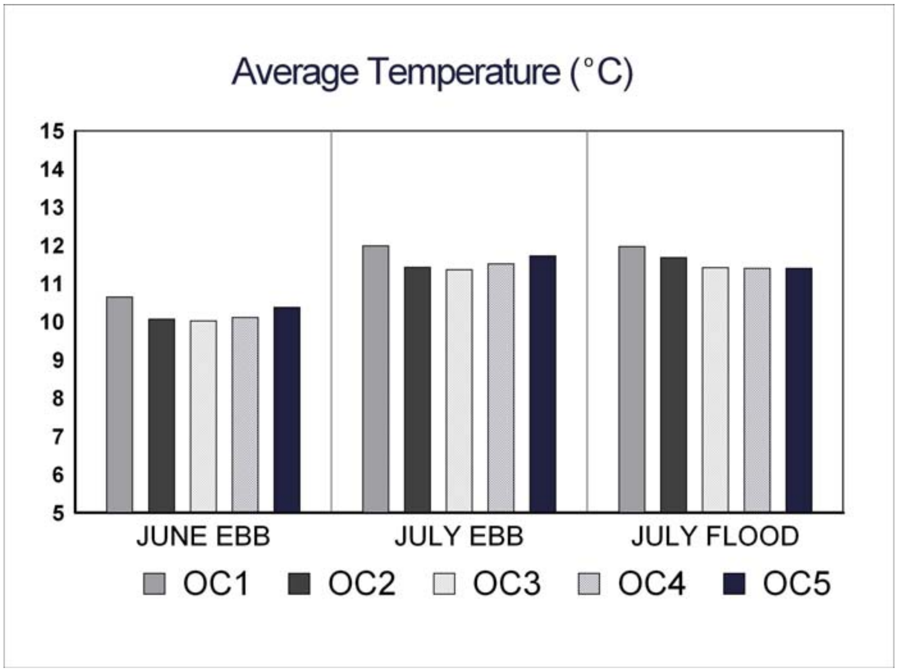

Figure 7. Average temperature of the water column at different tide stages at stations across Minas Passage at Cape Sharp, June & July 2009.

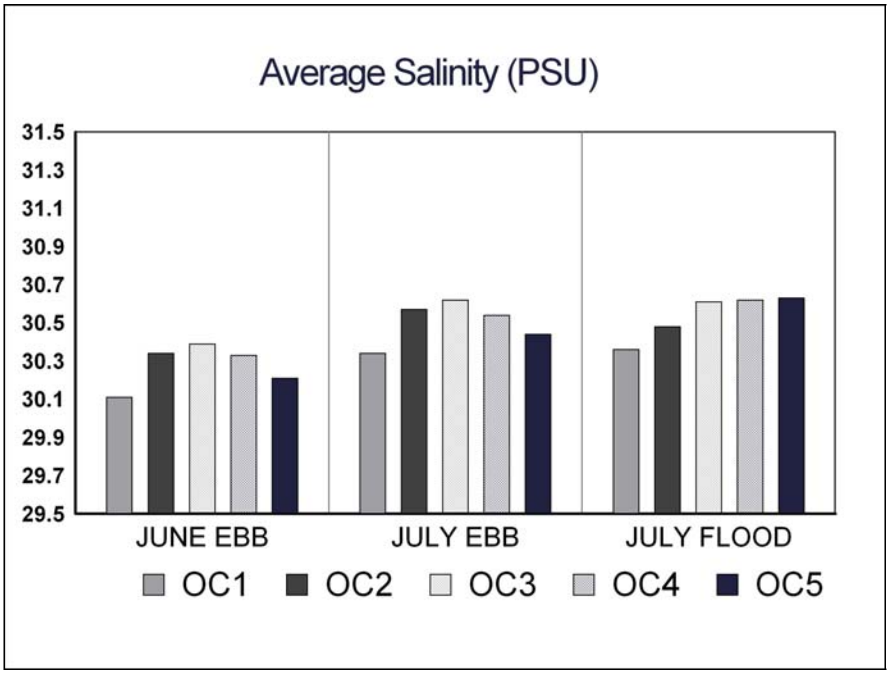

Figure 8. Average salinity of the water column at different tide stages at stations across Minas Passage at Cape Sharp, June & July 2009.

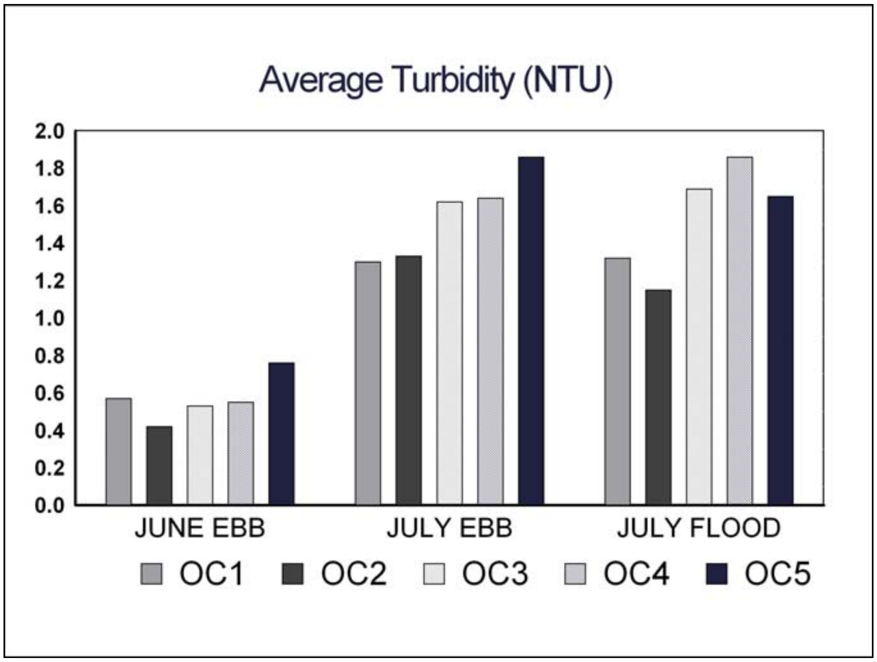

Figure 9. Average turbidity of the water column at different tide stages at stations across Minas Passage at Cape Sharp, June & July 2009.

Seasonal Variation of Temperature, Salinity and Turbidity—Water temperature increased throughout the summer, ranging from approximately 10.0 to 10.7 ˚C. in June; 11.4 to 12.3 ˚C. in July; and 14.2 to 14.8 ˚C. in August (Table B1)(Figure 10). Salinity also increased seasonally, from 30.1 - 30.4 ˚/oo in June; to 30.2 - 30.6 ˚/oo in July; and 30.8 - 31.0 ˚/oo in August (Figure 11). Turbidity was lowest in June ranging from 0.07 to 2.0 NTU; and values observed in July (0.7 to 4.9 NTU); and in August (0.8 to 4.3 NTU) were comparable (Figure 12). Temperatures and salinities were in agreement with ranges for the Bay as a whole summarized by Greenberg (1984) and Bousfield and Leim (1959) although the present study represents the most extensive sampling of the study site.

The seasonal pattern of water temperature shows lowest levels in winter, likely in January to March, rising to a peak in the fall (August-September)(Figure 10). Salinity in the present study did not follow a clear seasonal pattern and in the present study was unexpectedly highest in early March (Figure 11). The most reasonable explanation of the elevated salinity is the advection of a water mass from the outer Bay of Fundy, possibly as the result of a storm event. Turbidity was highest in February-March and lowest in the summer (Figure 12), particularly in June.

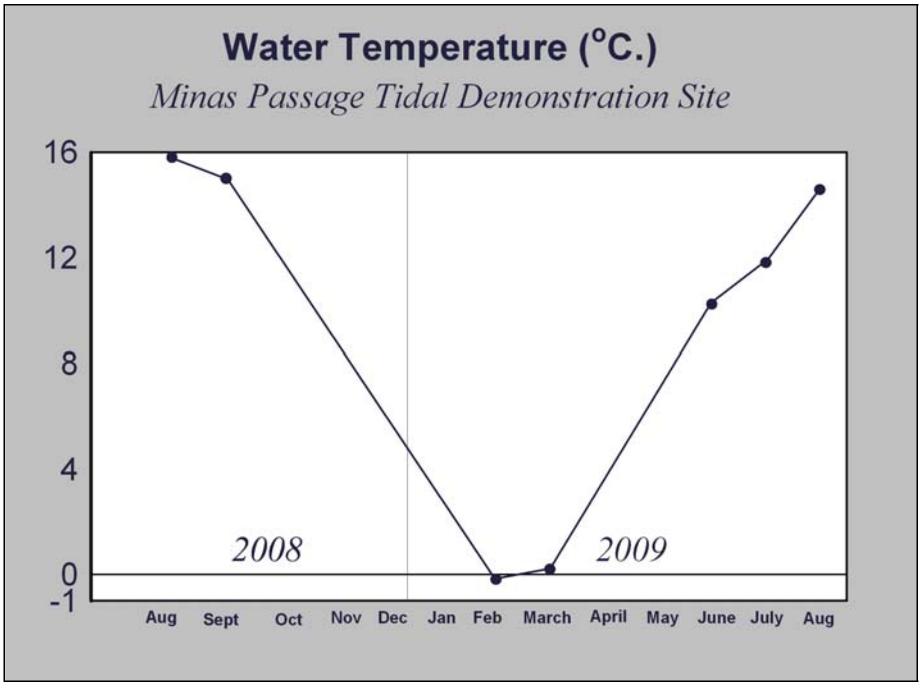

Figure 10. Annual variation in average water column temperature, Minas Passage study site, August 2008 to August 2009.

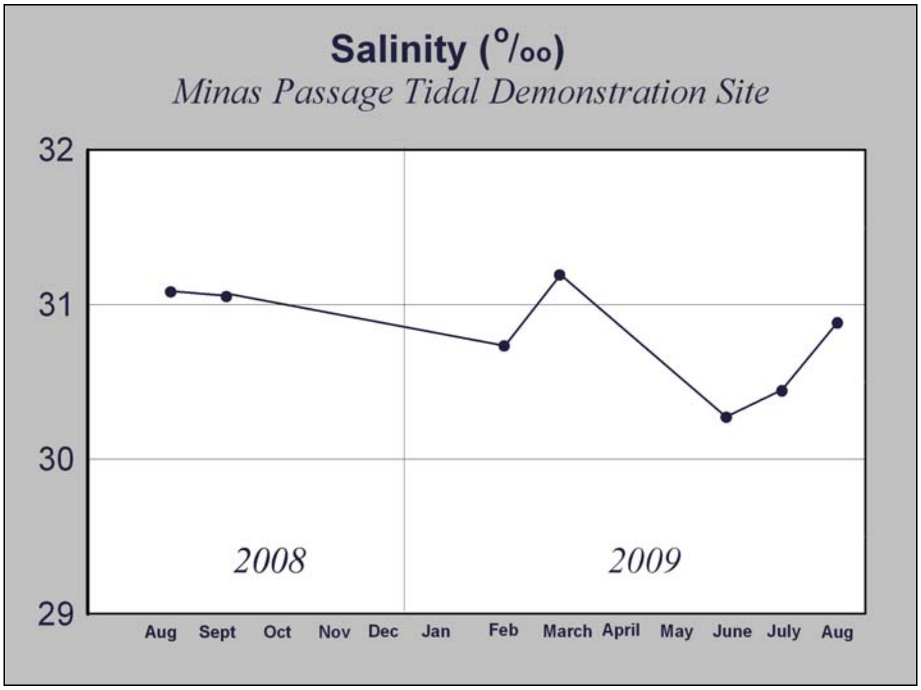

Figure 11. Annual variation in average water column salinity, Minas Passage study site, August 2008 to August 2009.

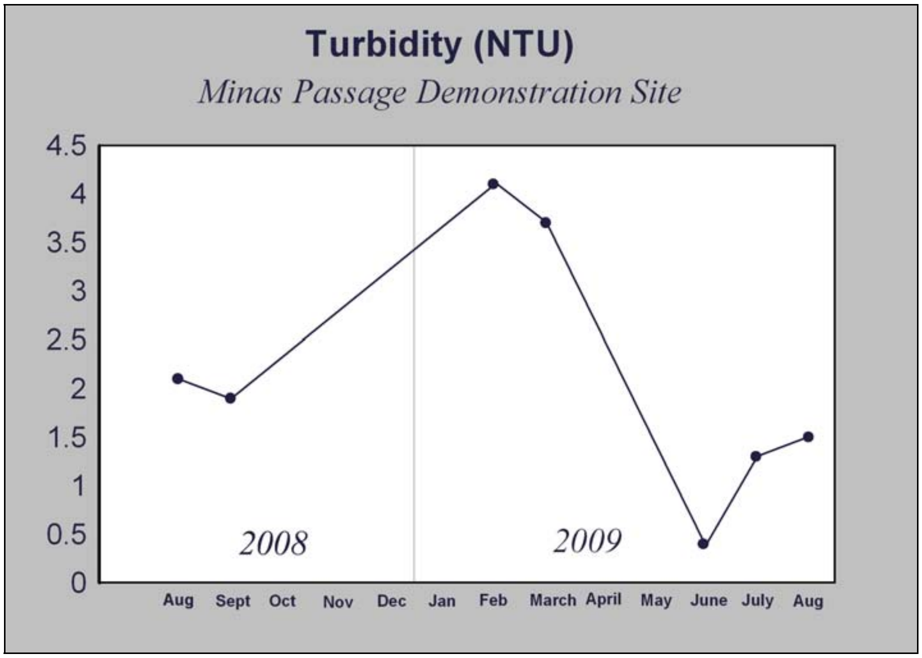

Figure 12. Annual variation in average water column turbidity, Minas Passage study site, August 2008 to August 2009.

Total Suspended Solids—Levels of total suspended solids were variable but occupied a similar range in all surveys, from 7.5 to 13.75 mg/L in June; 4.75 to 13.0 mg/L in July and 4.0 to 14.9 mg/L in August (Table 3; Figure 13). Levels were comparable to those observed in September 2009 at the site, but lower than those observed in February and March (Envirosphere Consultants (2009) and Table 4). These levels are higher than remotely sensed summer levels for the area (between 0 and 10 mg/L, Greenberg and Amos (1983)). Greenberg and Amos used summer suspended sediment levels of < 5 mg/L in Minas Passage and 1-2 mg/L in the Bay of Fundy to the west to represent levels for modeling purposes. Levels of 0.2 to 30.4 mg/L were reported for the Bay of Fundy as a whole (Miller 1966 from Pelletier and McMullen (1972)), and that study estimated summer values in the Minas Passage of 4-8 mg/L (which are slightly lower than measurements in our study) measured at stations at either end of Minas Passage/Minas Channel. Our levels are relatively low in terms of typical concentrations in coastal waters, however, and particularly for shallow areas in the adjacent Minas Basin. Greenberg and Amos (1983) reported summer concentrations of 1 to 200 mg/L throughout the Bay of Fundy, and 60 to 2300 mg/L immediately after ice breakup (Amos and Long 1980 from Greenberg and Amos (1983). Levels in Minas Basin have been reported to be from 72 to 2680 mg/L (Pelletier & McMullin 1972). Our study showed the highest concentrations in February-March when ice was present at the site but before breakup.

High variability of total suspended solids measurements complicated calibration of the turbidity sensor, which was one of the objectives of the 2009 survey program. Turbidity levels encountered are near the lower limit of detection of the OBS sensor, and also near the detection limits of the suspended solids method (0.5 mg/L). In the June survey (which was cut short because of damage to the camera mounting frame) all calibration samples had moderately high levels of total suspended solids, while turbidity levels were the lowest observed in any of the surveys (Figure 13). In July and August, a wide range of total suspended solids was measured, including a calibration series (see Table 3), but OBS measurements again occupied a narrow range of values although levels were higher than in the June survey.

A linear regression analysis of the data included all values of total suspended solids measured in the study. The linear regression on untransformed measurements of TSS and turbidity resulted in the best fit to the data, and resulted in a significant regression relationship ($p<0.001$), but explained only about half the variance in the data ($r^2 = 0.52$) (Figure 13):

$$\text{TSS (mg/L)} = 2.211\ \text{NTU} + 4.205,\quad n = 58$$

The calibration equation was similar to other calibration relationships in the literature in which there is an approximately one- to two-fold change in TSS for each unit of NTU (FDR & LMS Consultants 2005; Christensen et al. 2000; Boss et al. 2009). These studies included a larger range of measurements for TSS and turbidity, including order-of-magnitude higher values of maximum TSS, than in the present study. The relationship between TSS and turbidity measured by optical backscatter in a given situation varies depending on characteristics of the particulate matter (Boss *et al* 2009; Sutherland et al. 2000) and calibration equations from different areas, as well as use of lab calibrations, cannot be used as a substitute for *in situ* calibration of the instrument at the site (Boss *et al.* 2009). In the present study, the relatively high values of TSS measured in June when lower values were expected (based on turbidity) is anomalous, and should be verified by additional sampling. The y-intercept of the regression equation (4.2 mg/L) is probably higher than lowest levels that might be expected for the site, further supporting the need for additional measurements[5]. The higher values of TSS in the winter (February & March)(Envirosphere Consultants Limited 2009) were more reasonable, and together with the higher values of turbidity recorded at the time, reflected lower visibility in the water and cloudiness seen in the underwater video obtained at those times.

Table 4. Summary of Salinity, Temperature and Turbidity measurements at Station 19, a station central to the area proposed for tidal turbine installation, August 2008 to August 2009.

	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)	Depths Sampled (m)
August 18, 2008	31.08 (30.90 – 31.65)	15.8 (15.7 – 16.3)	2.1 (1.8 – 3.3)	0 – 22
September 23, 2008	31.05 (30.45 – 31.08)	15.0 (14.98-15.01)	1.9 (1.4 – 2.2)	0 – 52.5
February 2, 2009	30.73 (30.72 – 30.75)	-0.19 (-0.13 - -0.20)	4.1 (3.8 – 4.7)	0 – 51.4
March 10, 2009	31.19 (31.10 – 31.22)	0.20 (0.12 – 0.23)	3.7 (3.0 – 4.2)	0 – 52
June 18, 2009	30.27 (30.26 – 30.27)	10.23 (10.21 – 10.24)	0.38 (.13 – 1.92)	0 – 24.7
July 2, 2009	30.44 (30.37 – 30.51)	11.81 (11.58 – 11.98)	1.27 (0.96 – 3.27)	0 - 37
August 4, 2009	30.88 (30.79 – 30.97)	14.58 (14.31 – 14.83)	1.51 (1.03 – 3.33	0 – 38.7

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[5] Views of the water column illuminated in darkness in video of obtained concurrently at the site show bright particles against a relatively clear background (as well as a cloudy component in February-March, which must be attributed to the finer grain sizes (e.g. clays) expected to be in suspension at the time). Filters used for the TSS analysis were later examined to determine if larger particles were present, which could account for some of the larger levels of TSS recorded but no obvious larger particles were present.

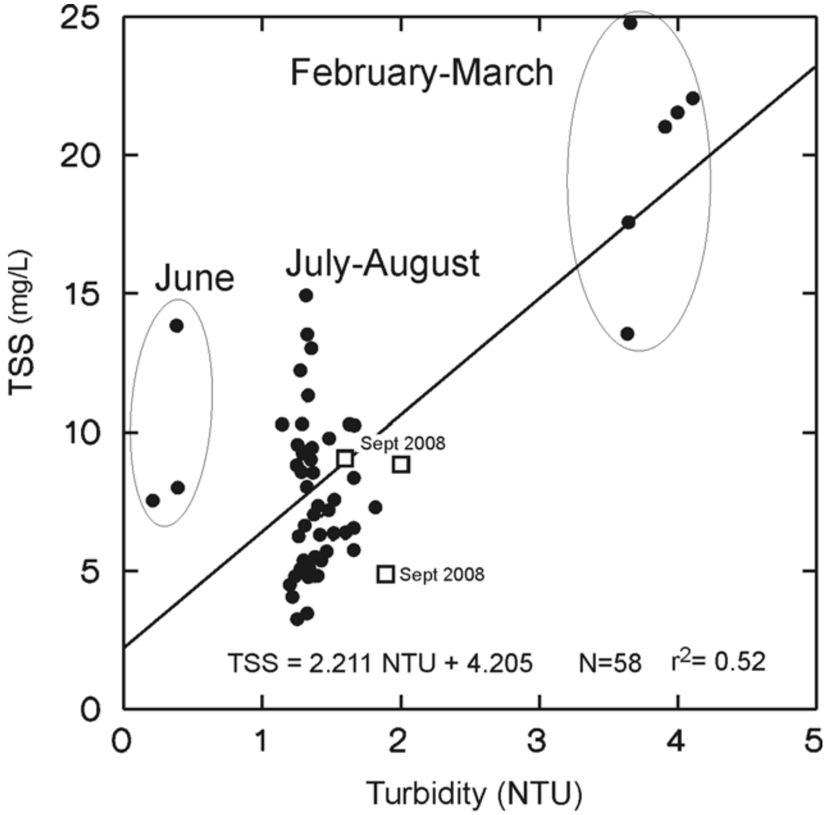

Figure 13. Linear regression relationship between total suspended solids (mg/L) and turbidity (NTU) measured by optical backscatter, at Minas Passage study site.

The present study has provided measurements of suspended sediment and turbidity in the June-August period. Together with measurements in February-March 2009 and September 2008 (reported in Envirosphere Consultants 2009), a range of levels of suspended sediments was sampled, from an annual low in June to moderately high late winter values. Despite the variation, suspended levels measured were relatively low, although slightly higher than estimates for the tidal demonstration site (Minas Passage from the literature) based on remote sensing and sampling in adjacent areas. The information collected in this study is useful as background to modeling oceanographic conditions and sediment transport through Minas Passage on an annual basis.

CONCLUSIONS AND RECOMMENDATIONS

Monitoring physical oceanographic parameters and turbidity at the tidal power demonstration site has provided baseline information on properties of the water, in particular mixing and natural turbidity levels. The information is relevant to various oceanographic studies involving assessment of impacts of tidal power installations, as well as modeling water and suspended sediment transport through Minas Passage. This program of monitoring was initiated to enable the assessment of changes in oceanographic conditions, specifically suspended sediments, related to tidal power installations—however the study has found that the area is typically characterized by low levels of suspended sediments and absence of local sources due to sediment removal by the strong currents in the area. Low levels of suspended sediments are difficult to measure and would require a considerable effort to allow the detection of differences and effects due to the tidal power installations, an effort which is probably not justified in terms of the cost of these measurements on the impacts of the suspended sediment. Peak suspended sediment levels occurring in the winter-early spring, a period which was not adequately sampled in the present study, may be important in overall annual sediment transport at the site. Measurement of peak levels would undoubtedly be of interest in terms of estimating sediment transport through the study area but again would not justify the cost in terms of project monitoring, unless closely linked and designed to support a parallel research study.

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Appendix A – Station Locations, Minas Passage, June to August 2009.

Table A1. Coordinates of physical oceanographic stations, Minas Passage, June – August, 2009.

Station	Date Time	Lat	Long	Northing	Easting	Depth (m)
June 18, 2009						
Station 19 Begin Cast 1	18/06/2009 11:00:51	45 22.0538	64 25.3607	5024767.75	388590.54	37.0
Station 19 End Cast 1	18/06/2009 11:12:48	45 22.2455	64 26.3075	5025144.66	387361.16	39.0
OC1 Begin Cast 2	18/06/2009 11:44:54	45 21.6968	64 23.6499	5024067.68	390811.96	34.5
OC1 End Cast 2	18/06/2009 11:49:10	45 21.7444	64 24.0503	5024164.88	390290.85	27.5
OC2 Begin Cast 3	18/06/2009 12:03:19	45 21.1153	64 23.7811	5022993.96	390622.03	69.0
OC2 End Cast 3	18/06/2009 12:10:36	45 21.1507	64 24.6589	5023079.48	389477.2	65.3
OC3 Begin Cast 4	18/06/2009 12:33:59	45 20.6340	64 23.8805	5022105.05	390476.79	94.6
OC3 End Cast 4	18/06/2009 12:43:02	45 20.7932	64 24.7714	5022420.12	389318.71	77.0
OC4 Begin Cast 5	18/06/2009 13:01:00	45 20.1071	64 23.9665	5021131.42	390347.55	89.1
OC4 End Cast 5	18/06/2009 13:08:19	45 20.2303	64 24.4644	5021370.86	389701.33	102.6
OC5 Begin Cast 6	18/06/2009 13:18:33	45 19.5850	64 24.0381	5020166.34	390237.24	31.6
OC5 End Cast 6	18/06/2009 13:23:44	45 19.6179	64 24.2355	5020231.75	389980.47	31.5
July 2-3, 2009						
Begin Cast 1 Site 19	02/07/2009 11:34:13	45 22.0996	64 25.6309	5024858.79	388239.39	42.5
Water Sample 1 Site 19 (deep)	02/07/2009 11:39:59	45 22.2399	64 26.0466	5025128.21	387701.48	36.5
Water Sample 2 Site 19 (mid-water)	02/07/2009 11:43:15	45 22.2841	64 26.3251	5025216.53	387339.47	40.8
Water Sample 3 Site 19 (surface)	02/07/2009 11:45:16	45 22.3195	64 26.4871	5025285.86	387129.22	40.1
End Cast 1 Site 19	02/07/2009 11:46:56	45 22.3551	64 26.6210	5025354.91	386955.66	41.5
Begin Cast 2 Site OC1	02/07/2009 12:29:06	45 21.6488	64 23.3500	5023972.03	391201.89	32.4
End Cast 2 Site OC1	02/07/2009 12:34:25	45 21.6946	64 23.9040	5024069.35	390480.21	31.3
Begin Cast 3 Site OC2	02/07/2009 12:49:28	45 21.1202	64 23.5288	5022997.32	390951.57	71.6
End Cast 3 Site OC2	02/07/2009 12:55:36	45 21.1608	64 24.3686	5023091.55	389856.51	64.7
Begin Cast 4 Site OC3	02/07/2009 13:15:47	45 20.6083	64 23.5746	5022050.54	390875.38	103.5
End Cast 4 Site OC3	02/07/2009 13:23:22	45 20.6916	64 24.4391	5022224.4	389749.29	84.4
Begin Cast 5 Site OC4	02/07/2009 13:40:51	45 20.1226	64 23.5692	5021151.11	390866.88	87.2
End Cast 5 Site OC4	02/07/2009 13:51:20	45 20.3747	64 24.4649	5021638.23	389705.35	108.0
Begin Cast 6 Site OC5	02/07/2009 14:04:52	45 19.5437	64 23.7559	5020083.47	390604.5	31.4
End Cast 6 Site OC5	02/07/2009 14:09:47	45 19.6095	64 24.0166	5020211.21	390266.11	32.5
Begin Cast 7 Site 19	02/07/2009 17:33:42	45 22.1753	064 25.8435	5025003.88	387964.41	40.4
Water Sample 4 Site 19 (deep)	02/07/2009 17:39:01	45 22.1308	064 25.4358	5024912.05	388495.05	30.1
Water Sample 5 Site 19 (middle)	02/07/2009 17:42:18	45 22.1058	064 25.1882	5024860.05	388817.38	22.4
Water Sample 6 Site 19 (shallow)	02/07/2009 17:44:20	45 22.0936	064 25.0321	5024833.87	389020.72	16.5
End Cast 7 Site 19	02/07/2009 17:45:32	45 22.0896	064 24.9305	5024824.13	389153.19	15.6
Begin Cast 8 Site OC1	02/07/2009 17:56:34	45 21.6962	064 23.8536	5024071.17	390546.05	34.7
End Cast 8 Site OC1	02/07/2009 18:00:12	45 21.6902	064 23.6938	5024056.44	390754.45	36.6
Begin Cast 9 Site OC2	02/07/2009 18:05:51	45 21.0992	064 23.7890	5022964.32	390611.2	69.6
End Cast 9 Site OC2	02/07/2009 18:11:00	45 20.9700	064 23.2923	5022713.88	391255.53	76.0
Begin Cast 10 Site OC3	02/07/2009 18:30:53	45 20.6674	064 24.1099	5022172.1	390178.34	87.9

Table A1. Coordinates of physical oceanographic stations, Minas Passage, June – August, 2009.

End Cast 10 Site OC3	02/07/2009 18:37:16	45 20.5265	064 23.3021	5021892.94	391228.58	113.2
Begin Cast 11 Site OC4	02/07/2009 18:56:27	45 20.2122	064 24.2142	5021331.64	390027.47	93.9
End Cast 11 Site OC4	02/07/2009 19:01:40	45 20.1141	064 23.5363	5021134.63	390909.57	86.8
Begin Cast 12 Site OC5	02/07/2009 19:10:34	45 19.5762	064 24.0744	5020150.87	390189.54	31.3
End Cast 12 Site OC5	02/07/2009 19:14:54	45 19.5685	064 23.8604	5020131.75	390468.8	32.1
Begin Cast 17 Site 19	03/07/2009 11:35:41	45 22.0469	64 25.2484	5024752.38	388736.89	31.1
End Cast 17 Site 19	03/07/2009 11:45:49	45 22.1055	64 25.7849	5024873.28	388038.6	42.3
Begin Cast 28 Site 3	03/07/2009 17:24:42	N45 22.1203	W064 26.2382	5024911.22	387447.47	43.9
End Cast 28 Site 3	03/07/2009 17:28:56	N45 22.0871	W064 26.0252	5024844.79	387724.37	45.9
Begin Cast 29 Site 9	03/07/2009 17:34:53	N45 21.8061	W064 26.3686	5024332.5	387266.87	48.0
End Cast 29 Site	03/07/2009 17:39:46	N45 21.7851	W064 26.2116	5024289.96	387471.11	31.2
August 4, 2009						
Begin Cast 1 Site 19	04/08/2009 13:42:08	45 22.0852	64 25.5078	5024829.28	388399.59	39.2
Water Sample 1 Site 19 (deep)	04/08/2009 13:46:03	45 22.1360	64 25.6571	5024926.79	388206.39	37.4
Water Sample 2 Site 19 (mid-water)	04/08/2009 13:51:19	45 22.2061	64 25.8848	5025061.87	387911.53	38.0
Water Sample 3 Site 19 (surface)	04/08/2009 13:55:14	45 22.2713	64 26.0669	5025186.82	387676.02	35.2
End Cast 1 Site 19	04/08/2009 13:55:54	45 22.2859	64 26.1019	5025214.67	387630.82	35.3
Begin Cast 2 Site 3	04/08/2009 14:02:35	45 21.9959	64 25.9043	5024673.12	387879.15	48.4
Water Sample 4 Site 3 (deep)	04/08/2009 14:07:17	45 22.0679	64 26.3798	5024817.5	387260.93	45.0
Water Sample 5 Site 3 (mid-water)	04/08/2009 14:13:25	45 22.1780	64 27.0161	5025036.27	386434.13	44.4
Water Sample 6 Site 3 (surface)	04/08/2009 14:17:21	45 22.2792	64 27.4553	5025234	385864.32	38.9
End Cast 2 Site 3	04/08/2009 14:17:41	45 22.2880	64 27.4921	5025251.16	385816.59	37.2
Begin Cast 3 Site 9	04/08/2009 14:50:57	45 21.6894	64 25.5745	5024097.97	388299.55	41.9
Water Sample 7 Site 9 (deep)	04/08/2009 14:56:05	45 21.8566	64 26.2073	5024422.24	387479.08	39.5
Water Sample 8 Site 9 (mid-water)	04/08/2009 15:02:21	45 22.0321	64 26.8474	5024762.16	386649.44	41.9
Water Sample 9 Site 9 (surface)	04/08/2009 15:05:26	45 22.0979	64 27.1832	5024891.89	386213.37	41.4
End Cast 3 Site 9	04/08/2009 15:05:48	45 22.1051	64 27.2259	5024906.23	386157.88	42.1
Begin Cast 4 Site 19	04/08/2009 20:14:20	45 22.1416	64 25.8614	5024941.9	387939.94	44.5
Water Sample 10 Site 19 (deep)	04/08/2009 20:17:52	45 22.0749	64 25.5127	5024810.32	388392.85	40.2
Water Sample 11 Site 19 (mid-water)	04/08/2009 20:22:54	45 21.9400	64 25.0331	5024549.5	389014.4	18.4
Water Sample 12 Site 19 (surface)	04/08/2009 20:24:58	45 21.8375	64 24.8237	5024354.9	389284.38	26.2
End Cast 4 Site 19	04/08/2009 20:25:06	45 21.8316	64 24.8101	5024343.67	389301.94	27.0
Begin Cast 5 Site 3	04/08/2009 21:01:50	45 22.1331	64 26.5643	5024942.53	387022.29	43.8
Water Sample 13 Site 3 (deep)	04/08/2009 21:06:57	45 21.9344	64 25.8278	5024557.47	387976.98	35.7
Water Sample 14 Site 3 (mid-water)	04/08/2009 21:12:27	45 21.6382	64 25.0410	5023990.87	388994.26	41.2
Water Sample 15 Site 3 (surface)	04/08/2009 21:15:33	45 21.4716	64 24.5867	5023671.99	389581.86	47.4
End Cast 5 Site 3	04/08/2009 21:15:53	45 21.4549	64 24.5374	5023639.94	389645.67	47.5
Begin Cast 6 Site 9	04/08/2009 21:31:26	45 21.3483	64 25.2343	5023458.55	388732.47	56.7
Water Sample 16 Site 9 (deep)	04/08/2009 21:35:31	45 21.1765	64 24.6283	5023126.54	389517.98	66.6
Water Sample 17 Site 9 (mid-water)	04/08/2009 21:40:55	45 21.0531	64 23.9301	5022882.16	390425.51	70.4
Water Sample 18 Site 9 (surface)	04/08/2009 21:44:52	45 20.9745	64 23.4358	5022725.45	391068.33	74.3
End Cast 6 Site 9	04/08/2009 21:45:02	45 20.9705	64 23.4166	5022717.61	391093.27	75.1

Table A2. Station information for additional CTD casts, July 3, 2009.

Station	Date Time	Lat	Long	Northing	Easting	Depth (m)
Begin Cast 18 Site TU 1	03/07/2009 12:16:13	45 22.2168	64 24.5031	5025049.87	389715.13	0.0
Water Sample TU 1 / End Cast 18	03/07/2009 12:19:06	45 22.2397	64 24.5708	5025093.82	389627.52	0.0
Begin Cast 19 Site TU 2	03/07/2009 12:23:34	45 22.2039	64 24.6617	5025029.61	389507.72	3.7
Water Sample TU 2 / End Cast 19	03/07/2009 12:26:48	45 22.2588	64 24.8305	5025135.13	389289.21	2.9
Begin Cast 20 Site TU 3	03/07/2009 12:31:40	45 22.2045	64 24.7105	5025031.84	389444.05	5.4
Water Sample TU 3 / End Cast 20	03/07/2009 12:34:46	45 22.2256	64 24.9216	5025075.74	389169.23	6.1
Begin Cast 21 Site TU 4	03/07/2009 12:36:38	45 22.1958	64 24.9751	5025021.79	389098.44	7.3
Water Sample TU 4 / End Cast 21	03/07/2009 12:40:52	45 22.2082	64 25.3355	5025053.05	388628.49	24.4
Begin Cast 22 Site TU 5	03/07/2009 12:49:45	45 22.2446	64 24.8582	5025109.47	389252.59	2.8
Water Sample TU 5 / End Cast 22	03/07/2009 12:52:55	45 22.2616	64 25.0491	5025145.33	389004.01	3.5
Begin Cast 23 Site TU 6	03/07/2009 12:55:13	45 22.2812	64 25.1986	5025185.06	388809.54	4.1
Water Sample TU 6 / End Cast 23	03/07/2009 12:59:52	45 22.3413	64 25.4741	5025302.69	388451.96	2.6
Begin Cast 24 Site TU 7	03/07/2009 13:16:58	45 22.1808	64 24.4701	5024982.46	389757.03	0.4
Water Sample TU 7 / End Cast 24	03/07/2009 13:19:43	45 22.2014	64 24.5537	5025022.51	389648.59	1.0
Begin Cast 25 Site TU 8	03/07/2009 13:21:40	45 22.2252	64 24.6392	5025068.53	389537.78	1.5
Water Sample TU 8 / End Cast 25	03/07/2009 13:24:35	45 22.2681	64 24.7968	5025151.57	389333.49	2.4
Begin Cast 26 Site TU 9	03/07/2009 13:29:04	45 22.1662	64 24.4305	5024954.52	389808.24	3.0
Water Sample TU 9 / End Cast 26	03/07/2009 13:31:26	45 22.1844	64 24.4786	5024989.32	389746.05	0.3
Begin Cast 27 Site TU 10	03/07/2009 13:33:51	45 22.1577	64 24.4058	5024938.22	389840.2	2.9
Water Sample TU 10 / End Cast 27	03/07/2009 13:36:08	45 22.1588	64 24.4334	5024940.89	389804.22	3.1

Appendix B – Summary of Salinity, Temperature and Turbidity Measurements, June to August 2009, Minas Passage.

Table B1. Physical oceanographic measurements, Minas Passage Study Site, June-August, 2009.

Date	Station	Tide Stage	Upcast/ Downcast	Obser- vations	Salinity (PSU				Temperature (˚ C.)				Turbidity (NTU)			
					x	S.D	Max.	Min	x	S.D	Max.	Min	x	S.D	Max.	Min.
June 18, 2009	19	Ebb	Downcast	452	30.27	0.001	30.27	30.27	10.23	0.002	10.24	10.23	0.42	0.126	1.92	0.16
June 18, 2009	19	Ebb	Upcast	238	30.27	0.006	30.29	30.26	10.23	0.01	10.24	10.21	0.34	0.088	0.56	0.13
June 18, 2009	OC1	Ebb	Downcast	195	30.10	0.003	30.11	30.1	10.66	0.01	10.69	10.64	0.56	0.079	0.77	0.33
June 18, 2009	OC1	Ebb	Upcast	237	30.11	0.004	30.12	30.1	10.65	0.006	10.67	10.63	0.57	0.142	1.45	0.25
June 18, 2009	OC2	Ebb	Downcast	515	30.33	0.021	30.3	30.2	10.09	0.06	10.3	10.02	0.46	0.11	1.15	0.14
June 18, 2009	OC2	Ebb	Upcast	572	30.34	0.019	30.36	30.29	10.07	0.07	10.25	10.02	0.42	0.116	0.97	0.07
June 18, 2009	OC3	Ebb	Downcast	725	30.39	0.009	30.4	30.33	10.04	0.027	10.17	10.01	0.58	0.156	1.79	0.25
June 18, 2009	OC3	Ebb	Upcast	748	30.39	0.007	30.39	30.35	10.03	0.032	10.15	10.01	0.53	0.114	0.91	0.16
June 18, 2009	OC4	Ebb	Downcast	968	30.32	0.031	30.37	30.19	10.14	0.07	10.42	10.04	0.61	0.09	1.0	0.33
June 18, 2009	OC4	Ebb	Upcast	332	30.33	0.035	30.37	30.25	10.12	0.074	10.31	10.04	0.55	0.09	1.07	0.30
June 18, 2009	OC5	Ebb	Downcast	392	30.21	0.008	30.22	30.18	10.37	0.027	10.46	10.35	0.85	0.14	2.01	0.56
June 18, 2009	OC5	Ebb	Upcast	222	30.21	0.006	30.22	30.19	10.38	0.025	10.45	10.36	0.76	0.1	1.09	0.51
July 2, 2009	3	Ebb	Downcast	419	30.58	0.018	30.61	30.55	11.58	0.033	11.62	11.50	1.53	0.168	2.75	1.14
July 2, 2009	3	Ebb	Upcast	334	30.58	0.007	30.60	30.57	11.55	0.013	11.58	11.52	1.45	0.138	2.12	1.09
July 3, 2009	3	Ebb+1	Downcast	438	30.39	0.001	30.39	30.39	11.97	0.003	11.98	11.97	1.31	0.099	1.76	0.99
July 3, 2009	3	Ebb+1	Upcast	505	30.39	0.004	30.40	30.30	11.97	0.003	11.98	11.97	1.30	0.097	1.7	1.06
July 3, 2009	3	Flood	Downcast	266	30.36	0.03	30.4	30.31	12.13	0.061	12.26	12.06	1.04	0.13	1.45	0.71
July 3, 2009	3	Flood	Upcast	335	30.37	0.03	30.34	30.32	12.12	0.06	12.3	12.05	0.98	0.13	1.6	0.65
July 3, 2009	9	Ebb+1	Downcast	379	30.48	0.03	30.51	30.4	11.71	0.06	11.88	11.65	1.34	0.139	1.0	1.89
July 3, 2009	9	Ebb+1	Upcast	489	30.49	0.011	30.51	30.47	11.68	0.023	11.73	11.64	1.31	0.097	1.0	1.63
July 3, 2009	9	Ebb	Downcast	643	30.64	0.005	30.66	30.56	11.43	0.037	11.54	11.4	1.46	0.21	2.65	.84
July 3, 2009	9	Ebb	Upcast	448	30.64	0.024	30.65	30.63	11.42	0.008	11.43	11.41	1.47	0.106	1.77	1.2
July 3, 2009	9	Flood	Downcast	301	30.31	0.051	30.38	30.23	12.14	0.075	12.3	12.05	1.14	0.12	1.64	0.87
July 3, 2009	9	Flood	Upcast	329	30.29	0.05	30.38	30.23	12.19	0.096	12.37	12.06	1.06	0.171	2.25	0.65
July 2, 2009	19	Ebb	Downcast	274	30.48	0.017	30.51	30.44	11.64	0.04	11.72	11.58	1.26	0.118	1.67	0.97
July 2, 2009	19	Ebb	Upcast	278	30.47	0.011	30.48	30.45	11.67	0.027	11.72	11.63	1.17	0.122	1.7	0.84
July 2, 2009	19	Flood	Downcast	356	30.39	0.005	30.4	30.38	11.93	0.02	11.96	11.91	1.31	0.23	3.27	1.0
July 2, 2009	19	Flood	Upcast	383	30.39	0.006	30.39	30.37	11.92	0.017	11.98	11.91	1.26	0.131	2.23	0.96
July 3, 2009	19	Ebb	Downcast	349	30.46	0.006	30.47	30.44	11.83	0.013	11.87	11.81	1.34	0.094	1.69	1.09
July 3, 2009	19	Ebb	Upcast	374	30.45	0.009	30.47	30.43	11.84	0.023	11.91	11.8	1.30	0.108	1.7	0.96
July 2, 2009	OC1	Flood	Downcast	270	30.37	0.009	30.39	30.36	11.96	0.021	11.98	11.92	1.41	0.122	1.95	1.15
July 2, 2009	OC1	Flood	Upcast	273	30.36	0.002	30.37	30.36	11.97	0.002	11.97	11.96	1.32	0.136	1.79	0.99
July 2, 2009	OC1	Ebb	Downcast	192	30.34	0.005	30.35	30.32	12.0	0.009	12.02	11.98	1.35	0.108	1.74	1.06
July 2, 2009	OC1	Ebb	Upcast	240	30.34	0.006	30.35	30.33	11.99	0.008	12.0	11.98	1.3	0.145	2.06	0.88
July 2, 2009	OC2	Ebb	Downcast	412	30.55	0.032	30.58	30.48	11.47	0.073	11.62	11.41	1.37	0.163	2.0	0.91
July 2, 2009	OC2	Ebb	Upcast	553	30.57	0.011	30.58	30.5	11.43	0.025	11.58	11.41	1.33	0.162	2.03	0.87
July 2, 2009	OC2	Flood	Downcast	351	30.48	0.003	30.48	30.47	11.68	0.008	11.69	11.67	1.22	0.125	2.55	0.97
July 2, 2009	OC2	Flood	Upcast	407	30.48	0.003	30.48	30.47	11.68	0.008	11.69	11.67	1.15	0.127	2.15	0.88
July 2, 2009	OC3	Ebb	Downcast	633	30.62	0.002	30.62	30.6	11.36	0.007	11.4	11.36	1.69	0.177	3.16	1.14
July 2, 2009	OC3	Ebb	Upcast	681	30.62	0.002	30.62	30.61	11.37	0.009	11.39	11.36	1.62	0.215	3.99	1.21
July 2, 2009	OC3	Flood	Downcast	510	30.61	0.002	30.61	30.60	11.42	0.005	11.43	11.42	1.76	0.233	4.92	1.36

Table B1. Physical oceanographic measurements, Minas Passage Study Site, June-August, 2009.

Date	Station	Tide Stage	Upcast/ Downcast	Obser- vations	Salinity (PSU				Temperature (˚ C.)				Turbidity (NTU)			
					x	S.D	Max.	Min	x	S.D	Max.	Min	x	S.D	Max.	Min.
July 2, 2009	OC3	Flood	Upcast	560	30.61	0.001	30.61	30.60	11.42	0.004	11.43	11.41	1.69	0.157	2.35	1.34
July 2, 2009	OC4	Ebb	Downcast	1314	30.55	0.042	30.61	30.44	11.51	0.091	11.77	11.38	1.63	0.16	2.65	1.15
July 2, 2009	OC4	Ebb	Upcast	671	30.54	0.041	30.61	30.48	11.52	0.088	11.65	11.38	1.64	0.17	3.42	1.25
July 2, 2009	OC4	Flood	Downcast	390	30.62	0.001	30.63	30.62	11.39	0.002	11.4	11.39	1.9	0.112	2.37	1.54
July 2, 2009	OC4	Flood	Upcast	403	30.62	0.001	30.62	30.62	11.4	0.003	11.4	11.39	1.86	0.149	2.72	1.57
July 2, 2009	OC5	Ebb	Downcast	260	30.43	0.009	30.44	30.41	11.75	0.028	11.82	11.72	1.91	0.164	3.05	1.61
July 2, 2009	OC5	Ebb	Upcast	383	30.44	0.004	30.45	30.42	11.73	0.018	11.83	11.72	1.86	0.163	2.43	1.39
July 2, 2009	OC5	Flood	Downcast	242	30.63	0.001	30.64	30.63	11.39	0.002	11.4	11.39	1.84	0.149	2.29	1.54
July 2, 2009	OC5	Flood	Upcast	233	30.63	0.002	30.64	30.63	11.4	0.003	11.4	11.39	1.65	0.172	2.07	1.33
August 4, 2009	3	Ebb	Downcast	524	30.92	0.004	30.93	30.91	14.45	0.012	14.47	14.43	1.61	0.174	2.49	1.17
August 4, 2009	3	Ebb	Upcast	551	30.92	0.003	30.93	30.91	14.45	0.01	14.47	14.43	1.56	0.158	2.23	1.21
August 4, 2009	3	Flood	Downcast	496	30.93	0.015	30.95	30.89	14.46	0.034	14.54	14.43	1.25	0.212	2.06	0.75
August 4, 2009	3	Flood	Upcast	537	30.94	0.003	30.94	30.93	14.45	0.005	14.46	14.44	1.27	0.165	1.76	0.88
August 4, 2009	9	Ebb	Downcast	598	31.01	0.013	31.02	30.93	14.21	0.073	14.48	14.17	1.46	0.198	2.93	0.85
August 4, 2009	9	Ebb	Upcast	691	31.01	0.002	31.02	31.01	14.20	0.009	14.21	14.18	1.49	0.188	4.33	1.0
August 4, 2009	9	Flood	Downcast	449	31.04	0.001	31.04	31.03	14.18	0.003	14.19	14.18	1.44	0.129	2.72	1.09
August 4, 2009	9	Flood	Upcast	396	31.04	0.002	31.04	31.03	14.18	0.006	14.19	14.17	1.38	0.137	1.71	1.0
August 4, 2009	19	Ebb	Downcast	318	30.94	0.022	30.97	30.89	14.39	0.053	14.49	14.31	1.62	0.179	3.33	1.28
August 4, 2009	19	Ebb	Upcast	455	30.95	0.025	30.97	30.90	14.38	0.061	14.51	14.31	1.54	0.221	2.5	1.0
August 4, 2009	19	Flood	Downcast	334	30.81	0.009	30.82	30.79	14.78	0.031	14.83	14.75	1.37	0.225	2.19	0.88
August 4, 2009	19	Flood	Upcast	418	30.81	0.005	30.82	30.79	14.76	0.016	14.79	14.75	1.51	0.225	2.99	1.03

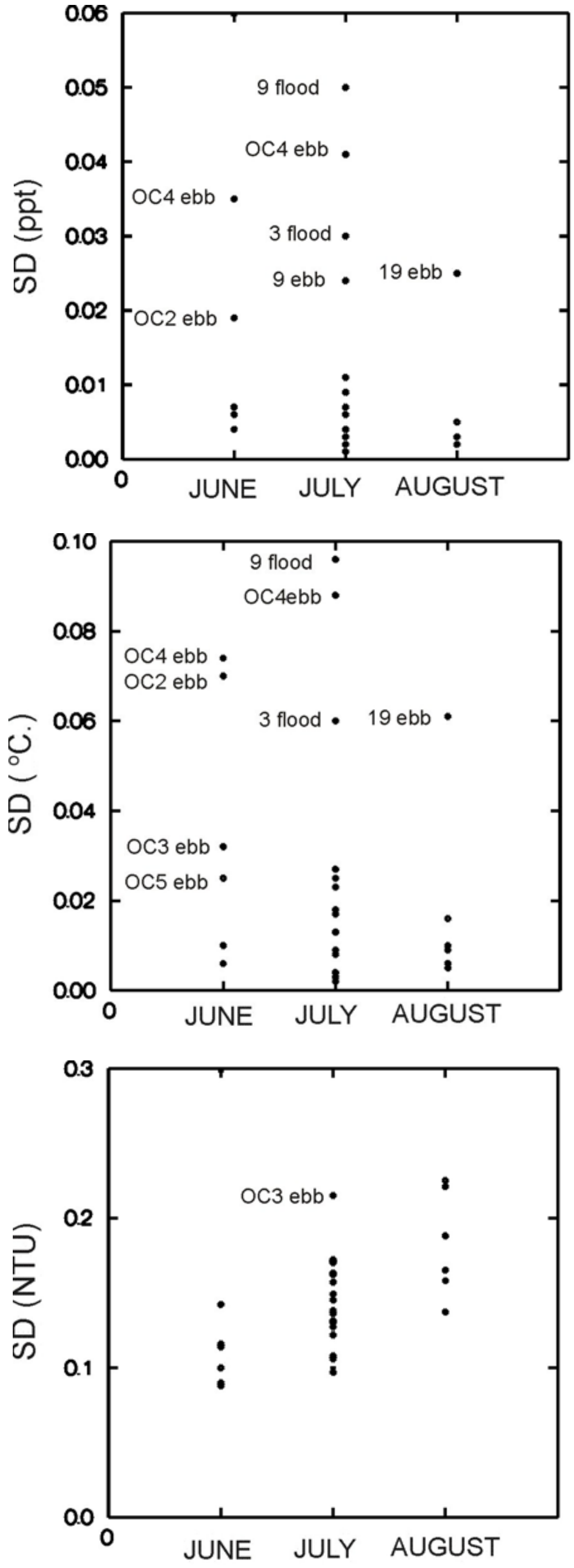


Figure B1. Standard deviation of salinity, temperature and turbidity measurements on upcasts, June-August 2009.

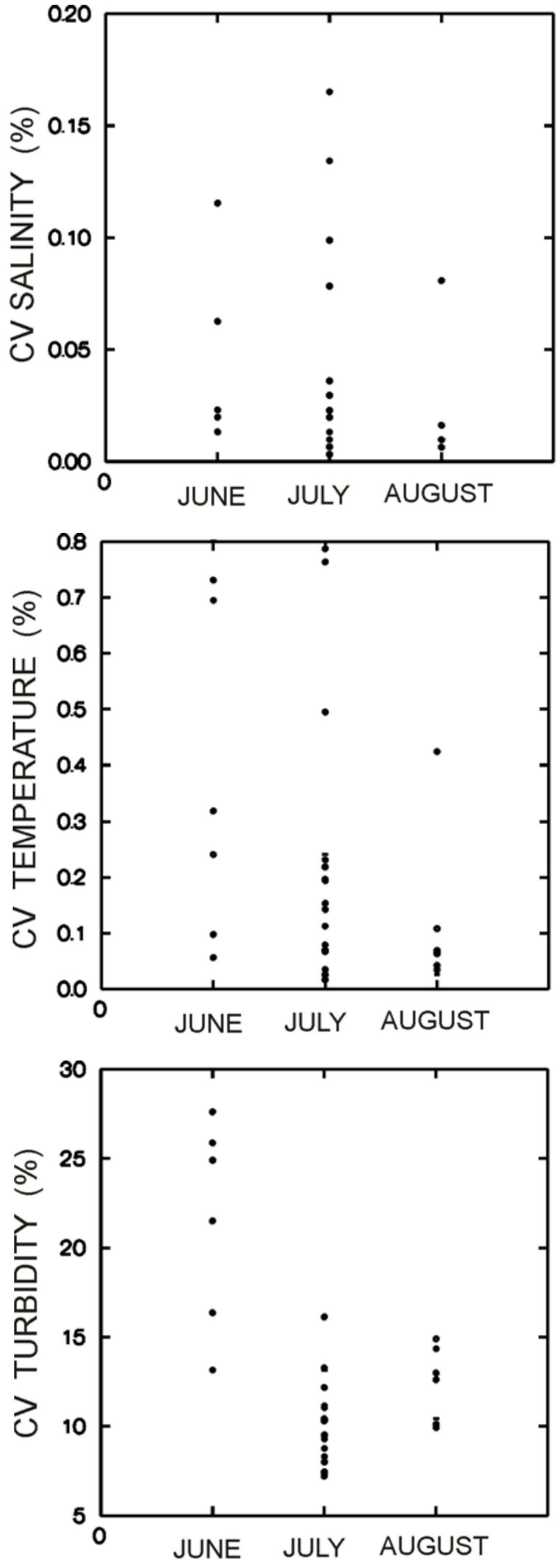


Figure B2. Coefficient of Variation (CV) of salinity, temperature and turbidity measurements on upcasts, June-August 2009.

Appendix C. Vertical profiles of Temperature, Salinity and Turbidity, Minas Passage, June 2009.

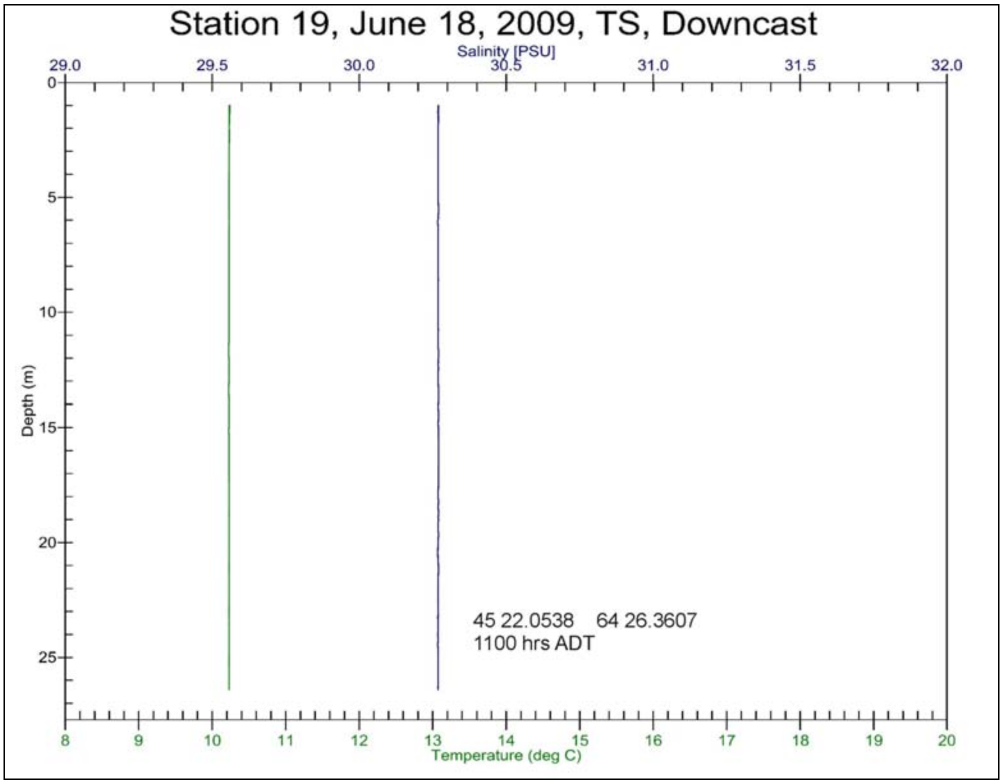


Figure C1. Vertical profile of temperature and salinity, Station 19, Minas Passage study site, June 18, 2009.

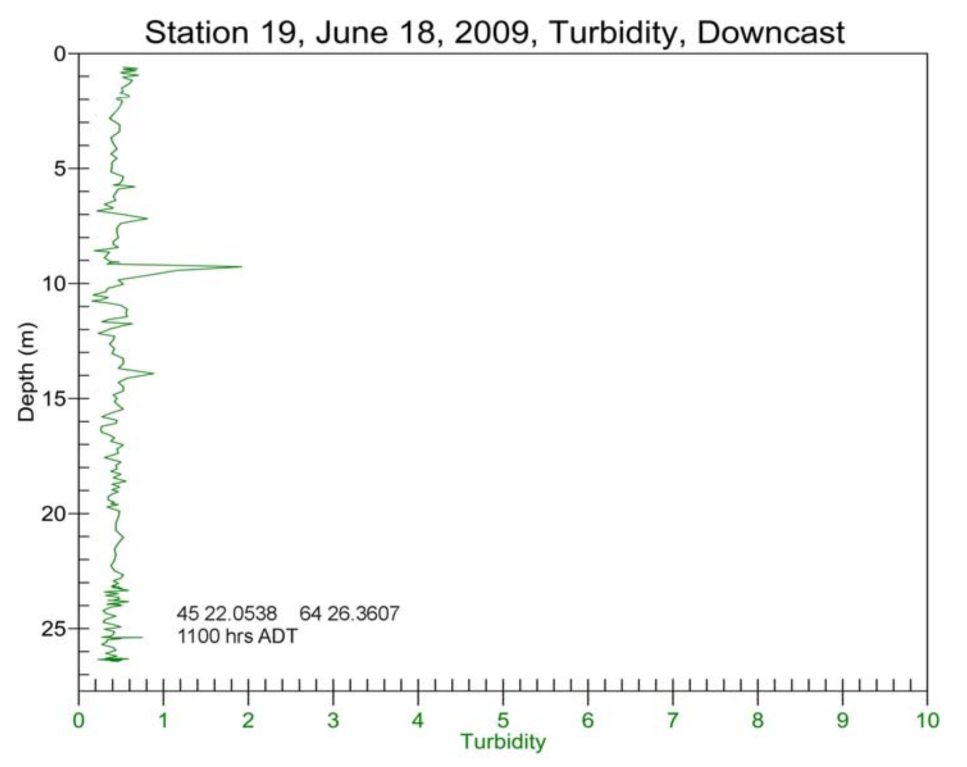


Figure C2. Vertical profile of turbidity (NTU), Station 19, Minas Passage study site, June18, 2009.

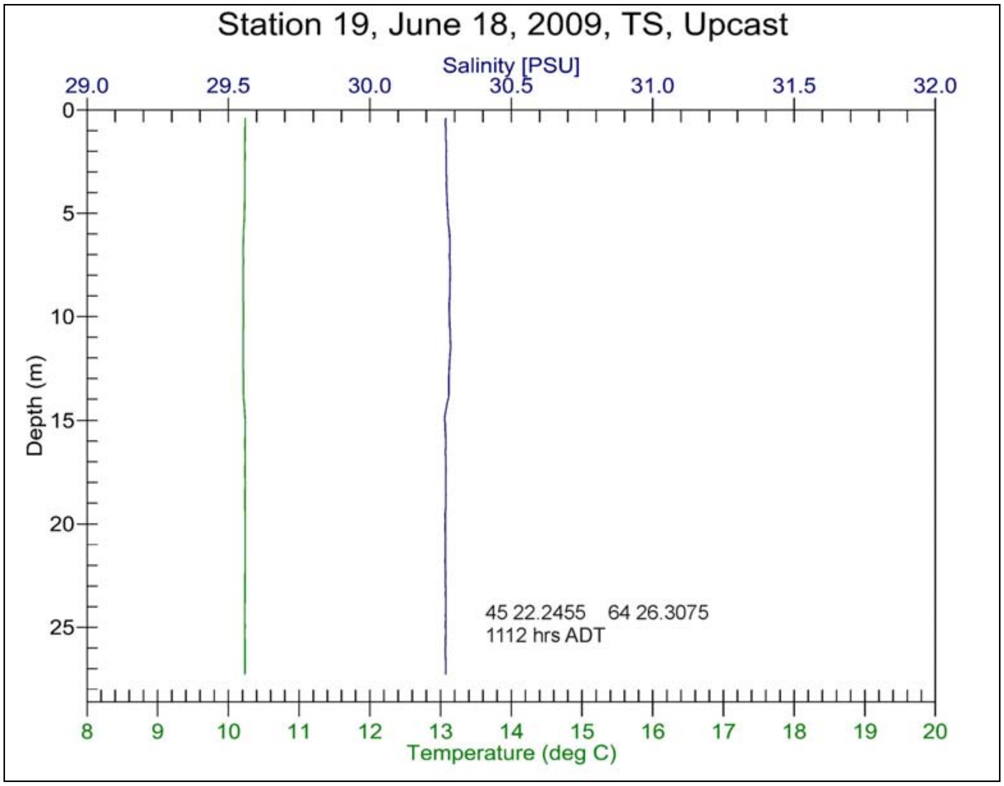


Figure C3. Vertical profile of temperature and salinity at Station 19, Minas Passage study site, June 18, 2009.

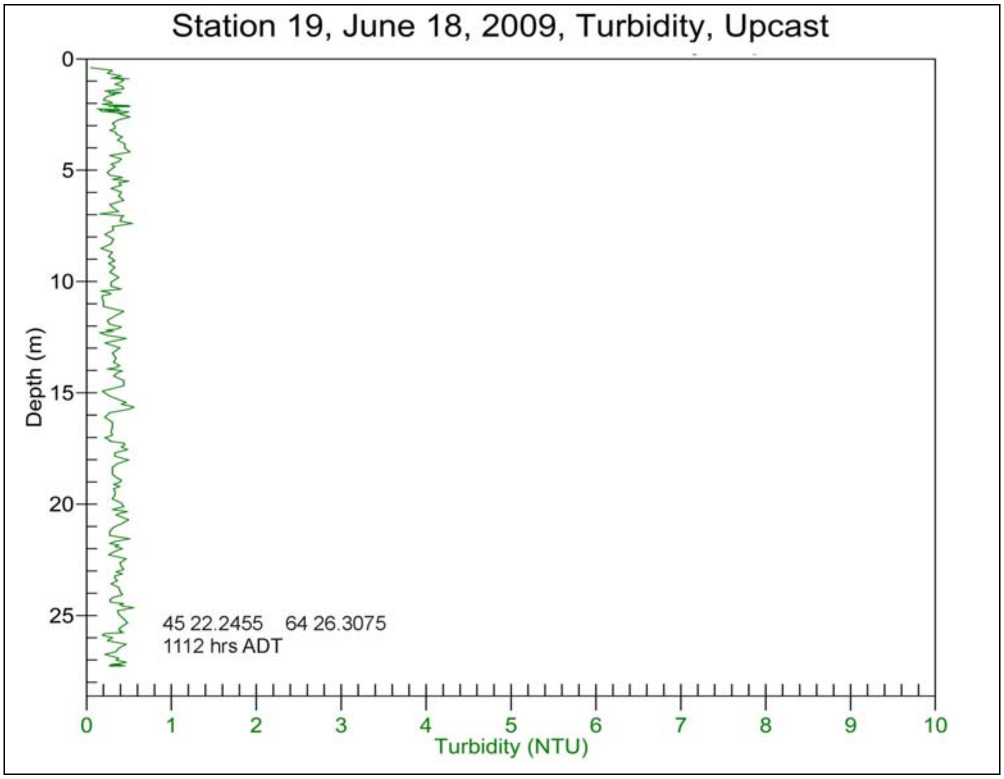


Figure C4. Vertical profile of turbidity (NTU) at Station 19, Minas Passage study site, June 18, 2009.

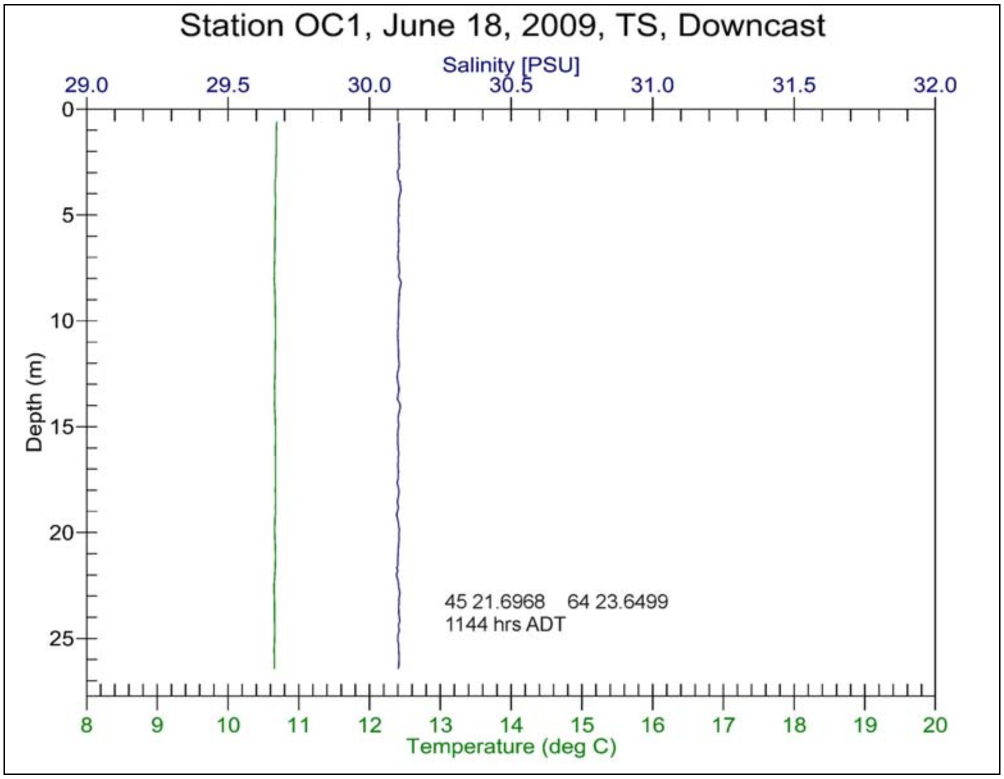


Figure C5. Vertical profile of temperature and salinity at Sta. OC1, Minas Passage study site, June 18, 2009.

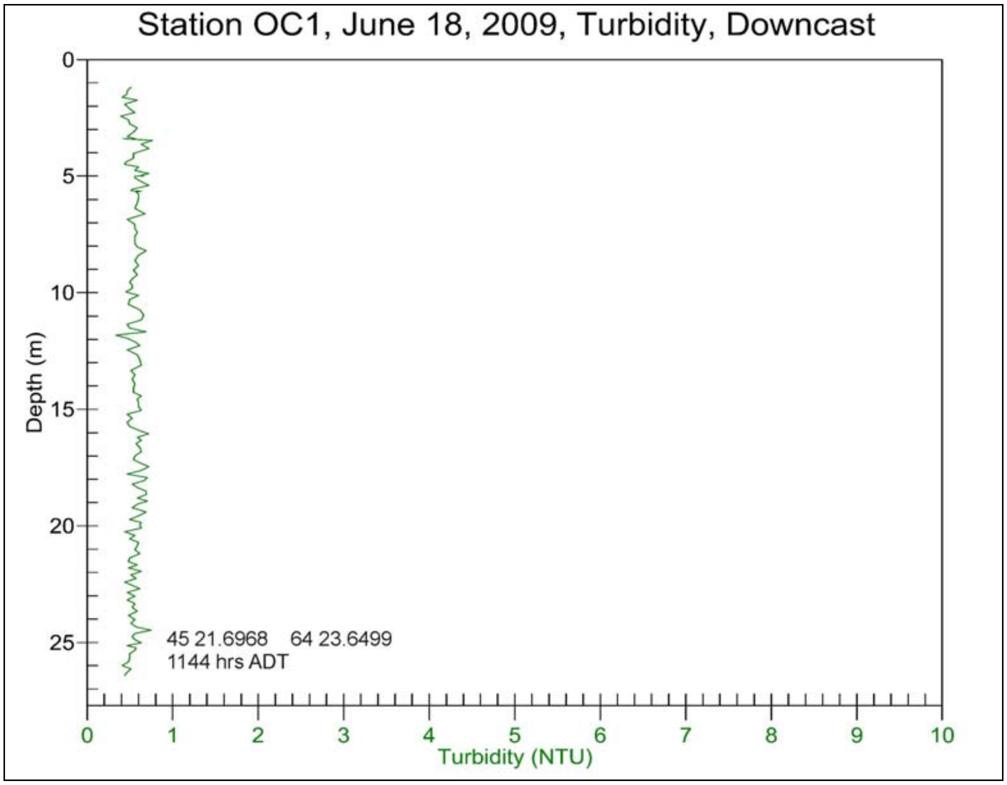


Figure C6. Vertical profile of turbidity (NTU) at Station OC1, Minas Passage study site, June 18, 2009.

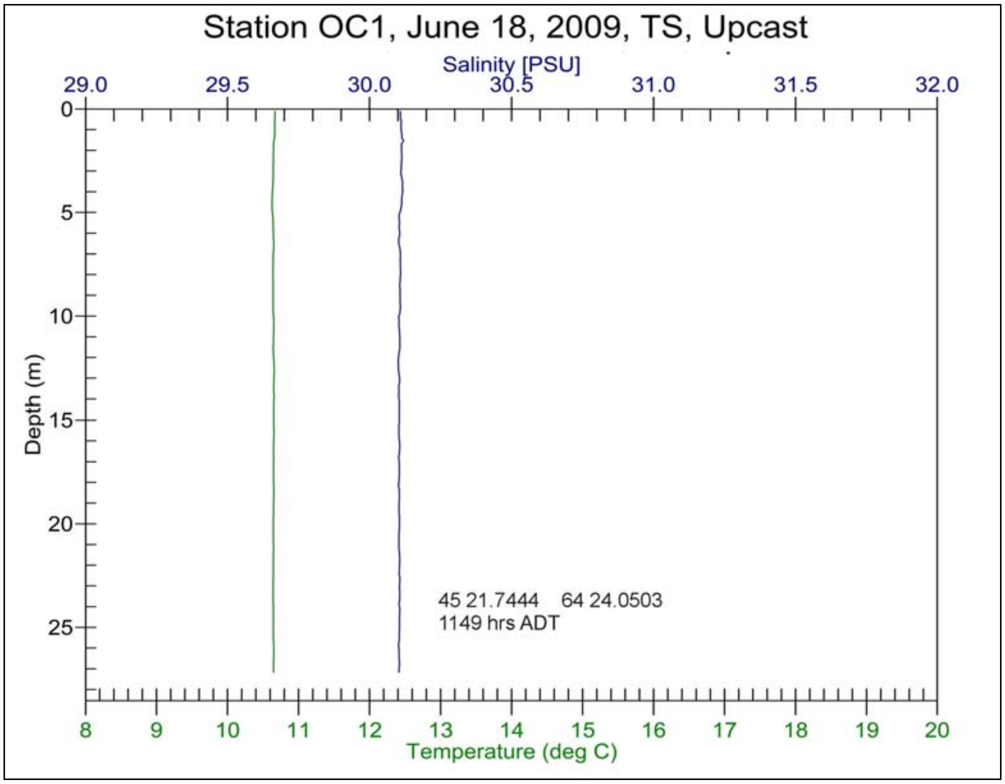


Figure C7. Vertical profile of temperature and salinity at Sta. OC1, Minas Passage study site, June 18, 2009.

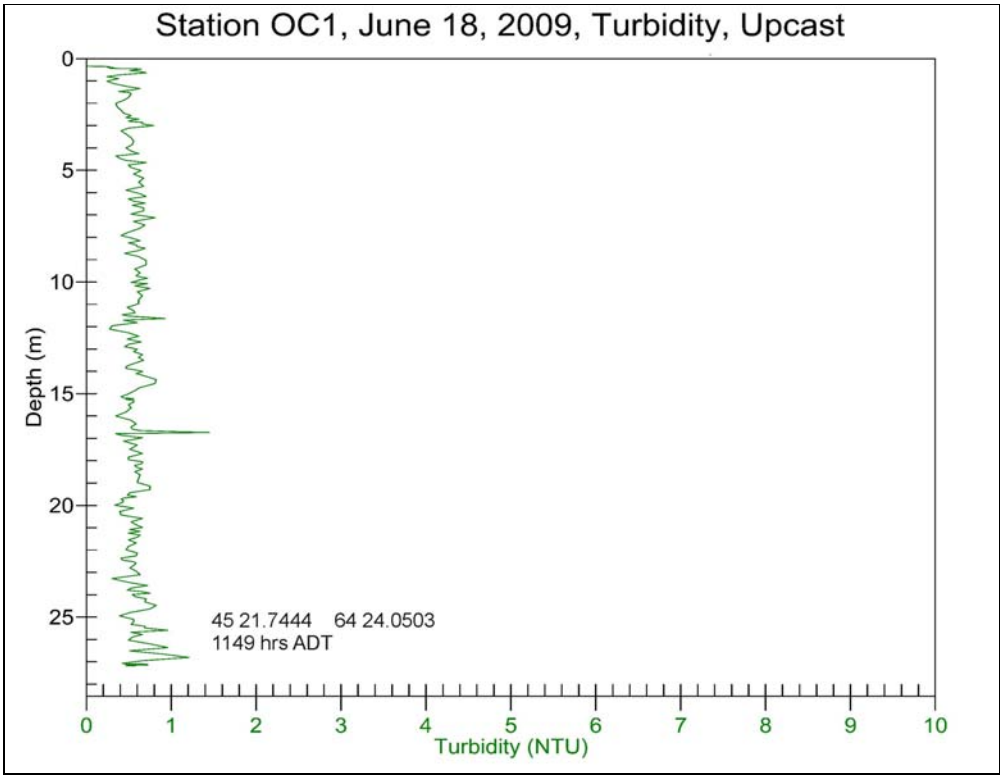


Figure C8. Vertical profile of turbidity (NTU) at Station OC1, Minas Passage study site, June 18, 2009.

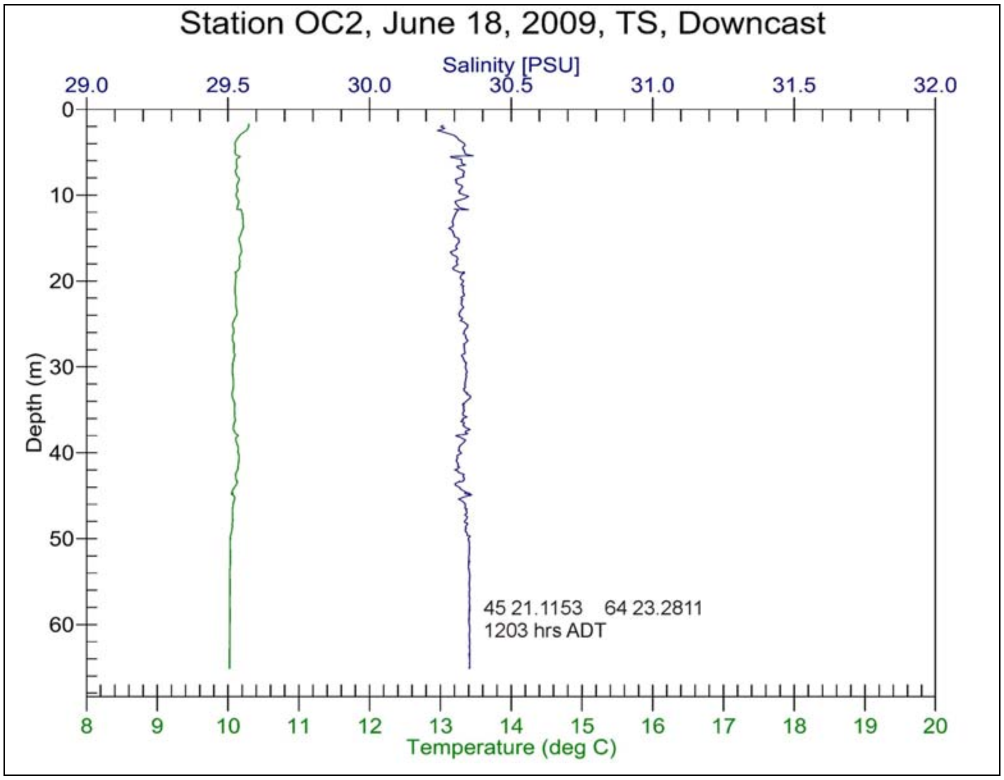


Figure C9. Vertical profile of temperature and salinity at Sta. OC2, Minas Passage study site, June 18, 2009.

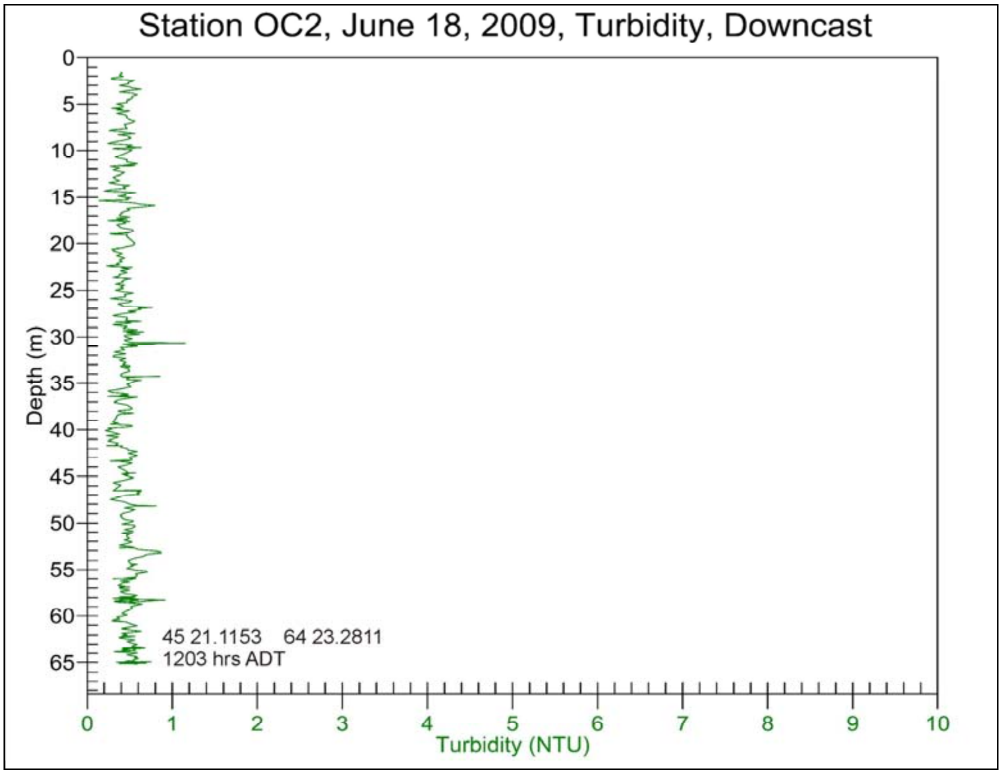


Figure C10. Vertical profile of turbidity (NTU) at Station OC2, Minas Passage study site, June 18, 2009.

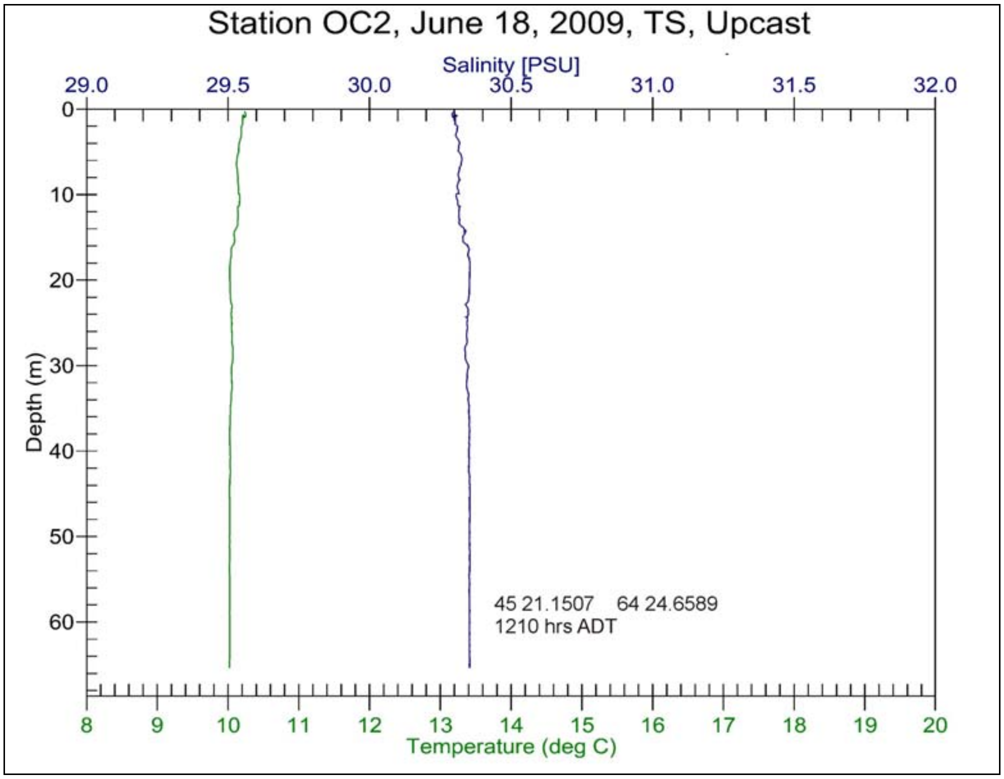


Figure C11. Vertical profile of temperature and salinity at Sta. OC2, Minas Passage study site, June 18, 2009.

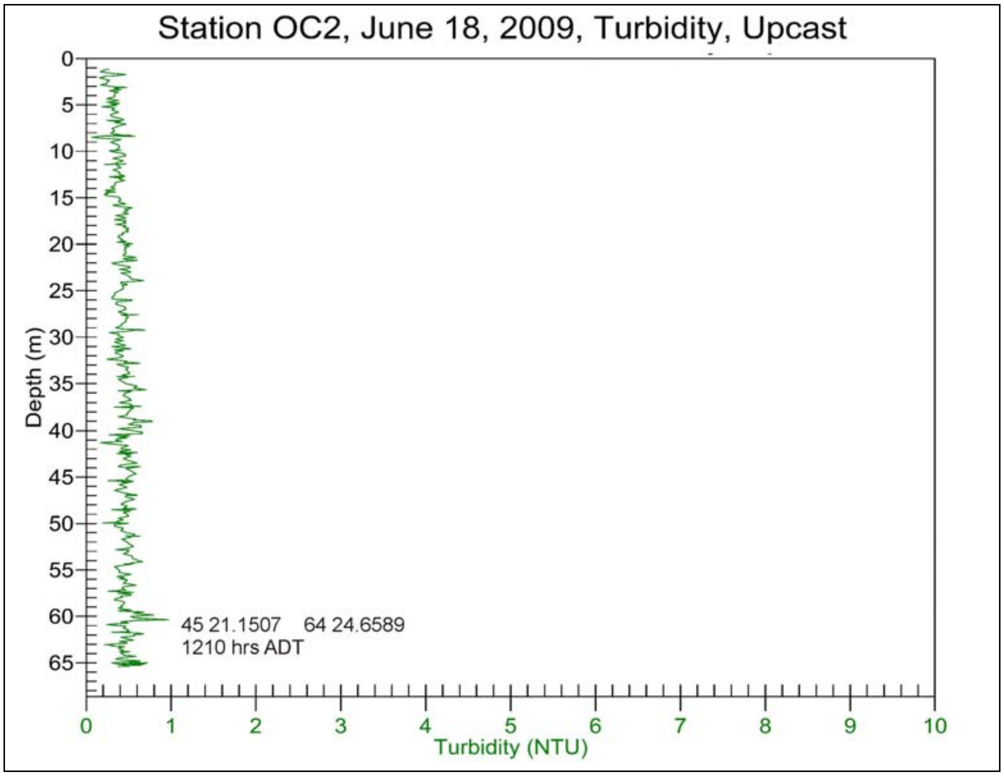


Figure C12. Vertical profile of turbidity (NTU) at Station OC2, Minas Passage study site, June 18, 2009.

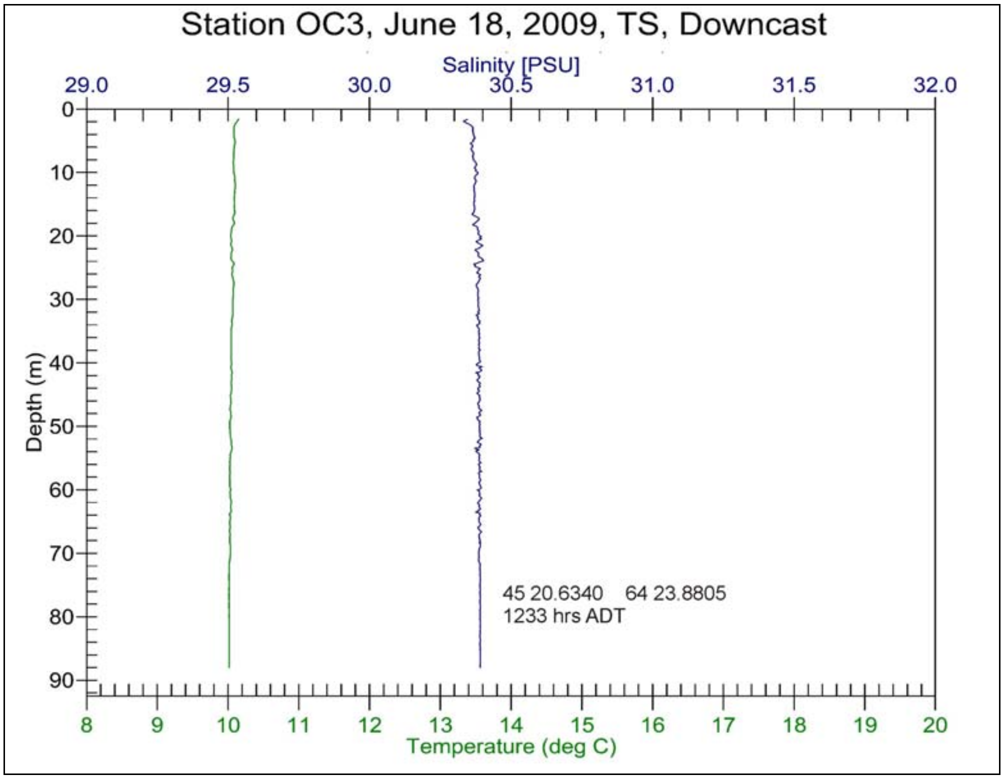


Figure C13. Vertical profile of temperature and salinity at Sta. OC3, Minas Passage study site, June 18, 2009.

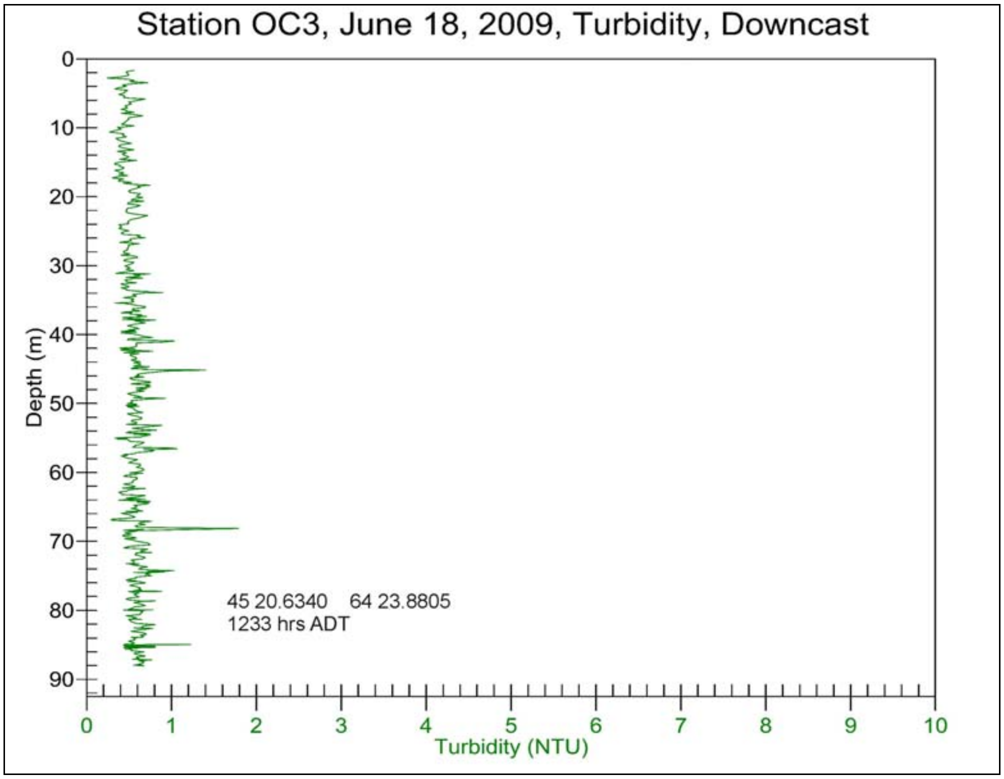


Figure C14. Vertical profile of turbidity (NTU) at Station OC3, Minas Passage study site, June 18, 2009.

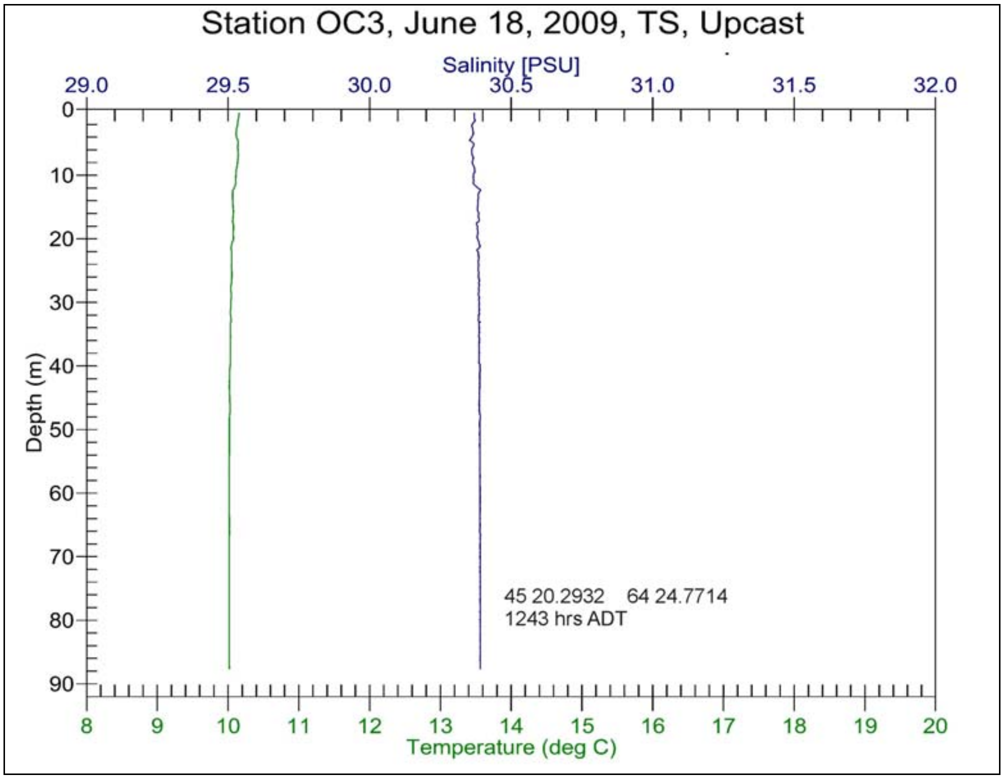


Figure C15. Vertical profile of temperature and salinity at Sta. OC3, Minas Passage study site, June 18, 2009.

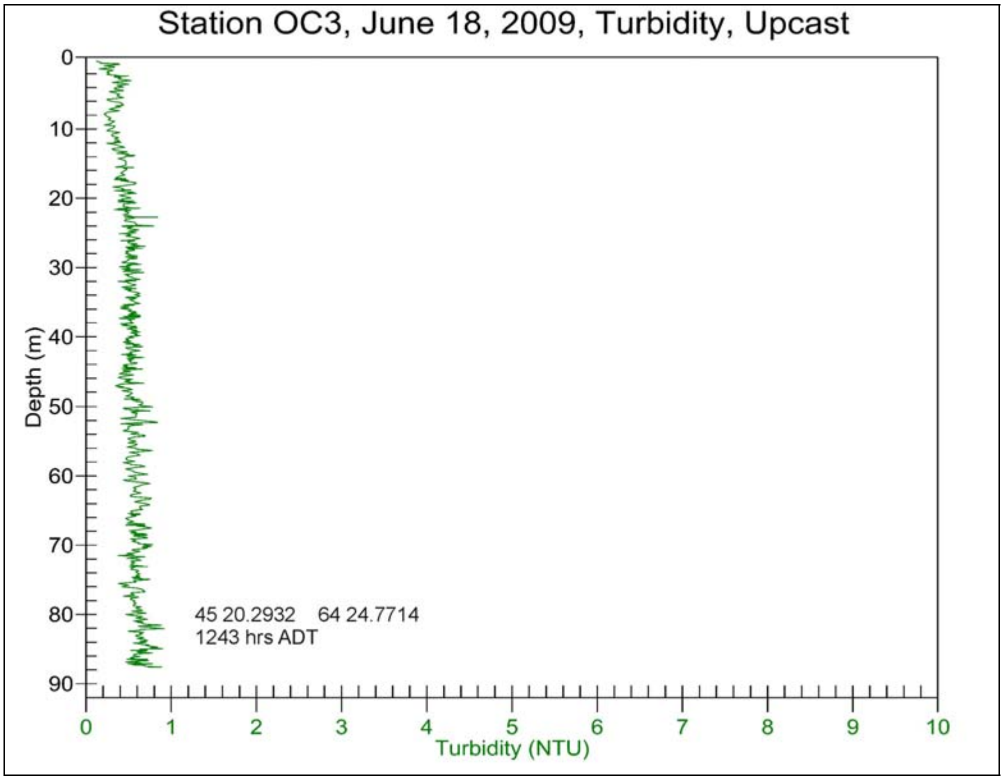


Figure C16. Vertical profile of turbidity (NTU) at Station OC3, Minas Passage study site, June 18, 2009.

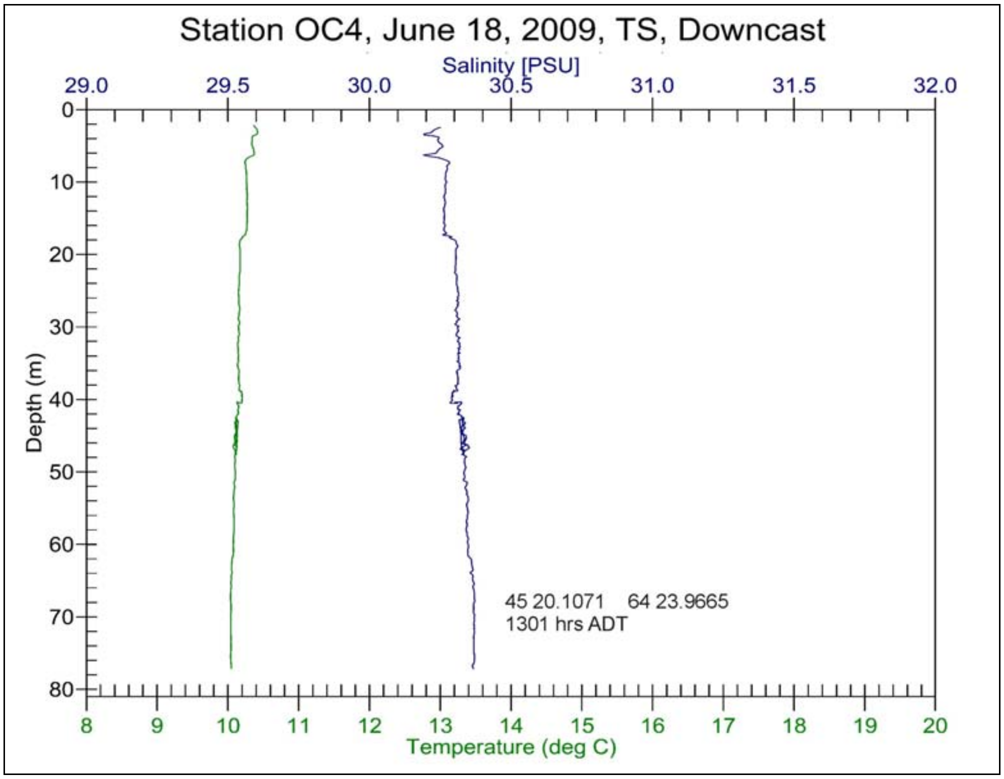


Figure C17. Vertical profile of temperature and salinity at Sta. OC4, Minas Passage study site, June 18, 2009.

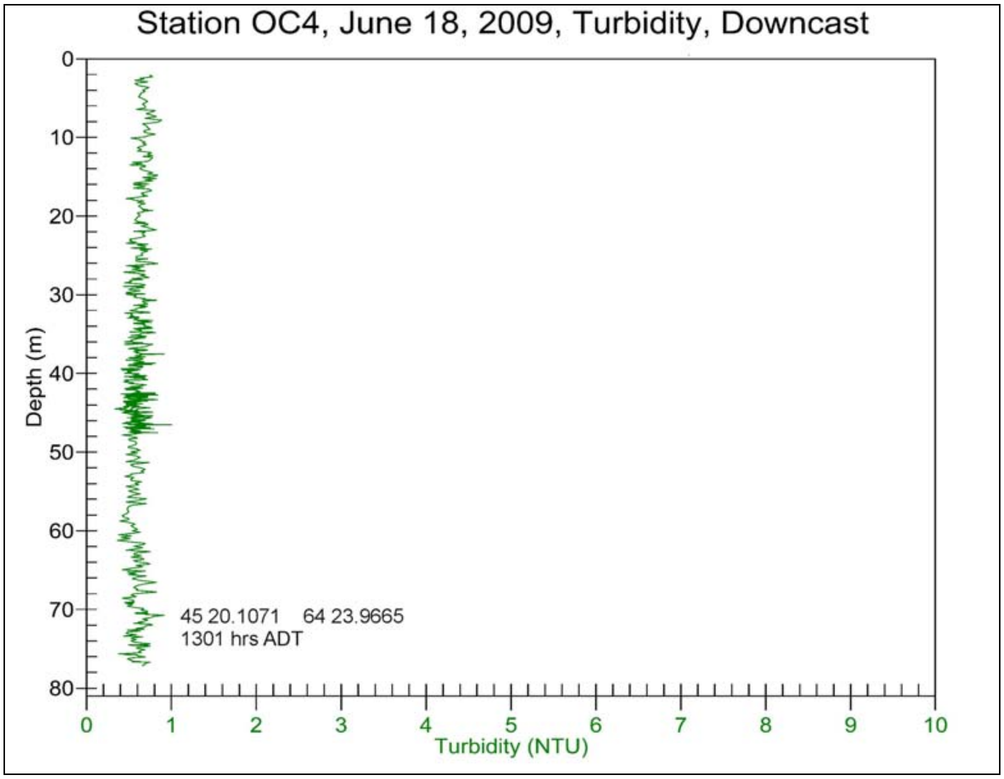


Figure C18. Vertical profile of turbidity (NTU) at Station OC4, Minas Passage study site, June 18, 2009.

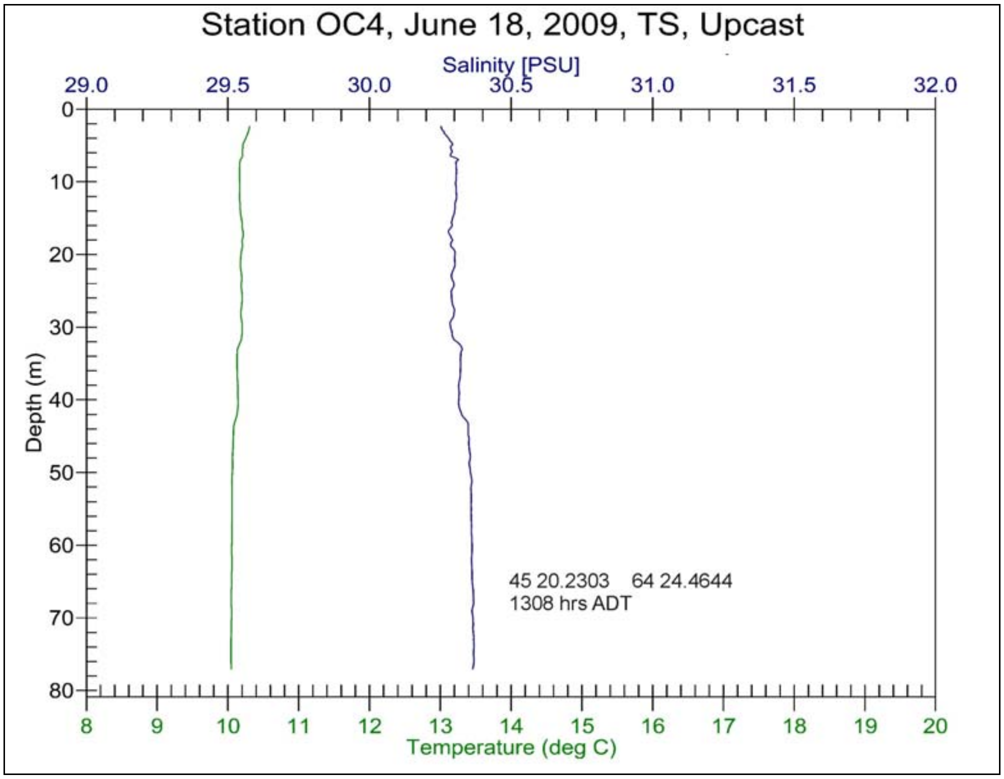
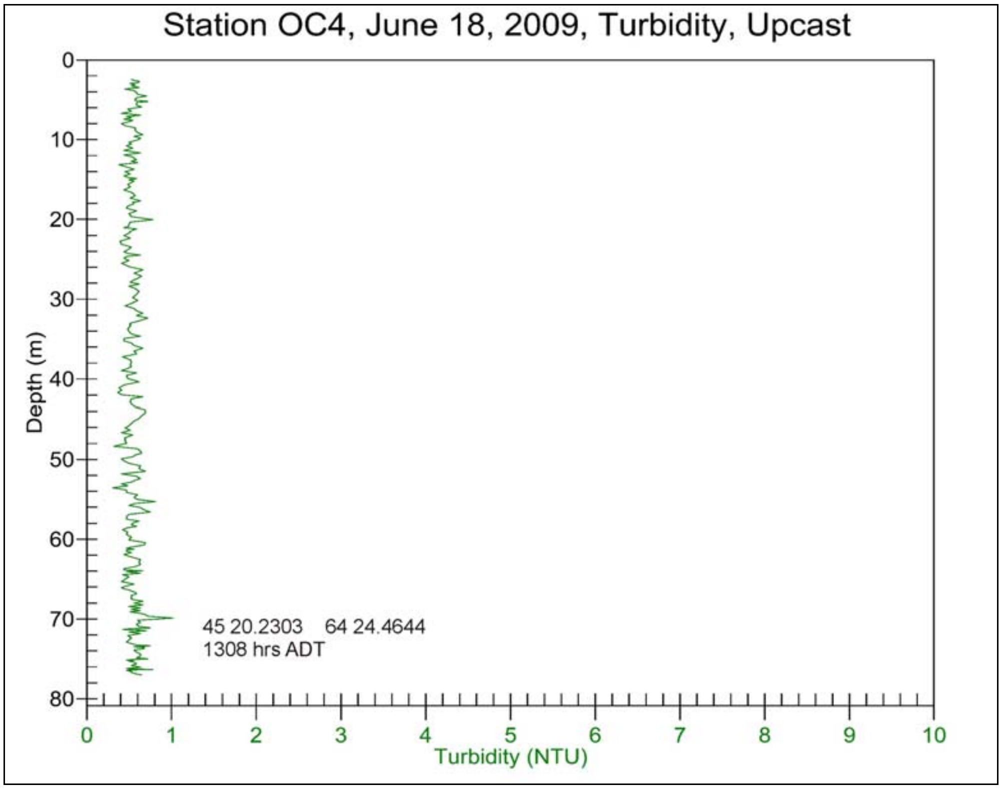


Figure C19. Vertical profile of temperature and salinity at Sta. OC4, Minas Passage study site, June 18, 2009.



FigureC20. Vertical profile of turbidity (NTU) at Station OC4, Minas Passage study site, June 18, 2009.

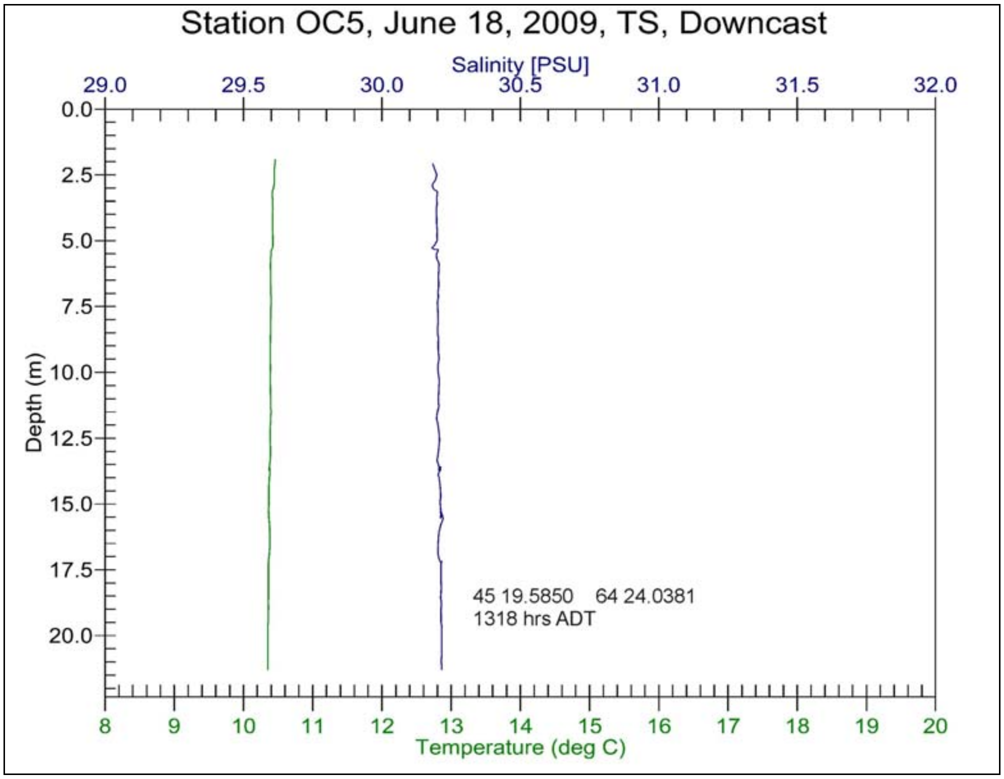


Figure C21. Vertical profile of temperature and salinity at Sta. OC5, Minas Passage study site, June 18, 2009.

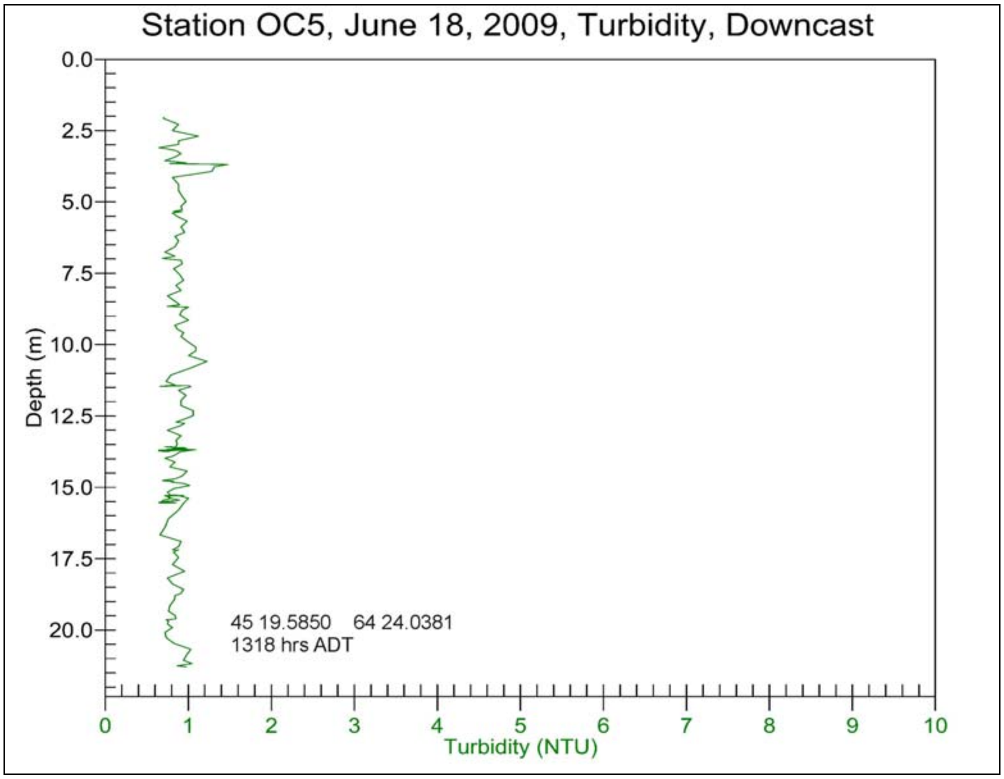


Figure C22. Vertical profile of turbidity (NTU) at Station OC5, Minas Passage study site, June 18, 2009.

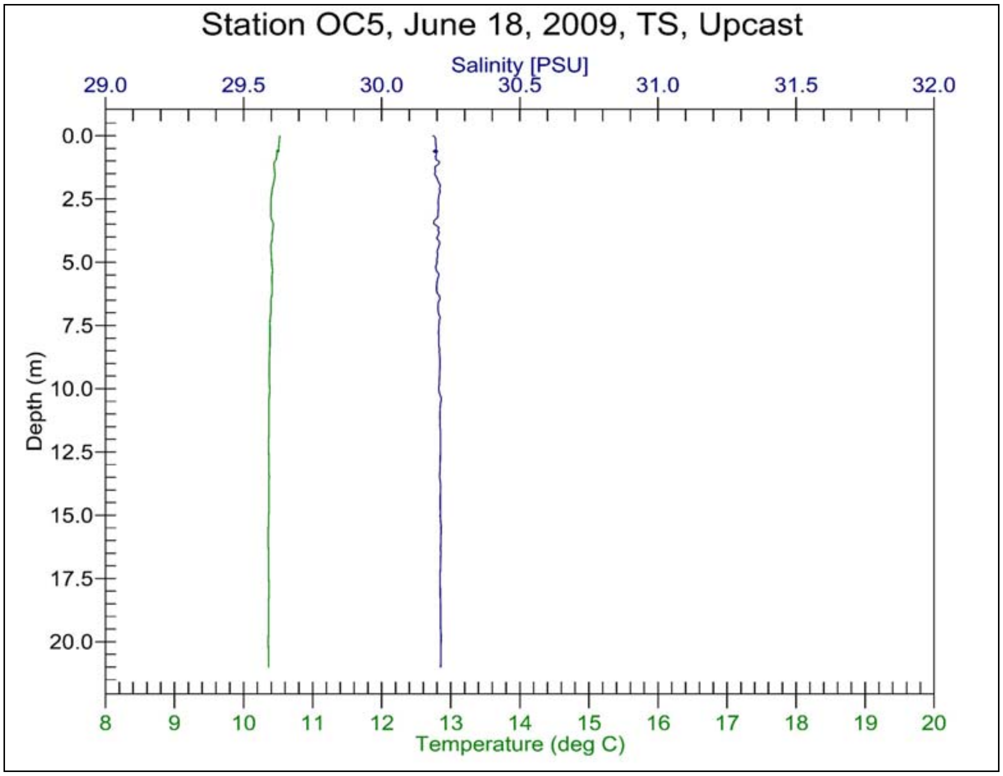


Figure C23. Vertical profile of temperature and salinity at Sta. OC5, Minas Passage study site, June 18, 2009.

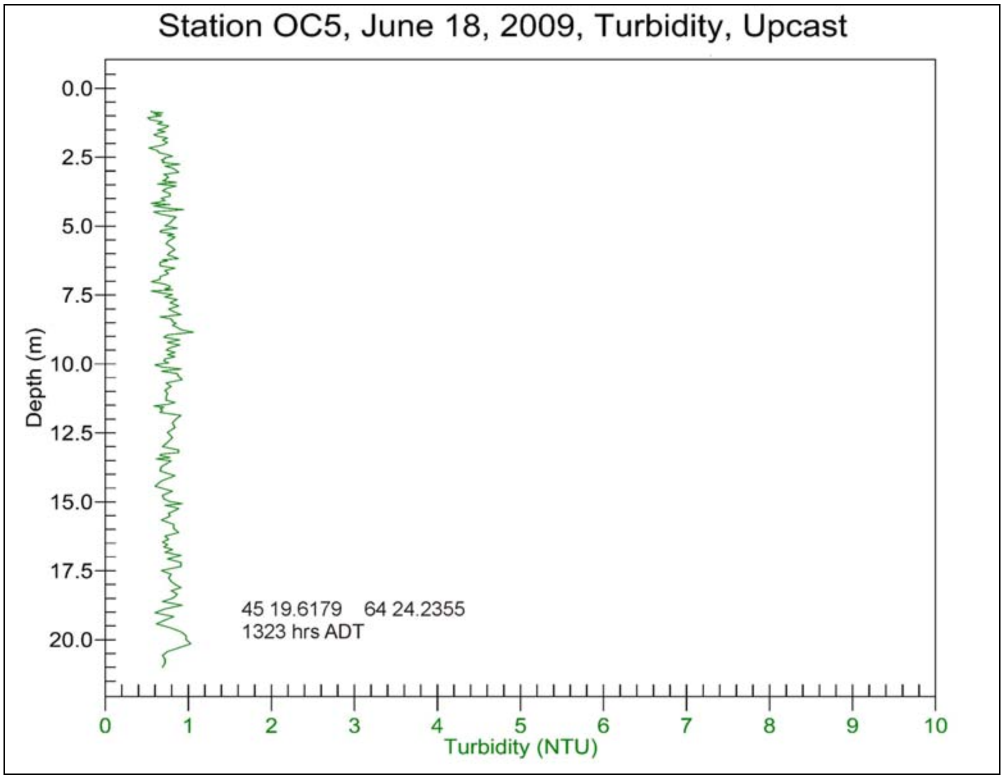


Figure C24. Vertical profile of turbidity (NTU) at Station OC5, Minas Passage study site, June 18, 2009.

Appendix D. Vertical profiles of Temperature, Salinity and Turbidity, Minas Passage, July 2009.

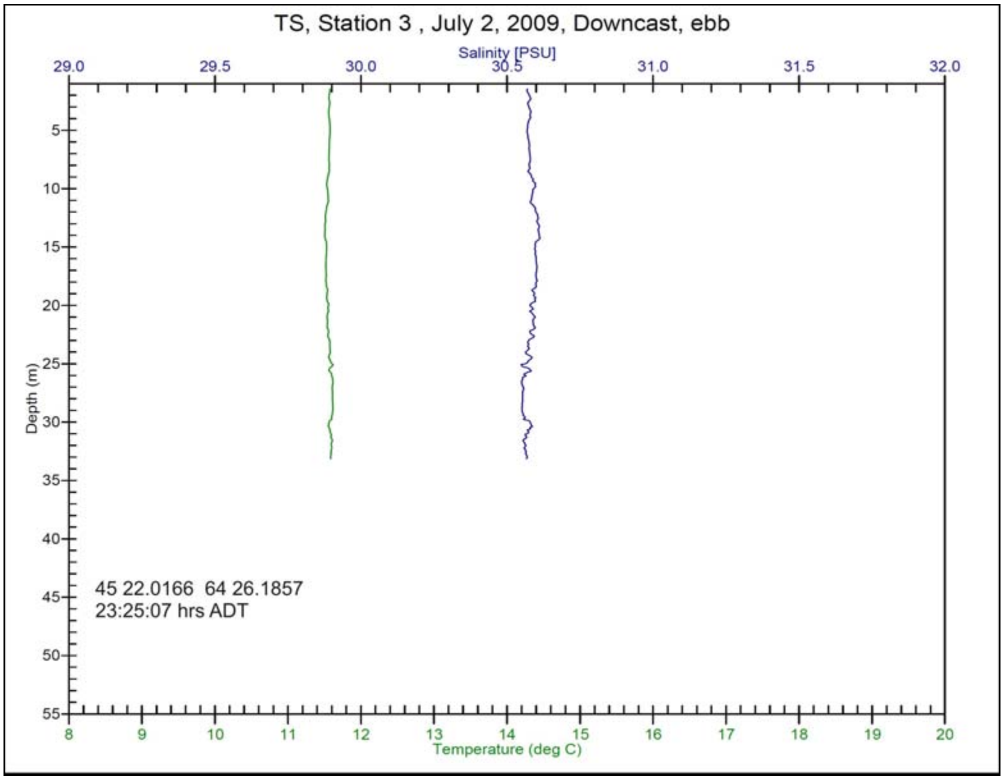


Figure D1. Vertical profile of temperature and salinity at Station 3, Minas Passage study site, July 2, 2009.

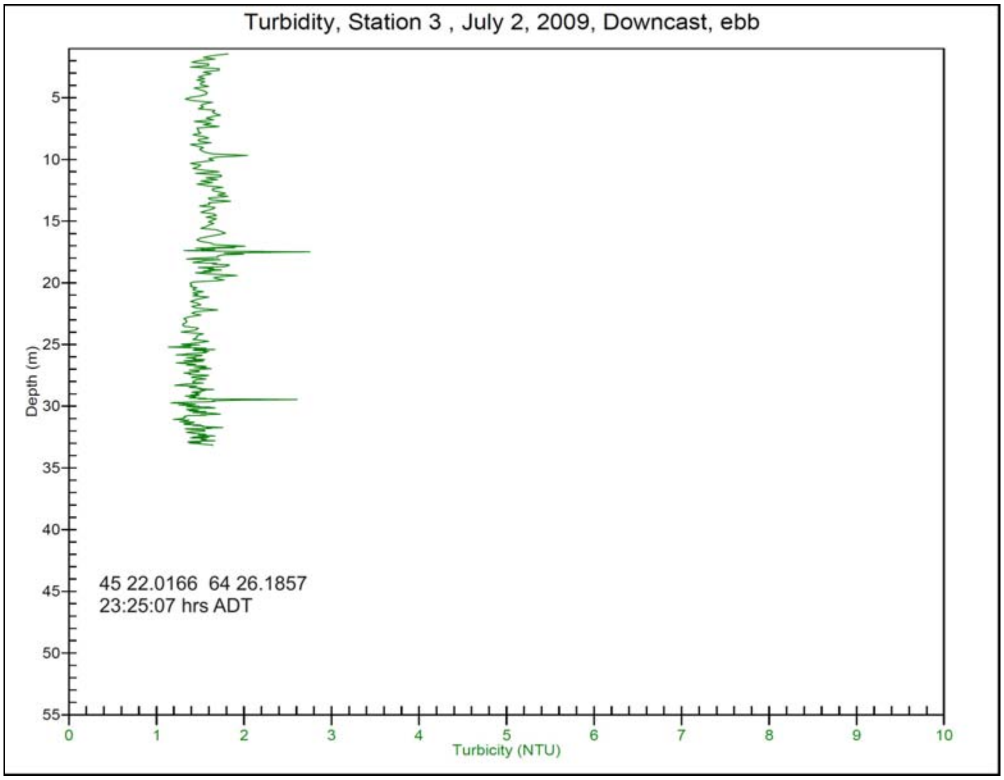


Figure D2. Vertical profile of turbidity (NTU) at Station 3, Minas Passage study site, July 2, 2009.

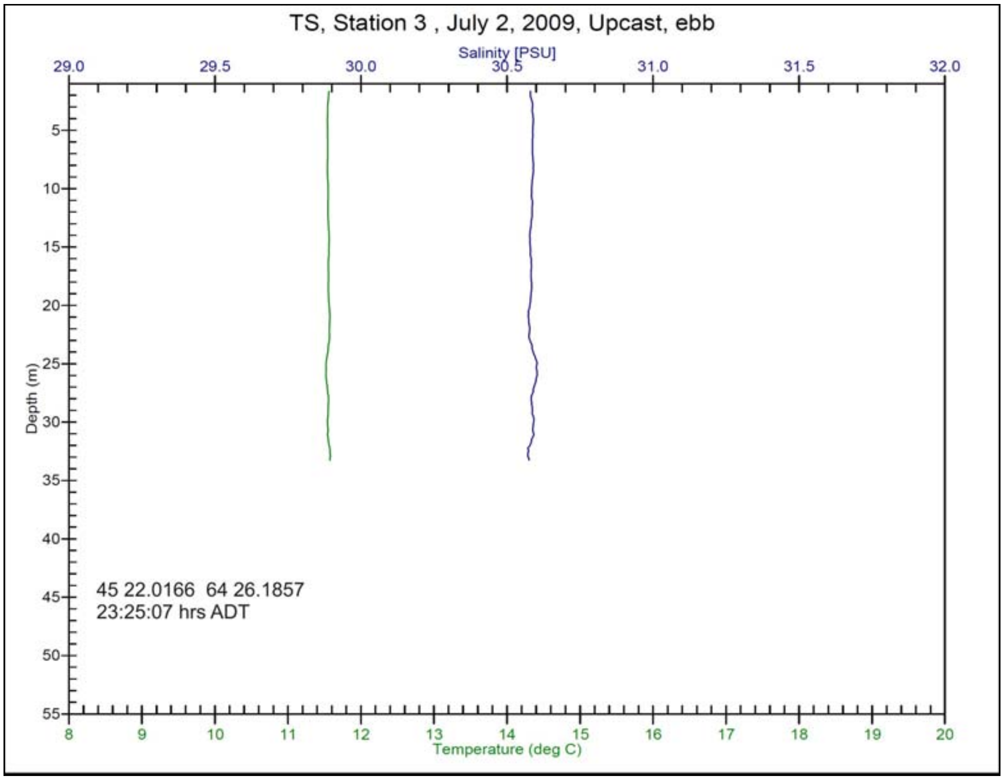


Figure D3. Vertical profile of temperature and salinity at Station 3, Minas Passage study site, July 2, 2009.

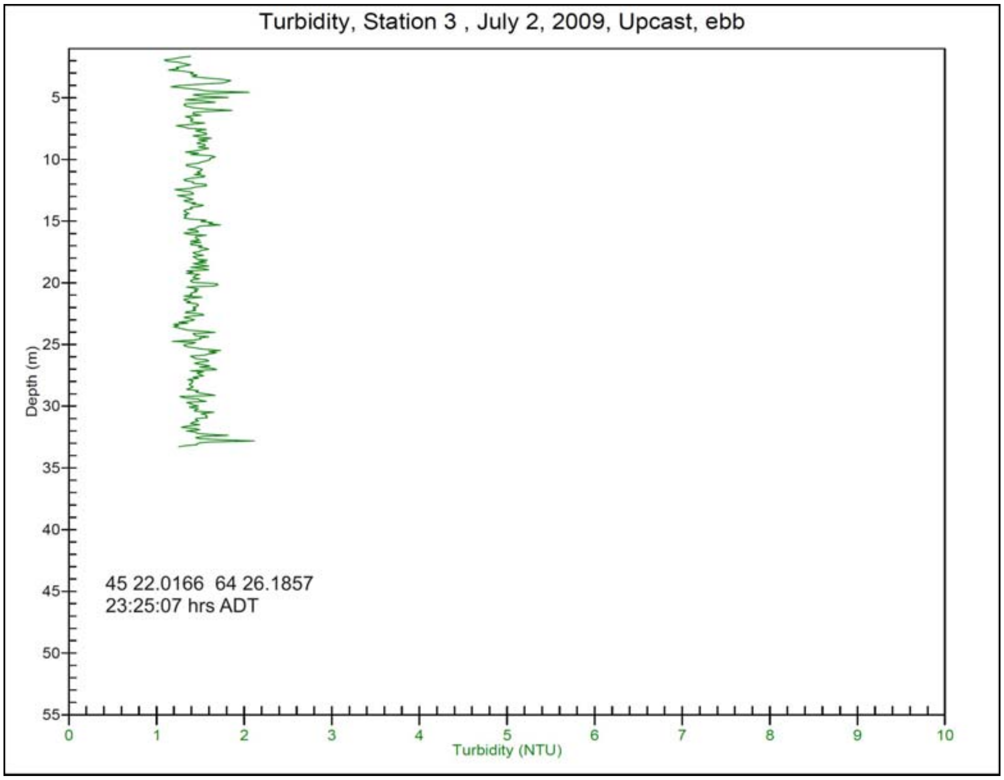


Figure D4. Vertical profile of turbidity (NTU) at Station 3, Minas Passage study site, July 2, 2009.

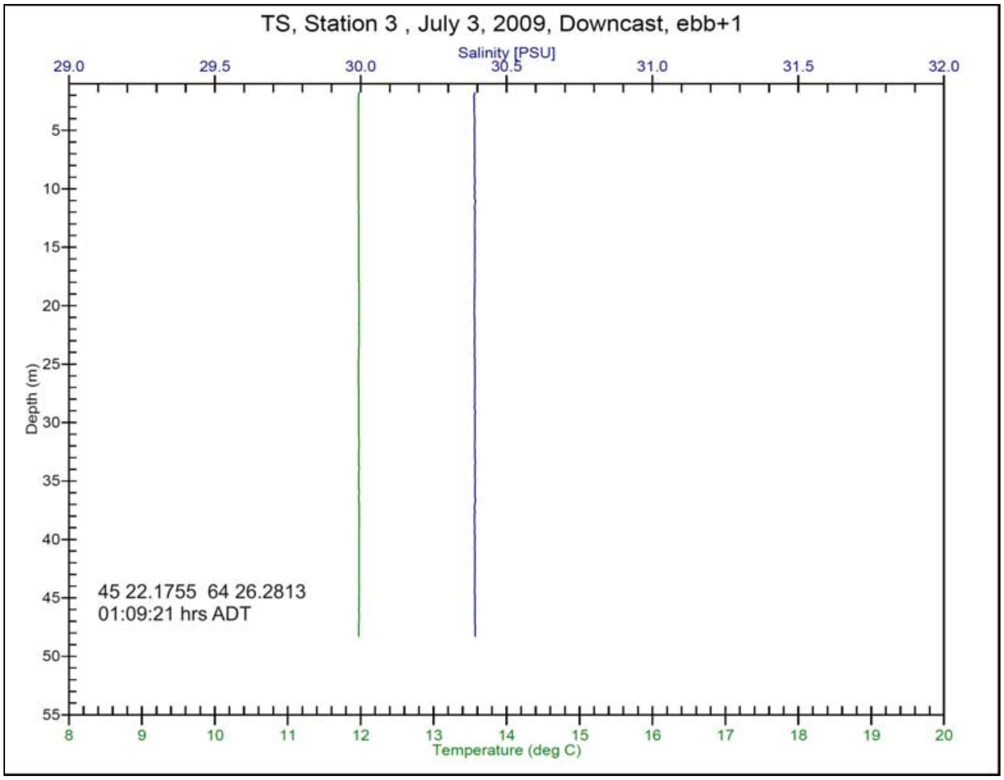


Figure D5. Vertical profile of temperature and salinity at Station 3, Minas Passage study site, July 3, 2009.

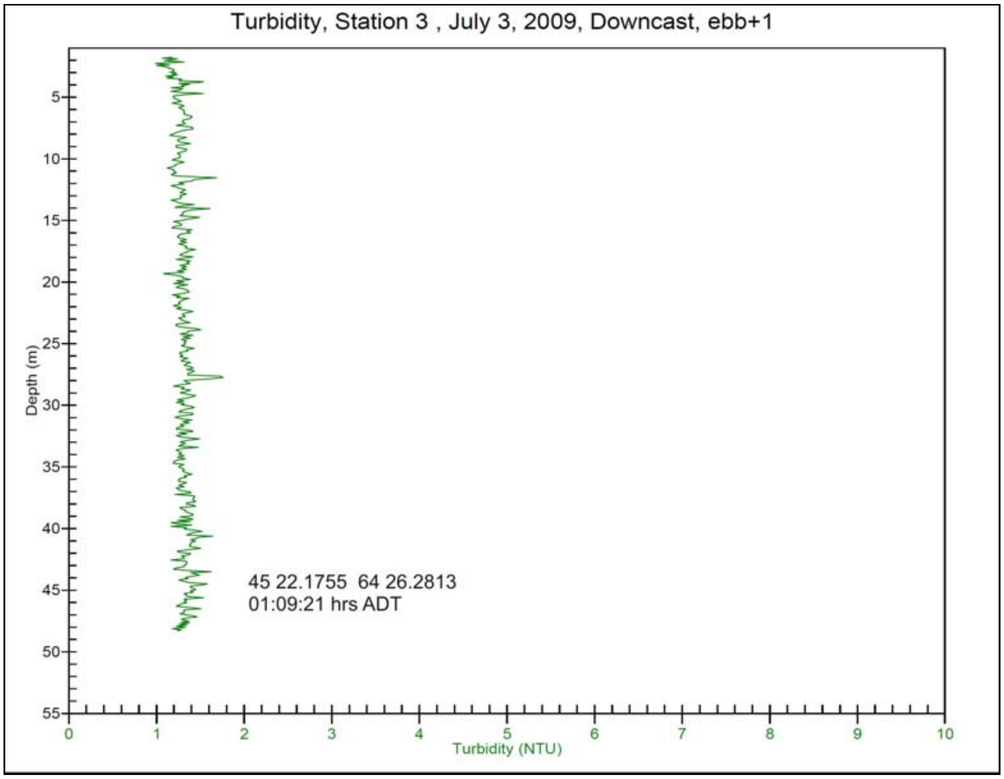


Figure D6. Vertical profile of turbidity (NTU) at Station 3, Minas Passage study site, July 3, 2009.

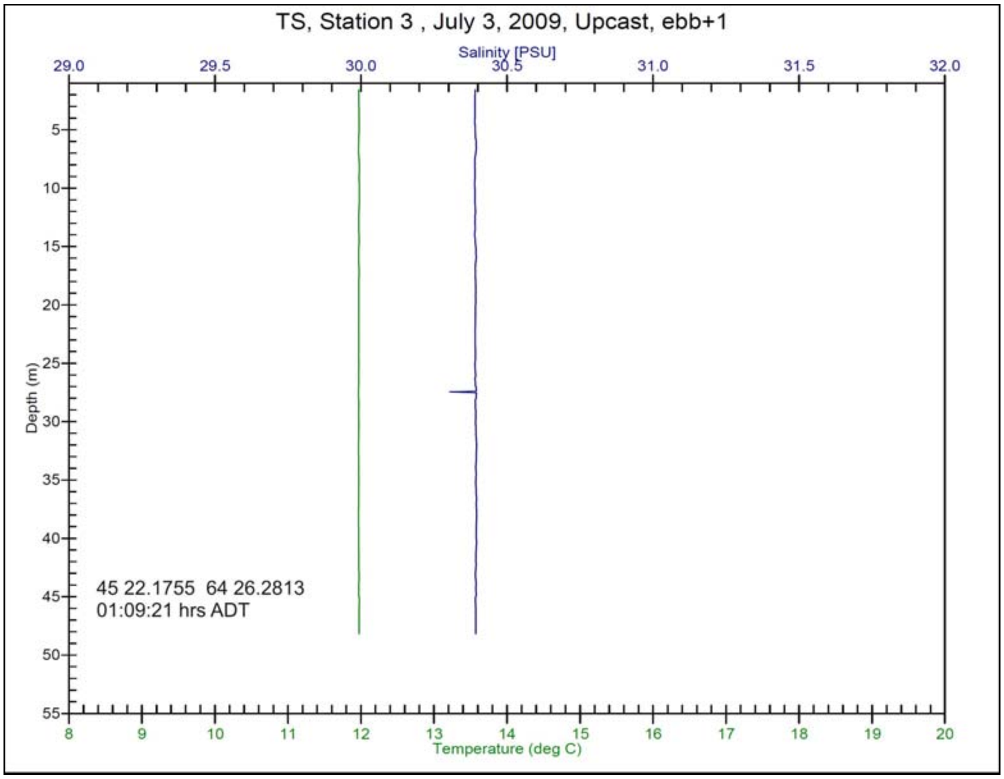


Figure D7. Vertical profile of temperature and salinity at Station 3, Minas Passage study site, July 3, 2009.

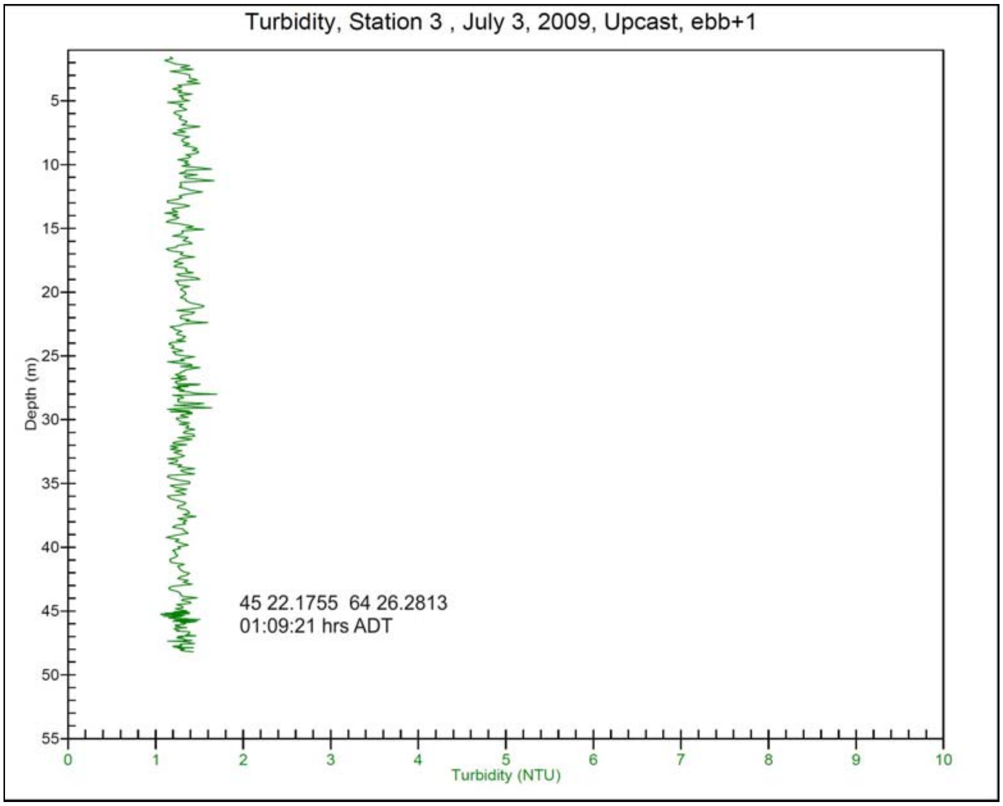


Figure D8. Figure 6. Vertical profile of turbidity (NTU) at Station 3, Minas Passage study site, July 3, 2009.

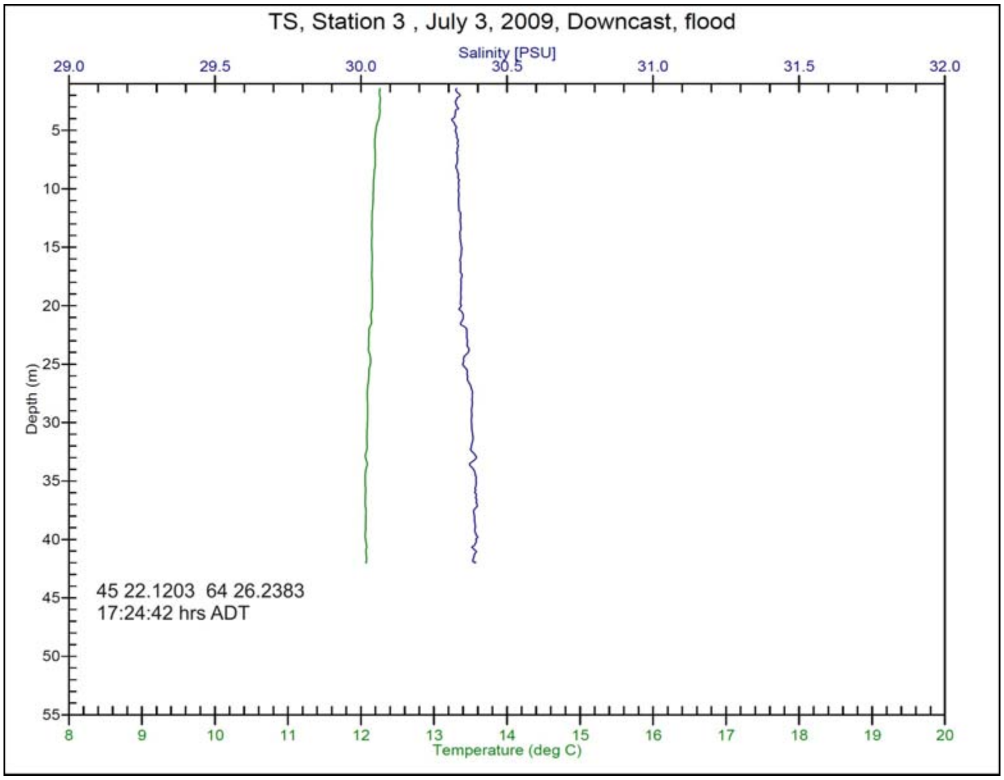


Figure D9. Vertical profile of temperature and salinity at Station 3, Minas Passage study site, July 3, 2009.

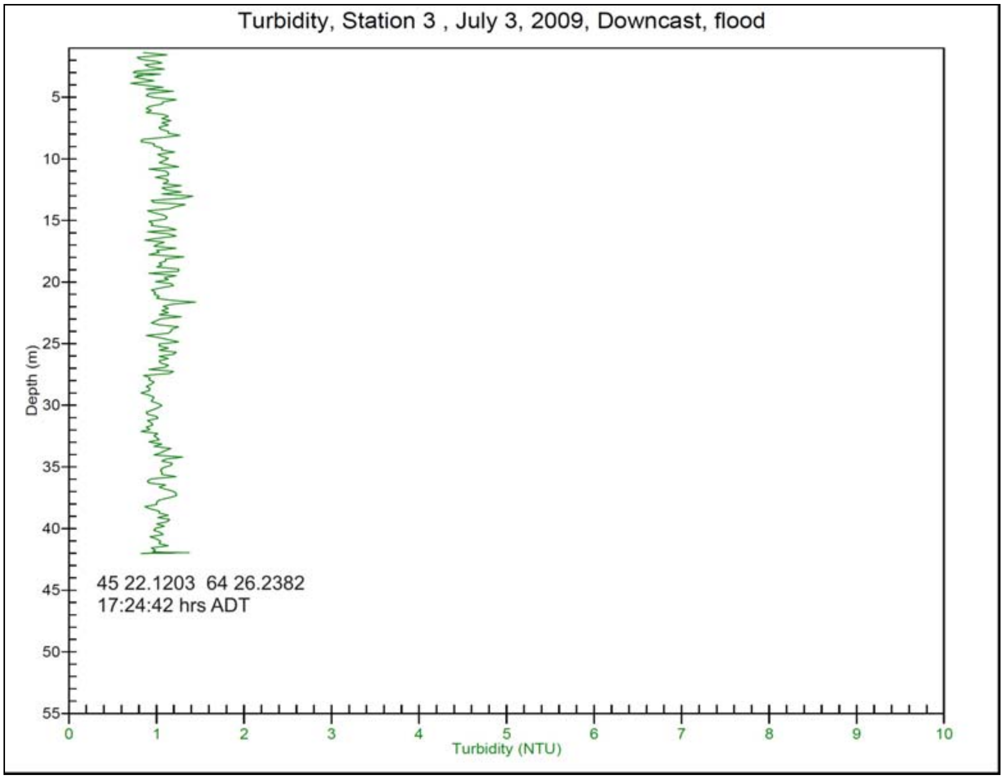


Figure D10. Vertical profile of turbidity (NTU) at Station 3, Minas Passage study site, July 3, 2009.

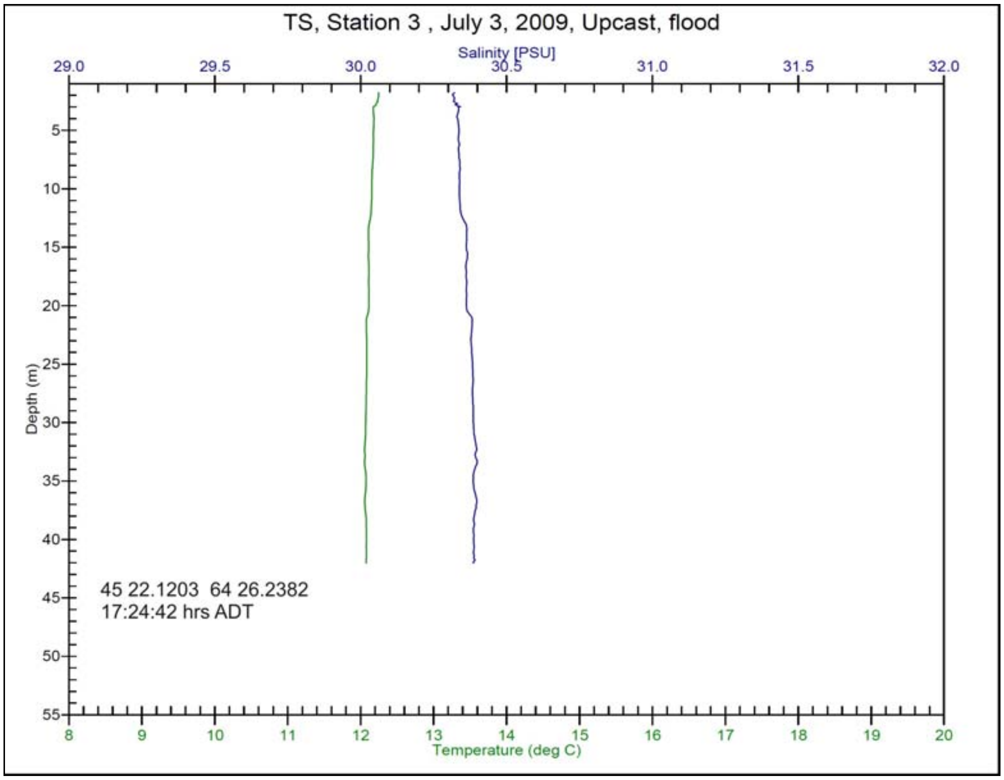


Figure D11. Vertical profile of temperature and salinity at Station 3, Minas Passage study site, July 3, 2009.

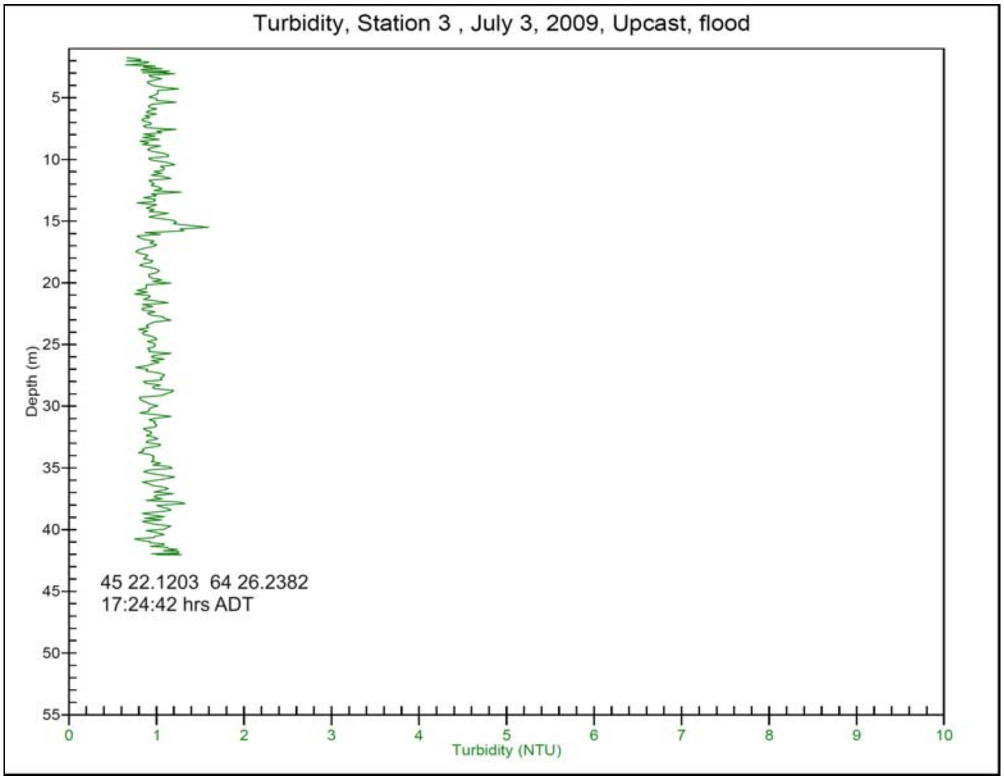


Figure D12. Vertical profile of turbidity (NTU) at Station 3, Minas Passage study site, July 3, 2009.

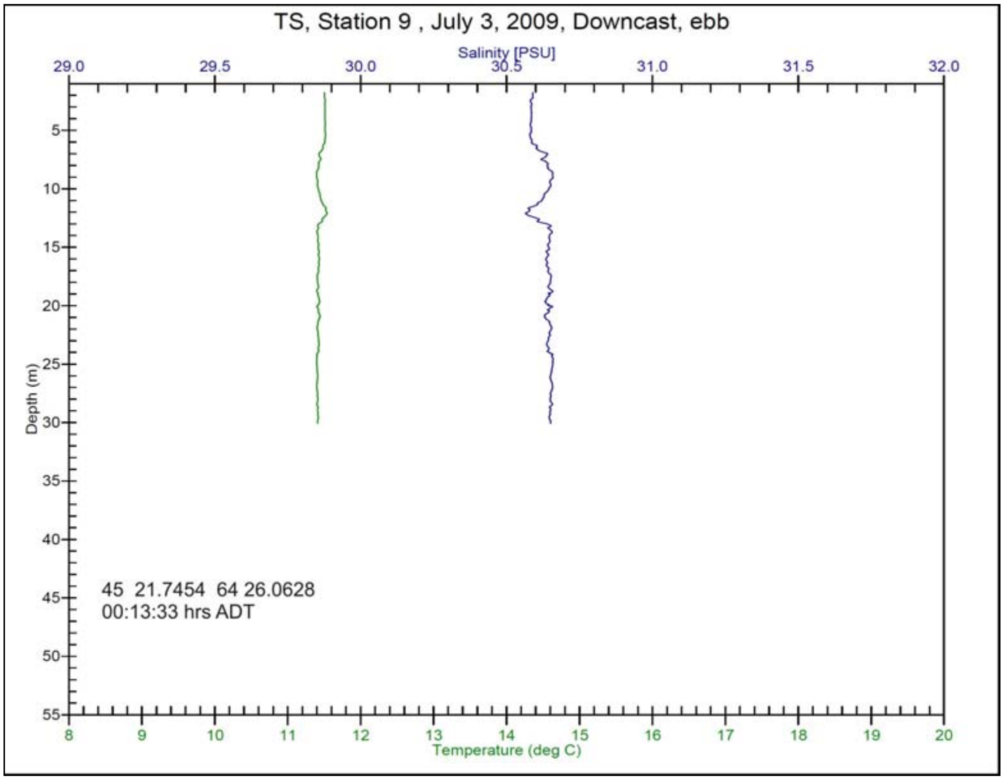


Figure D13. Vertical profile of temperature and salinity at Station 9, Minas Passage study site, July 3, 2009.

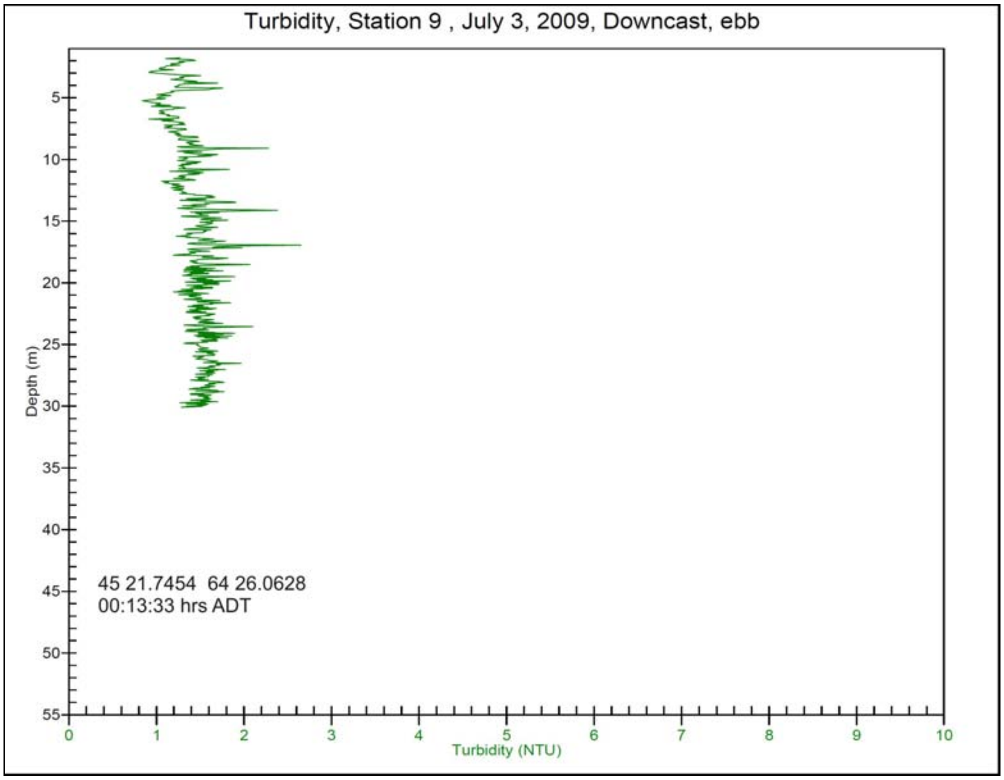


Figure D14. Vertical profile of turbidity (NTU) at Station 9, Minas Passage study site, July 3, 2009.

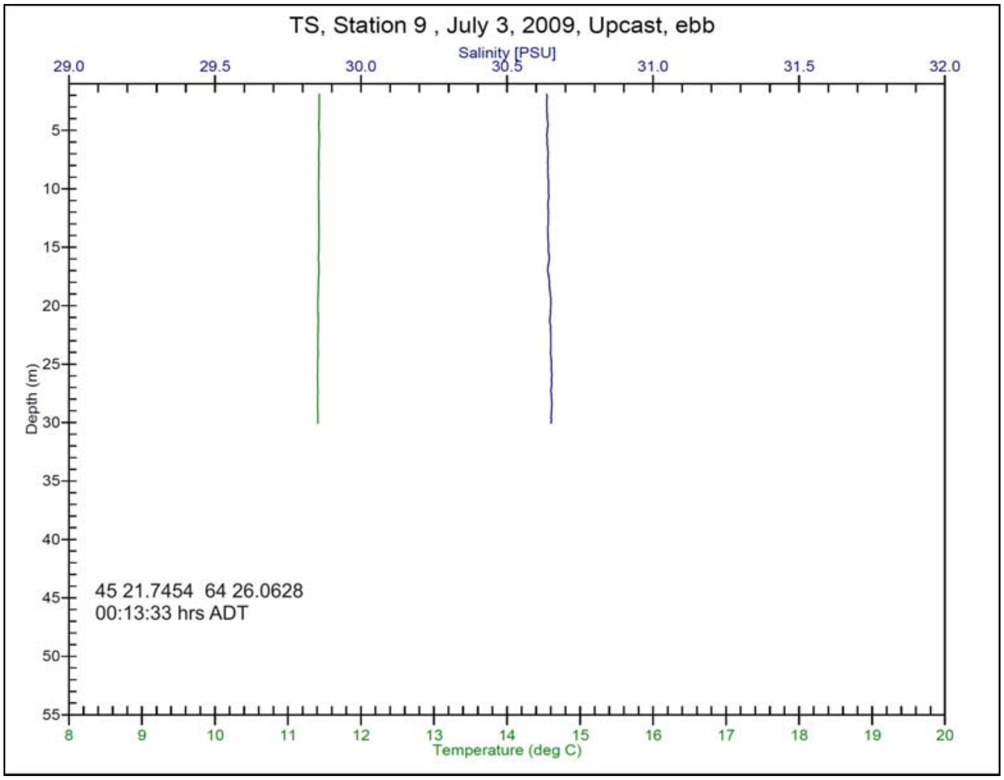


Figure D15. Vertical profile of temperature and salinity at Station 9, Minas Passage study site, July 3, 2009.

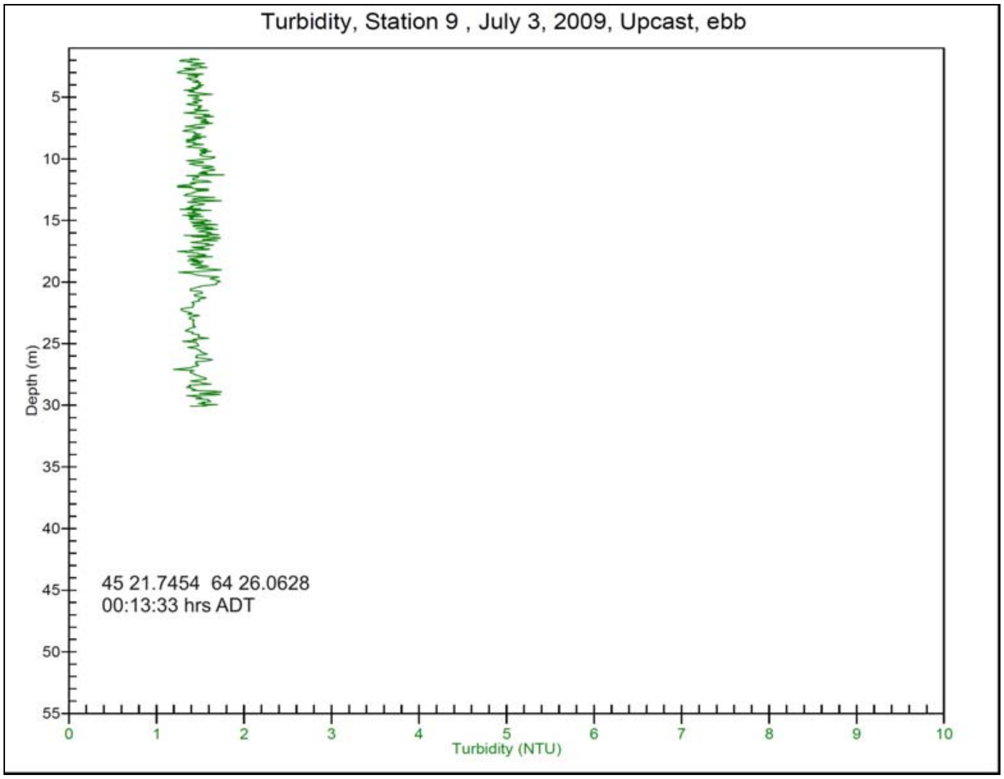


Figure D16. Vertical profile of turbidity (NTU) at Station 9, Minas Passage study site, July 3, 2009.

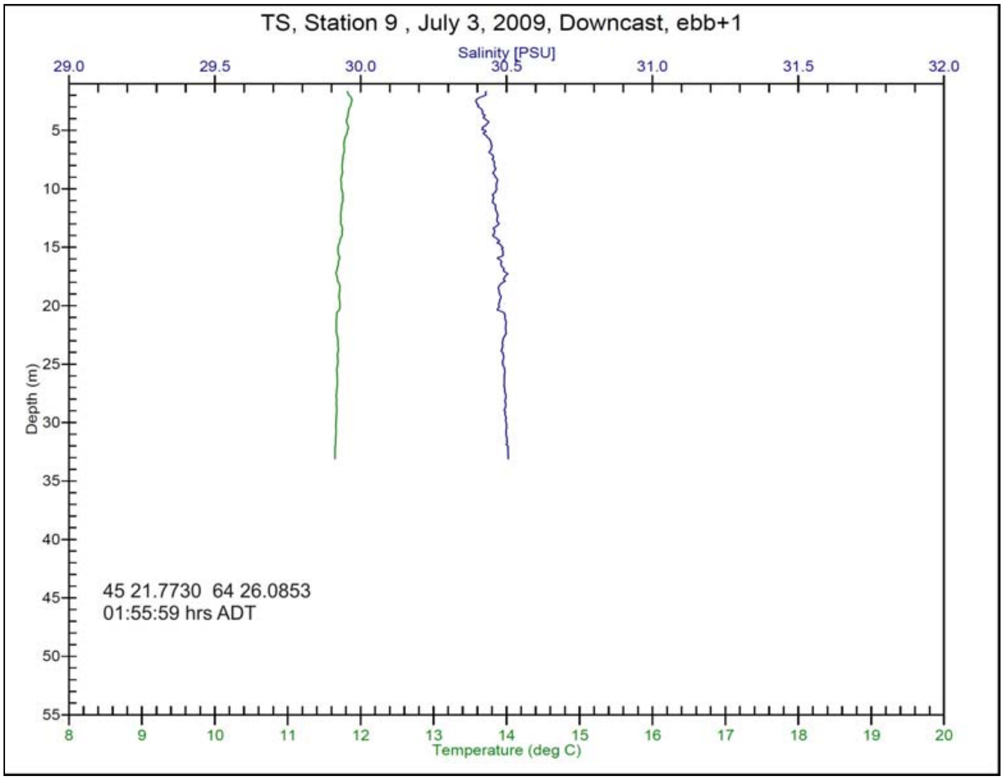


Figure D17. Vertical profile of temperature and salinity at Station 9, Minas Passage study site, July 3, 2009.

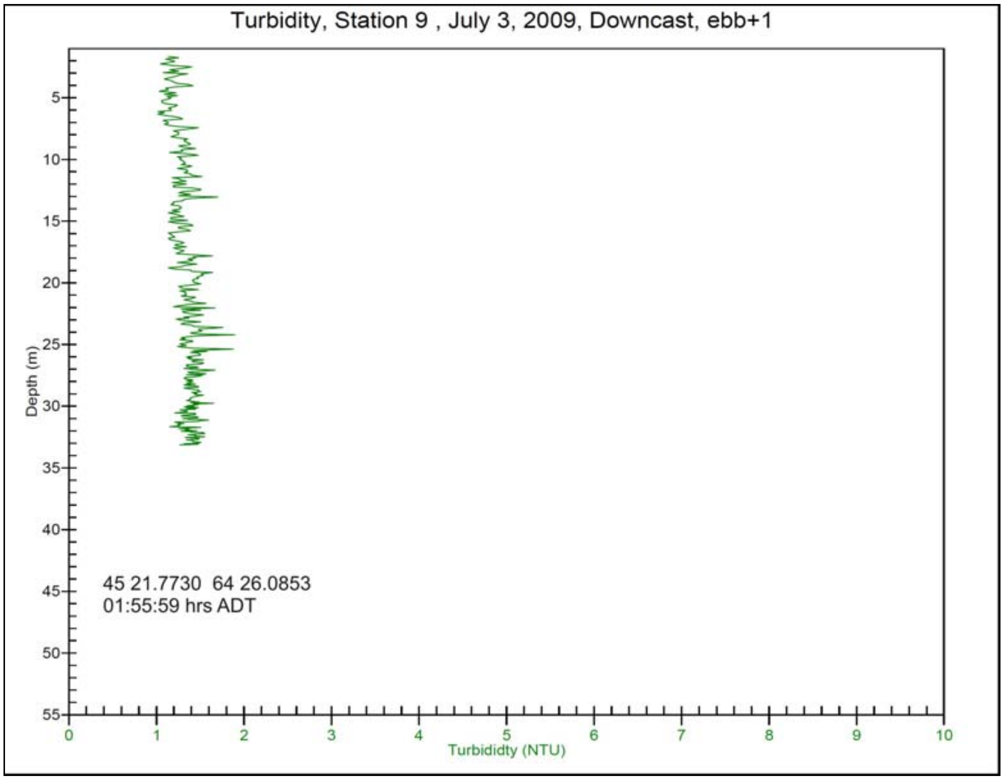


Figure D18. Vertical profile of turbidity (NTU) at Station 9, Minas Passage study site, July 3, 2009.

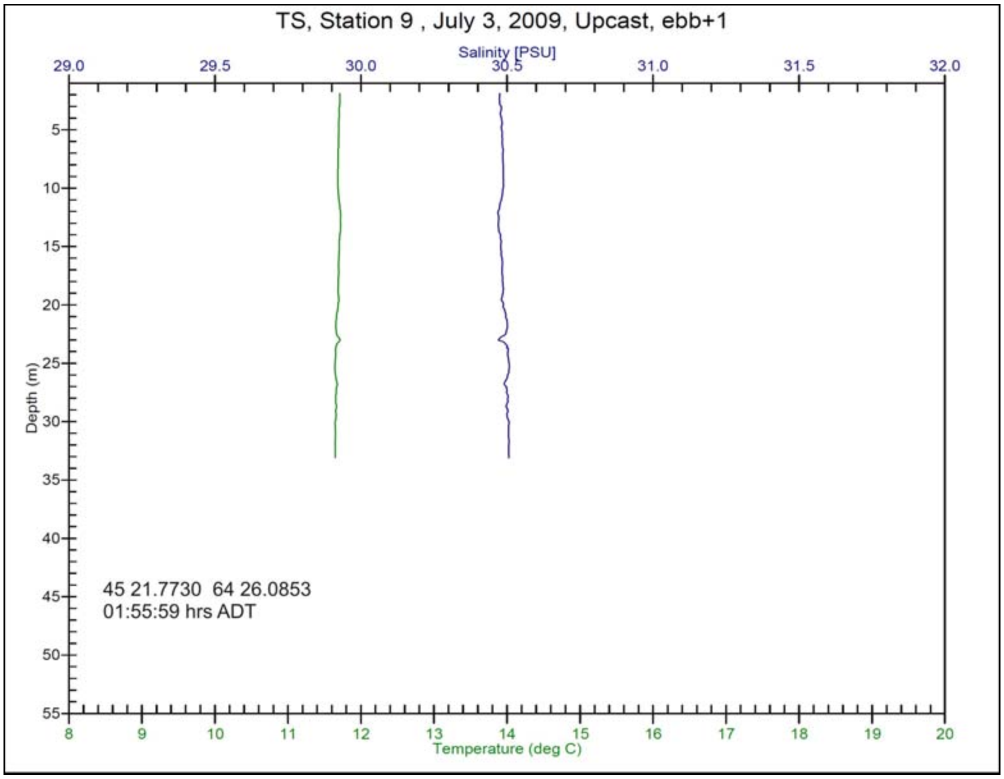


Figure D19. Vertical profile of temperature and salinity at Station 9, Minas Passage study site, July 3, 2009.

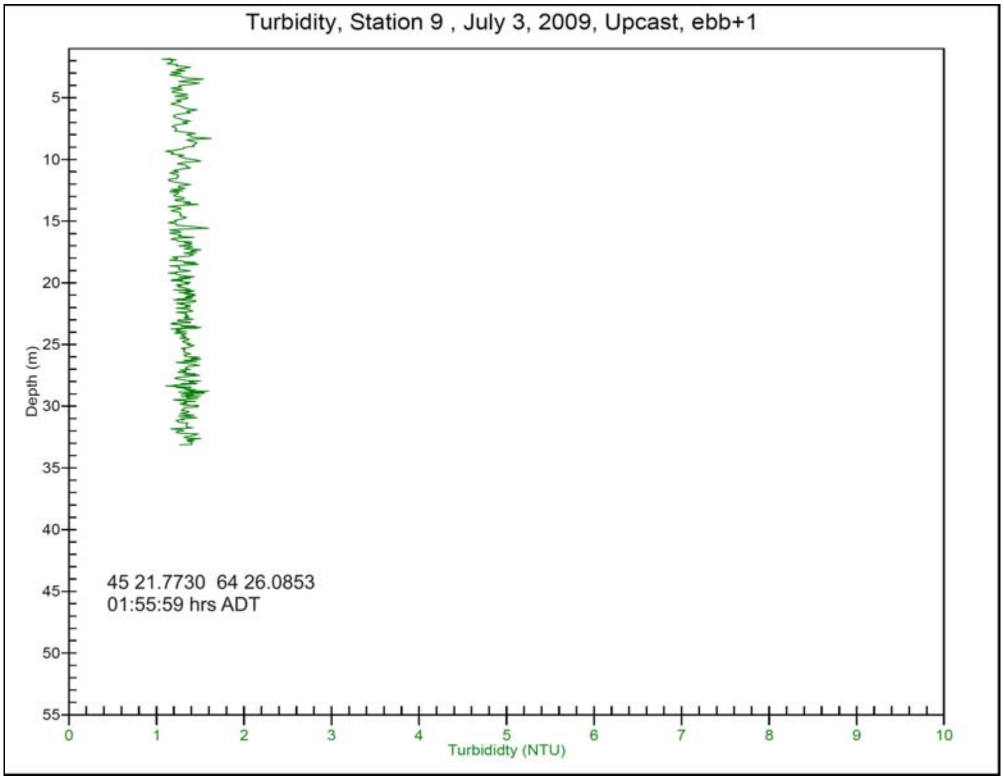


Figure D20. Vertical profile of turbidity (NTU) at Station 9, Minas Passage study site, July 3, 2009.

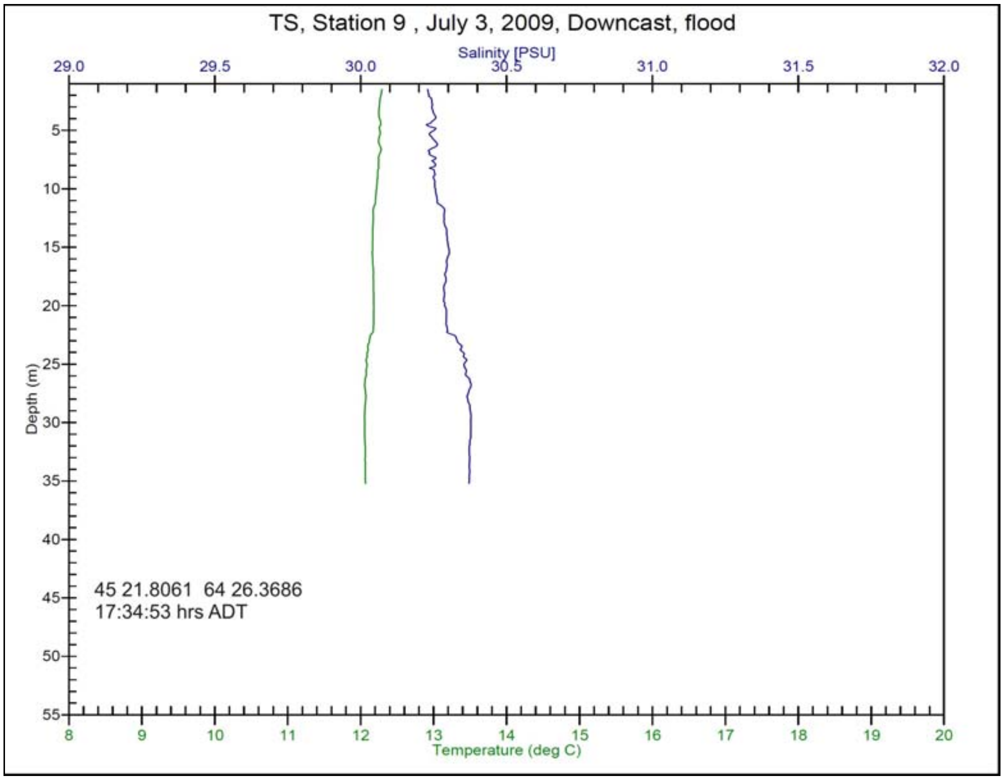


Figure D21. Vertical profile of temperature and salinity at Station 9, Minas Passage study site, July 3, 2009.

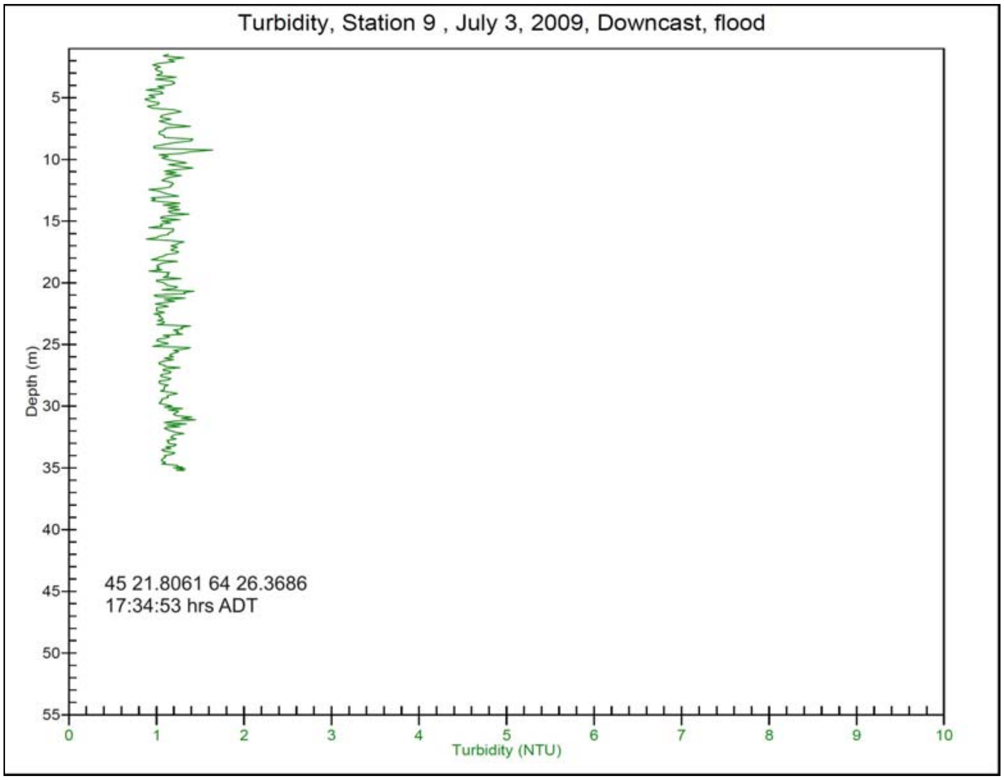


Figure D22. Vertical profile of turbidity (NTU) at Station 9, Minas Passage study site, July 3, 2009.

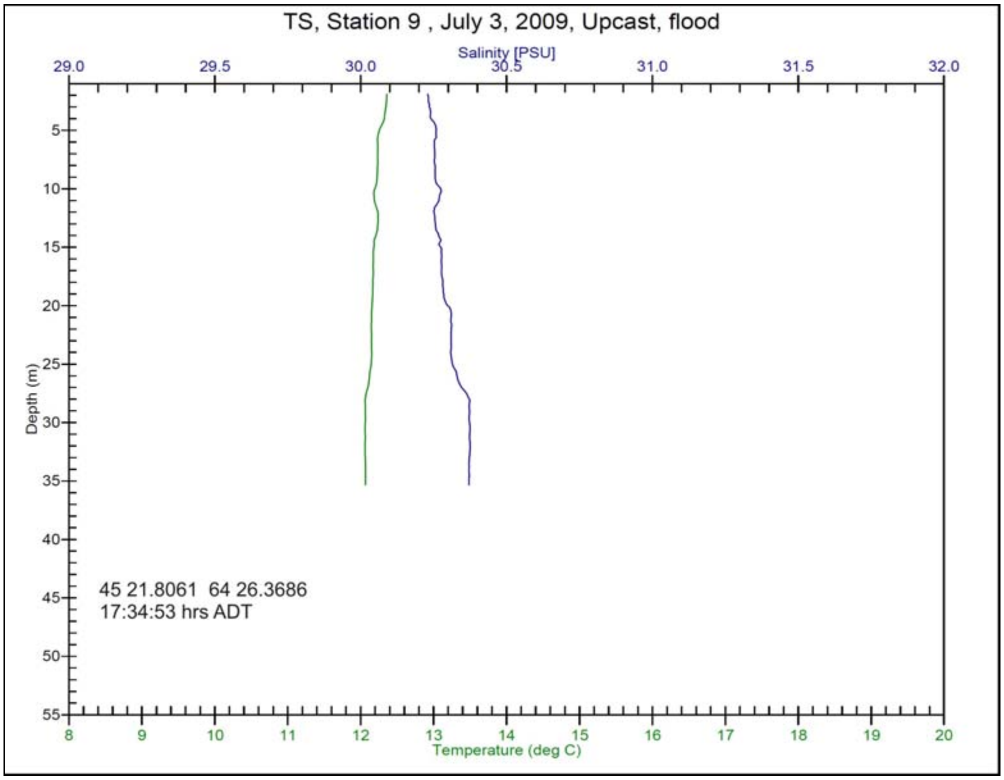


Figure D23. Vertical profile of temperature and salinity at Station 9, Minas Passage study site, July 3, 2009.

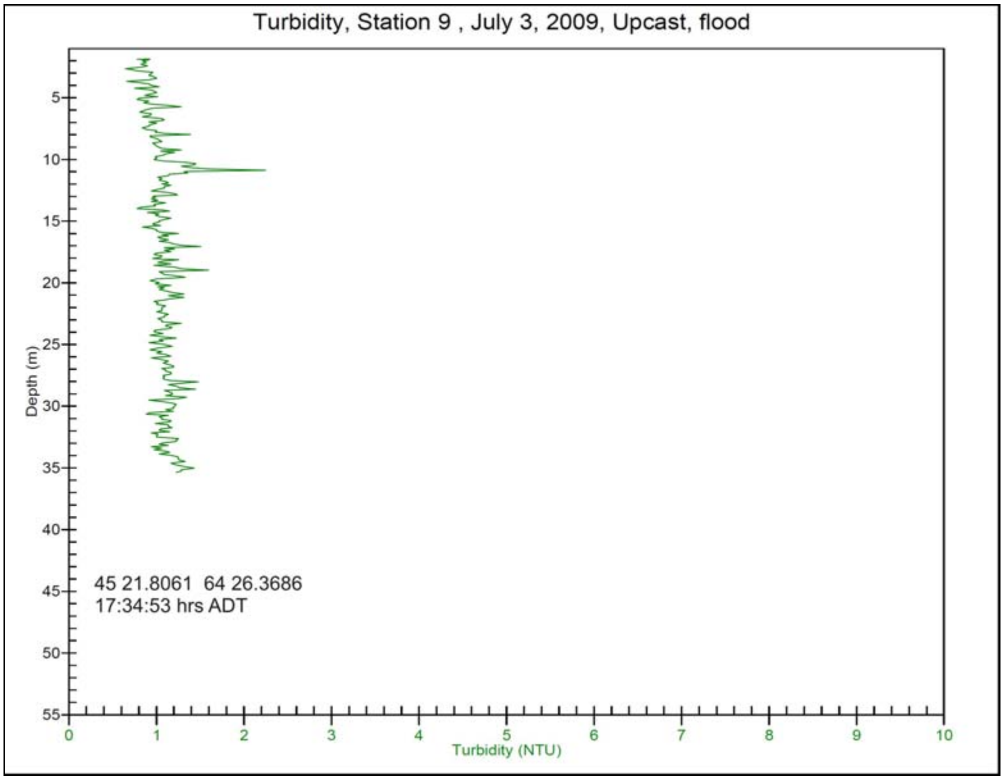


Figure D24. Vertical profile of turbidity (NTU) at Station 9, Minas Passage study site, July 3, 2009.

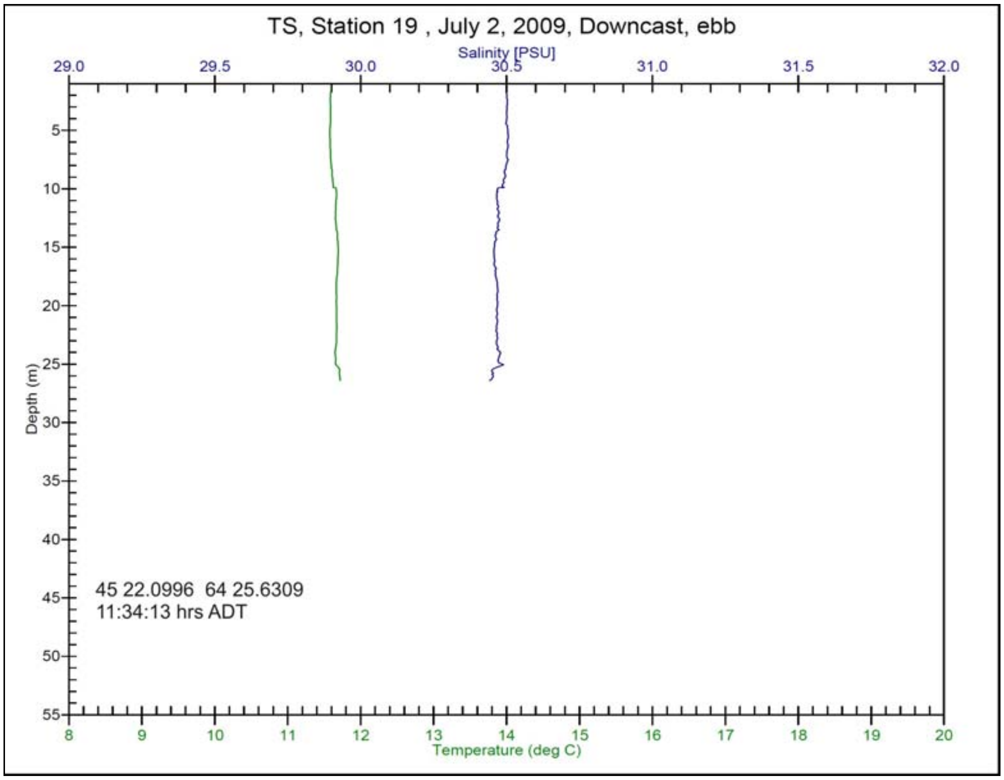


Figure D25. Vertical profile of temperature and salinity at Station 19, Minas Passage study site, July 2, 2009.

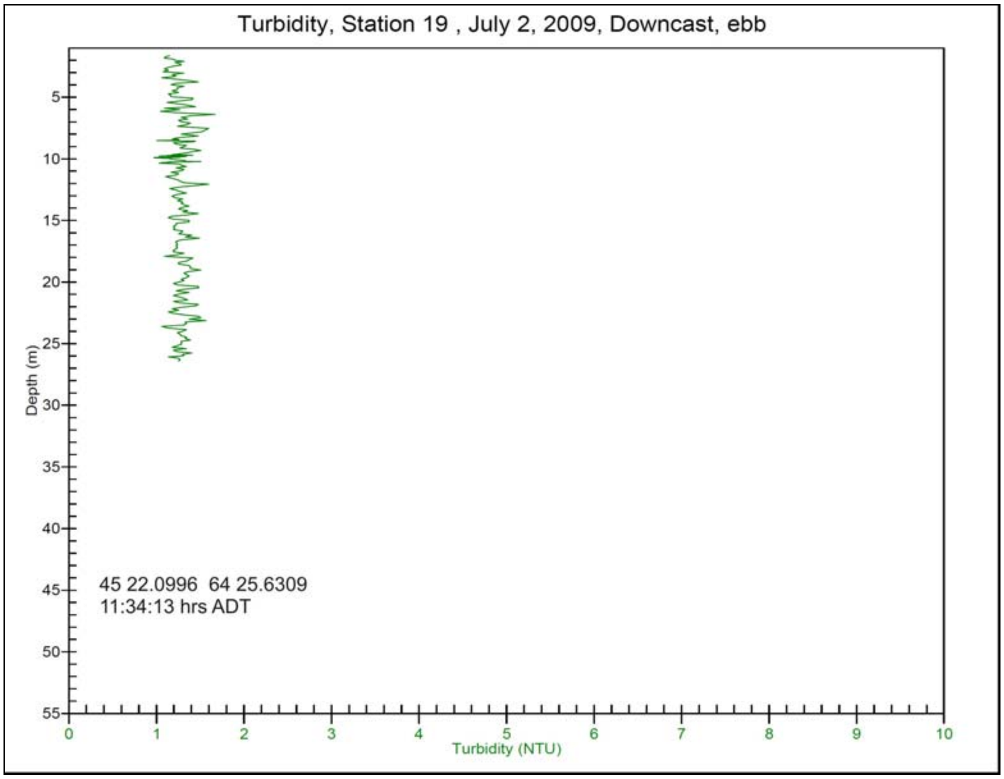


Figure D26. Vertical profile of turbidity (NTU) at Station 19, Minas Passage study site, July 2, 2009.

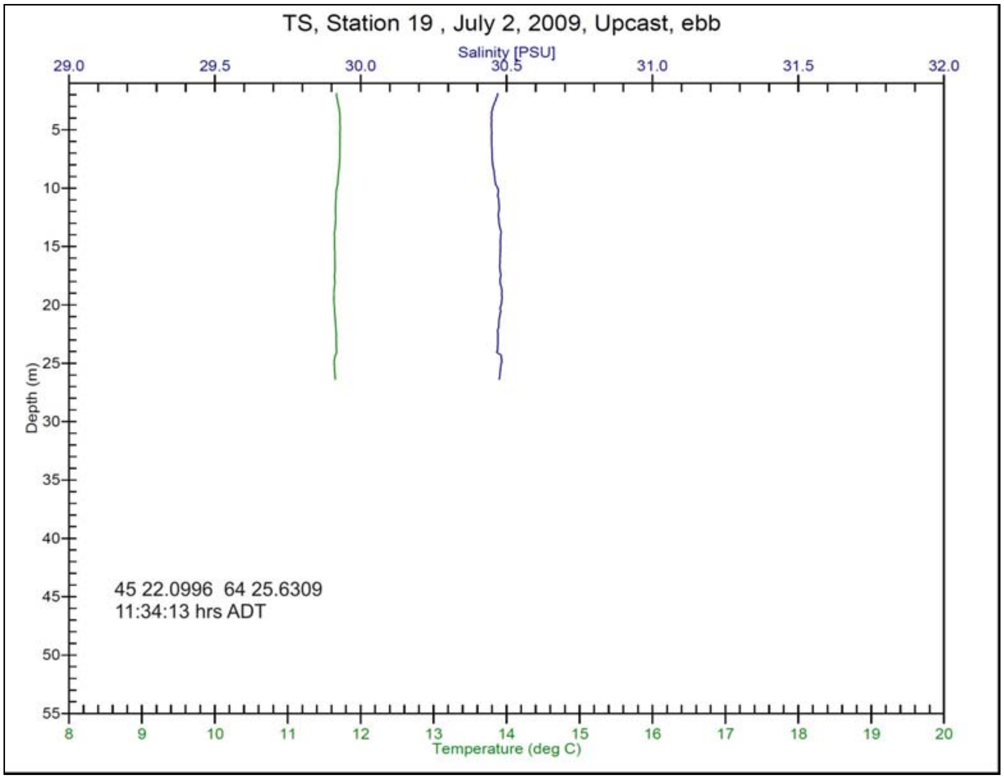


Figure D27. Vertical profile of temperature and salinity at Station 19, Minas Passage study site, July 2, 2009.

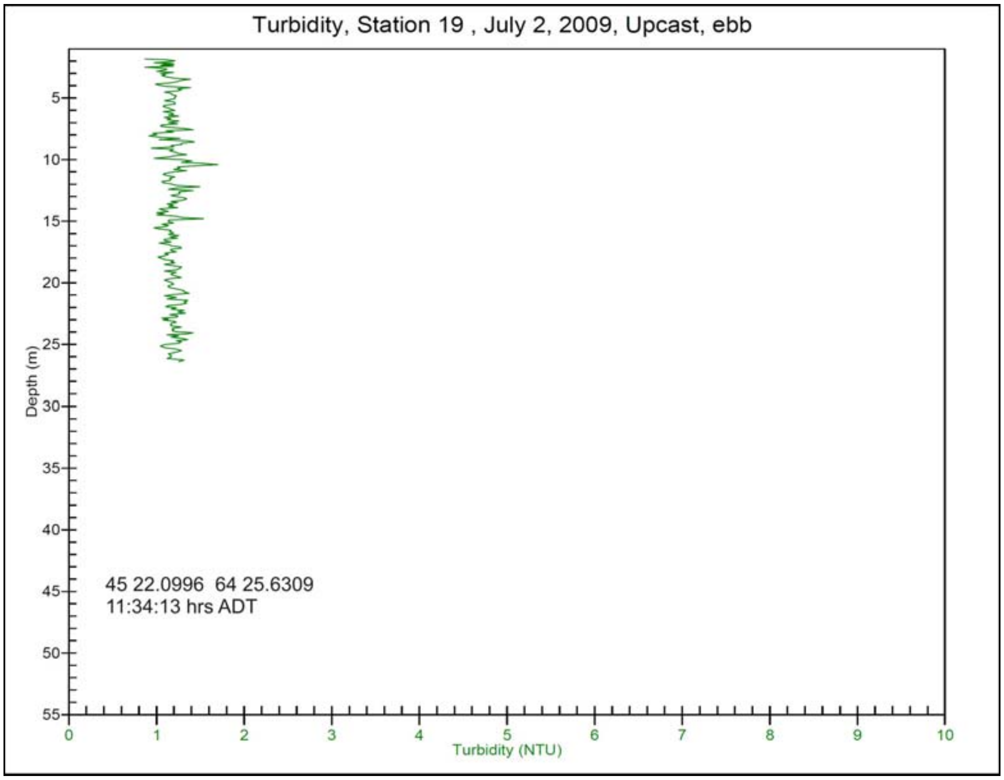


Figure D28. Vertical profile of turbidity (NTU) at Station 19, Minas Passage study site, July 2, 2009.

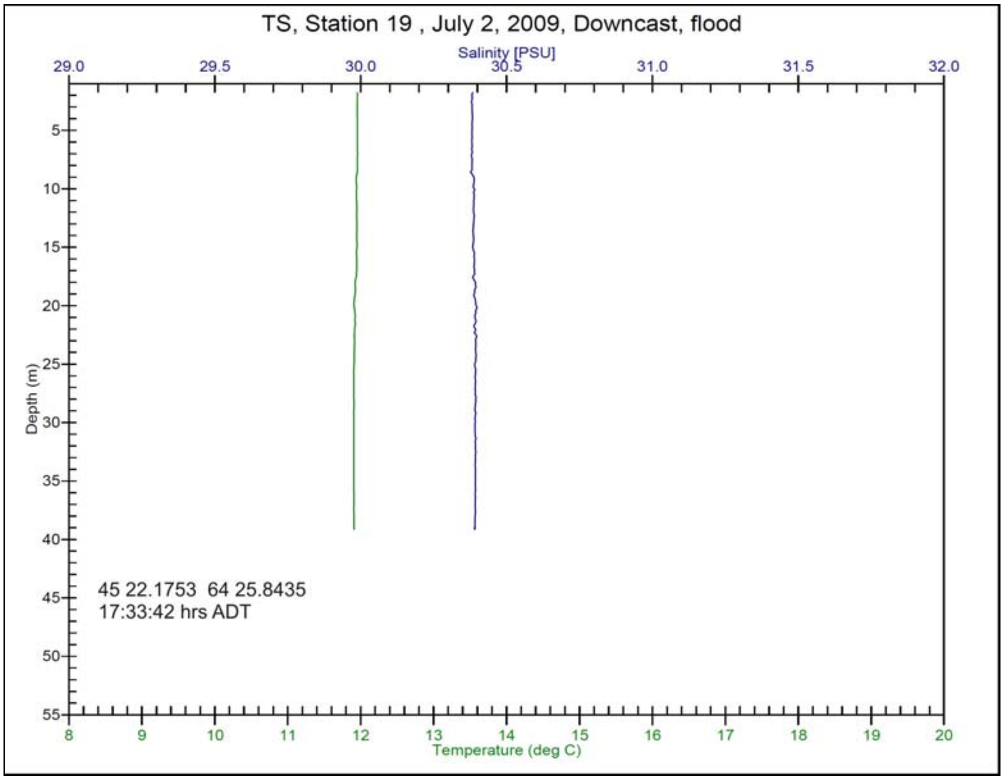


Figure D29. Vertical profile of temperature and salinity at Station 19, Minas Passage study site, July 2, 2009.

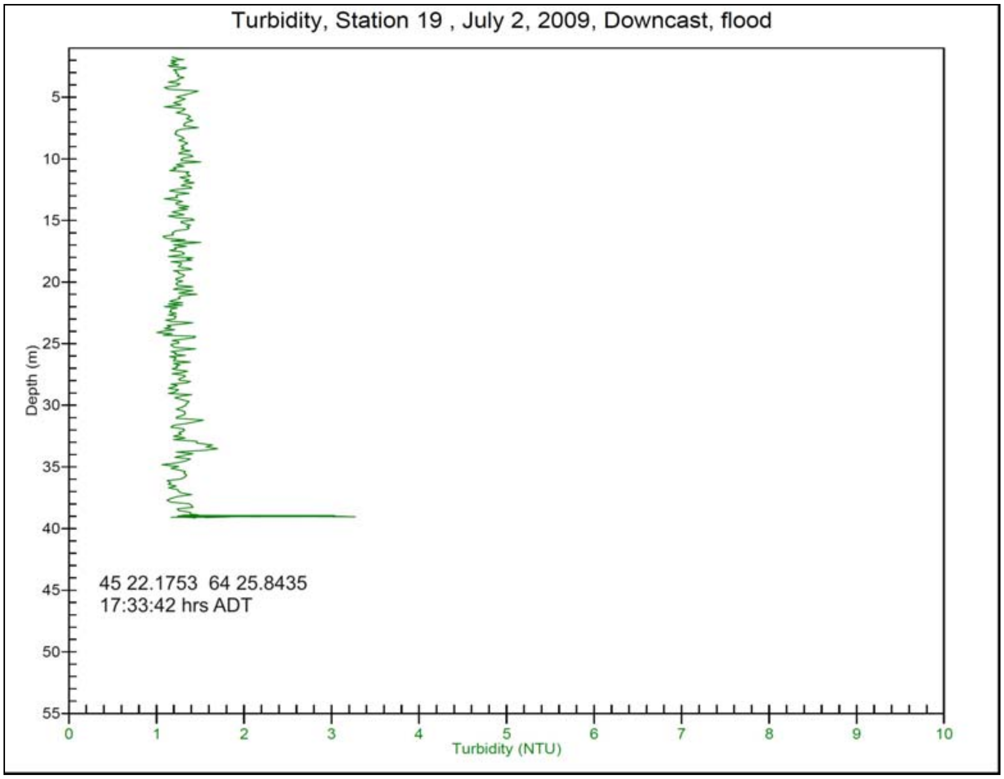


Figure D30. Vertical profile of turbidity (NTU) at Station 19, Minas Passage study site, July 2, 2009.

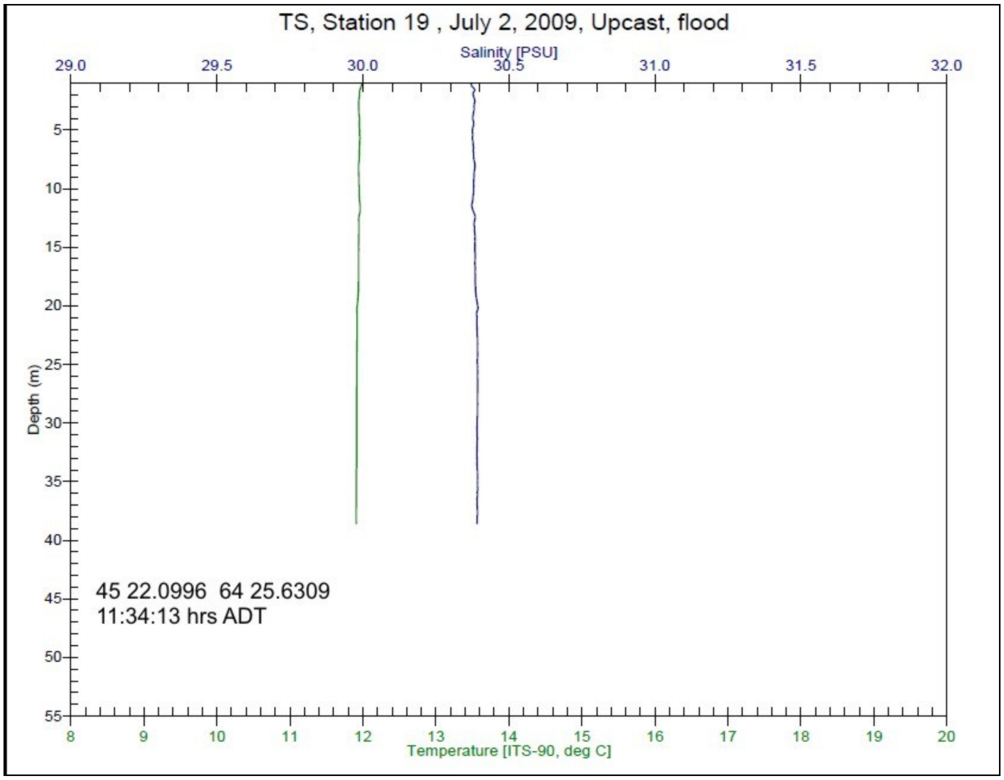


Figure D31. Vertical profile of temperature and salinity at Station 19, Minas Passage study site, July 2, 2009.

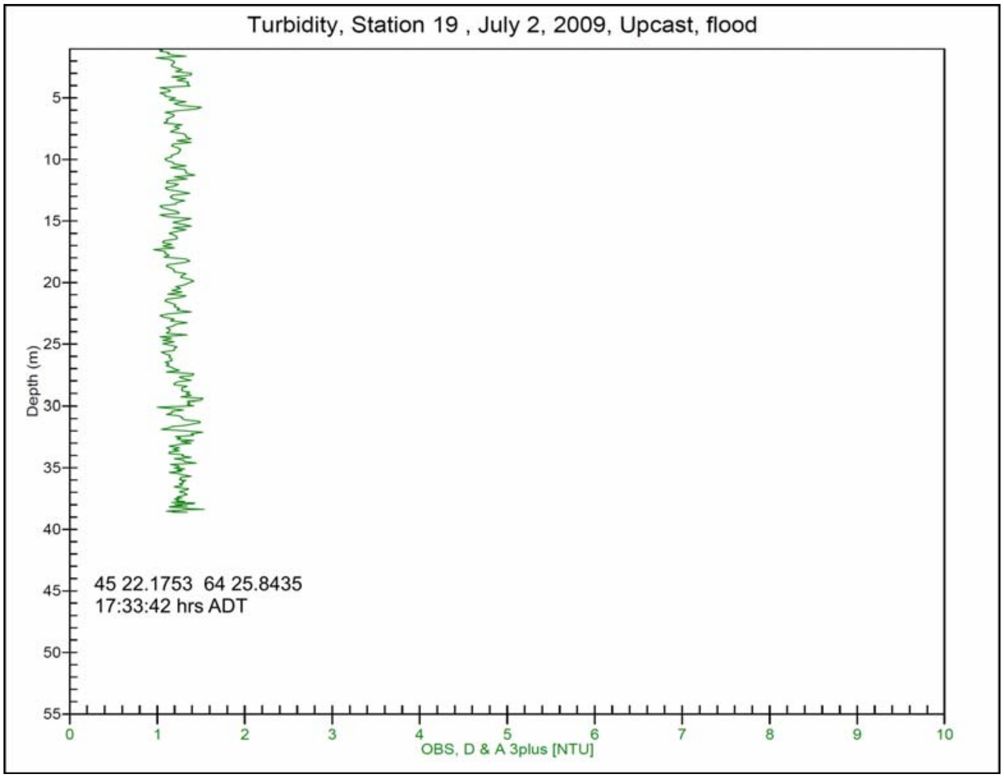


Figure D32. Vertical profile of turbidity (NTU) at Station 19, Minas Passage study site, July 2, 2009.

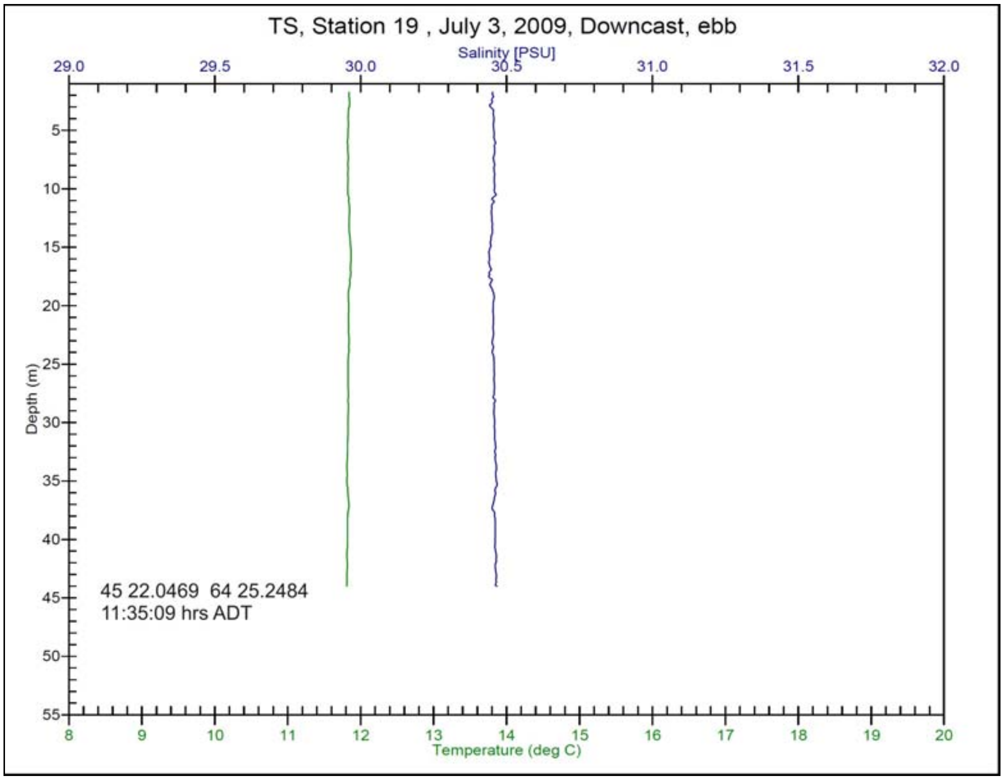


Figure D33. Vertical profile of temperature and salinity at Station 19, Minas Passage study site, July 3, 2009.

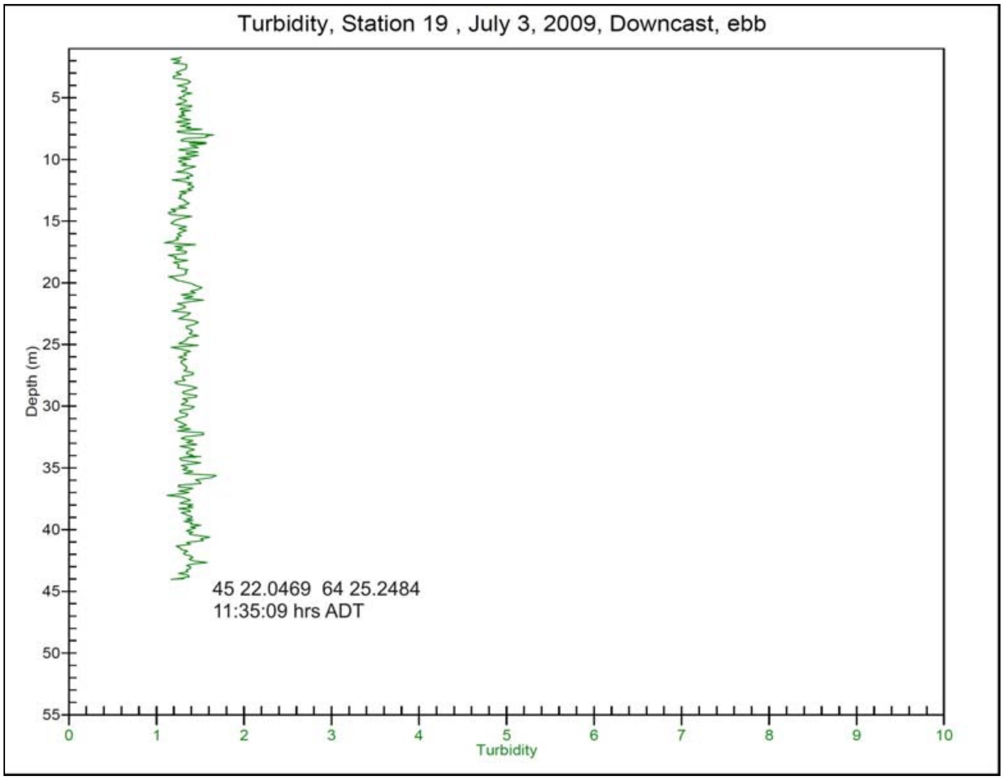


Figure D34. Vertical profile of turbidity (NTU) at Station 19, Minas Passage study site, July 3, 2009.

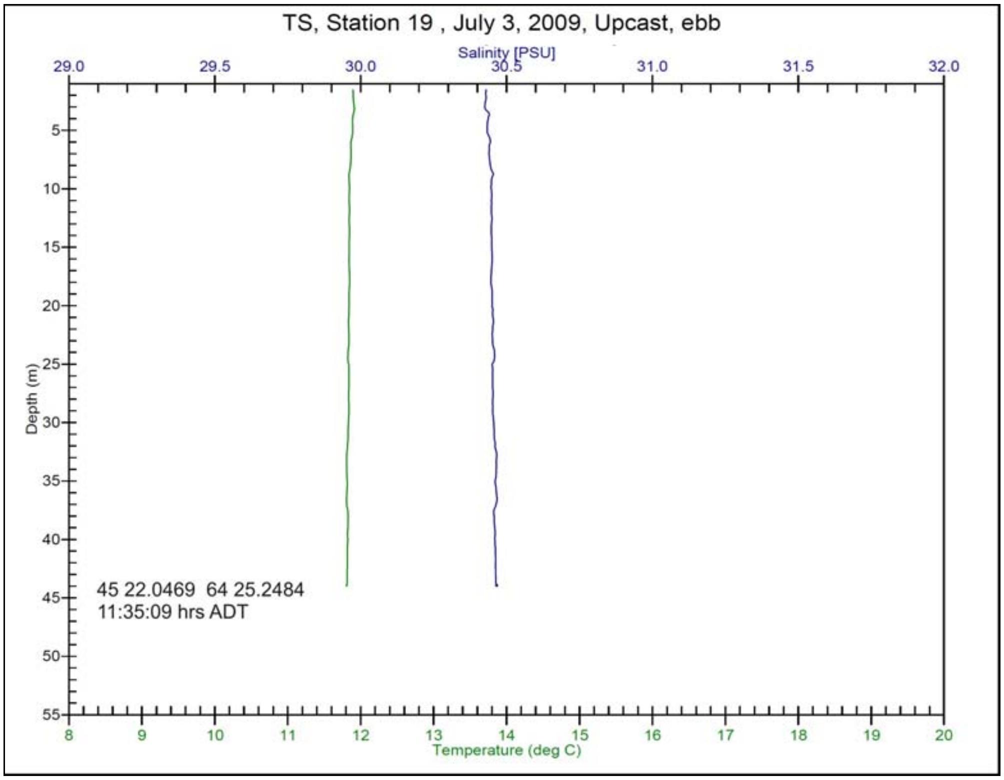


Figure D35. Vertical profile of temperature and salinity at Station 19, Minas Passage study site, July 3, 2009.

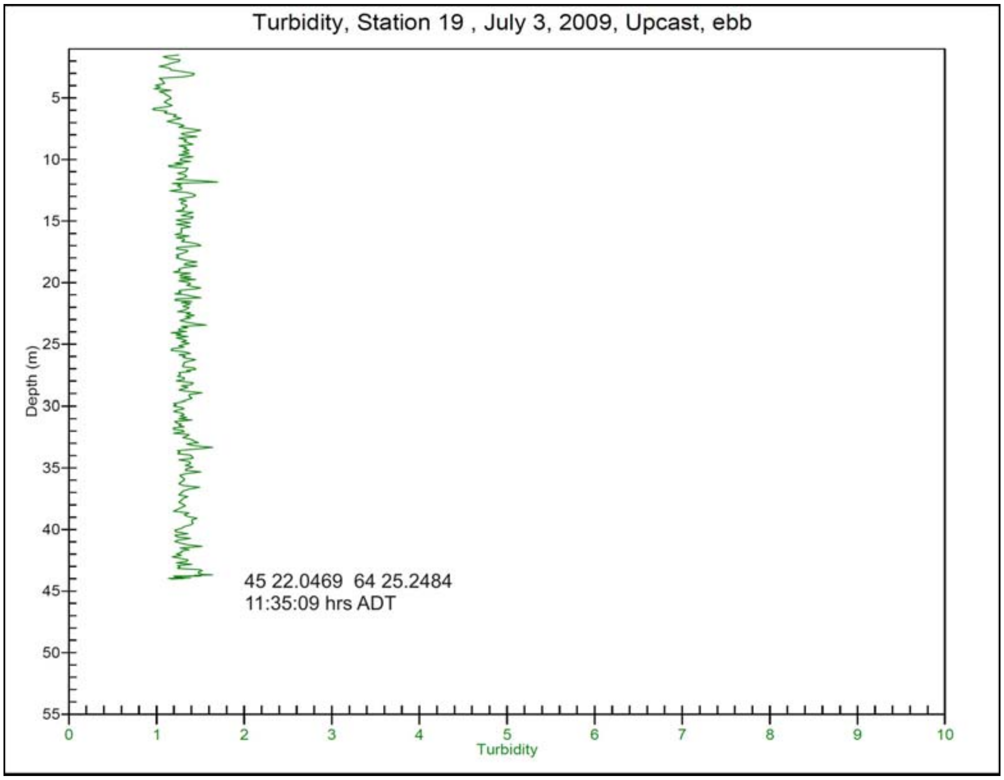


Figure D36. Vertical profile of turbidity (NTU) at Station 19, Minas Passage study site, July 3, 2009.

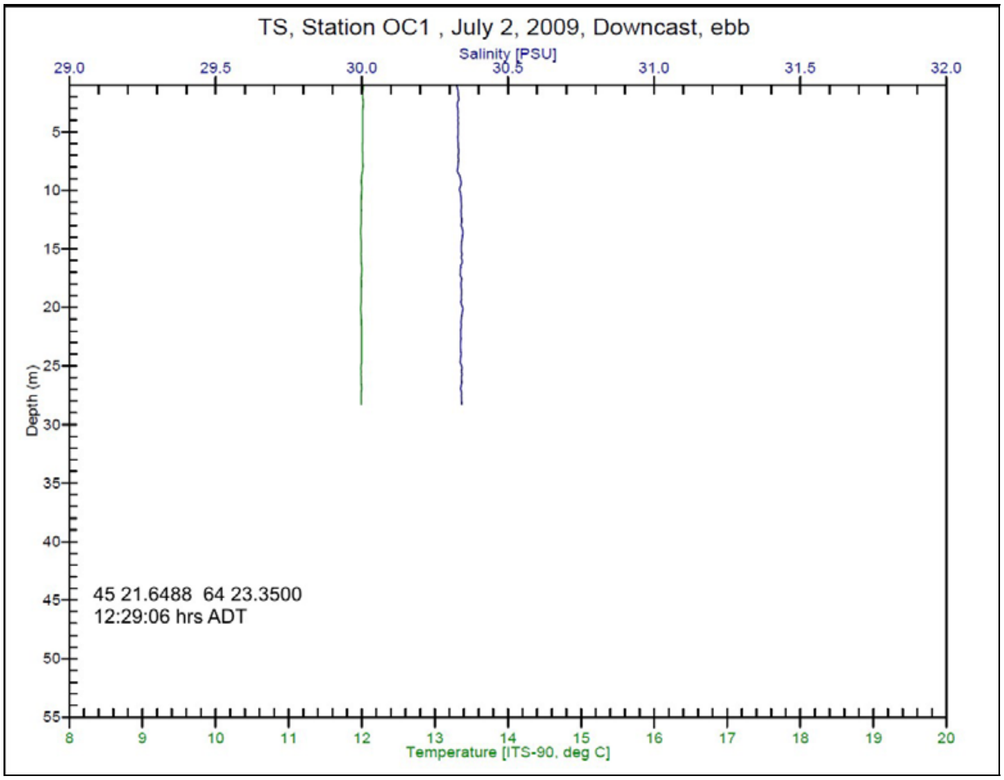


Figure D37. Vertical profile of temperature and salinity at Sta. OC1, Minas Passage study site, July 2, 2009.

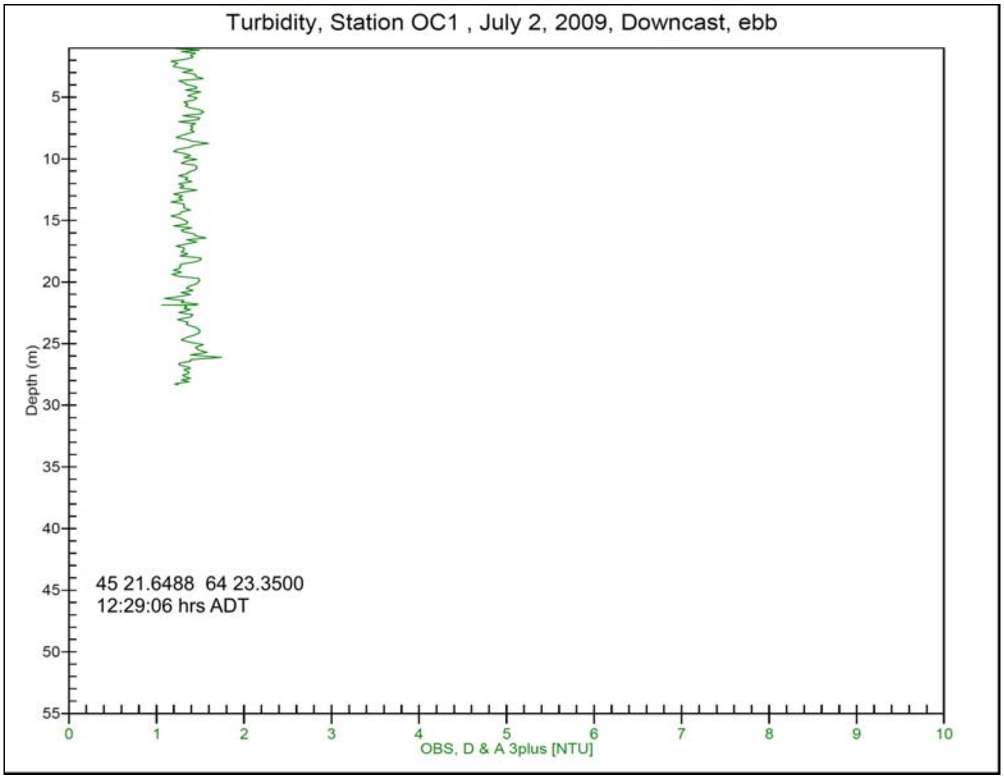


Figure D38. Vertical profile of turbidity (NTU) at Station OC1, Minas Passage study site, July 2, 2009.

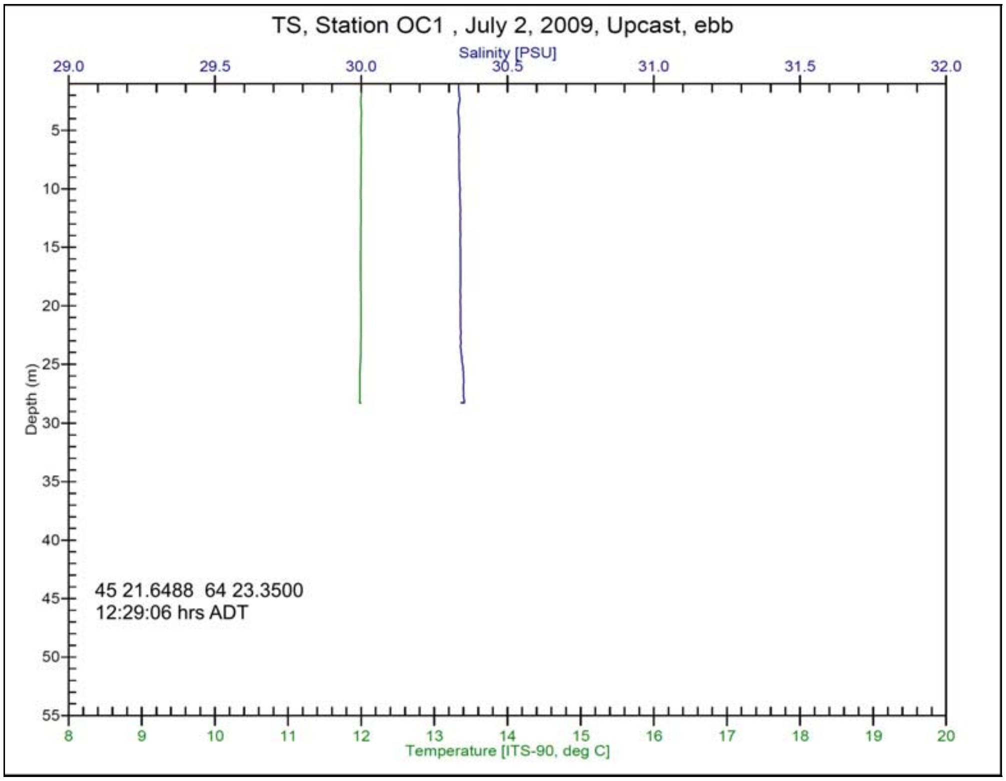


Figure D39. Vertical profile of temperature and salinity at Sta. OC1, Minas Passage study site, July 2, 2009.

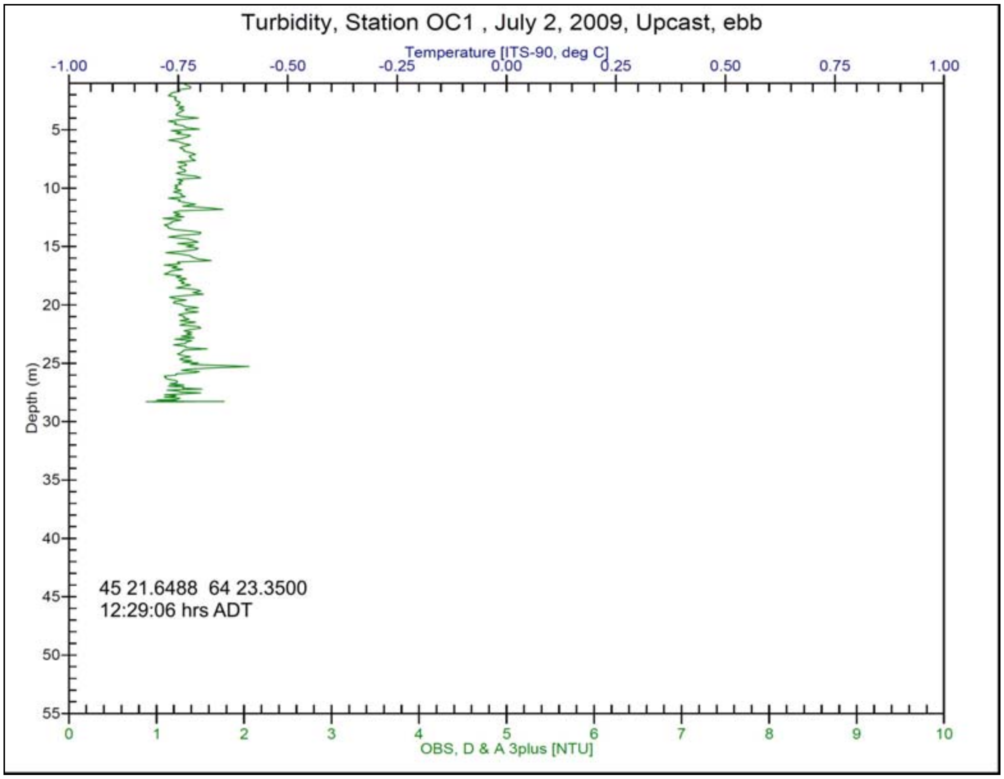


Figure D40. Vertical profile of turbidity (NTU) at Station OC1, Minas Passage study site, July 2, 2009.

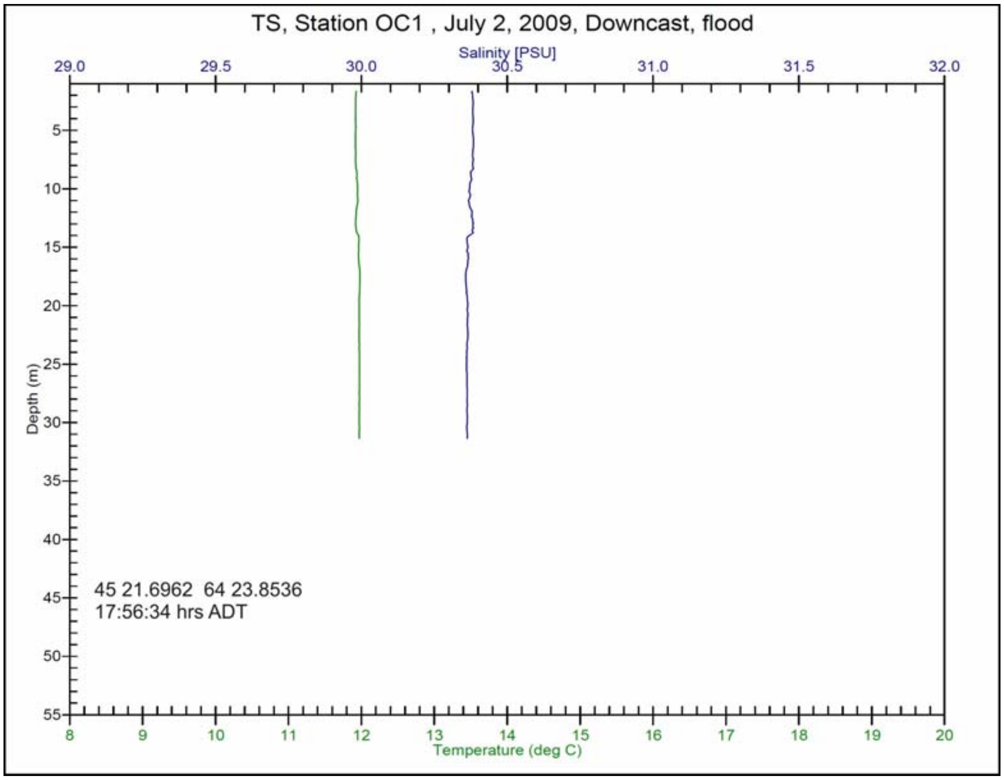


Figure D41. Vertical profile of temperature and salinity at Sta. OC1, Minas Passage study site, July 2, 2009.

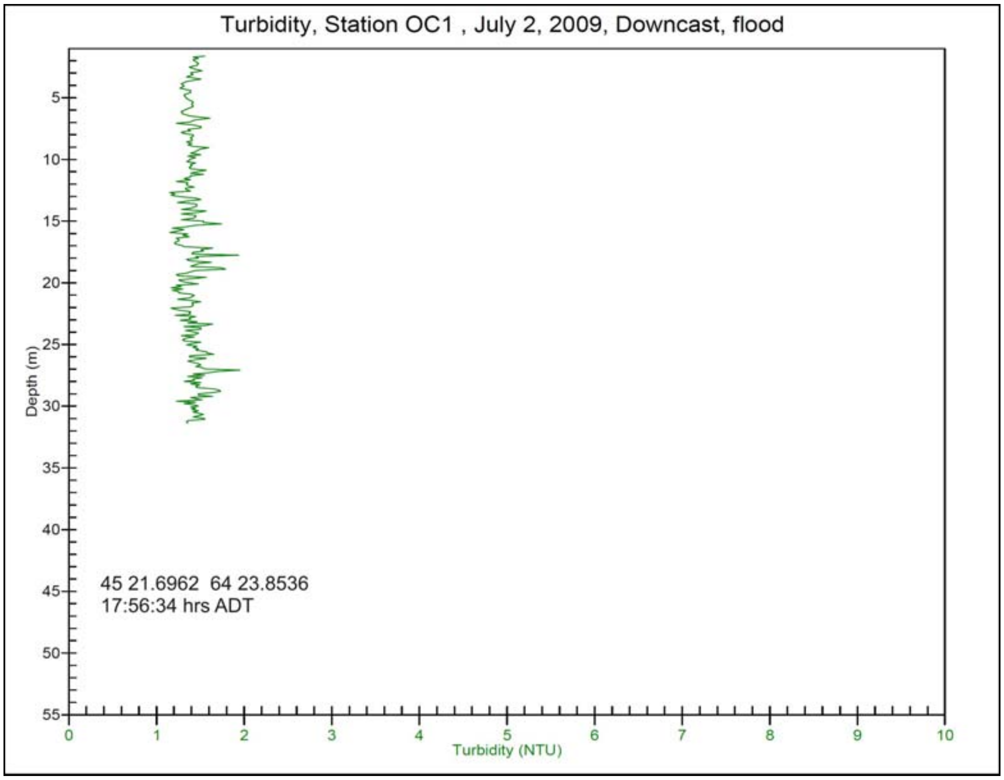


Figure D42. Vertical profile of turbidity (NTU) at Station OC1, Minas Passage study site, July 2, 2009.

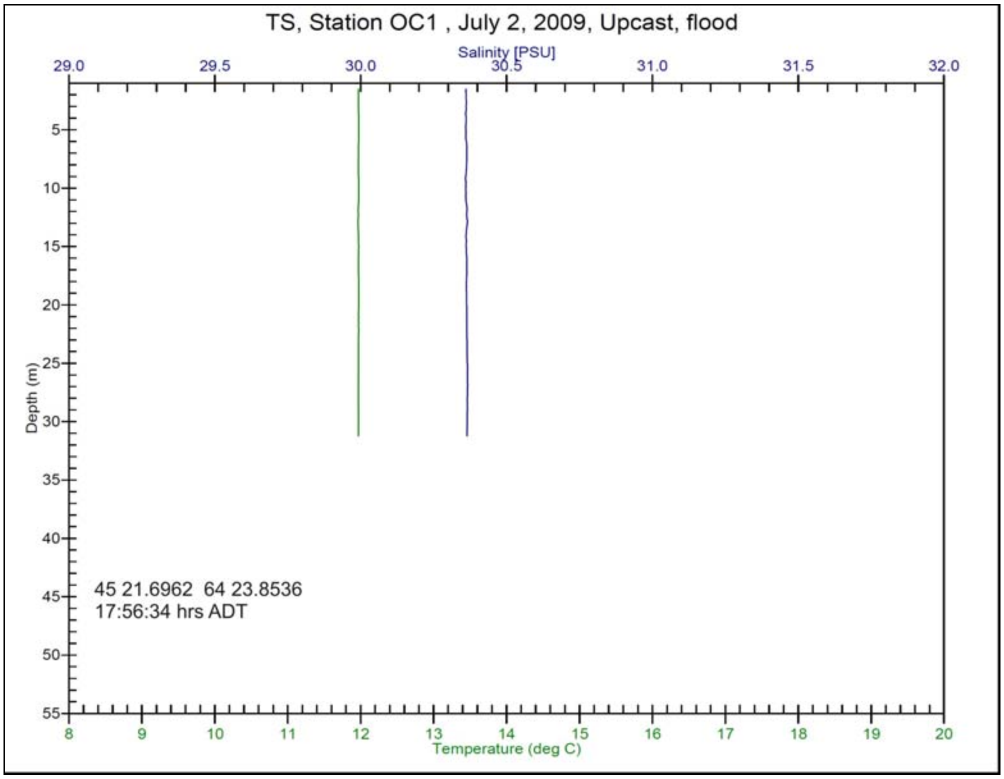


Figure D43. Vertical profile of temperature and salinity at Sta. OC1, Minas Passage study site, July 2, 2009.

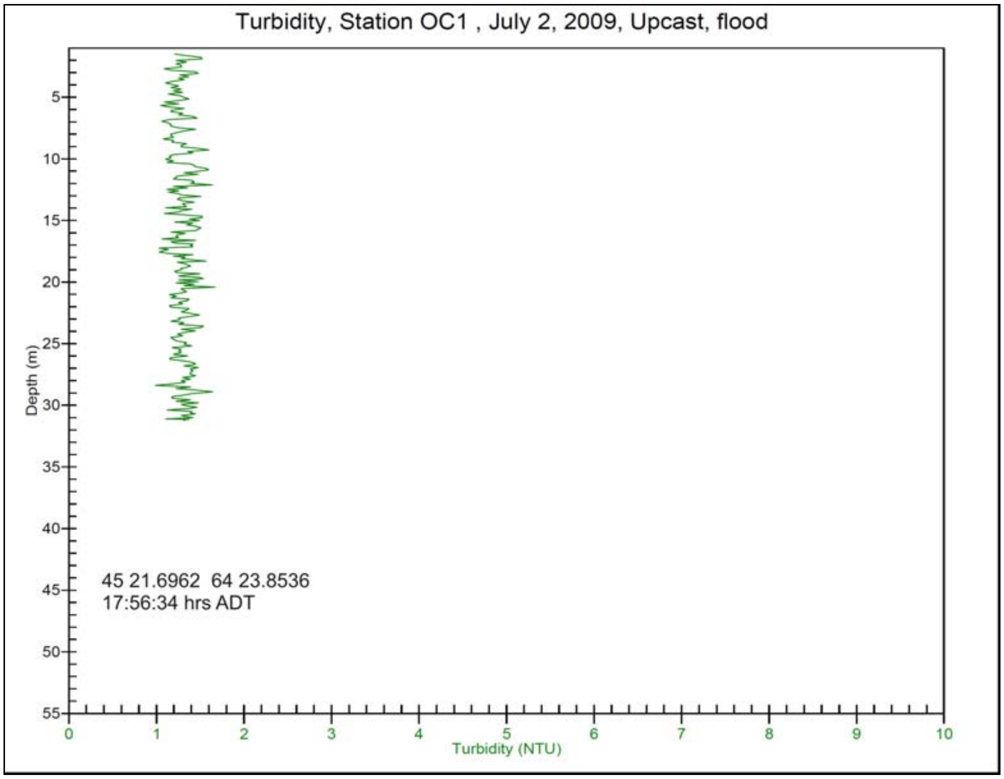


Figure D44. Vertical profile of turbidity (NTU) at Station OC1, Minas Passage study site, July 2, 2009.

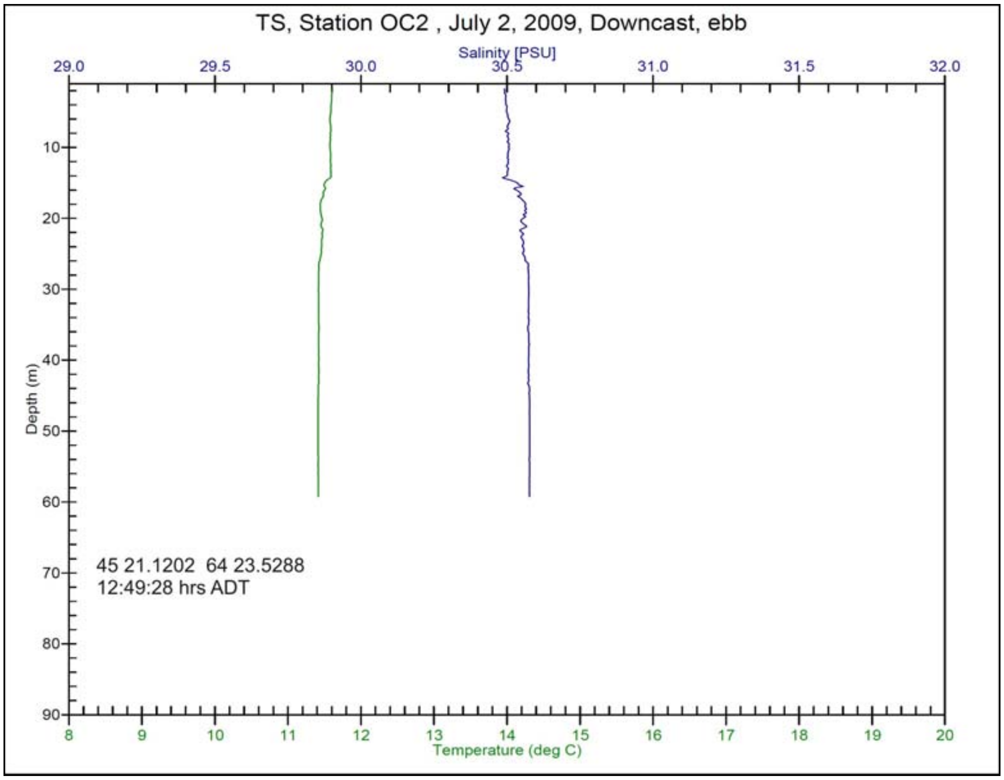


Figure D45. Vertical profile of temperature and salinity at Sta. OC2, Minas Passage study site, July 2, 2009.

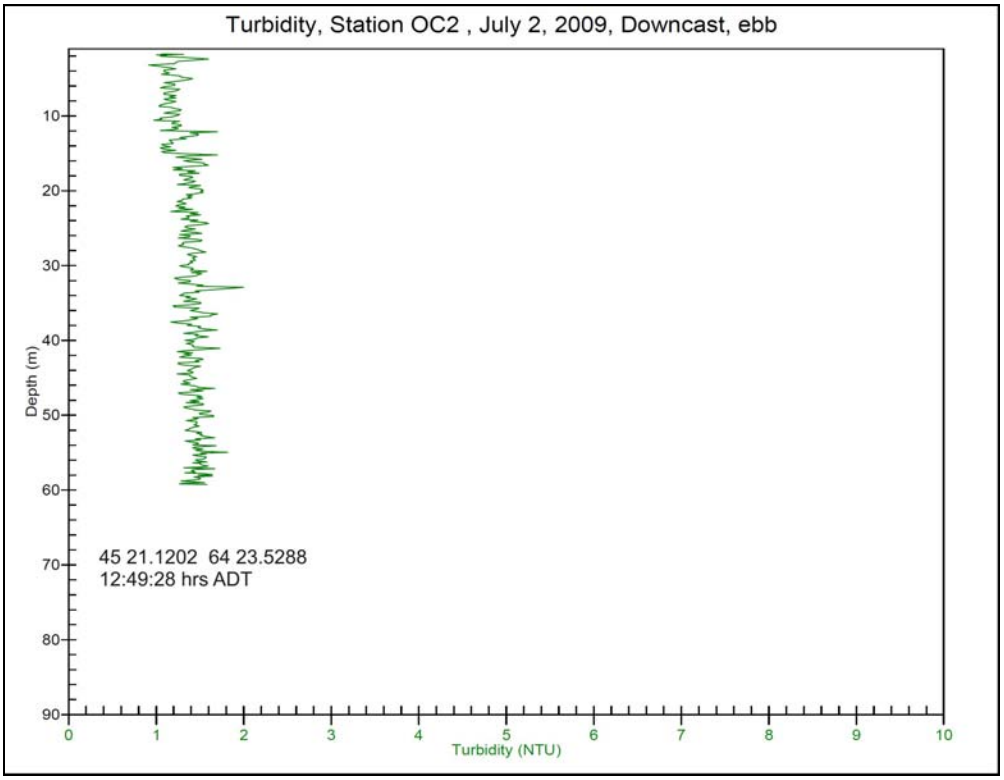


Figure D46. Vertical profile of turbidity (NTU) at Station OC2, Minas Passage study site, July 2, 2009.

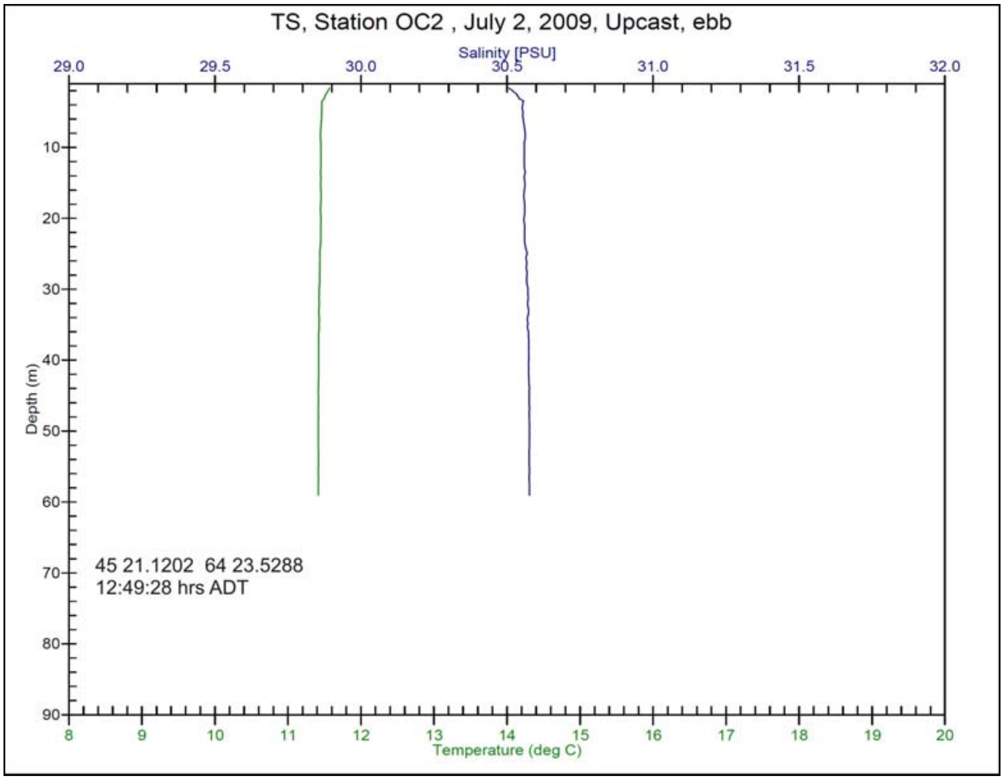


Figure D47. Vertical profile of temperature and salinity at Sta. OC2, Minas Passage study site, July 2, 2009.

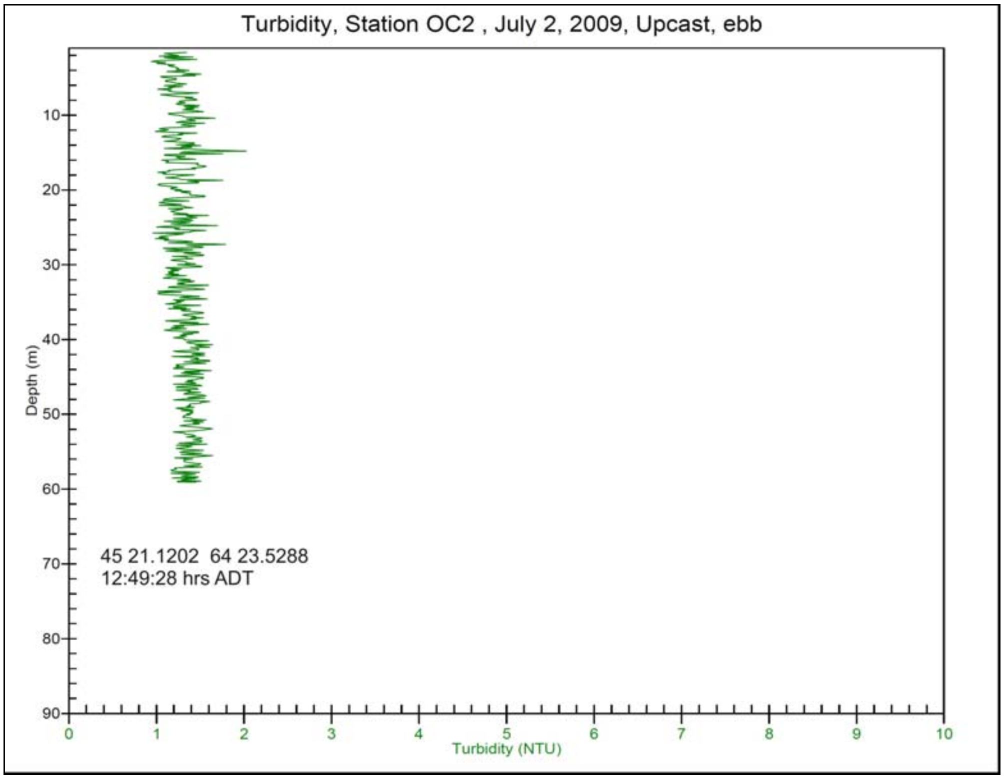


Figure D48. Vertical profile of turbidity (NTU) at Station OC2, Minas Passage study site, July 2, 2009.

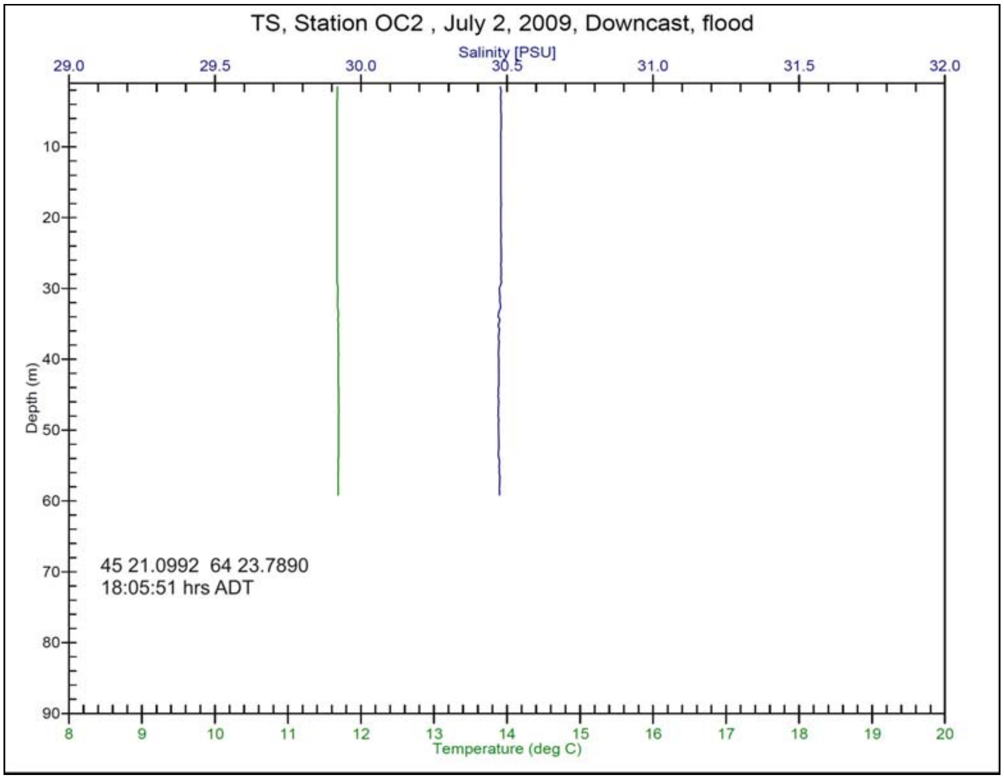


Figure D49. Vertical profile of temperature and salinity at Sta. OC2, Minas Passage study site, July 2, 2009.

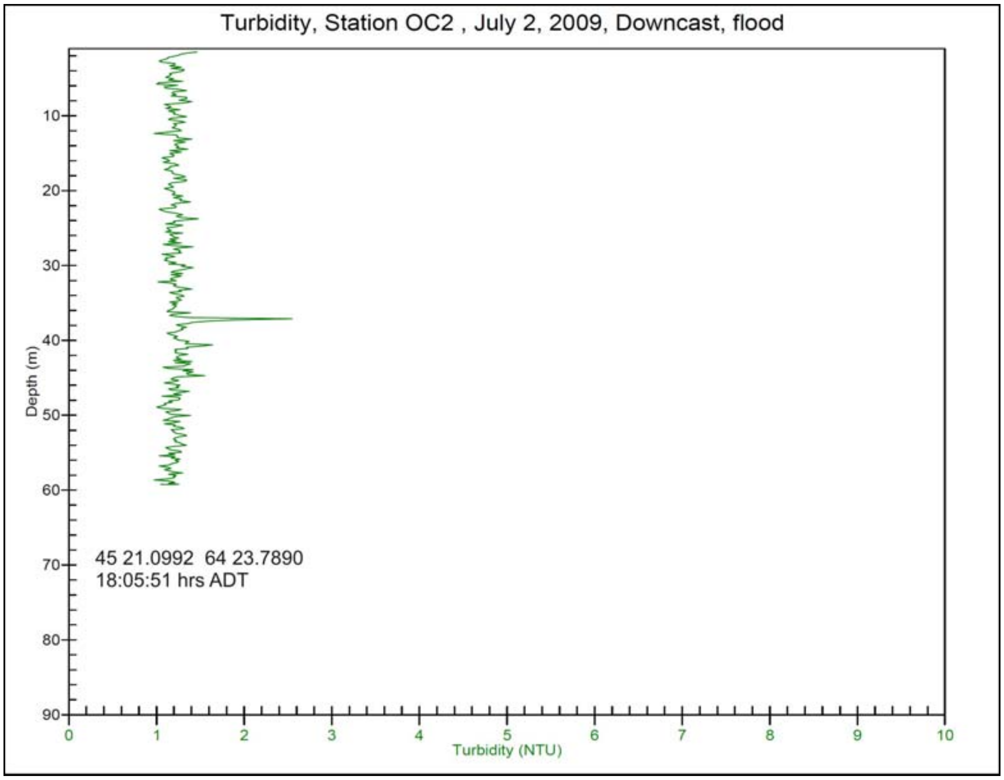


Figure D50. Vertical profile of turbidity (NTU) at Station OC2, Minas Passage study site, July 2, 2009.

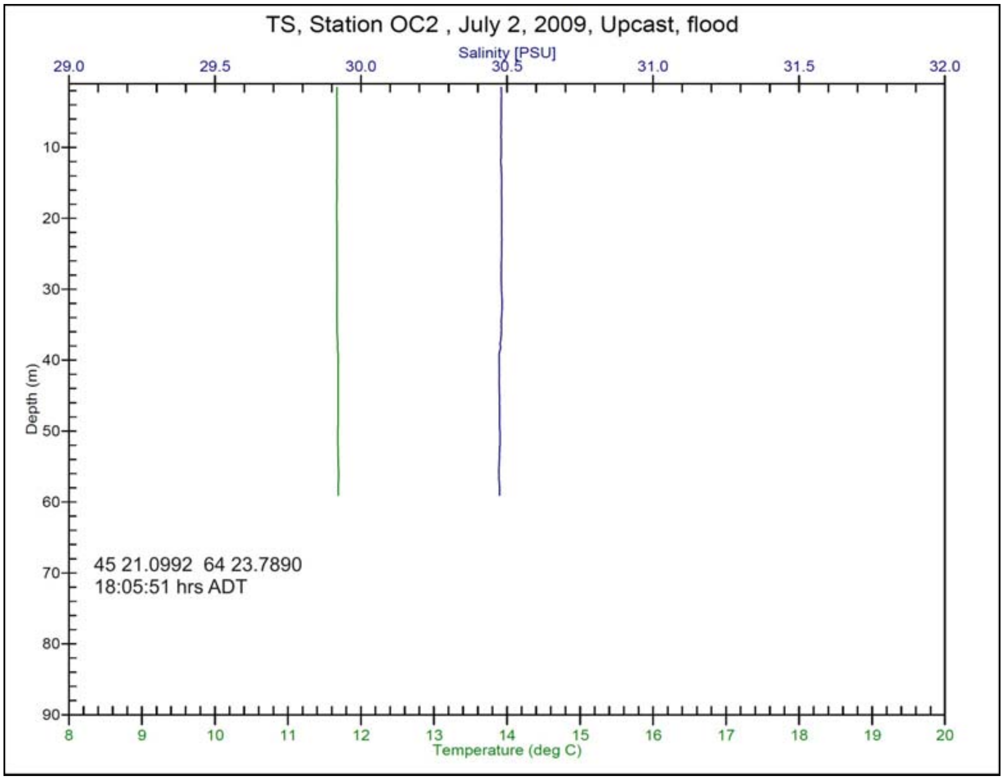


Figure D51. Vertical profile of temperature and salinity at Sta. OC2, Minas Passage study site, July 2, 2009.

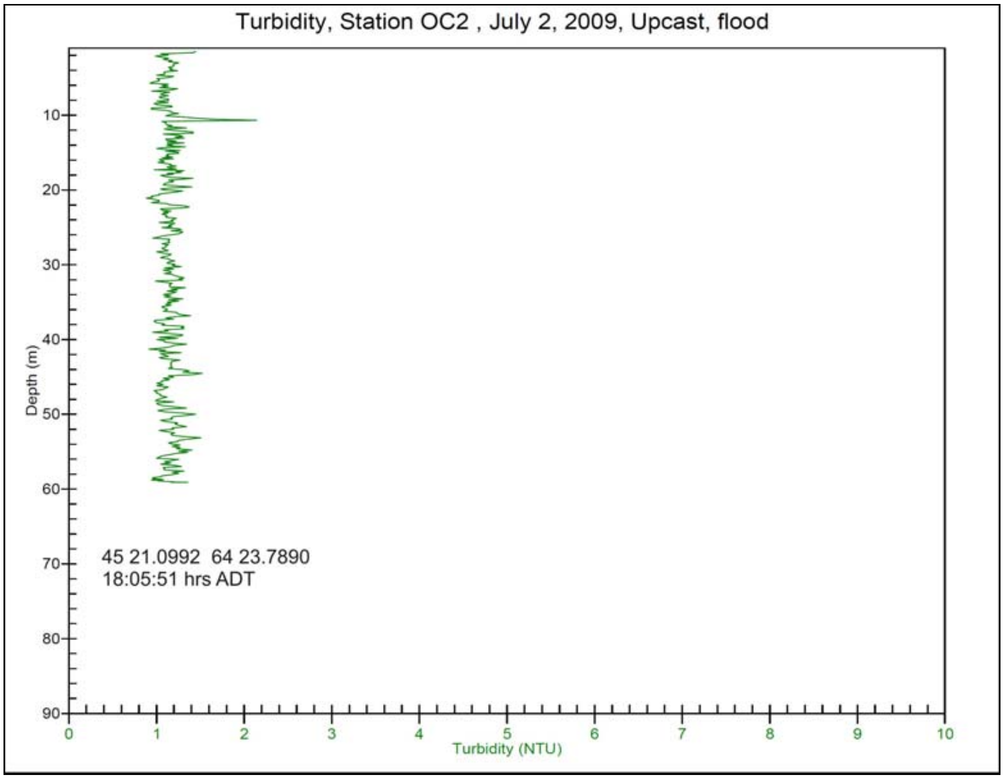


Figure D52. Vertical profile of turbidity (NTU) at Station OC2, Minas Passage study site, July 2, 2009.

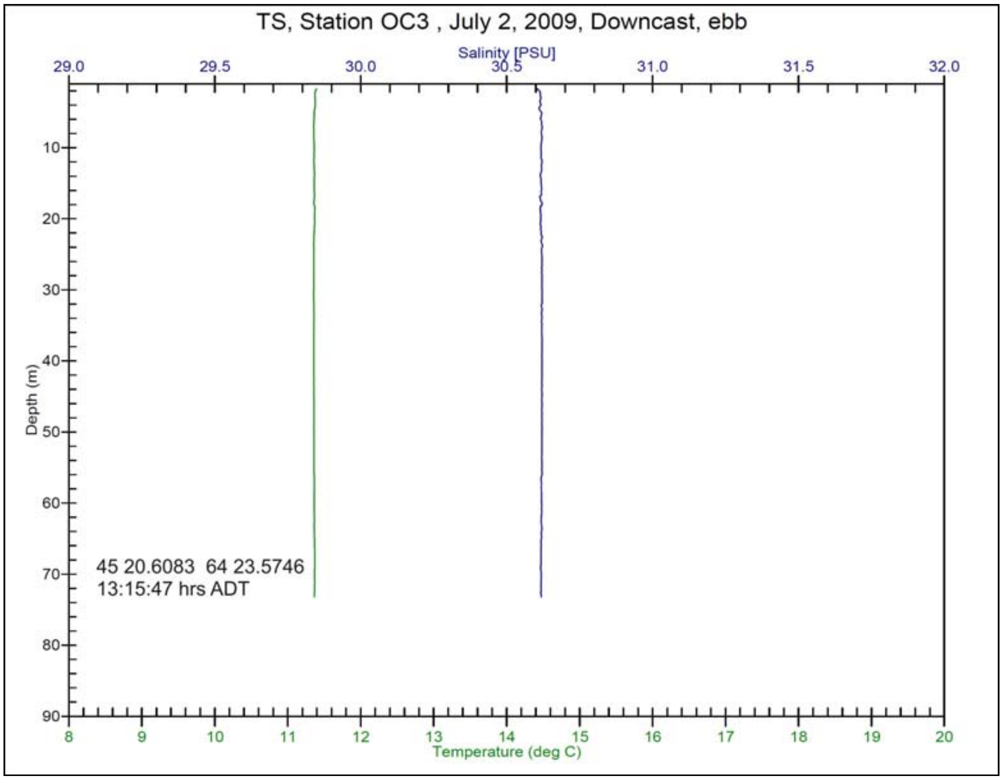


Figure D53. Vertical profile of temperature and salinity at Sta. OC3, Minas Passage study site, July 2, 2009.

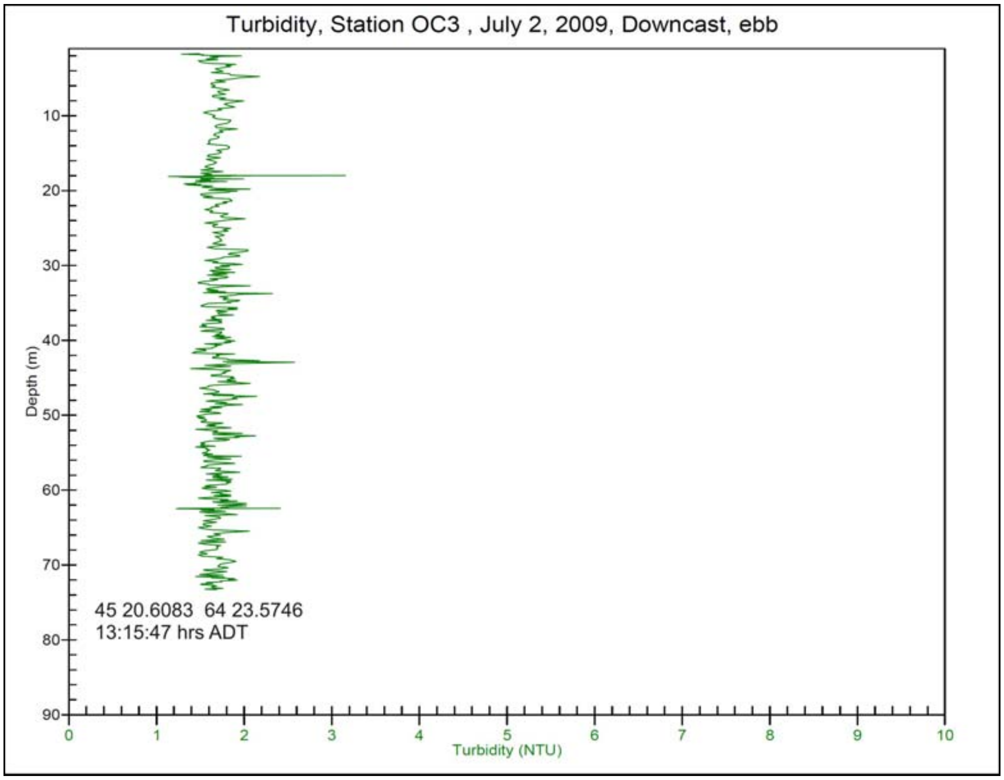


Figure D54. Vertical profile of turbidity (NTU) at Station OC3, Minas Passage study site, July 2, 2009.

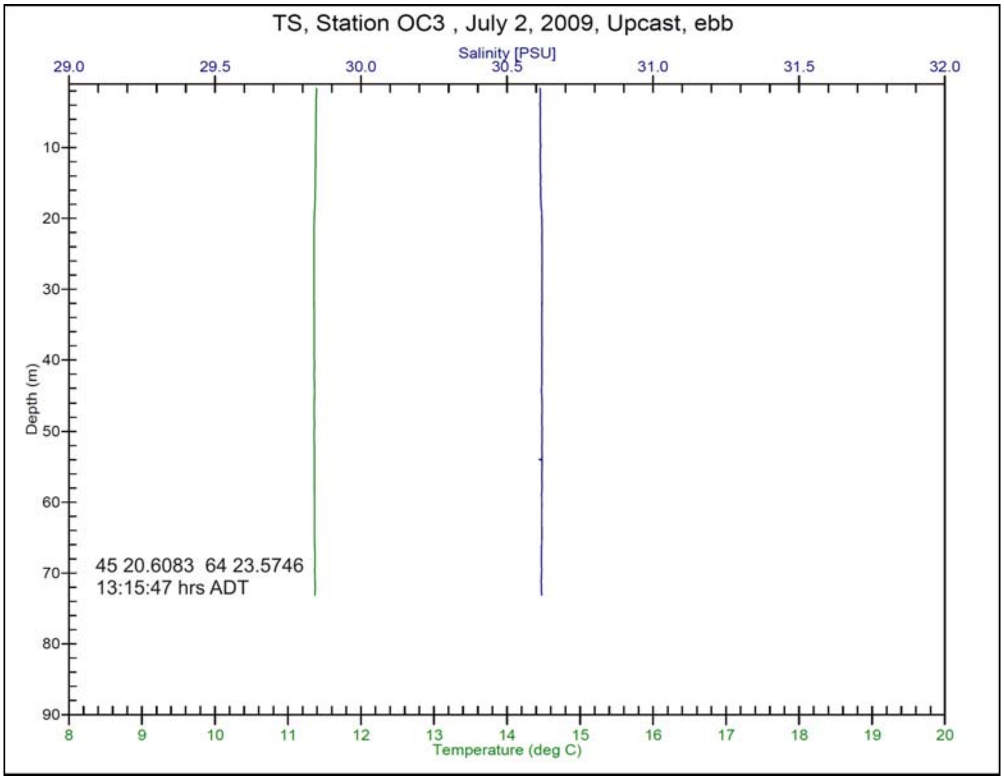


Figure D55. Vertical profile of temperature and salinity at Sta. OC3, Minas Passage study site, July 2, 2009.

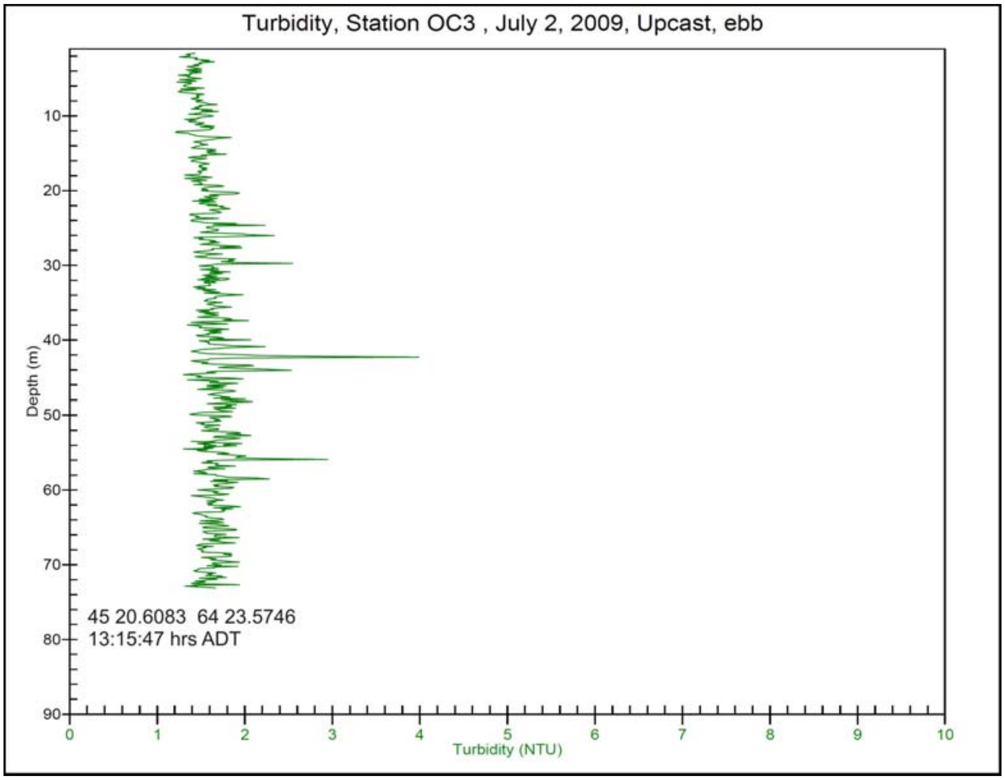


Figure D56. Vertical profile of turbidity (NTU) at Station OC3, Minas Passage study site, July 2, 2009.

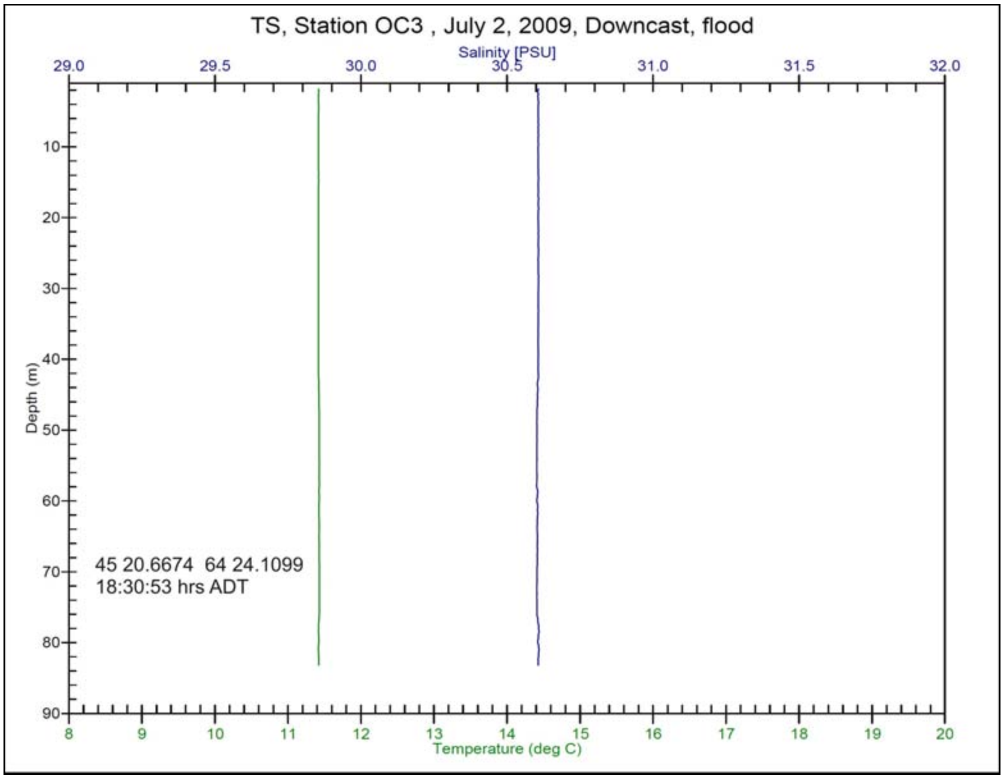


Figure D57. Vertical profile of temperature and salinity at Sta. OC3, Minas Passage study site, July 2, 2009.

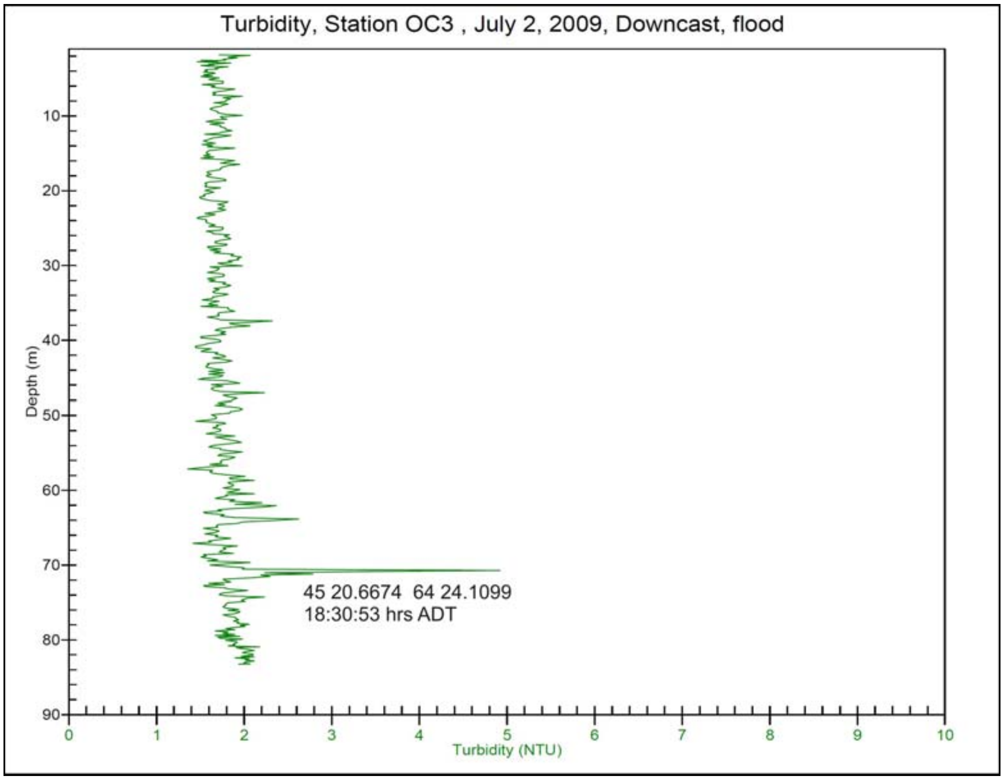


Figure D58. Vertical profile of turbidity (NTU) at Station OC3, Minas Passage study site, July 2, 2009.

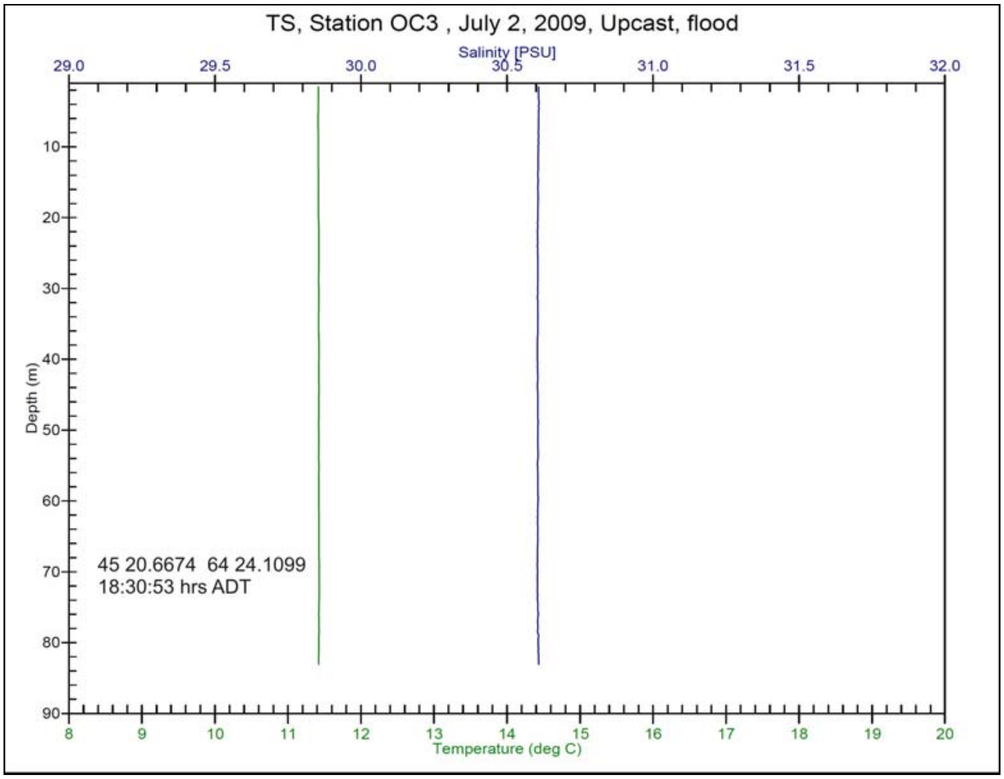


Figure D59. Vertical profile of temperature and salinity at Sta. OC3, Minas Passage study site, July 2, 2009.

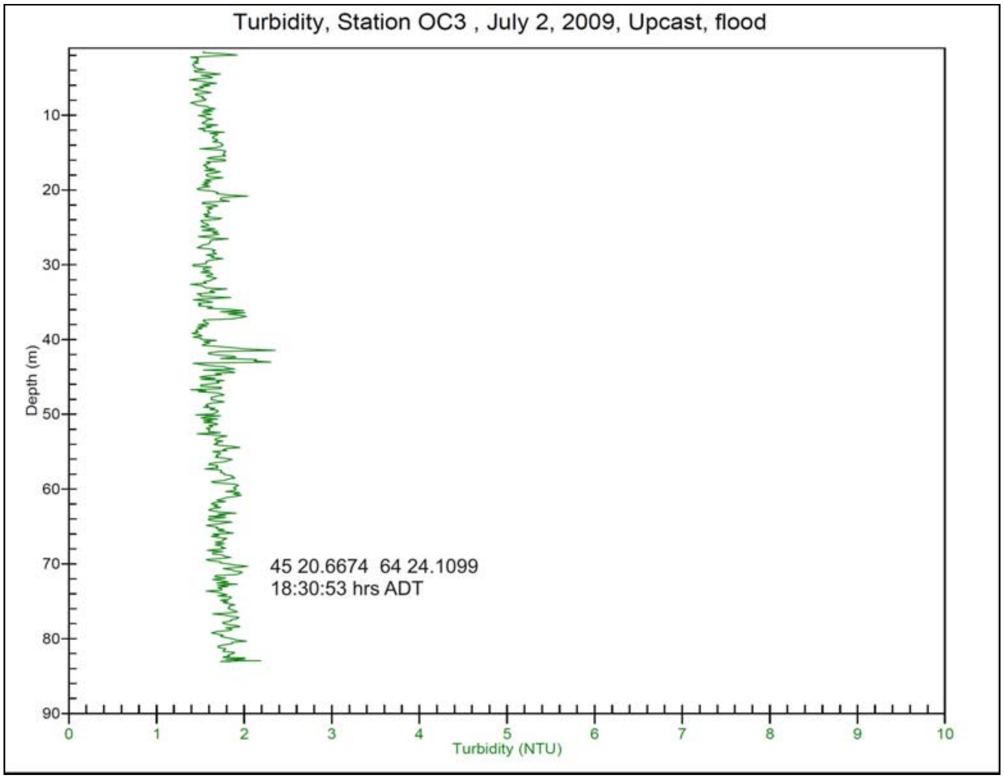


Figure D60. Vertical profile of turbidity (NTU) at Station OC3, Minas Passage study site, July 2, 2009.

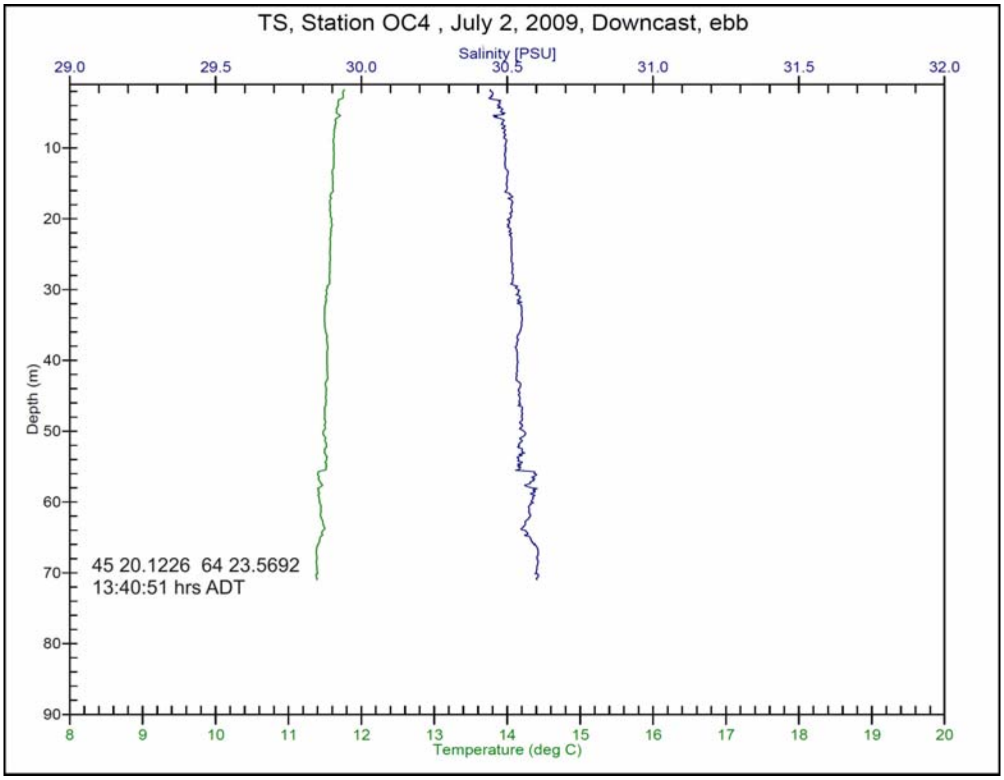


Figure D61. Vertical profile of temperature and salinity at Sta. OC4, Minas Passage study site, July 2, 2009.

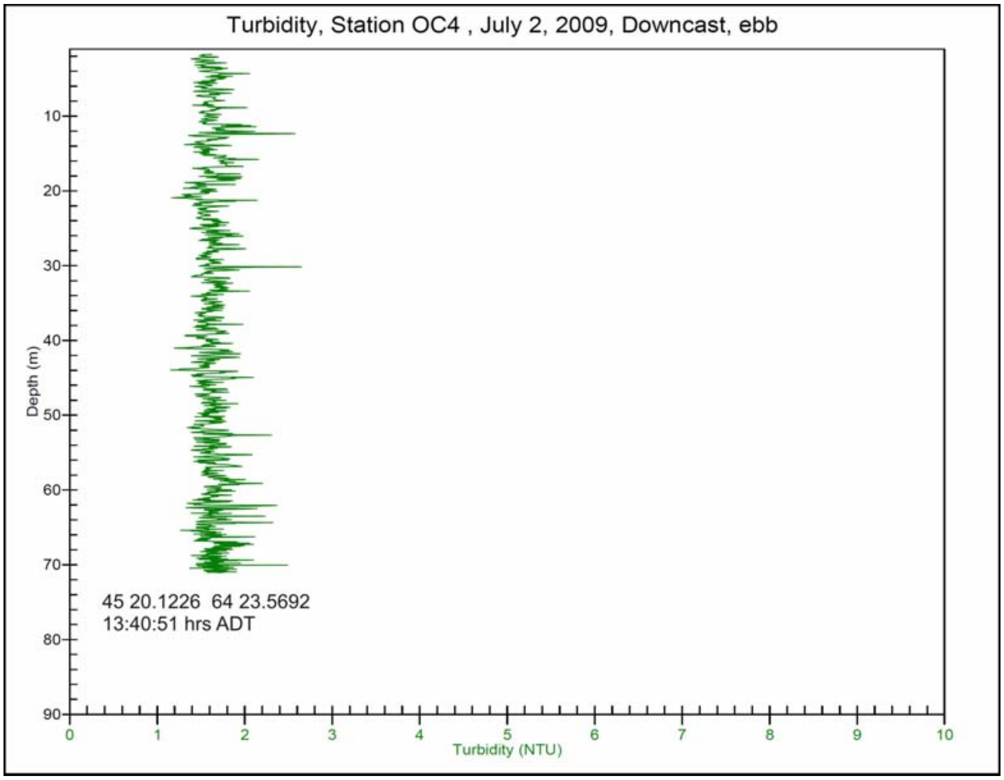


Figure D62. Vertical profile of turbidity (NTU) at Station OC4, Minas Passage study site, July 2, 2009.

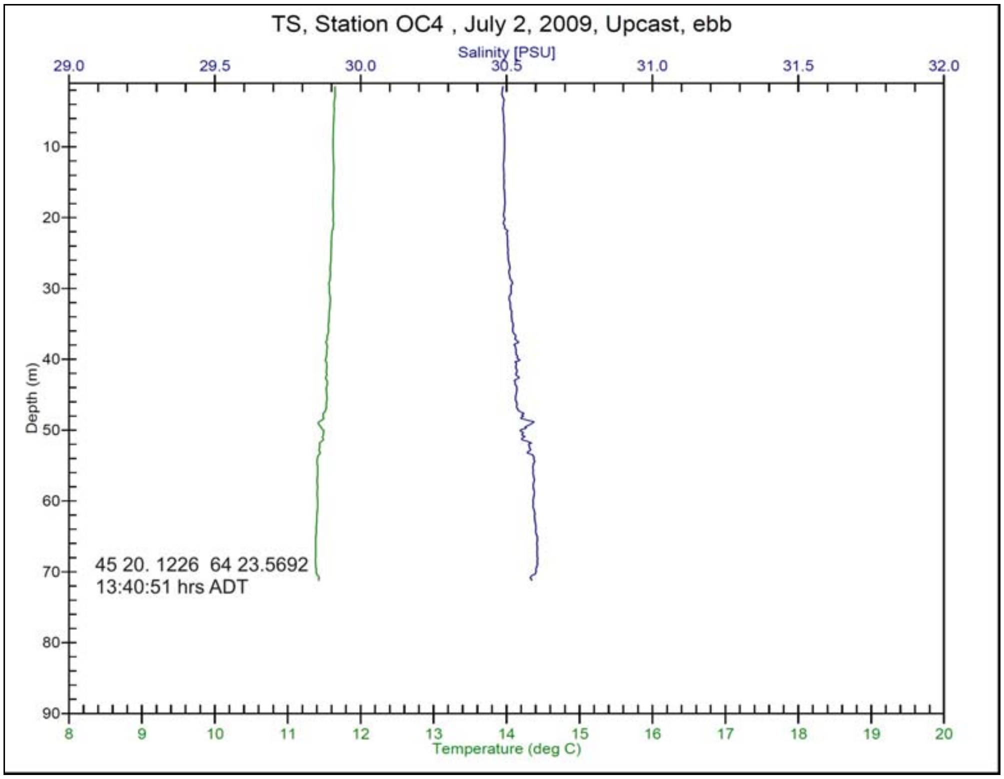


Figure D63. Vertical profile of temperature and salinity at Sta. OC4, Minas Passage study site, July 2, 2009.

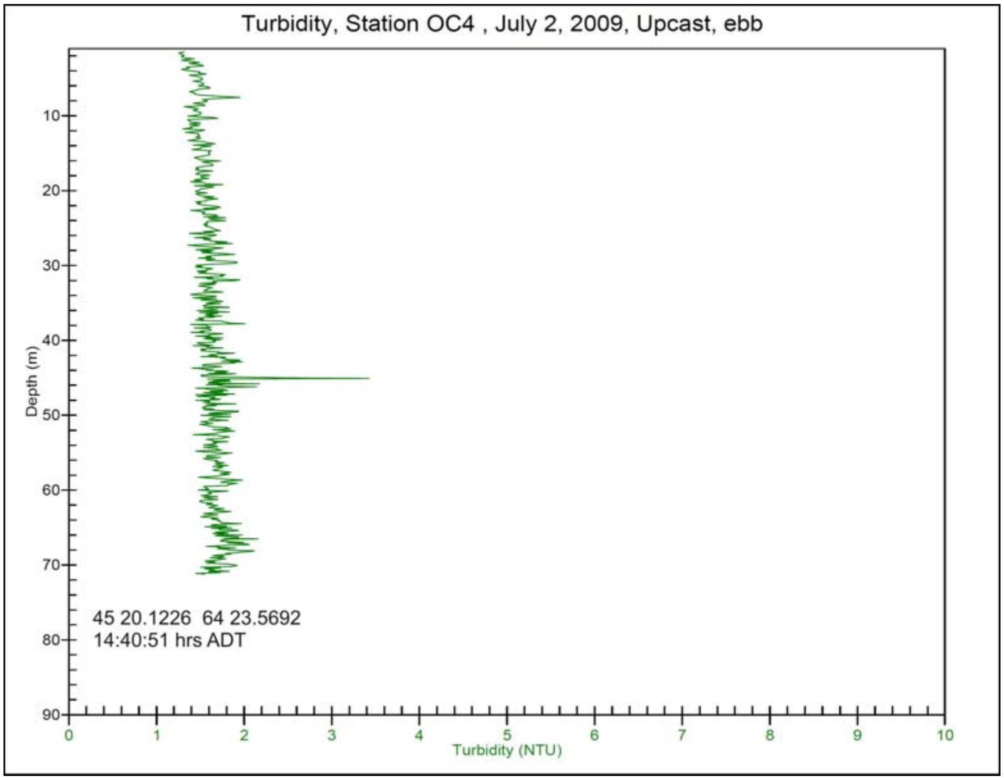


Figure D64. Vertical profile of turbidity (NTU) at Station OC4, Minas Passage study site, July 2, 2009.

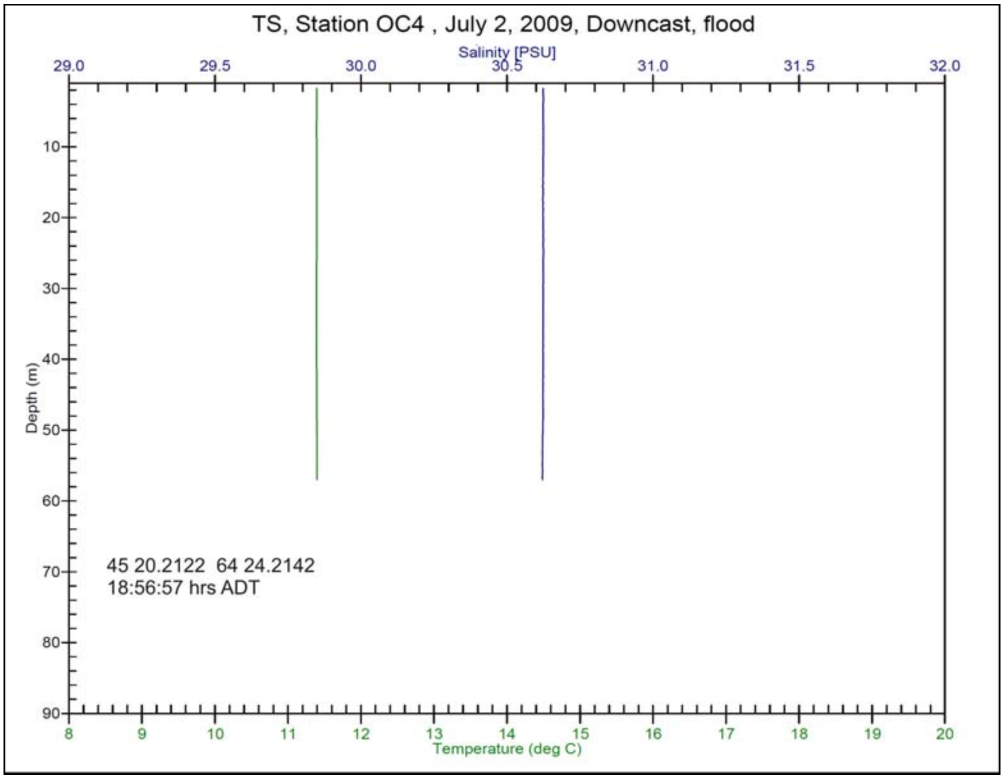


Figure D65. Vertical profile of temperature and salinity at Sta. OC4, Minas Passage study site, July 2, 2009.

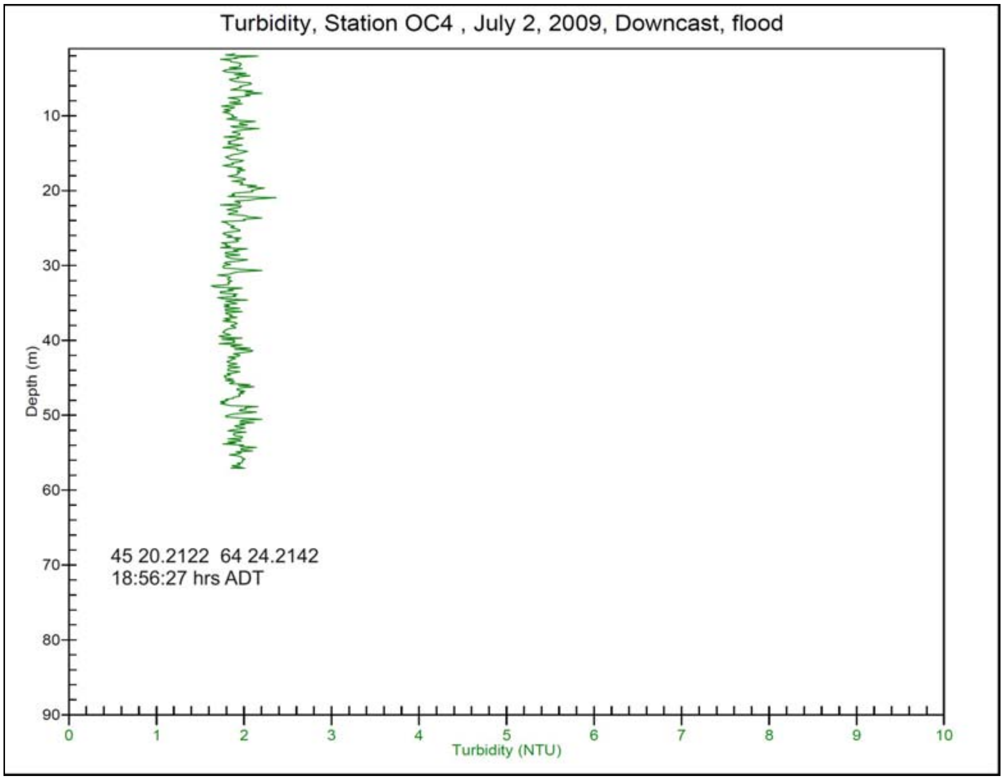


Figure D66. Vertical profile of turbidity (NTU) at Station OC4, Minas Passage study site, July 2, 2009.

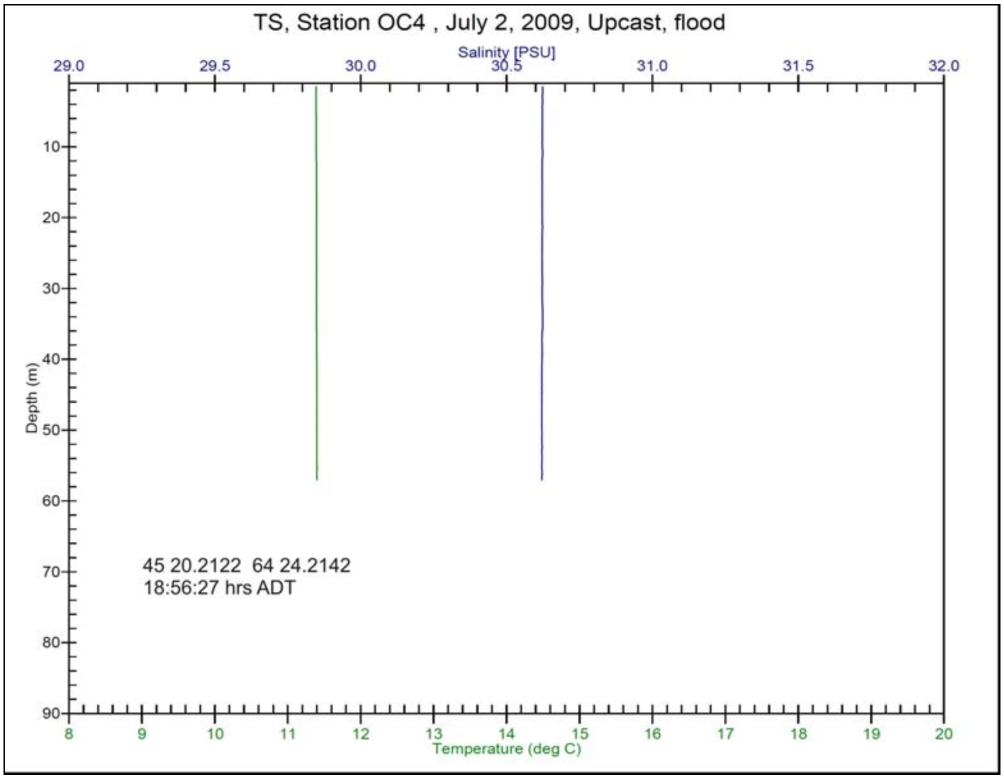


Figure D67. Vertical profile of temperature and salinity at Sta. OC4, Minas Passage study site, July 2, 2009.

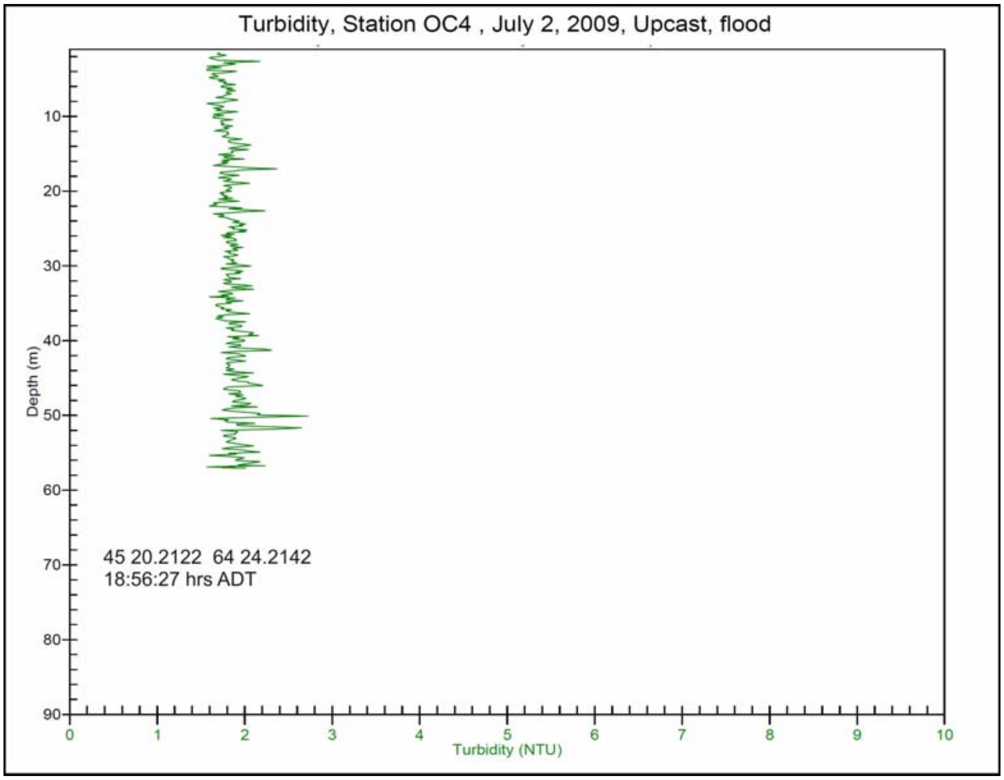


Figure D68. Vertical profile of turbidity (NTU) at Station OC4, Minas Passage study site, July 2, 2009.

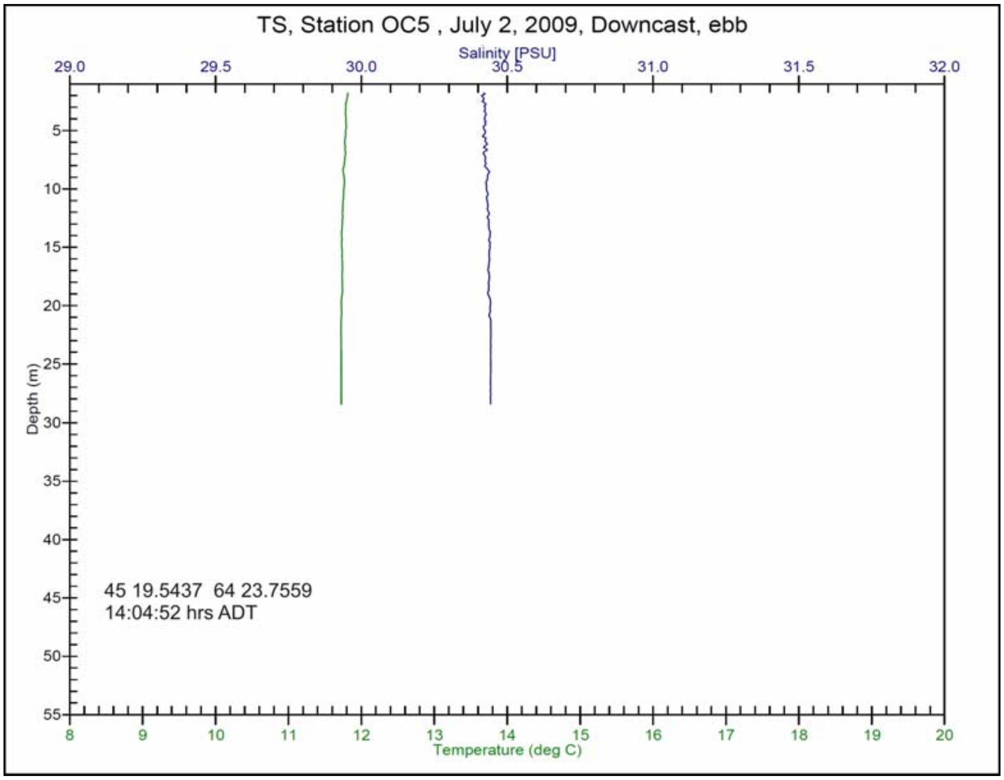


Figure D69. Vertical profile of temperature and salinity at Sta. OC5, Minas Passage study site, July 2, 2009.

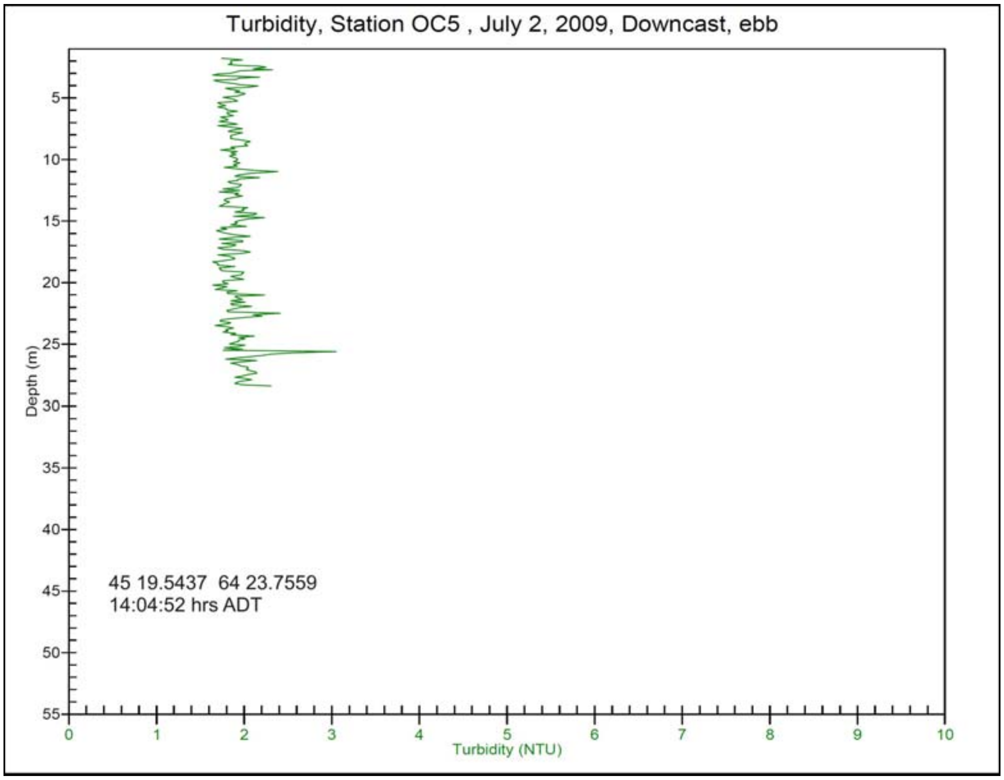


Figure D70. Vertical profile of turbidity (NTU) at Station OC5, Minas Passage study site, July 2, 2009.

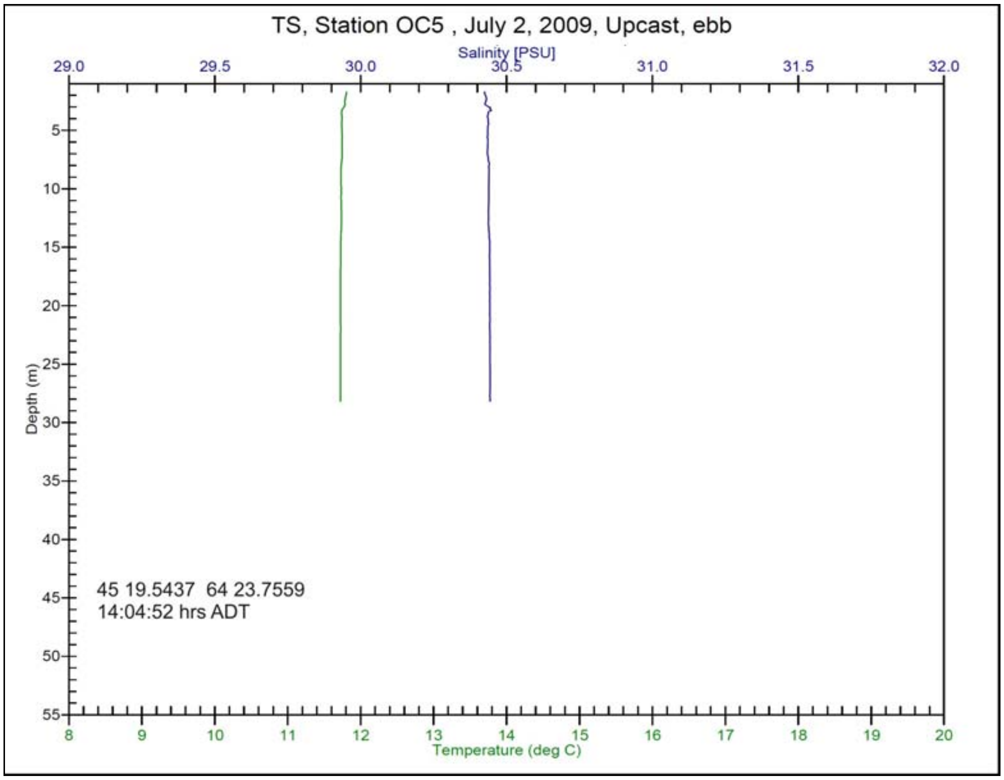


Figure D71. Vertical profile of temperature and salinity at Sta. OC5, Minas Passage study site, July 2, 2009.

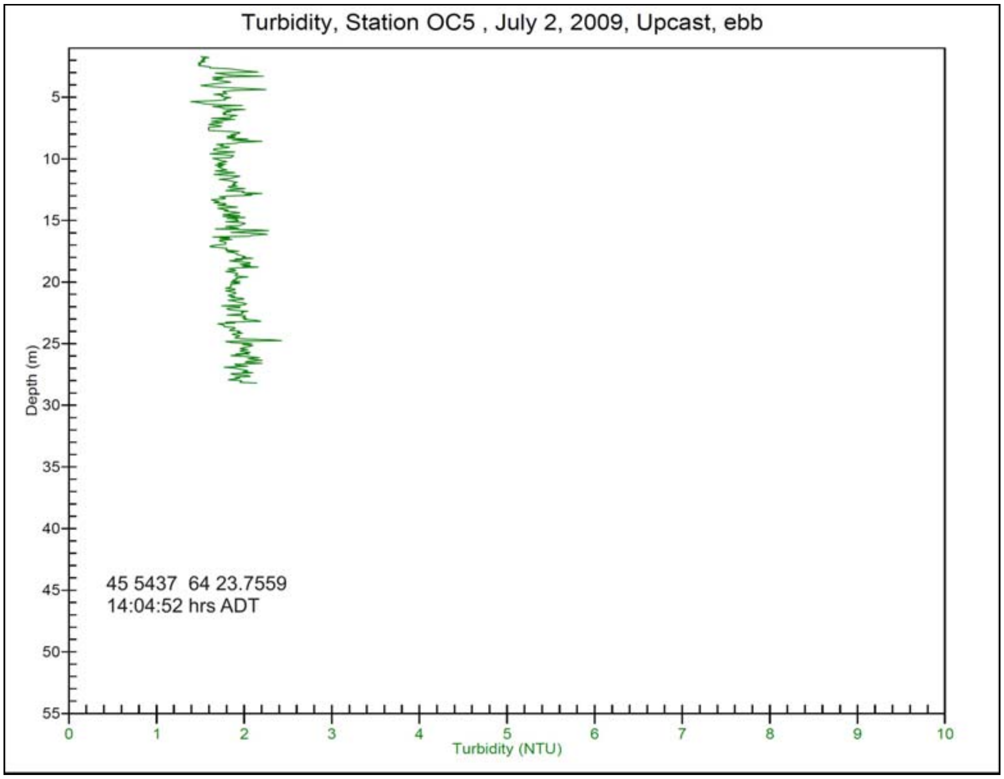


Figure D72. Vertical profile of turbidity (NTU) at Station OC5, Minas Passage study site, July 2, 2009.

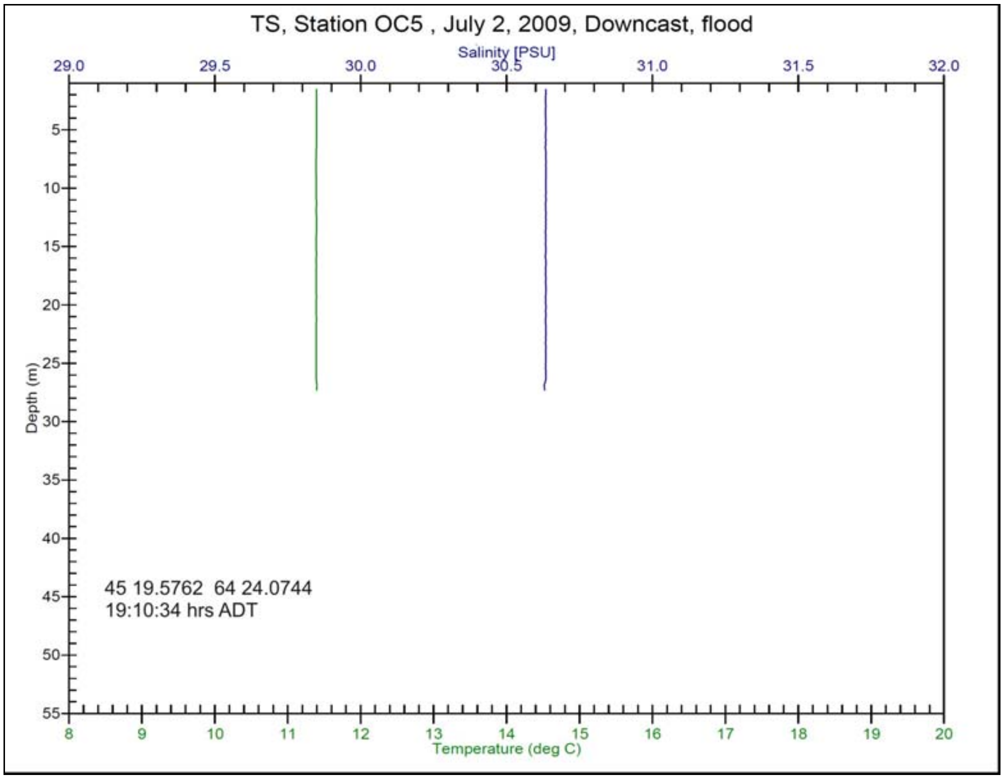


Figure D73. Vertical profile of temperature and salinity at Sta. OC5, Minas Passage study site, July 2, 2009.

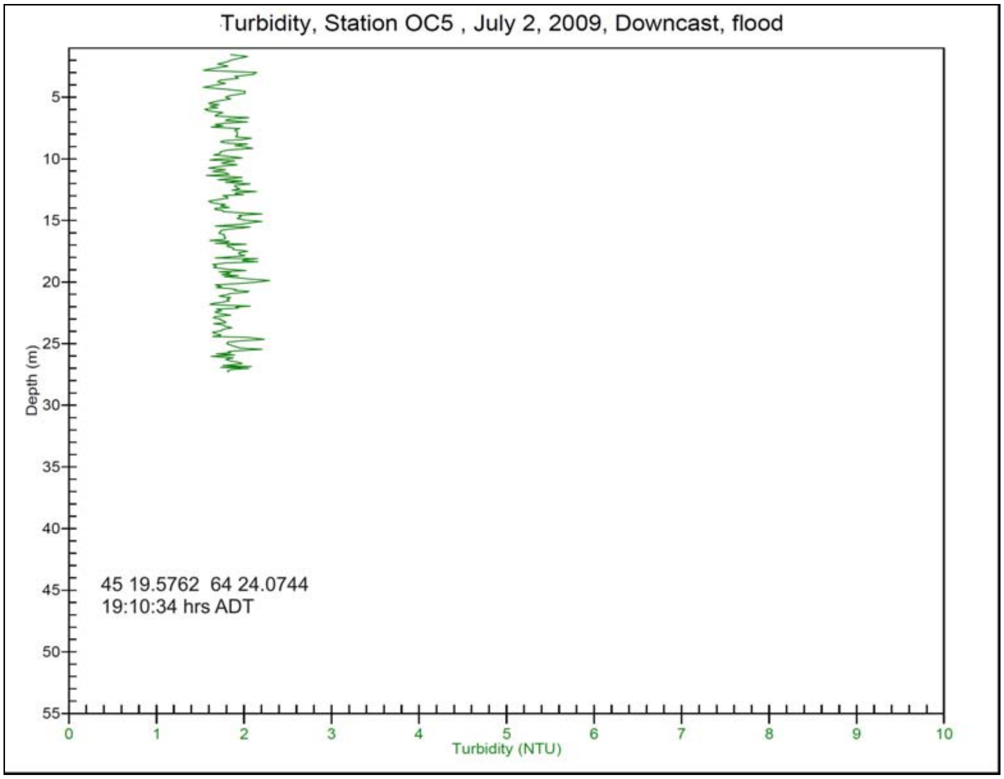


Figure D74. Vertical profile of turbidity (NTU) at Station OC5, Minas Passage study site, July 2, 2009.

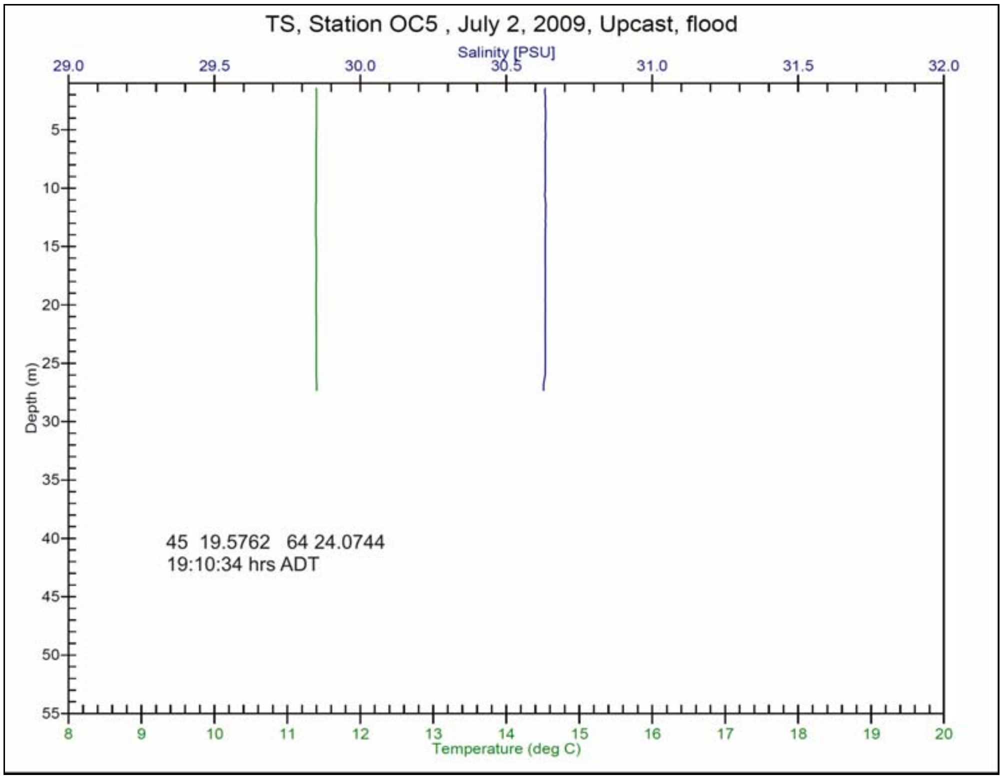


Figure D75. Vertical profile of temperature and salinity at Sta. OC5, Minas Passage study site, July 2, 2009.

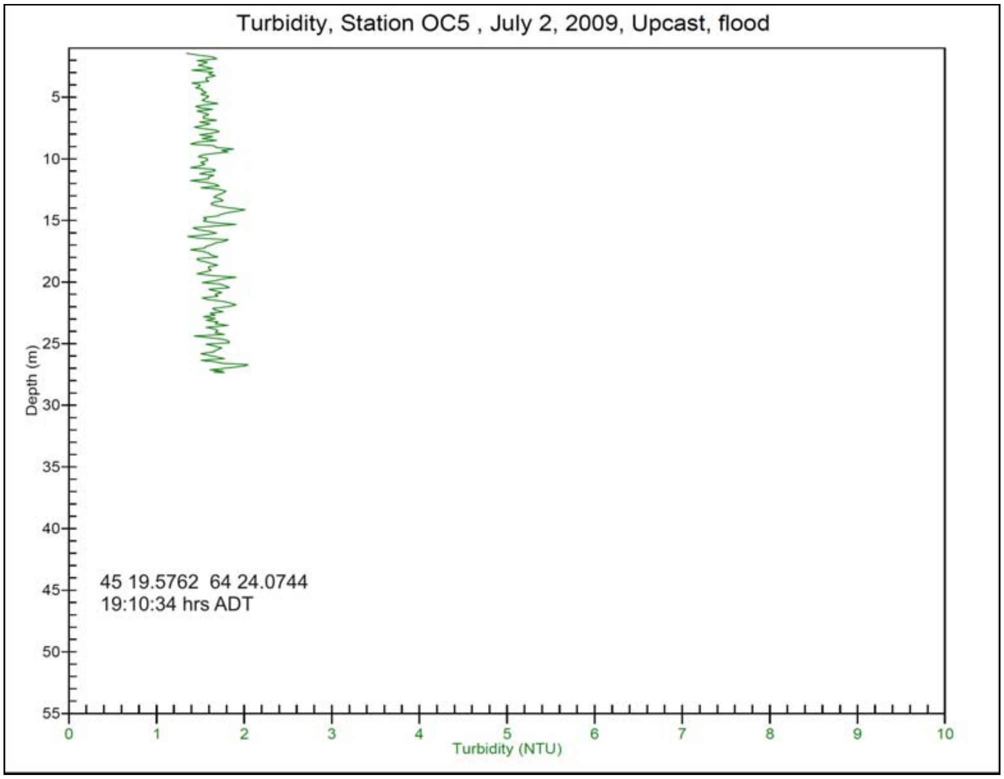


Figure D76. Vertical profile of turbidity (NTU) at Station OC5, Minas Passage study site, July 2, 2009.

Appendix E. Vertical profiles of Temperature, Salinity and Turbidity, Minas Passage, August 2009.

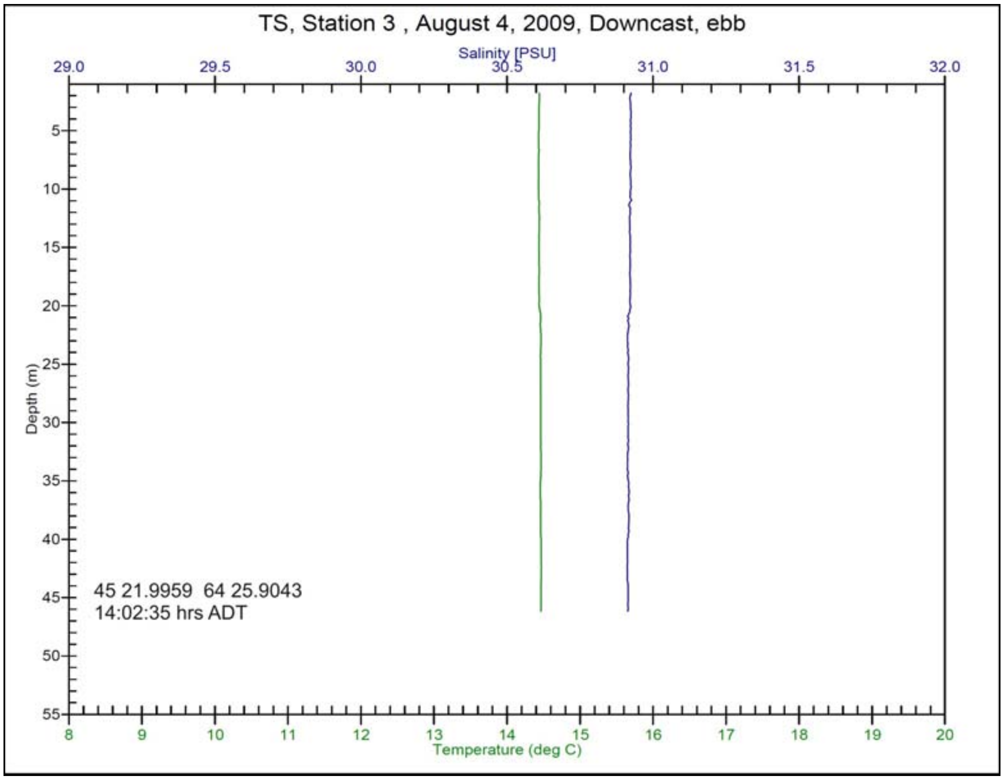


Figure E1. Vertical profile of temperature and salinity at Station 3, Minas Passage study site, Aug. 4, 2009.

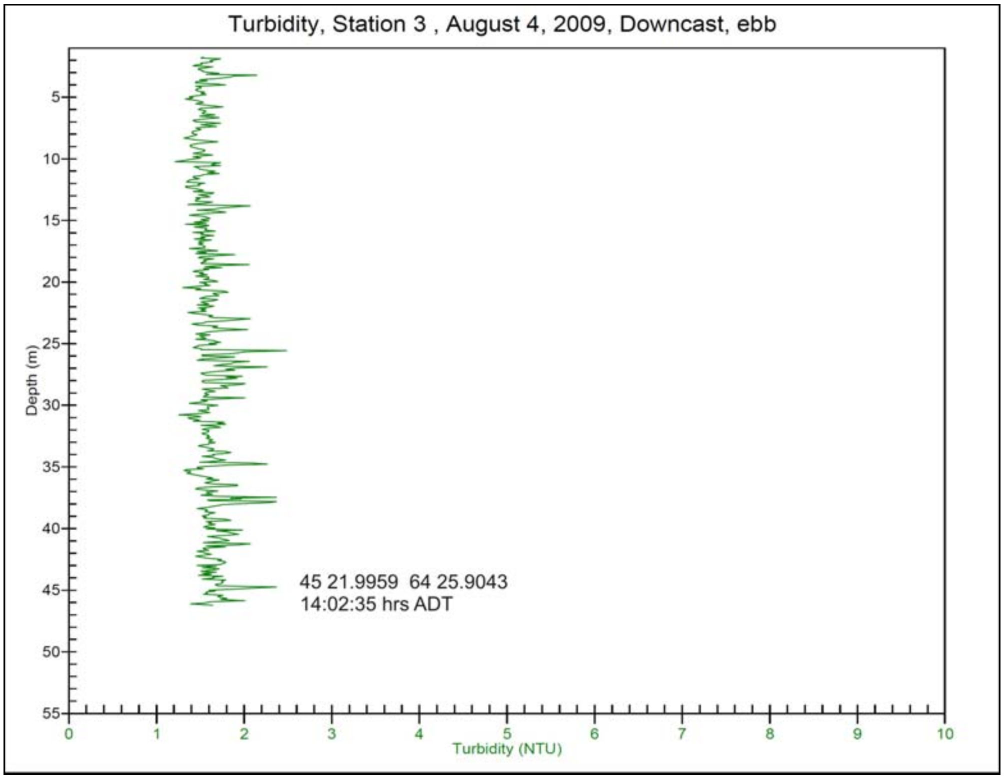


Figure E2. Vertical profile of turbidity (NTU) at Station 3, Minas Passage study site, August 4, 2009.

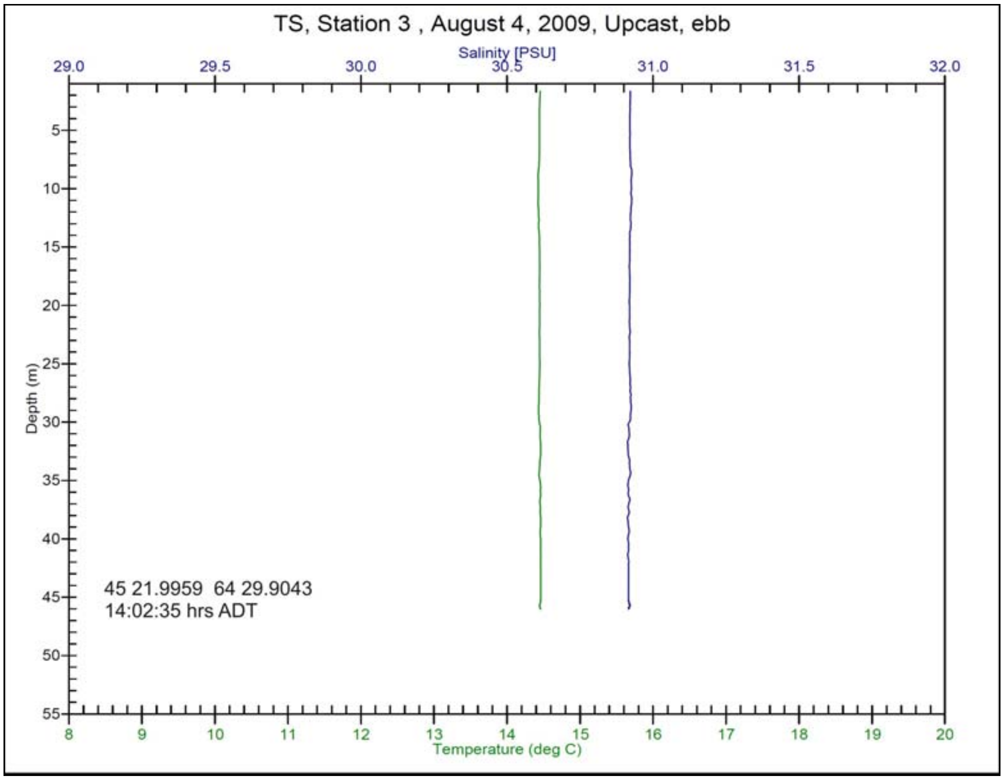


Figure E3. Vertical profile of temperature and salinity at Station 3, Minas Passage study site, Aug. 4, 2009.

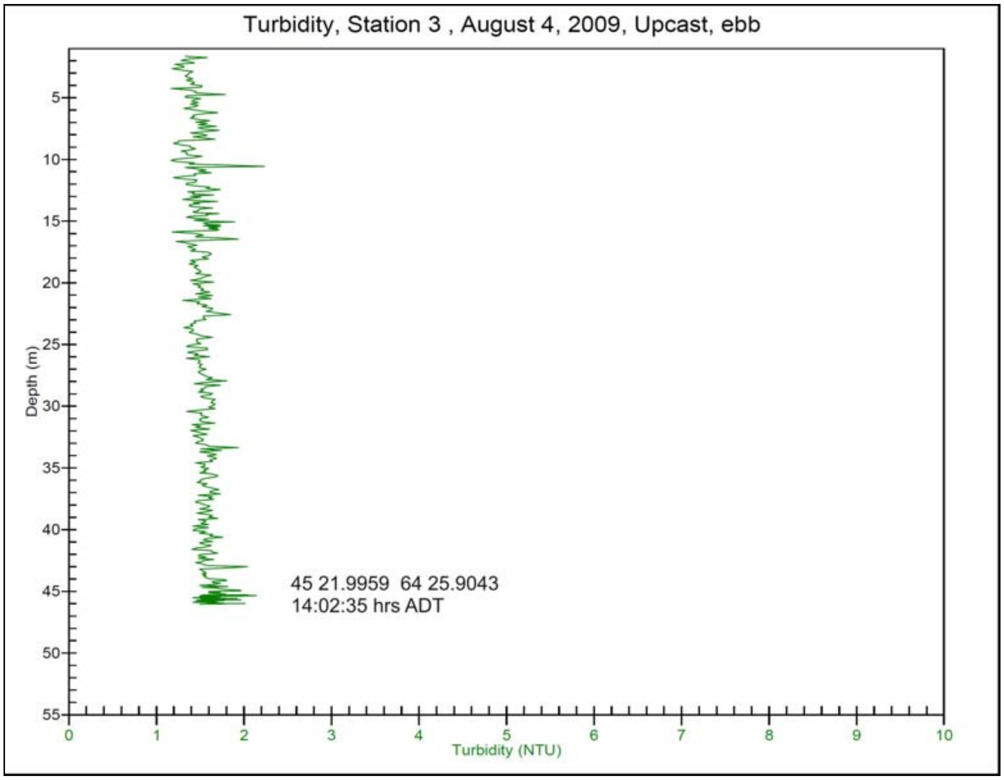


Figure E4. Vertical profile of turbidity (NTU) at Station 3, Minas Passage study site, August 4, 2009.

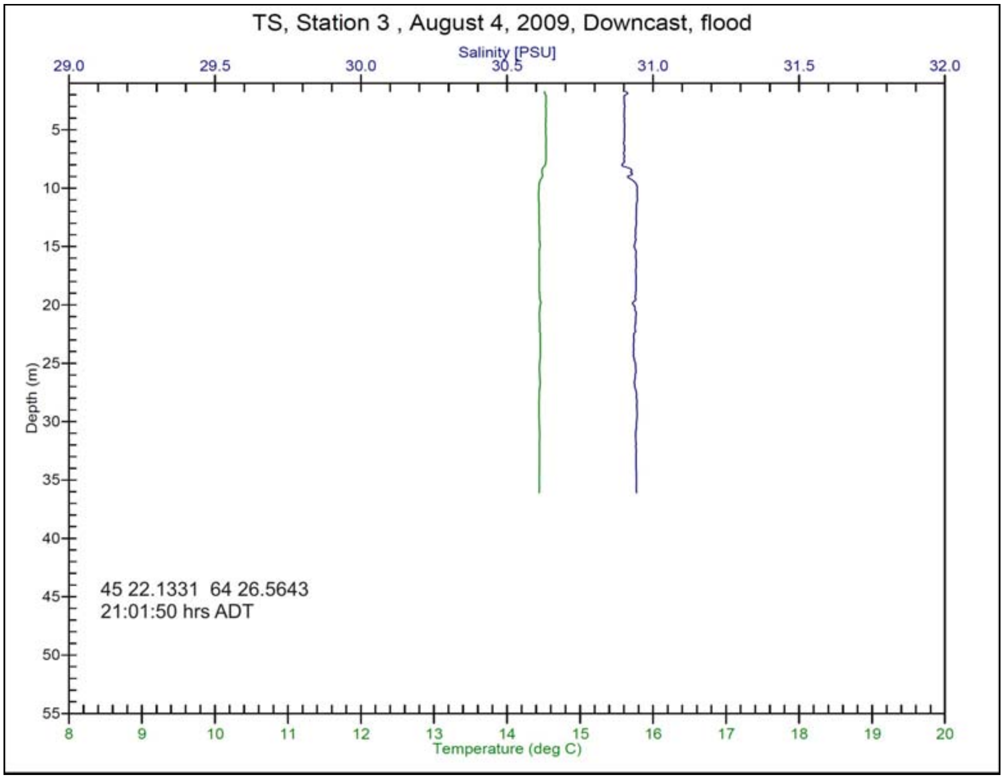


Figure E5. Vertical profile of temperature and salinity at Station 3, Minas Passage study site, Aug. 4, 2009.

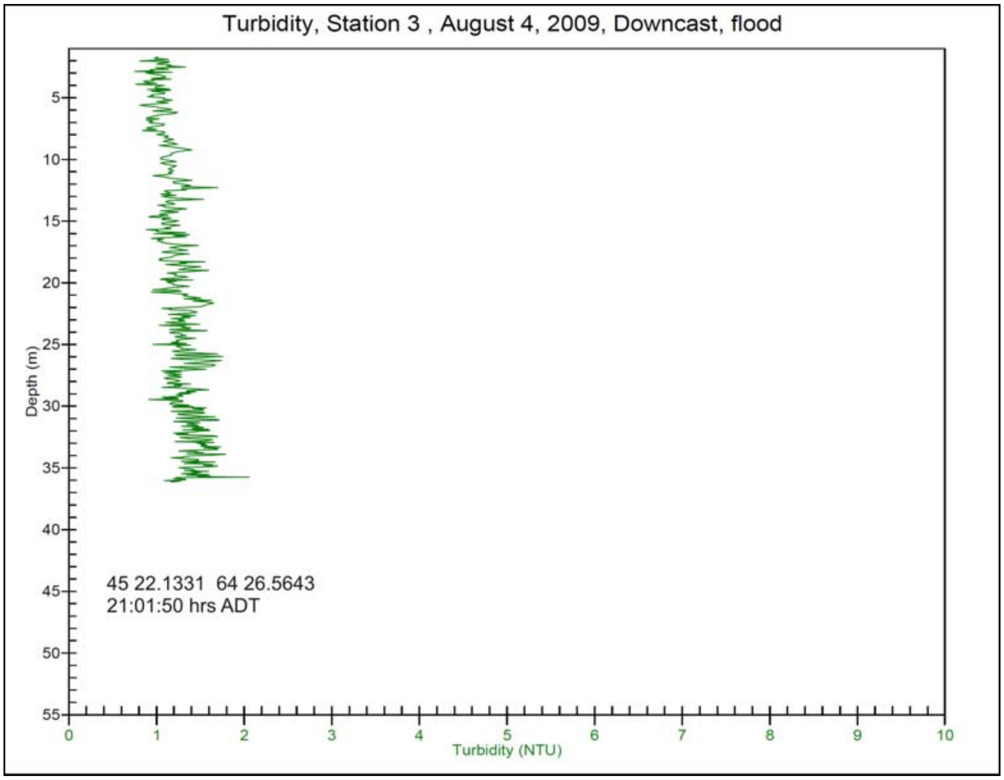


Figure E6. Vertical profile of turbidity (NTU) at Station 3, Minas Passage study site, August 4, 2009.

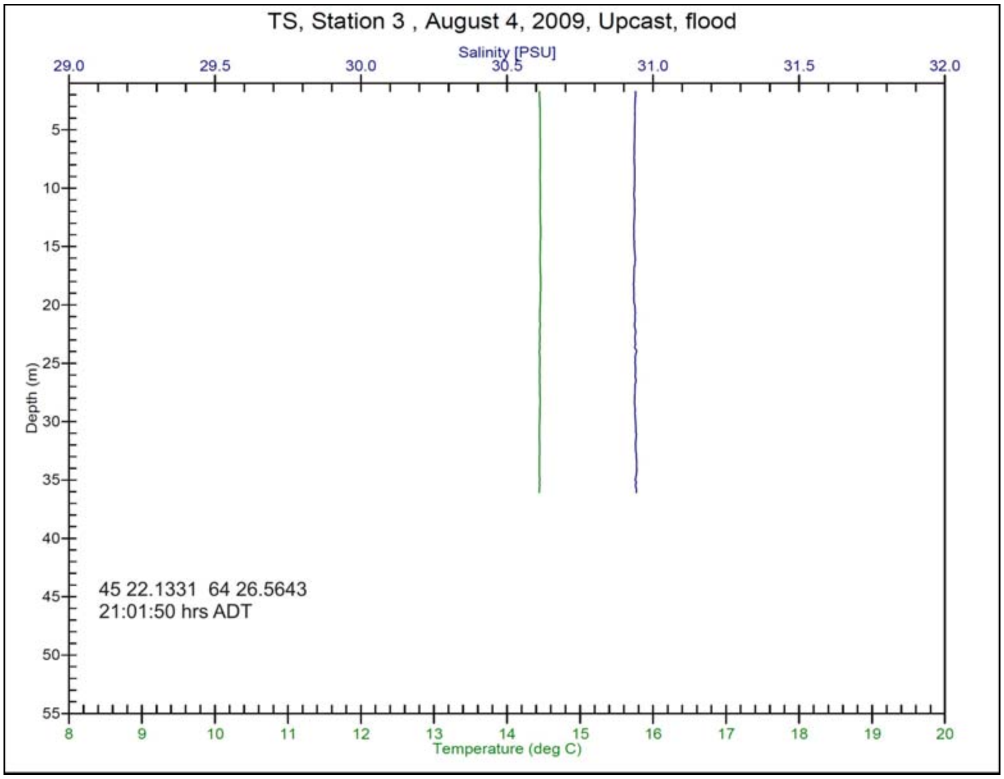


Figure E7. Vertical profile of temperature and salinity at Station 3, Minas Passage study site, Aug. 4, 2009.

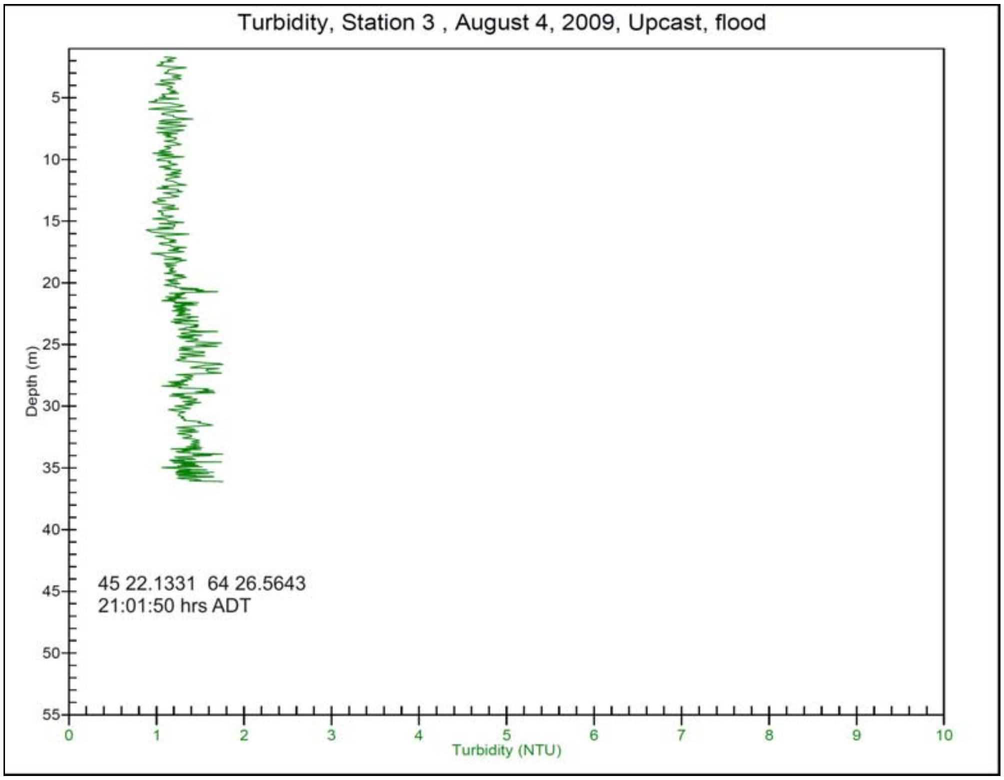


Figure E8. Vertical profile of turbidity (NTU) at Station 3, Minas Passage study site, August 4, 2009.

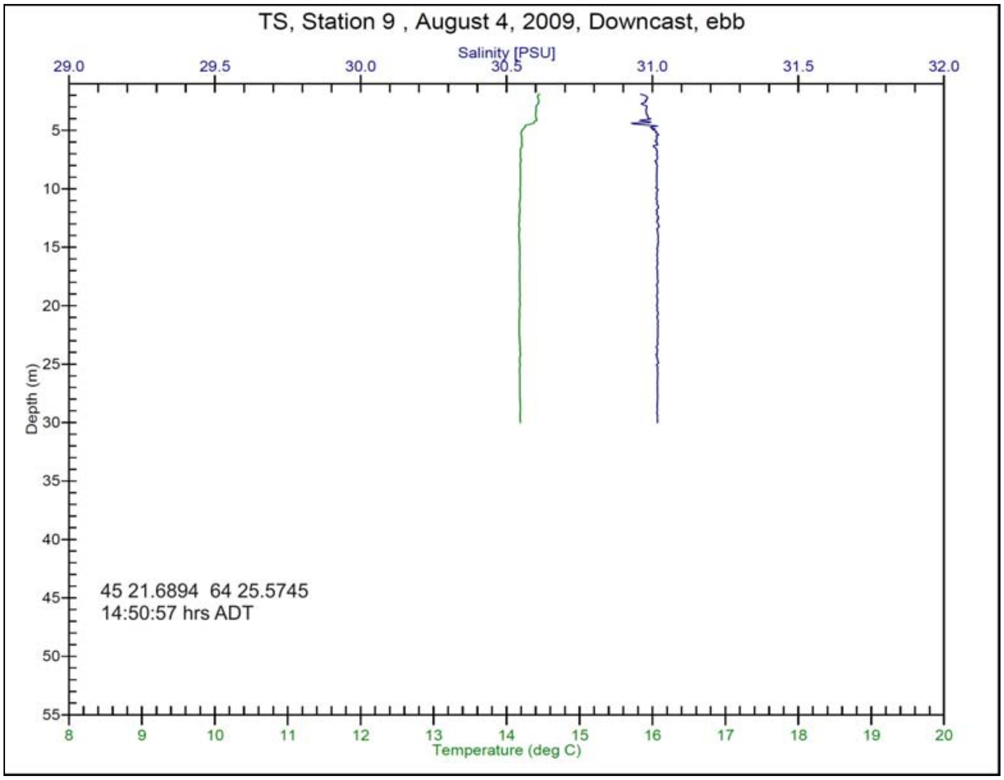


Figure E9. Vertical profile of temperature and salinity at Station 9, Minas Passage study site, Aug. 4, 2009.

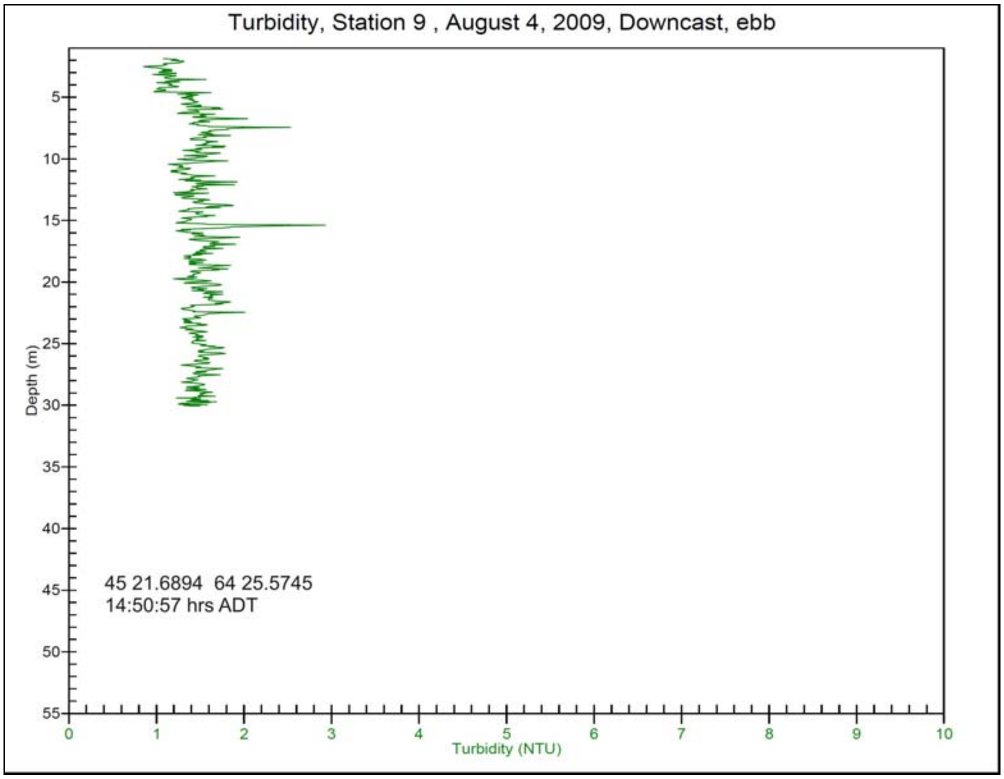


Figure E10. Vertical profile of turbidity (NTU) at Station 9, Minas Passage study site, August 4, 2009.

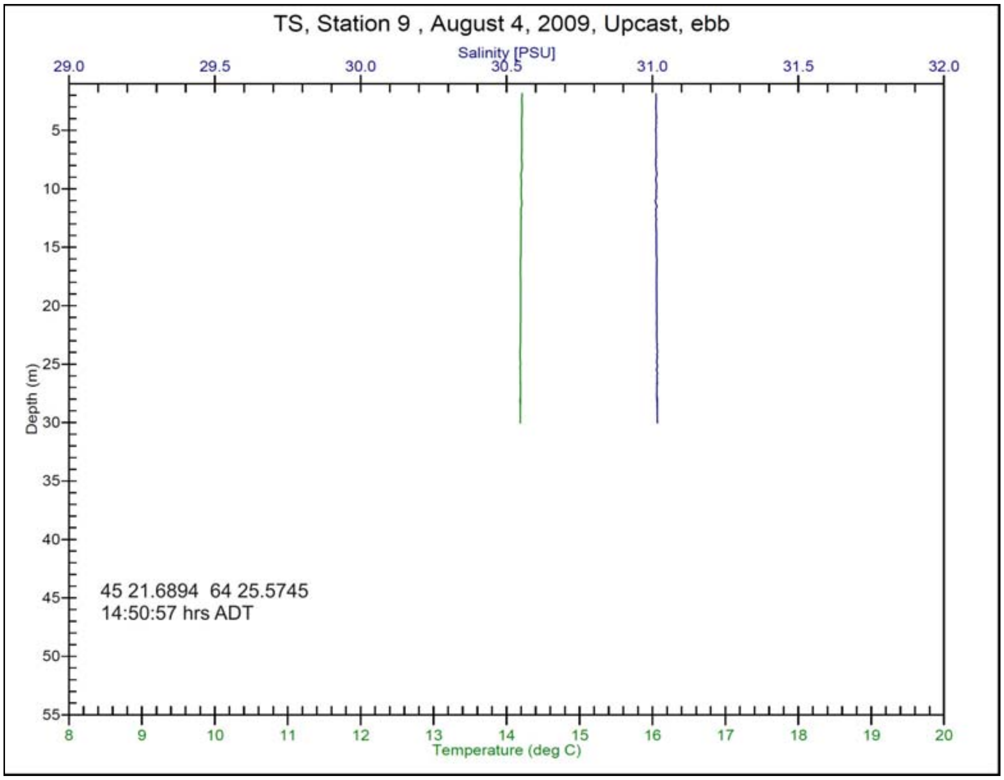


Figure E11. Vertical profile of temperature and salinity at Station 9, Minas Passage study site, Aug. 4, 2009.

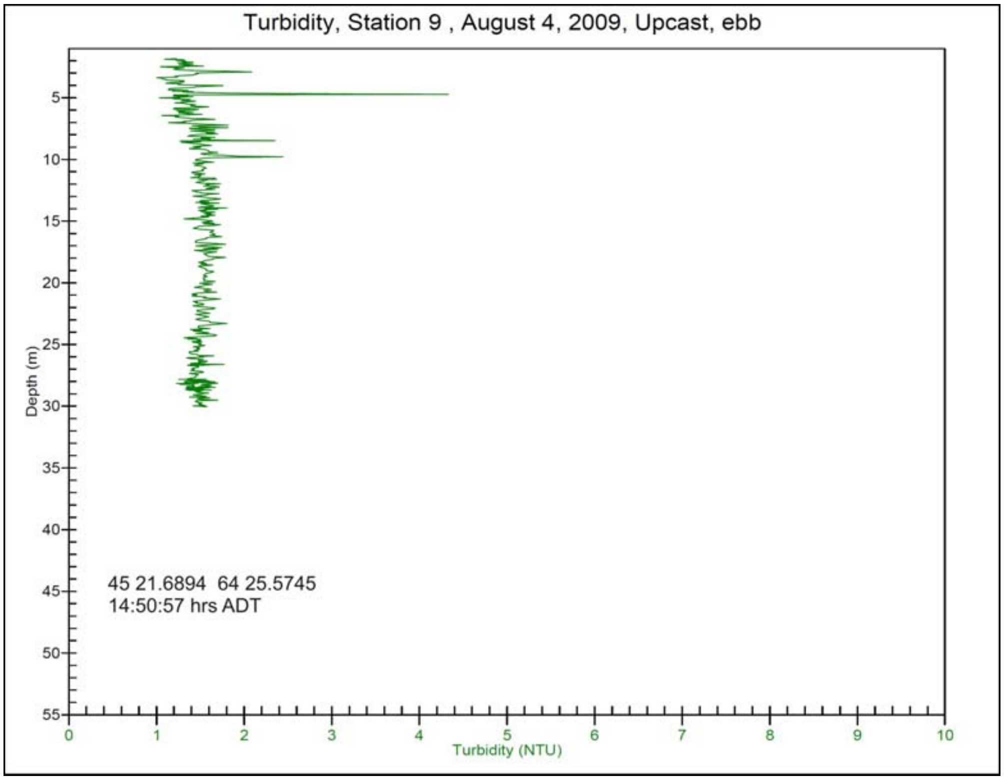


Figure E12. Vertical profile of turbidity (NTU) at Station 9, Minas Passage study site, August 4, 2009.

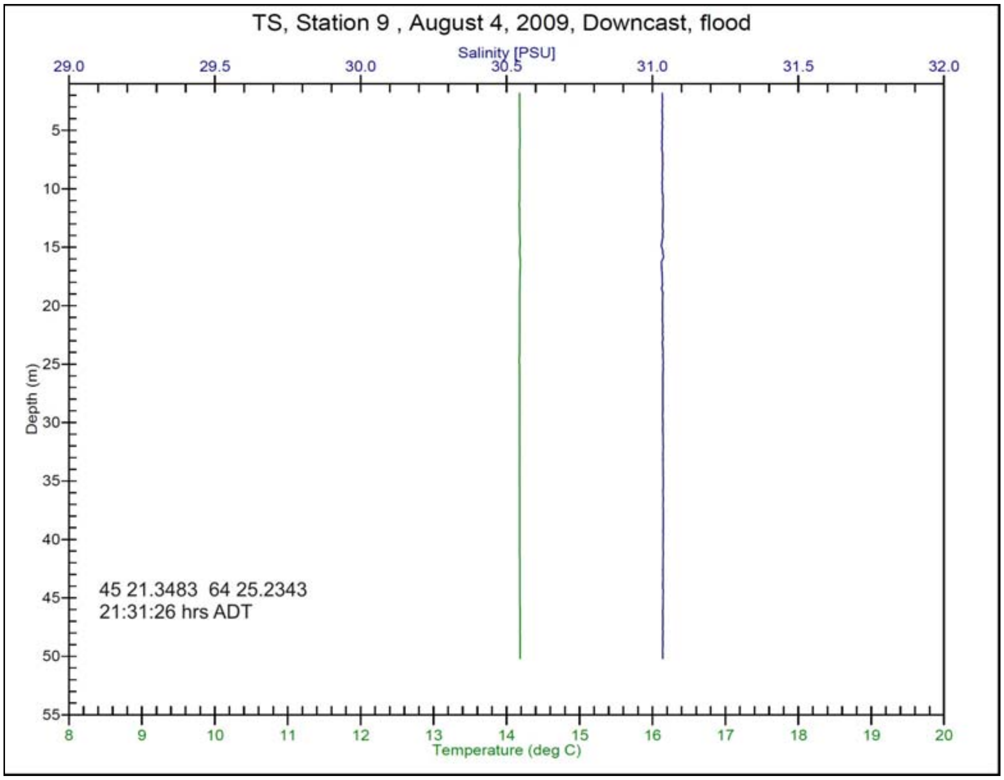


Figure E13. Vertical profile of temperature and salinity at Station 9, Minas Passage study site, Aug 4, 2009.

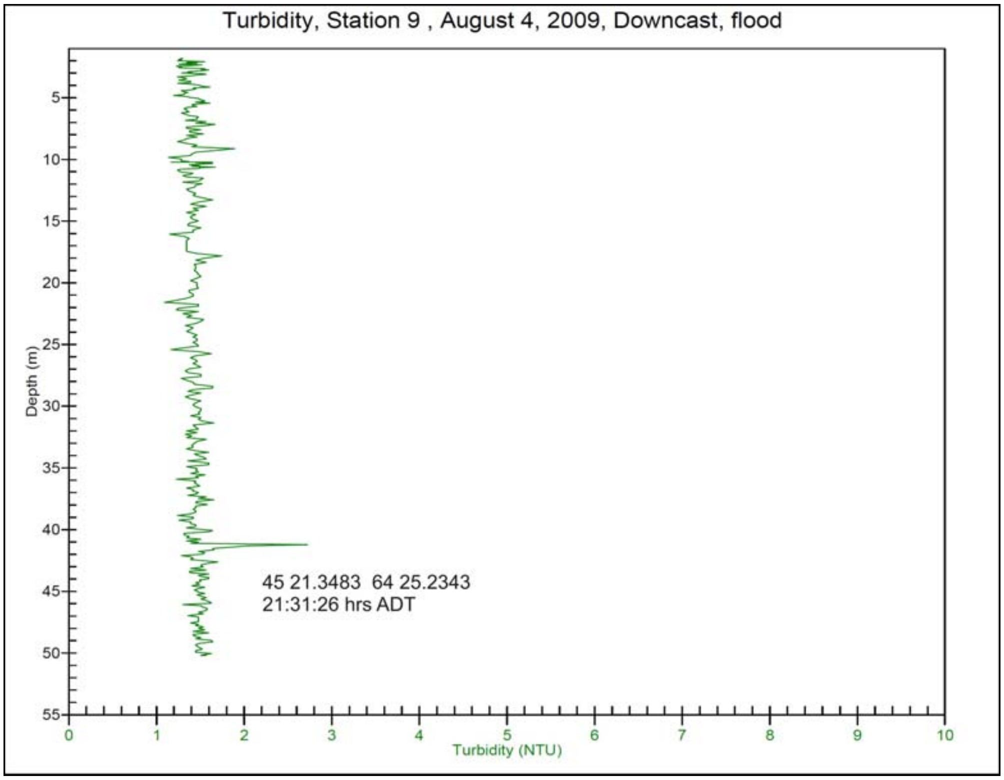


Figure E14. Vertical profile of turbidity (NTU) at Station 9, Minas Passage study site, August 4, 2009.

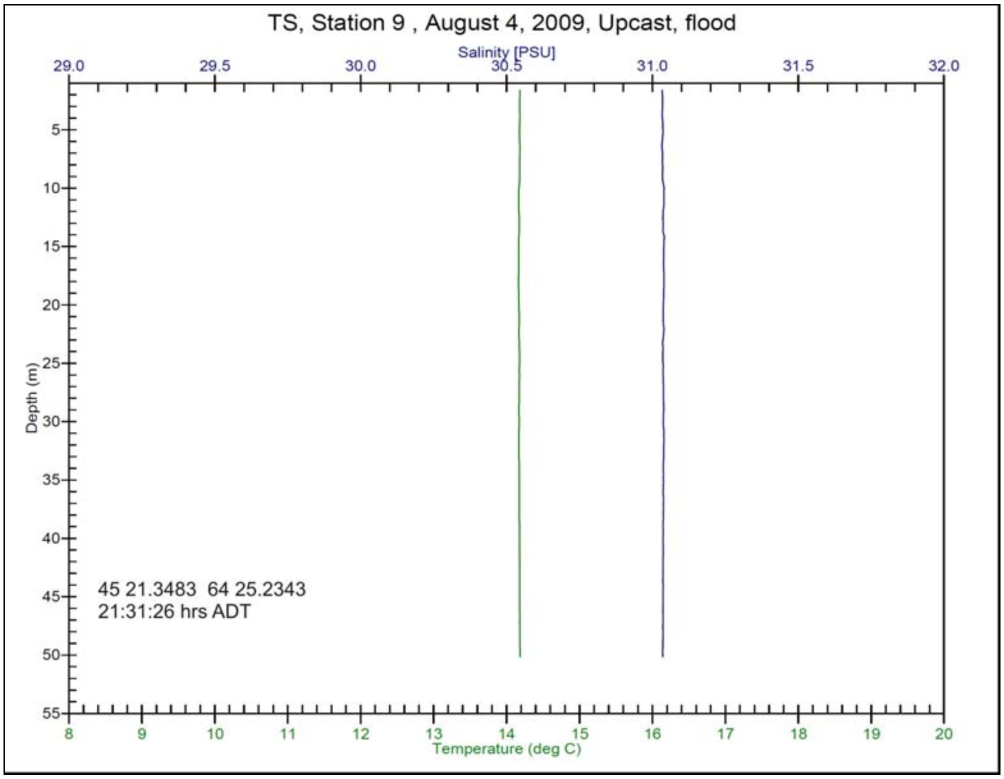


Figure E15. Vertical profile of temperature and salinity at Station 9, Minas Passage study site, Aug 4, 2009.

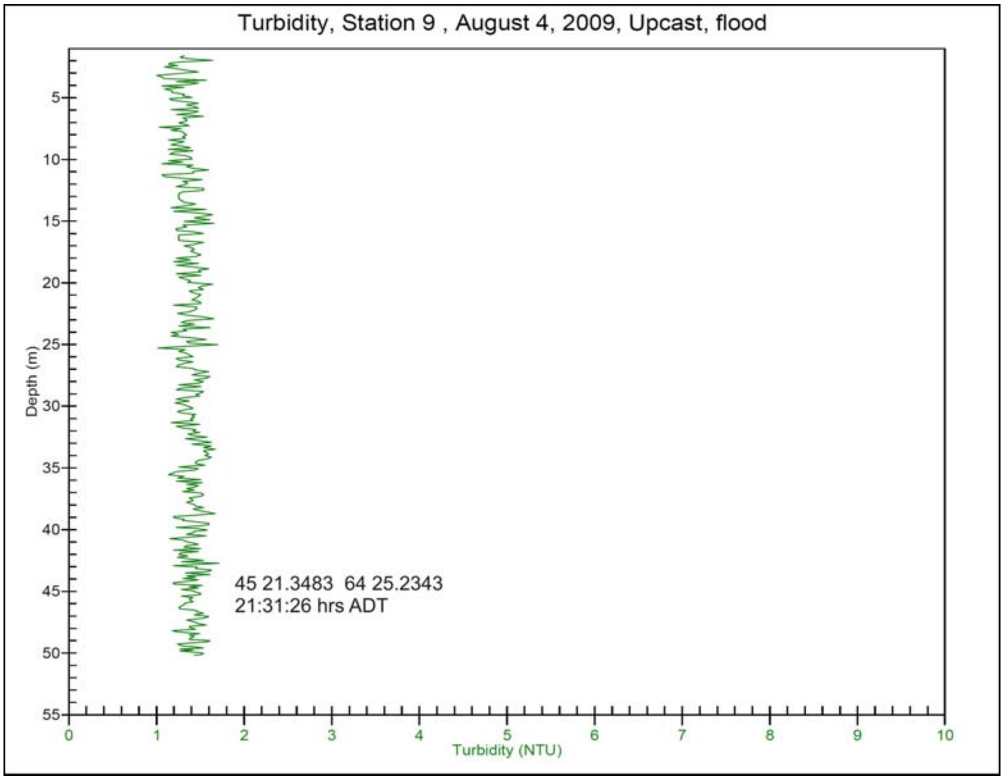


Figure E16. Vertical profile of turbidity (NTU) at Station 9, Minas Passage study site, Aug 4, 2009.

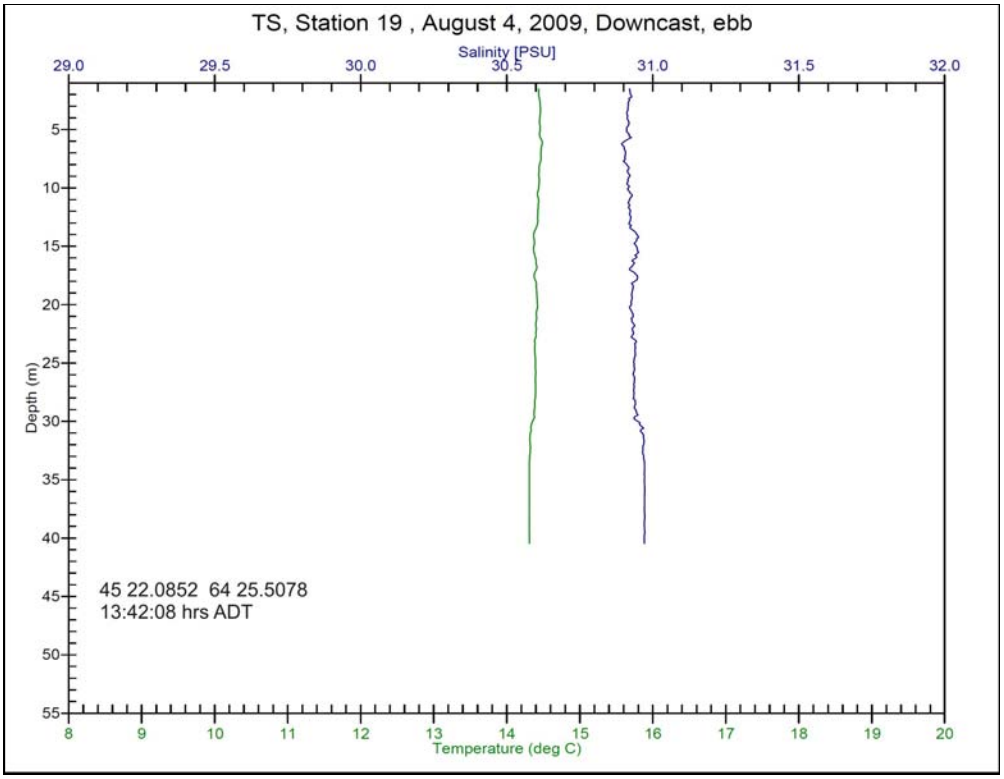


Figure E17. Vertical profile of temperature and salinity at Station 19, Minas Passage study site, Aug. 4, 2009.

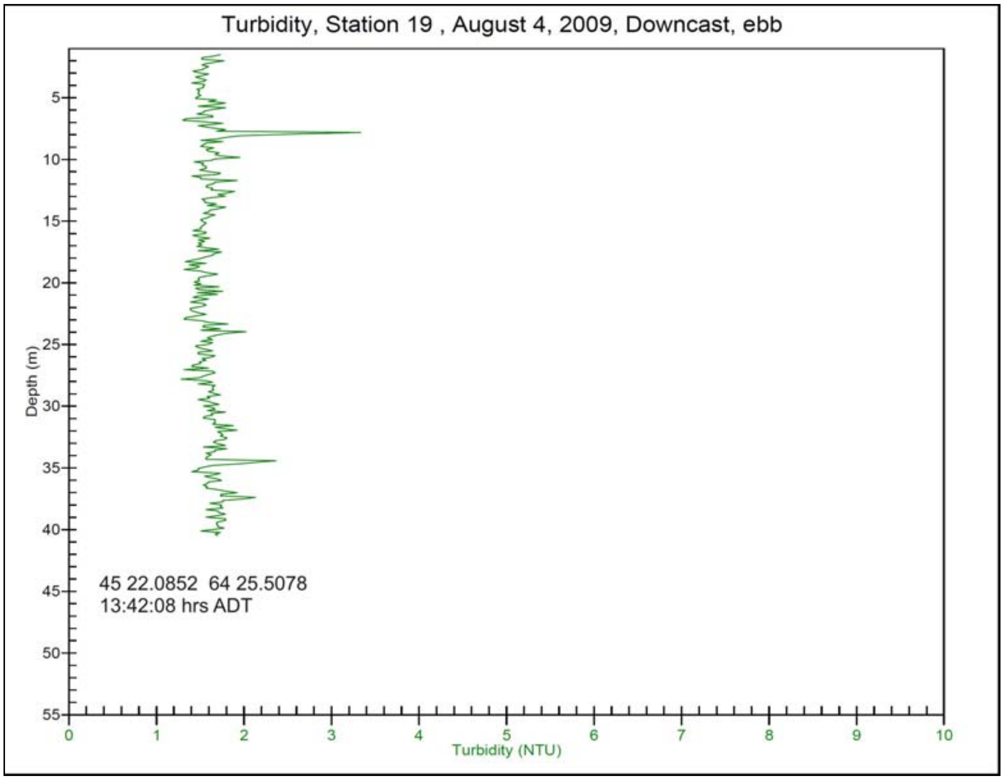


Figure E18. Vertical profile of turbidity (NTU) at Station 19, Minas Passage study site, August 4, 2009.

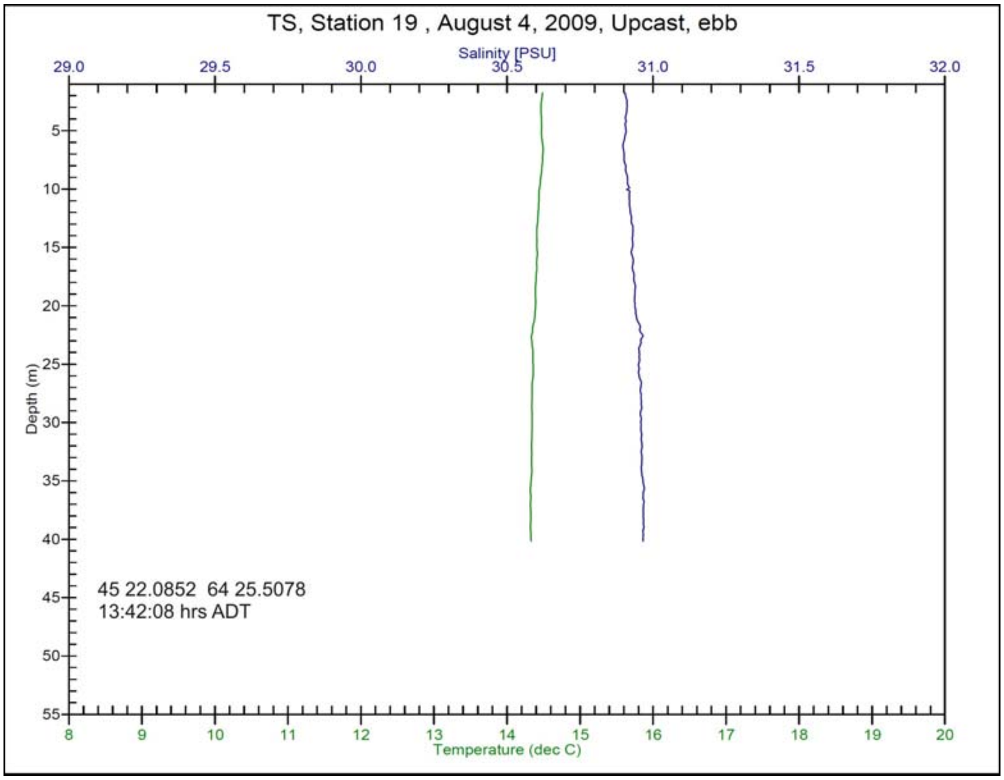


Figure E19. Vertical profile of temperature and salinity at Station 19, Minas Passage study site, Aug. 4, 2009.

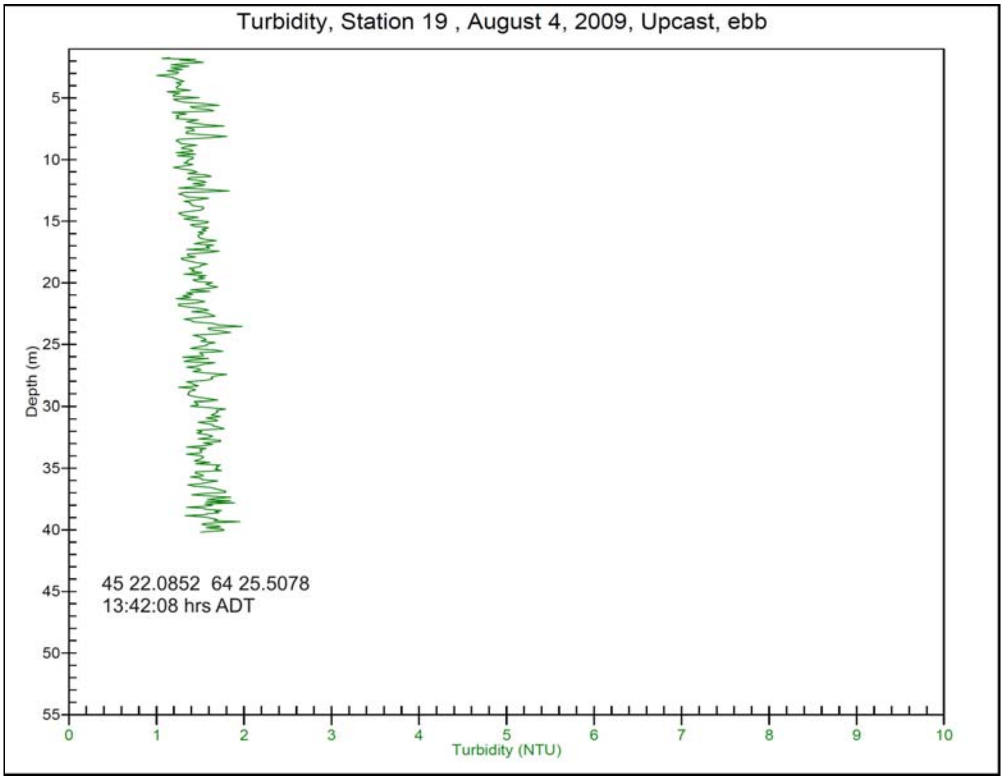


Figure E20. Vertical profile of turbidity (NTU) at Station 19, Minas Passage study site, August 4, 2009.

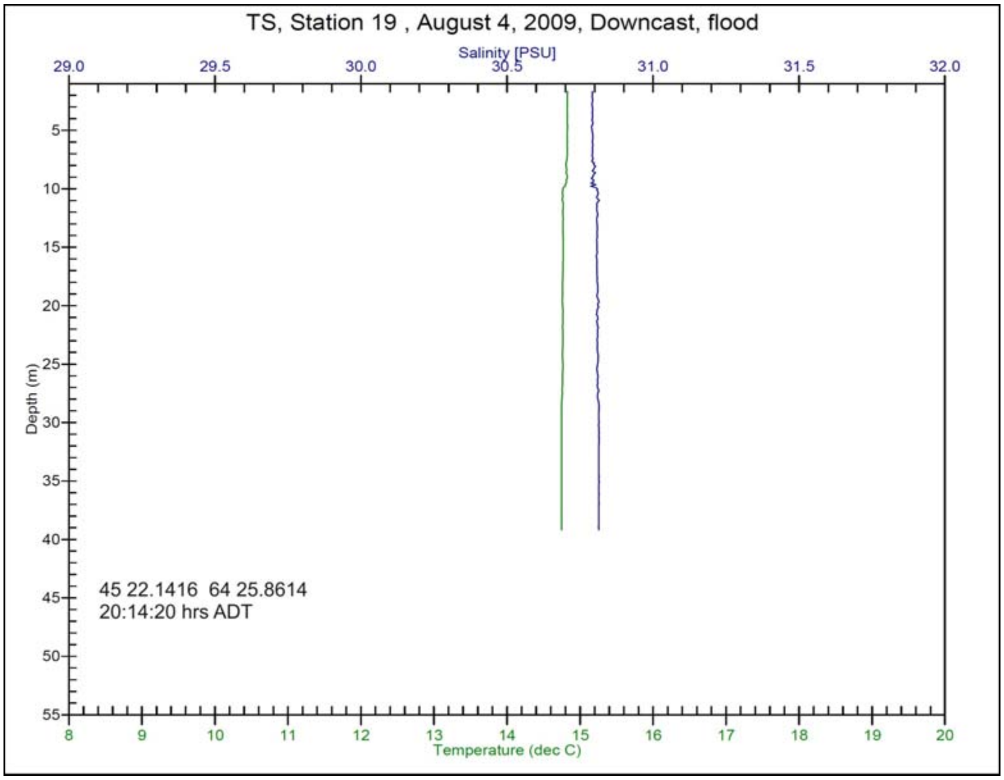


Figure E21. Vertical profile of temperature and salinity at Station 19, Minas Passage study site, Aug. 4, 2009.

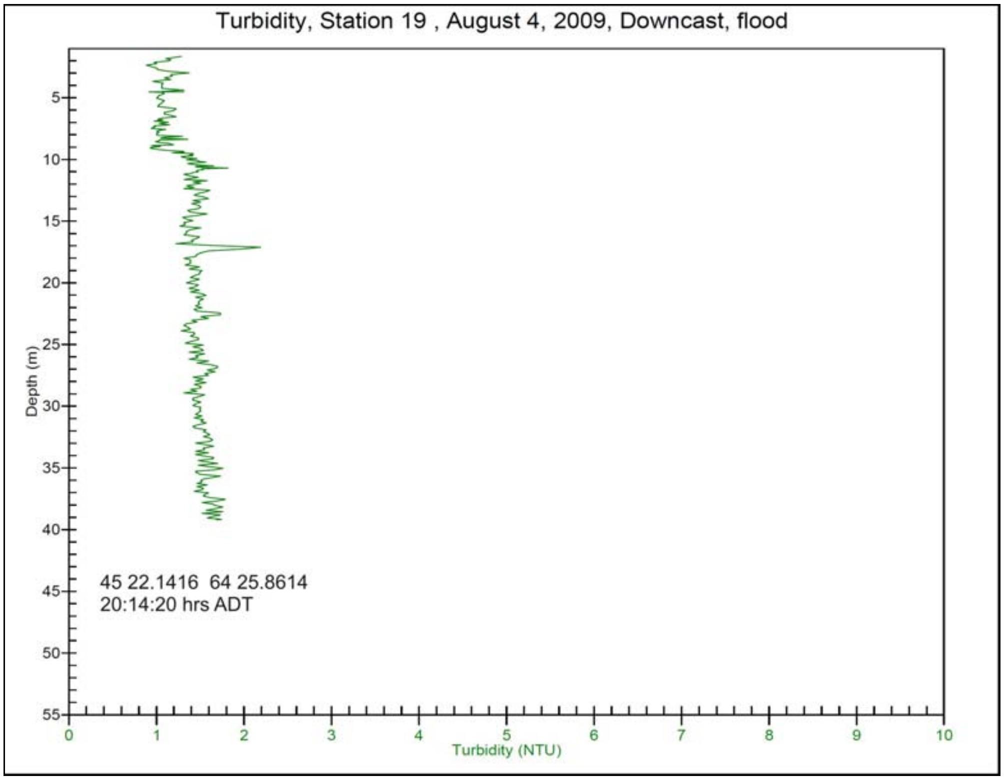


Figure E22. Vertical profile of turbidity (NTU) at Station 19, Minas Passage study site, August 4, 2009.

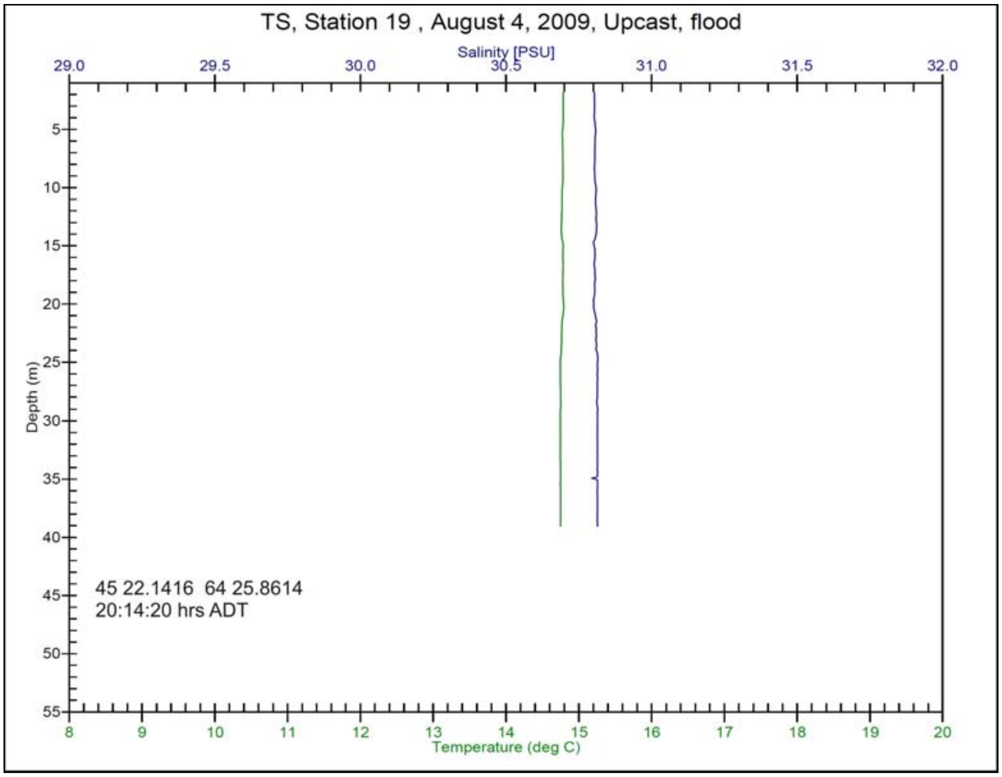


Figure E23. Vertical profile of temperature and salinity at Station 19, Minas Passage study site, Aug. 4, 2009.

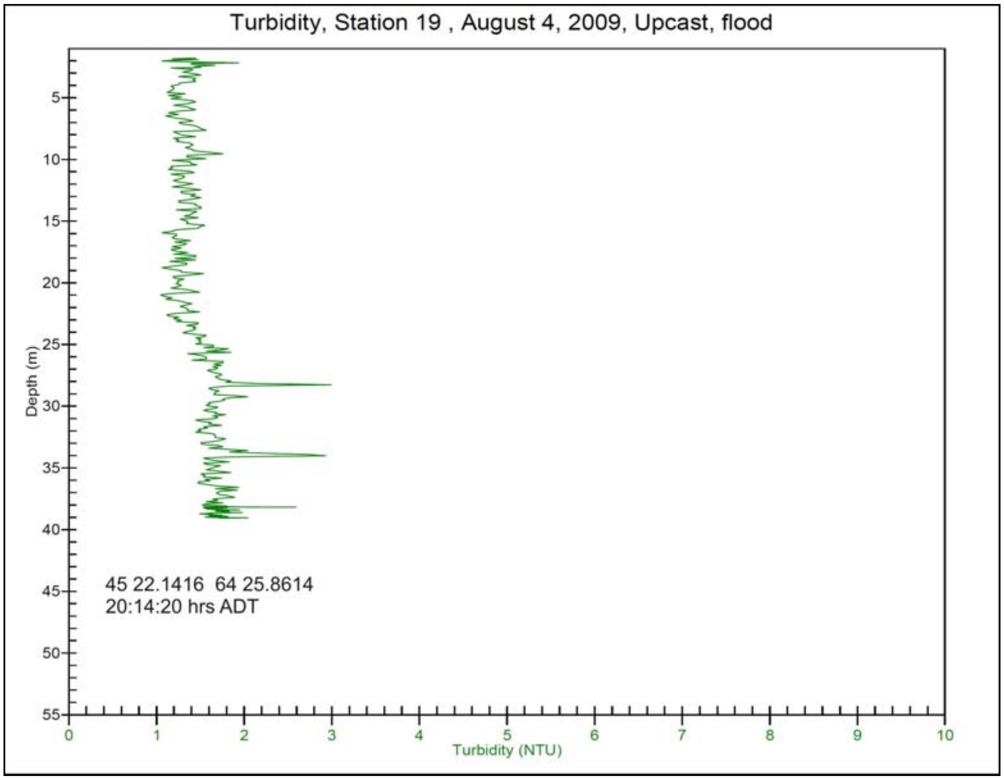


Figure E24. Vertical profile of turbidity (NTU) at Station 19, Minas Passage study site, August 4, 2009.