Canadian Technical Report of

Fisheries and Aquatic Sciences 2246

1998

Compilation of Suspended Particulate Matter (SPM) recorded in the Shepody Bay/Petitcodiac River System.

by

T.M. Schell

Science Branch
Maritimes Region
Fisheries and Oceans Canada
Bedford Institute of Oceanography
P.O. box 1006
Dartmouth, Nova Scotia B2Y 4A2
Canada

Correct citation for this publication:

Schell, T.M. 1998. Compilation of Suspended Particulate Matter (SPM) recorded in the Shepody Bay/Petitcodiac River System. Can.Tech.Rep.Fish.Aquat.Sci.2246: vii + 29p.

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Schell, T..M. 1998. Compilation of Suspended Particulate Matter (SPM) recorded in the Shepody Bay/Petitcodiac River System. Can.Tech.Rep.Fish.Aquat.Sci. 2246: vii + 29p.

In 1967/68 the New Brunswick Department of Transportation constructed the Moncton-Riverview causeway, which includes 5 spill gates and a fishway to provide passage to several stocks of anadromous fish. Fisheries catches and enumeration data indicate that efforts to provide fish passage at the causeway have failed. As a result, the Petitcodiac River has changed from being one of the more important shad producing rivers of the Maritimes to being one that produces only a few shad. In an attempt to revive declining stocks, Fisheries and Oceans has recommended an annual period of free flow with the opening of one or all five gates from 1 April - 15 December in the Petitcodiac River to accommodate and maximize anadromous fish passage and production in this system. Concern has been expressed that this action could mobilize the sediment deposited below the causeway, causing a negative impact on fishing activities in Shepody and Chignecto Bays. The purpose of this review of historical data on the Petitcodiac River/Shepody Bay system is to investigate the background levels of Suspended Particulate Material (SPM) in the water column while the fishgates of the Petiticodiac Causeway were being operated in their normal manner, to provide a comparision to the SPM concentrations if the gates are opened. A general literature review also was carried out. This review found that although considerable work has been conducted in Chignecto Bay, only very limited data exist for Shepody Bay and the Petitcodiac River.

RÉSUMÉ

Schell, T..M. 1998. Compilation of Suspended Particulate Matter (SPM) recorded in the Shepody Bay/Petitcodiac River System. Can.Tech.Rep.Fish.Aquat.Sci. 2246: vii + 29 p.

En 1967-1968, le ministère des Transports du Nouveau-Brunswick a construit la chaussée de Moncton-Riverview, qui comprend 5 vannes de décharge et une passe migratoire permettant le passage de plusieurs stocks de poissons anadromes. Les prises des pêcheurs et les données de dénombrement révèlent que les moyens pris pour assurer le passage du poisson ont échoué. De ce fait, la Petitcodiac, qui était une des sources d'aloses les plus importantes des Maritimes, ne produit plus que quelques-uns de ces poissons. Soucieux de revitaliser les stocks en déclin, le ministère des Pêches et des Océans a recommandé qu'on établisse chaque année un libre écoulement dans la Petitcodiac, en ouvrant une ou la totalité des cinq vannes du 1^er^ avril au 15 décembre, afin de faciliter et d'optimiser le passage et la production de poissons anadromes dans le réseau hydrographique. Certains se sont inquiétés de ce que cette mesure risque de remettre en mouvement les sédiments déposés en aval de la chaussée, ce qui aurait des répercussions néfastes sur la pêche dans les baies de Shepody et de Chignecto. La présente étude des données historiques sur le réseau hydrographique de la Petitcodiac et de la baie de Shepody a pour but d'examiner les niveaux naturels de particules en suspension dans la colonne d'eau pendant les périodes d'exploitation normale des vannes de la chaussée de la Petitcodiac, afin de les comparer aux concentrations particulaires obtenues si les vannes sont ouvertes. Par ailleurs, on a procédé à une enquête bibliographique, d'où il ressort que la baie de Chignecto a fait l'objet de travaux documentaires considérables, mais que les données portant sur la baie de Shepody et sur la Petitcodiac sont très limitées.

INTRODUCTION

In 1967/68 the New Brunswick Department of Transportation constructed the Moncton-Riverview causeway, which includes 5 spill gates and a fishway to provide passage to several stocks of anadromous fish. Fisheries catches and enumeration data indicate that efforts to provide fish passage at the causeway have failed (Ritter, 1993). As a result, the Petitcodiac River has changed from being one of the more important shad producing rivers of the Maritimes to being one that produces only a few shad. Declining recruitment in other species - rainbow smelt, alewife (gaspereau), striped bass, sea-run brook trout and the Atlantic salmon also has been documented (Ritter 1993).

In an attempt to revive declining stocks, Fisheries and Oceans has recommended an annual period of free flow with the opening of one or all five gates from 1 April - 15 December in the Petitcodiac River to accommodate and maximize anadromous fish passage and production in this system (Ritter, 1993). Concern has been expressed that this action could mobilize the sediment deposited below the causeway, causing a negative impact on fishing activities in Shepody and Chignecto Bays.

The purpose of this review of historical data on the Petitcodiac River/Shepody Bay system is to investigate the background levels of Suspended Particulate Material (SPM) in the water column while the fishgates of the Petitcodiac Causeway were being operated in their normal manner, to provide a comparison to the SPM concentrations if the gates are opened. During the gathering of information for the data review, several government departments (provincial & federal), universities, industry and research institutes were approached and asked to contribute data (Amos, Tee and Zaitlin, 1991; Keizer and Gordon, 1985; Keizer *et al.,* 1987; Gordon *et al.,* 1987; Ritter, 1993; Wildish, 1997). A general literature review also was carried out. This review found that although considerable work has been conducted in Chignecto Bay, only very limited data exist for Shepody Bay and the Petitcodiac River. The focus of most investigations has been the Cumberland Basin (Amos and Asprey, 1981; Keizer and Gordon, 1985; Keizer *et al.,* 1987; Gordon *et al.,* 1987) as noted in the bibliography.

Location

The name, Petitcodiac, has several origins. In Mi'kmaq language, "Pet-kout-koy-ek", means "the bend in a bow fitted to an arrow." It's present form is attributed to the early Acadian settlers who referred to the bend or elbow in the river at Moncton, as Le Coude or the elbow and an early English name for the Moncton settlement was The Bend (Ecoversite, 1998).

The Petitcodiac River System covers most of the Southeast of New Brunswick and includes the Petitcodiac and five tributary rivers - the North, Anagance, Pollet, Coverdale, and Little Rivers (Figure 1a and c). The river includes a 34 km estuary. The Petitcodiac River has its source in the low hills North and East of Moncton, draining a catchment of approximately 2300 km^3, including reclaimed marshland used for extensive agriculture

(Wildish, 1997). The Petitcodiac is joined by the Memracook River before entering Shepody Bay. There is one gauging station at the village of Petitcodiac on the river which has been operating since 1961. Recent hydrographs suggest a decline in discharge, presumably due to the upstream abstraction (Wildish, 1997).

The causeway built in 1968 between Moncton and Riverview created a headpond, Lake Petitcodiac, which stays at the high tide level most of the year and has shortened the estuary by two-thirds. Prior to the construction of the causeway, saltwater intrusion from Chignecto Bay occurred in the river to a point above Moncton, near Salisbury. Since the causeway was constructed, the river downstream has been gradually filling with silt. The river width in Moncton is now 20% as wide as it was in 1967. The change in the river's water course over time has dramatically decreased the Petitcodiac River's tidal bore from 120 cm to 5 cm with a resulting decrease in its carrying/flushing capacity. It has been estimated that silt can accumulate at a rate of over 1 cm per day and it has taken less than 30 years for the river to shrink to 90% of its original capacity (Ecoversite, 1998). The Petitcodiac estuary, like other upper Bay of Fundy estuaries, is subject to an unstable equilibrium between the dynamic changes in the height of sea level and balancing the amount of coastal soil erosion (Wildish, 1997).

Physical Oceanography

Chignecto Bay is a high energy environment dominated by semi-diurnal tides with a spring-neap tidal range of 11.3 m to 7.2 m. These large tidal ranges are the result of the Bay's near resonance with the Gulf of Maine/Bay of Fundy system (Garrett, 1972). The associated tidal prism is 5.56 km^3, causing peak currents speeds of between 1 and 2 m s^{-1} (Tee and Amos, 1991). These currents are eroding the previously deposited muddy sediments and creating a transgressive sand unit dominated by large scale bedforms (sand waves, 2-D and 3-D megaripples and sand ribbons) (Amos, *et al.*, 1991). The length of the Bay is parallel to the dominant NE-SW winds and is therefore subject to storm wave influences having a fetch of approximately 140 km. Waves propagated from the Bay of Fundy to Chignecto Basin are significant at the heads of Shepody Bay and Cumberland Basin (Amos, *et al.*, 1991). The Bay is presently exposed to peak significant wave heights of about 2 m.

Residual circulation near the estuary mouth is inward along the eastern margins (0.01 m s^{-1}) and seaward along the western margins . Suspended sediment is transported out of the system as a result of this residual circulation (6.3 x 10 m^3 y^{-1}) (Amos, *et al.*, 1991). Water transport in Shepody Bay is driven by tides and freshwater discharge (G. Bugden, pers.comm.; Gordon, *et al.*, 1987). Tides result in mixing (and in some cases residual flows) and the freshwater discharge induces an estuarine circulation, advection or "flushing" (G. Bugden, pers. comm.) Flushing represents the one-way movement of fresh water, entering the head of Cumberland Basin and Shepody Bay, through the system to the sea. According to the data presented by Holloway (1981), the amount of fresh water entering Shepody Bay (or Boundary 6 on their map) is 1.26 times the amount discharged from Cumberland Basin. Using the data of Keizer and Gordon (1985), the calculated freshwater discharge from the mouth of Shepody Bay into Chignecto Basin can range from 12.6 x 10^6 m^3 d^{-1} in spring (April 1979) to 4.9 x 10^6 m^3 d^{-1} in the fall (October 1979). The mean residence time of waters in Chignecto Basin is 41 days for Cumberland Basin fresh water, 33 days for Shepody Bay fresh water and 32 days for tidal salt water. The composition of Chignecto Bay waters is estimated to be 1% Cumberland Basin fresh water, 18% Shepody Bay fresh water and 81% tidal salt water. Superimposed on this tidal circulation is the fresh water flow, characterized by a mean transit time of 9.6 days and a residual counterclockwise circulation (Keizer and Gordon, 1985).

Modelling studies of the turbid macrotidal Chignecto Basin predict the water column to be well mixed for the greater part of its length, but slightly stratified near its mouth (Garrett *et al.*, 1978). Mixing (mixing:diffusion/dispersion) represents the 2-way exchange of water and is driven by a variety of forces which include tides, winds and river discharge (G. Bugden, per.comm.). The most important is thought to be tidally-driven dispersion (Holloway, 1981). At all seasons of the year, salinity decreases from an average of 31 at the mouth of Chignecto Bay to an average of 25 to 29 at the mouths of Cumberland Basin and Shepody Bay (Keizer and Gordon, 1985).

Studies of the nutrient fluxes in Shepody Bay, Cumberland and Chignecto Basins did not show a significant variation in the concentration of dissolved nutrients with depth except during the brief slack water period (10-15 minutes) when substantial but unpredictable variations sometimes occurred (Keizer and Gordon, 1985). At the mouth of Chignecto Bay and at Cape Enrage, phosphate concentrations were higher on the southeastern side of the channel while no cross channel variation in phosphate concentration were noted at the mouths of Cumberland Basin and Shepody Bay (Keizer and Gordon, 1985). These cross-channel variations reflect the presence of a residual circulation pattern has also been detected in three dimensional current meter arrays (Tee, unpubl.) In August 1978, nitrate and silicate concentrations were the highest at the mouths of Shepody Bay and Cumberland Basin, and decreased in a uniform manner towards the mouth of Chignecto Bay. The nitrate and silicate levels, sampled during five scientific missions from 1977 to 1980, tended to be the strongest in the winter and summer and weakest in the spring and fall (Keizer and Gordon, 1985).

Despite being a high energy turbid environment, there is well supported evidence of patchiness, or laterally discrete water bodies being maintained. Remote sensing data from this area (Amos and Asprey, 1981; Amos and Topliss, 1985) indicate patchy surface anomalies of water reflectivity on the order of a few hundred meters or less in dimension - which correlate well with surface suspended sediment concentrations (Keizer and Gordon, 1985). The remote sensing data is ground-truthed by field evidence of well defined water masses, scaled on the order of tens of metres, which passed the sampling vessel on numerous occasions and contained high SPM concentrations (Keizer and Gordon, 1985). These visually well-defined turbid ribbons, which meander through the sampling sites, tend to suggest that estimates of mass sediment transport are questionable (Amos 1987). The water masses of Cumberland Basin and Shepody Bay are separated by a turbid front that is visible in central Chignecto Bay during low water (Amos 1987). Such fronts are well-defined and can be linear or sinuous. They are usually found during the ebb stage of the tide where water masses from adjoining basins meet (Amos 1987).

Sedimentology

Chignecto Bay is a "muddy" estuary due to the nature of its main sediment sources, primarily the eroding Paleozoic mudstone cliff in the outer part of the Bay (Plint 1987). Waves play a major role in the reworking and resuspension of seabed sediments and in releasing fine sand through cliff erosion. The average cliff recession rates for Shepody Bay, Cumberland Basin, and Chignecto Bay between 1947 and 1975 were 0.19, 0.20, and 0.37 m y^{-1} respectively, with the highest rate of erosion occurring in wave dominated areas such as the western side of Chignecto Bay and at the mouths of Shepody Bay and Cumberland Basin (Amos *et al.*, 1991). Sediment input from this source is approximately 1.0 x 10^6 m^3 y^{-1} (Hildebrand, *et al.*, 1980; Amos, *et al.*, 1991). Current scouring and erosion of the seabed, which is primarily composed of laminated silts and clays, supplies approximately 6 x 10^6 m^3 y^{-1} (Amos and Zaitlin, 1985). Both sediment supply mechanisms are most active in the spring and autumn seasons when the wave action is the greatest (Amos *et al.*, 1991). Fluvial input of sediment, approximately 0.3 x 10^6 m^3 y^{-1}, is low in comparison to the other two sources. Fluvial supply increases during spring break up or freshets (Amos 1987). A total of 7.3 x 10^6 m^3 y^{-1} of sediment is mobilized each year and 99% of this volume is transported in suspension (Amos, *et al.*, 1991).

Sediment transport pathways in Chignecto Bay are said to be complex, with net transport of bed load and suspended material headward along the Bay margins, but seaward through the centre (Amos and Asprey, 1981). The turbidity levels decrease exponentially down the axis of the estuary from the inner to the outer Chignecto Bay (Amos and Asprey, 1981). The general movement of fine sediments is seaward in the Bay of Fundy and Chignecto Bay is a net exporter of sediment (Amos 1987). A volume of 5.5 x 10^6 m^3 y^{-1} is transported in suspension to the Bay of Fundy during fair weather conditions, and a further volume of 1.8 x 10^6 m^3 y^{-1} is discharged during storms (Amos 1987). There are no major sinks for fine-grained sediment in Chignecto Bay. Intertidal mudflats are ephemeral and most salt marshes have been reclaimed and the remaining surfaces are lagged by coarse material or poorly developed sandflats (Amos 1987). Material is kept in suspension until it can escape to the quiescent deeper parts of the Bay of Fundy, where fine-grained sediments are presently accumulating as LaHave Clay (Fader *et al.*, 1977).

Sand occurs subtidally at Bay margins and moves headward as sand waves, megaripples and sand ribbons (Amos 1987). Gravel is found dispersed throughout the upper part of Chignecto Bay and is transported by ice-rafting during the winter months (Gordon and Desplanque, 1983). Gravel and muddy sandy gravel dominate the outer and axial parts of Chignecto Bay. Gradually, muddy sands prevail along the eastern margin of Chignecto Bay and the axial parts of Shepody and Cumberland Basin. Gravelly muds and sandy muds are found along the western margin of Chignecto Bay , throughout Shepody and in isolated patches elsewhere. Muds predominate on the littoral margins of Shepody Bay and Cumberland Basin and are least abundant sublittorally (Amos *et al.*, 1991). Clean sand occurs only in the region of the mouth of the Petitcodiac River in Shepody Bay, along the eastern margin of Chignecto Bay and off Cape Chignecto (Amos *et al.*, 1991). In general, the bottom sediments are poorly sorted, multimodal and commonly contain a gravel sized component (Amos *et al.*, 1991). An analysis of the heavy mineral content of the bottom sediments indicates that the source is derived locally from the surrounding lithologies (Amos *et al.*, 1991).

Data Coverage & Availability

There is a very limited amount of data available that can be used as a baseline for evaluating changes in the sedimentary environment in Shepody Bay and the Petitcodiac River. Cruises conducted by DFO and NRCan in the late 1970's are the main source. Much of the data collected was in response to a plan to develop tidal power in the upper Bay of Fundy, therefore, studies were concentrated in Cumberland Basin rather than Shepody Bay. However, some stations were located at the mouth of Shepody Bay and in Chignecto Bay, principally during one scientific mission in 1977 where 19 spot stations and one 14-hour anchor station were occupied in Chignecto Bay (figure 1b). There were 2 scientific missions in 1978 and 1979, and one in 1980. A total of six anchor stations, located approximately in a line across the mouth of Shepody Bay where it meets Chignecto, were occupied during these missions. There are no water samples from Shepody Bay and the lower section of Petitcodiac River.

For the 1977 scientific mission, samples were collected hourly through the water column for total suspended material (SPM) concentration, raw particle size analysis and disaggregated inorganic grain size analysis (DIGS)(Appendix 1). Total SPM values for the surface water only were collected during the other missions (Amos & Asprey, 1981; Gordon *et al.*, 1987).

In addition to the direct sampling, there were also a few thematic maps produced from aerial surveys in 1974, 1975 and 1978 in the area that provide an estimate of the surface Suspended Sediment Concentration (SSC) in the upper 0.5 to 1.0 m of the water column (C. Amos, pers. comm. ; Amos & Asprey, 1981; Amos and Topliss, 1985; Topliss, *et al.*, 1990). The surface suspended sediment concentrations in Chignecto Bay were evaluated using transformed Landsat Multispectral Scanner data (Amos and Alfoldi, 1979). The satellite data were calibrated from samples collected throughout Chignecto Bay (Munday *et al.*, 1979; Tee and Amos, 1991).

A set of 24 total SPM samples were recently collected by A. St.-Hilaire (1997) from 3 sites in the Petitcodiac River. One station was located above the Moncton Causeway and 2 sites were located below.

RESULTS

Appendix 1 describes the methods of analysis for samples collected during the scientific missions described above. Appendix 2 contains plots of the size distributions for the samples collected during the 1977 mission. Summary plots of total SPM values found in some of the reports listed above are found in Appendix 3.

1977

Data collected from Chignecto Bay in 1977 are listed in the appendices. Total SPM, raw water sample particle size and DIGS (disagreggated inorganic grain-size spectra or filtered water samples) were determined using the methods of Kranck and Milligan (1979) for the spot stations. At the anchor station, 115, samples were analyzed from raw water particle size and DIGS, but not for total SPM. Total SPM values ranged from 10 - 40 mg l^{-1}.

1978 - 1980

Results from the 1978-80 sampling are found in Amos and Asprey, (1981), Keiser *et al.*, (1984), Amos (1987) and Amos *et al.,* (1991). Stations were located in approximately the same location in all years with the exception of Station 4 which was west of the other three stations (Figure 1b). Stations 4 and 5 were sampled in May 1978, Station 9 was sampled in August, and Station 16 was sampled in April 1979. Total SPM values ranged from 10 - 120 mg l^{-1}. Concentrations varied with time of year, the spring-neap cycle and with tidal stage (Appendix 3).

SATELLITE DATA

Two thematic maps with data recorded in Shepody Bay were compiled from LANDSAT1 images for 14 July, 1974 taken 3:20h after the high tide period and 03 May, 1975 0:30h after High Water (Amos and Alfoldi,1979). Three representative "stations" were chosen from each map to demonstrate the proximal to distal trends in the surface SSC characteristics of the river emptying into the Bay. At the midpoint of the mouth of Shepody Bay the surface SSC was calculated to range from 6 to 10 mg l^{-1}. In the centre of Shepody Bay, a value of 10 to 34 mg l^{-1} was calculated. At the centre of the mouth of the Petitcodiac River where it empties into Shepody Bay, the surface SSC values range from 34 to 62+ mg l^{-1}. The second thematic map compiled for 03 May, 1975 gave values at the midpoint of the mouth of Shepody Bay the surface SSC ranging from 0 to 3 mg l^{-1}. In the centre of Shepody Bay, a value of 3 to 6 mg l^{-1} was calculated. At the centre of the mouth of the Petitcodiac River where it empties into Shepody Bay , the surface SSC values range from 12 to 23 mg l^{-1}. It states in the report that on the second sampling, there was greater wave activity than the 1974 map image.

A thematic map compiled from LANDSAT data for June 5, 1978 taken near the high tide period was also available (Amos and Asprey 1981). At the midpoint of the mouth of Shepody Bay the surface SSC was calculated to range from 1.45 to 4.44 mg l^{-1}. In the centre of Shepody Bay, a value of 41.3 to 126 mg l^{-1} was calculated. At the centre of the mouth of the Petitcodiac River where it empties into Shepody Bay , the surface SSC values range from 1187 - 3604 mg l^{-1}. The later measurement of surface SSC continues up the thalweg (or central channel) of the river.

SWATH BATHYMETRY

In 1997, the Canadian Hydrographic Survey carried out SWATH mapping of the bottom topography in the outer reaches of Chignecto Bay. Results are available through Canadian Hydrographic Service and the Geological Survey of Canada - Atlantic (Parrot *et al.*, 1997).

DISCUSSION

Total SPM concentrations in the Petitcodiac River/Shepody Bay system generally increased with water depth, often by as much as an order of magnitude. SPM levels in surface waters decreased with increasing distance downstream from the river mouth. Concentrations at equivalent water depths downstream displayed a similar but less dramatic trend.

Amos (*et al.*, 1991) found a large seasonal variation in Surface Sediment Concentration (SSC) in all 3 bays (Amos *et al.*, 1991). Concentrations were the highest during ice break up which usually occurs in February or March, and least during January and December. SSC decreased steadily throughout the summer as a result of deposition on the littorial mudflats (Hildebrand *et al.*, 1980) but increased again as a result of wave resuspension during the autumn (October and November).

Sediment concentrations on station were greatest near the bed during low water and least near the surface during high water (Amos, 1987). Particle settling was significant at current speeds less than 0.5 m s^{-1}, at these times the sediment concentration decreased exponentially with height above bed. Above speeds of 0.8 m s^{-1}, particulate matter moved upward through the water column and, between 0.5 to 0.8 m s^{-1} the concentration with depth remained steady (Amos 1987).

Suspended particulate matter in the upper Chignecto Bay was found to be composed largely of fine silt-sized angular lithic fragments (70-90%), with lesser amounts of clay (10-20%) and sand (Amos 1987; Amos *et al.*, 1991). The nature of the particles were predominantly siliceous and the Particulate Organic Carbon content was low (Keizer *et al.*, 1984). Unlike other estuaries, the clay component of the SPM is constant along the length of Shepody Bay suggesting that the estuary is very well mixed. Examination of material suspended in Shepody Bay with an electron microscope indicated that less than 5 % of the SPM was found in flocs or aggregates, and between 85 and 95% of the suspended materials were inorganic. Coulter Counter analysis of the partially disaggregated samples showed the modal size of the suspended sediment to range from 10 to 30 microns over all stages of the tide (Amos *et al.*, 1991).

SUMMARY

The highly energetic nature of the upper Bay of Fundy is reflected in the range of SPM values found in the documents examined. The wide variation in suspended sediment concentration over both time and spatial scales makes its characterization almost impossible. Total SPM values can vary by an order of magnitude with depth in the water column, over distances of a few kilometers and within hours at the same location. It is thought that the natural variation in SPM values within this large and physically dynamic system will likely mask any small impact resulting from modification of the flow in the upper Petitcodiac River (C. Amos; T. Milligan, pers.comm.).

Acknowledgements: I would like to express my appreciation of G.Bugden, K. Muschenheim, C. Amos and T. Milligan for their time, and conversations in reviewing this technical report. In addition, C. Amos provided access to his unpublished data files in this geographic area, and helpful discussions. Also the raw SPM data provided from the Hudson scientific mission is the work of the late Kate Kranck, which has been inherited by the Particle Dynamics Lab and is published posthumously.

BIBLIOGRAPHY

Amos, C.L., Gordon, D.C., Daborn, G.R. and F.D. Ewing. 1979. Cruise report no. 79-004, C.S.S. Hudson (28 March - 6 April, 1979). Atlantic Geoscience Centre, Natural Resources Canada. 12pp.

Amos, C.L. and Alfoldi, T.T. 1979. The determination of suspended sediment concentration in a macrotidal system using Landsat data. *Journal of Sedimentary Petrology* **49(1):**

Amos, C.L. and Asprey, K.W. 1981. An interpretation of Oceanographic and Sediment Data from the Upper Bay of Fundy. *Bedford Institute of Oceangraphy Report Series:* **BI-R-15**. September 1981. 143pp.

Amos, C.L., and B.L. Topliss. 1985. Discrimination of suspended particulate matter in the Bay of Fundy using the NIMBUS-7 coastal zone scanner. *Canadian Journal of Remote Sensing*. **11**: 85-92.

Amos, C.L. and B.A. Zaitlin. 1985. The effect of changes in tidal ranges on a sublittoral macrotidal sequence, Bay of Fundy, Canada. *Geo-Marine Letters.* **4:** 161-169.

Amos, C.L. 1987. Fine-grained sediment transport in Chignecto Bay, Bay of Fundy, Canada. *Continental Shelf Research*. **7(11/12):** 1295-1300.

Amos, C.L., and Tee, K.T., 1991. Suspended sediment transport processes in Cumberland Basin, Bay of Fundy. *Journal of Geophysical Research*. **94(C10):** 14,407 - 14,417.

Amos, C.L., Tee, K.T., and B.A. Zaitlin. 1991. The post-glacial evolution of Chignecto Bay, Bay of Fundy, and its modern environment of deposition. In, *Clastic Tidal Sedimentology*. D.G. Smith, G.E. Reinson, B.A. Zaitlin and R.A. Rahmani (eds.). Canadian Society of Petroleum Geologists Memoir **16:** 59-90.

Arnold, D.C. 1979. (editor). Bay of Fundy Environmental Research Workshop, November 1978. Chignecto Research Group of Mount Allison University Internal Note # 12, 40pp.

Beaulieau, G.T. 1970. Report on the Petitcodiac River Causeway. Resource Development Branch, manuscript report No. 70-11. Fisheries Service, Dept. of Fisheries and Forestry Canada, Halifax, NS. 12pp.

Cardy, W.F.G. 1984. Moncton Region Planning Region, Water Resources Review. Report I-8402. Water Resources Branch, New Brunswick Department of the Environment. pp. 40-64.

Daborn, G.R. 1977. (editor). Fundy Tidal Power and the Environment. The Acadia University Institute, Wolfville, Nova Scotia. Note # 28. 304pp.

Ecoversite. 1998. Petitcodiac River Reference Guide (10pp), and other information. (http://www.moncton.ca/ecoversite/mission.html).

Fader, G.B. , L.H. King and B. MacLean. 1977. Surficial geology of the eastern Gulf of Maine and Bay of Fundy. *Marine Science Papers 19. Geological Survey of Canada Paper* **76-17:** 23p + chart.

Fader, G.B. 1996. Swath bathymetry map of the Cape Enrage area, New Brunswick. Geological Survey of Canada - Atlantic, Bedford Institute of Oceanography.

Garrett, C.J.R. 1972. Tidal resonance in the Bay of Fundy and Gulf of Maine. *Nature.* **283:** 441-443.

Garrett, C.J.R., J.R Kelly, and D.A. Greenberg. 1978. Tidal mixing versus thermal stratification in the Bay of Fundy and the Gulf of Maine. *Atmosphere Ocean* **16:** 403-423.

Gordon, Jr., D.C., and C. Desplanque. 1983. Dynamics and environmental effects of ice in the Cumberland Basin of the Bay of Fundy. *Canadian Journal of Fisheries and Aquatic Sciences.* **40(9):** 1331-1342.

Gordon, Jr., D.C., P.D. Keizer, P. Schwinghamer, and G.R. Daborn. 1987. Ecological Evaluation of the Cumberland Basin ecosystem model. *Continental Shelf Research.* **7(11/12):** 1477-1482.

Greenberg, D.A. 1979. A numerical model investigation of tidal phenomenon in the Bay of Fundy. *Estuarine Coastal Shelf Science.* **20:** 2205-227.

Greenberg, D.A. 1983. Modelling the mean baratropic circulation in the Bay of Fundy and Gulf of Maine. *Marine Geodesy* **2:** 161-187.

Hildebrand, L.P., MacDormand, E.B., Nelson, D.R., Powell, C.G., Rodgers, N.A., and J.A. Walker. 1980. Activities of the Job Corps Program; Fundy Tidal Power Development. National Research Council of Canada, Halifax. ***NSERC Project 16-01-002N.*** 176pp.

Holloway, P.E. 1981. Longitudinal mixing in the upper reaches of the Bay of Fundy. *Estuarine Coastal Shelf Science.* **13:** 495-515.

Keizer, P.D. and D.C. Gordon, Jr. 1985. Nutrient Dynamics in Cumberland Basin - Chignecto Bay, A Turbid Macrotidal Estuary in the Bay of Fundy, Canada. *Netherlands Journal of Sea Research* **19(3/4):** 193-205.

Keizer, P.D., D.C. Gordon, Jr., P. Schwinghamer, G.R. Daborn, and W. Ebenhoech. 1987. Cumberland Basin Ecosystem Model: Structure, Performance and Evaluation. *Canadian Technical Report of Fisheries and Aquatic Sciences.* No. **1547:** xviii + 202pp.

Kranck, K. and Milligan, T.G. 1979. The use of the Coulter Counter in studies of particle-size distributions in aquatic environments. *Bedford Institute Rep. Ser.* **B1-R-79-7.**

Kranck, K. 1986. Settling behavior of cohesive sediment. In, J. Mehta [ed.]. Estuarine Cohesive Sediment Dynamics. Springer-Verlag. p.151-169.

Munday, J.C., Jr., Alfoldi, T.T. and C.L. Amos. 1979. Bay of Fundy verification of a system for multidate Landsat measurement of suspended sediment. In, *Satellite Hydrology* , M. Deutsch, D.R. Wiesnet and A. Rango (eds.). Minneapolis: American Water Resources Association., pp.

Parrot, R., Fader, G., Shaw, J., and J. Hughes-Clarke. 1997. Multibeam Bathymetric Data for Regional Assessment of Marine Geology. *In*, Oceans '97 MTS/IEE Conference, Halifax Nova Scotia, October 6 - 9. 6pp.

Plant, S. 1985. (compiler). Bay of Fundy Environmental and Tidal Power Bibliography (second edition). Can. Tech. Rep. Fish. Aq. Sci. no. 1339: vi, 430pp.

Plint, A.G. 1986. Slump blocks, intraformational conglomerates and associated erosional structures in Pennsylvanian fluvial strata of eastern Canada. *Sedimentology.* **33:** 387-399.

Ritter, J. 1993. Review of briefing package to RDG on the Petitcodiac River causeway. Fisheries and Oceans Canada, Freshwater and Anadromous Fish Division. 20pp.

Scott, D.B., and D.A. Greenberg. 1983. Relative sea-level rise and tidal development in the Fundy tidal system. *Canadian Journal of Earth Sciences.* **20(10):** 1554-1564.

Tee, K.T. and C.L. Amos. 1991. Tidal and buoyancy-driven currents in Chignecto Bay, Bay of Fundy. *Journal of Geophysical Research.* **96(c8):** 15 197 - 15 216.

Topliss, B.J., C.L. Amos, and P.R. Hill. 1990. Algorithms for remote sensing of high concentration, inorganic suspended sediments. *Int. J. Remote Sensing.* **11(6):** 947-966.

Wildish, D. J. 1997. Petitcodiac Estuary and the Moncton/Riverview Causeway. Fisheries and Oceans Canada, St. Andrew's Biological Station. 10pp.

Appendix 1: Methods.

Three methods of collecting SPM values were employed. They are the disaggregated particle size distributions of water column material (total), retained material from filtered water samples (inorganics), and bottom sediment analyses. The differences between the three types of sampling demonstrate the differences in how the Suspended Particulate Matter (SPM) concentration is recorded at the same station. There are plots of SPM levels with increasing water depth from the surface towards the bottom, and SPM plots of concentrations over time for the three water sample depths, which reflect the influence of the tidal cycle.

The differences in the sample types in disaggregated and thus SPM calculations are as follows:

1.) Total = raw unfiltered, unsonified water samples that are run through a model TAII Coulter Counter.

2.) Inorganic = SPM are calculated from mass retained on a 0.8 mm filter which is ashed at a low temperature to remove the filter and digested with 35% hydrogen peroxide to remove the organics. It is the remaining inorganic material that is resuspended and sonified and then measured on the TAII Coulter Counter.

3.) Bottom sediments = a representative subsample of a grab or core sample is digested to remove the organics and subsequently resuspended and sonified and sized with the Coulter Counter model TAII.

The relevance of the shapes of disaggregated particle size distributions (inorganic, total and bottom sediments) are interpreted in Kranck (1979) and Kranck and Milligan (1986). In general, the distribution of floc or aggregation deposited material may be described a linear or flat distribution on a log/log plot of particle diameter (microns) versus concentration (PPM) for water and filtered samples or % equivalent weight for bottom sediments (Kranck, *et al.*, 1996). This flat-lying or flocced distribution shows that each particle size class is equally represented in the deposition of the aggregated material. The slope of this line, **m**, is also known as the source slope, and when it deviates from a value close to 0, resuspension and sorting events are suspected. If the value of the source slope remains the same, then it can also be said that the source of material being deposited from suspension has not changed greatly from its original source. A quadratic expression in the distribution is thought to reflect a sediment sorting event, thus leading to an increase "peakedness" with increasing rounds of resuspension and sorting, and subsequent deposition of particle size classes of larger diameter are required in order to be able to deposit (Kranck, *et al.*, 1996).

Appendix 2: Grain size plots for the data collected in 1977.

Grain Size distributions - Inorganic SPM

The auto-increment in line boldness indicates sample depths (Figure 2), beginning with the solid line at 0 m water depth (or surface), and line boldness decreasing with increasing depth. The surface water samples (bold solid lines) have a stronger flocced signature, while the samples at depth have an increasing source slope or content of 1-round or single-grain sorted material.

Stations at the outer mouth of Shepody Bay (50 & 62) are well flocced with relatively flat-lying distributions or constant source slopes (Figure 2), while progressing up stream to stations 51, 52, 53 & 61, 62 in the lower mid section of the Bay - the distributions are still substantially influenced by flocculation, but are gradually showing a slight influence of 1-round or single-grain sorting peakedness in the coarser grain fraction. Stations in the middle section of Shepody Bay, 54, 55, 56 & 59, are all very well flocced with little sorting influence (Figure 2). Stations 57 & 58, located in the middle area of the Bay but are closer to shore, show a distinct peakedness or increasing source slope in the coarser size spectrum indicating a sorting influence, as well as a flat-lying flocced distribution in the finer particle size spectrum (Figure 2).

Station 115, the anchor station in 1977 is located between stations 54 and 53 and nearby 56, and its distributions even over time, have similar grain size distribution shapes to the neighboring stations (Figure 2). Thus indicating that the tidal cycle in this location does not seem to significantly alter the particle size distributions.

Grain Size distributions - Total SPM

In general, all total SPM grain size spectra show a stronger influence of one round sorting and not quite as floc dominated as the inorganic SPM grain size distributions (Figure 3). The distributions do not appear markedly different from each other based upon their locations.

Again, overall concentrations are greater with increasing depth (solid lines = 0 m water depth or surface waters, while the dashed lines indicate increasing water depth). The maximum grain size in suspension is about 100 microns.

Grain Size distributions - Bottom Sediments

The grain size distributions of the bottom sediments (Figure 4), generally do not show much of a comparable pattern to the SPM distributions (Figures 2 and 3). Maximal grain sizes of 1000 microns are present in the bottom sediment samples, and are the distributions are somewhat one-round single-grain sorted.

APPENDIX 3: Summary plots of SPM data.

SPM concentrations in the surface waters with time

All stations are in approximately the same location (Figure 1), except Station 4 which is slightly off to the east of the other three stations. Stations 4 and 5 were sampled in May, Station 9 was sampled in August and Station 16 was sampled in April. There are two groups of apparent trends of SPM concentrations over time (Figure 9).

Stations 5 and 9, were sampled on neap tides and do not have a strong variation in SPM concentration between the flood and ebb stages (Figure 9). The flood stage does have elevated levels of SPM (concentrations of 80 - 100 mg l^{-1}), while the ebb stage has a slightly lower concentration range of 60 - 80 mg l^{-1}. Station 5 SPM concentrations that were sampled in March are also significantly greater than the neap tide sample at station 9 that was sampled in August.

During spring tides, stations 4 and 16, show an increase in SPM concentration from 20 to 120 mg l^{-1} from the ebb to the flood stage (Figure 9). SPM concentrations at Station 4, which were sampled in March are also significantly greater than the other spring tide sample at Station 16, which was sampled in April.

The surface water SPM concentrations for Anchor station 115 are significantly less than the mid depth levels, which are again less than the bottom water concentrations (Figure 10). The surface and mid water SPM concentrations mirror the rise and fall of the flood and ebb tides, whereas the bottom water SPM levels are generally high and relatively constant over the tidal cycle. The total SPM concentration values for each of the three water depths are approximately twice that for the respective inorganic sample depths.

Inorganic SPM

The inorganic SPM concentrations all increase with increasing water depth (Figure 5). Anchor Station 115 (Figure 6) results are not as conclusive. Some of the SPM concentrations at the surface are approximately the same as those at depth, with peak levels occurring at the mid depths.

Total SPM

Total SPM concentrations with depths (Figure 7) are not as conclusive as the inorganic SPM profiles with depth (Figure 6). The general trend is for increasing values with depth, but there are a few profiles (independent of actual station locations relative to the river source) that peak at mid-depths. Also in these profiles the SPM values for the surface and bottom depths are approximately equal, or have a greater difference between the surface and mid depths but the mid-depths and bottom concentrations are approximately equal.

In general, the SPM concentrations increase with increasing water depths at Anchor Station 115 (Figure 8) with the exceptions of four casts (115.04, 115.06, 115.11, 115.12) wherein the levels decrease with depth. Again, usually the greatest increase in concentrations occurs between the surface and mid depth.

Table 1: Station locations

Year	Cruise	Station	Latitude (N)	Longitude (W)
1977	Dawson 77-023	50	45°24.5	65°18
1977	Dawson 77-023	51	45°28.4	65°11
1977	Dawson 77-023	52	45°28	65°10.3
1977	Dawson 77-023	53	45°32	64°52
1977	Dawson 77-023	54	45°37	64°40.5
1977	Dawson 77-023	55	45°31.7	64°40.5
1977	Dawson 77-023	56	45°33.3	64°45.3
1977	Dawson 77-023	57	45°35.8	64°46.5
1977	Dawson 77-023	58	45°32.8	64°58.4
1977	Dawson 77-023	59	45°29	64°57.3
1977	Dawson 77-023	60	45°25.5	64°56.6
1977	Dawson 77-023	61	45°21.7	65°05
1977	Dawson 77-023	62	45°17	65°13
1977	Dawson 77-023	115	45°34	64°46.95
1978	MFV Oran II	4	45°43.2	64°27.5
1978	MFV Oran II	5	45°43.4	64°35.3
1978	Dawson 78-025	9	45°43.8	64°34.7
1979	Dawson 79-004	18	45°43.6	64°35.2
1979	Dawson 79-034	25	45°43.7	64°35.1
1980	Dawson 80-003	28	45°43.5	64°35.2

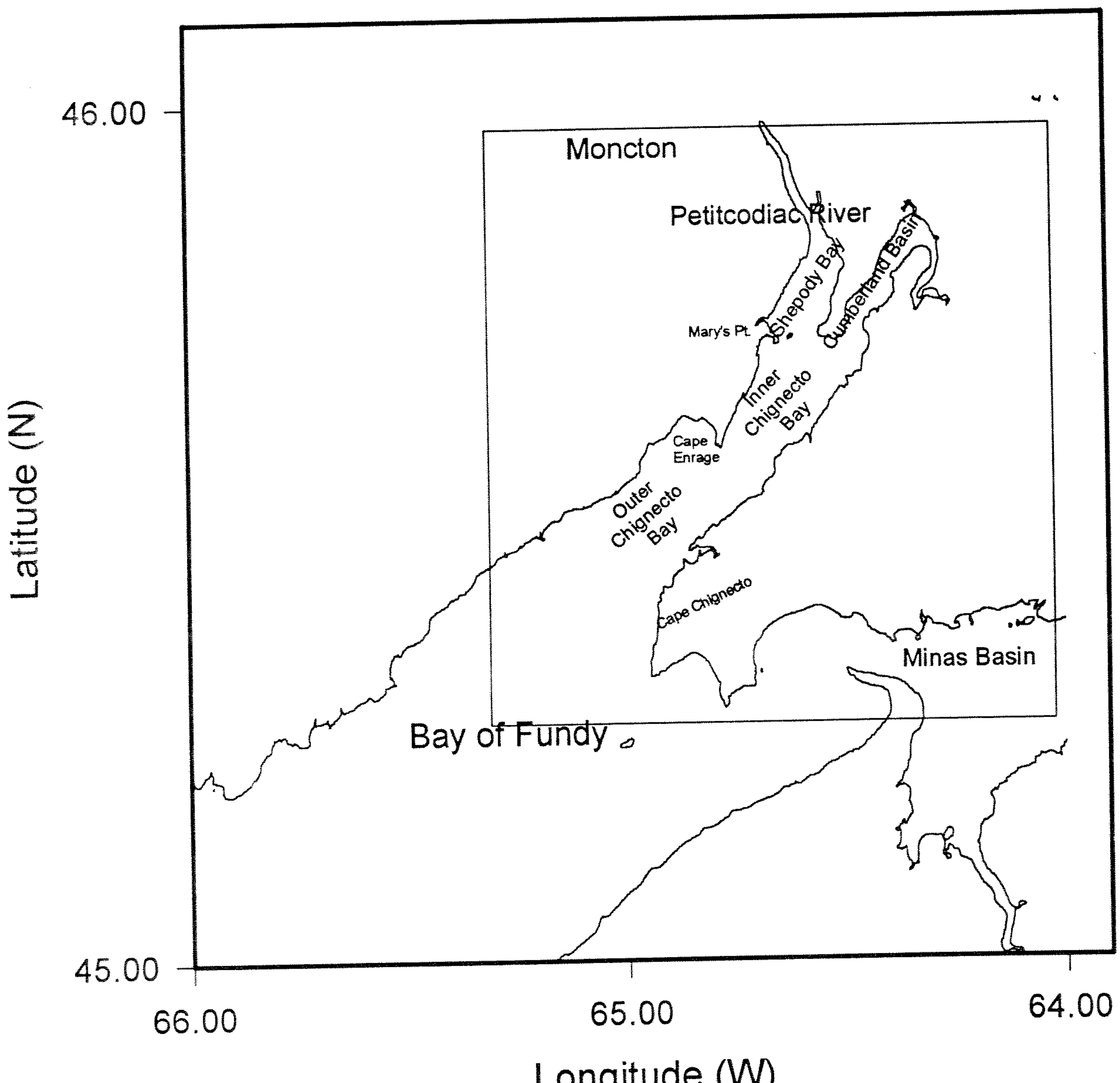

Figure 1a. Area map, the smaller inner square indicates the area of coverage for Figure 1b., and the sample locations.

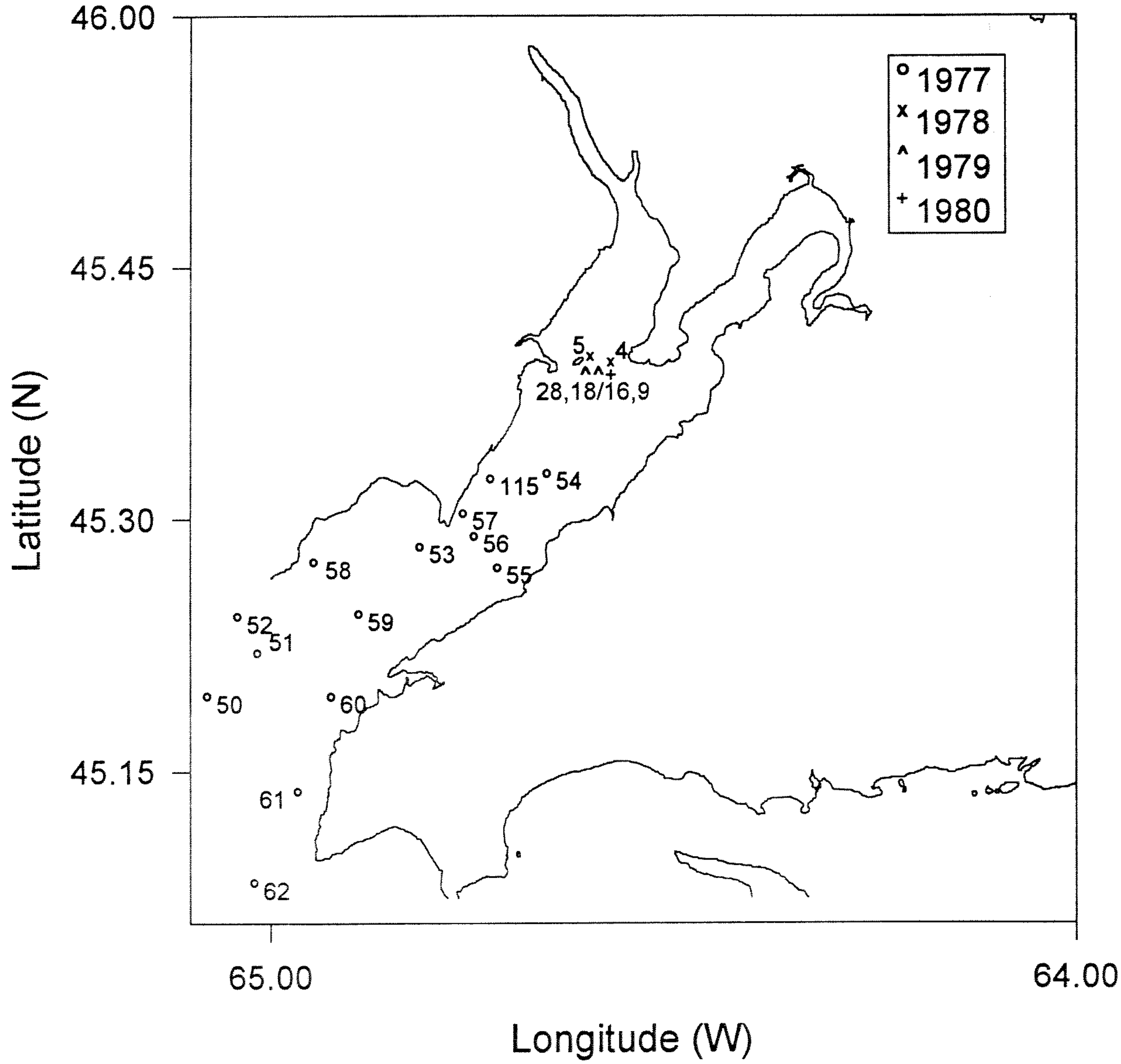

Figure 1b. Location of data samples, with symbols to indicate sampling years. The corresponding cruise numbers are given in Appendix 1.

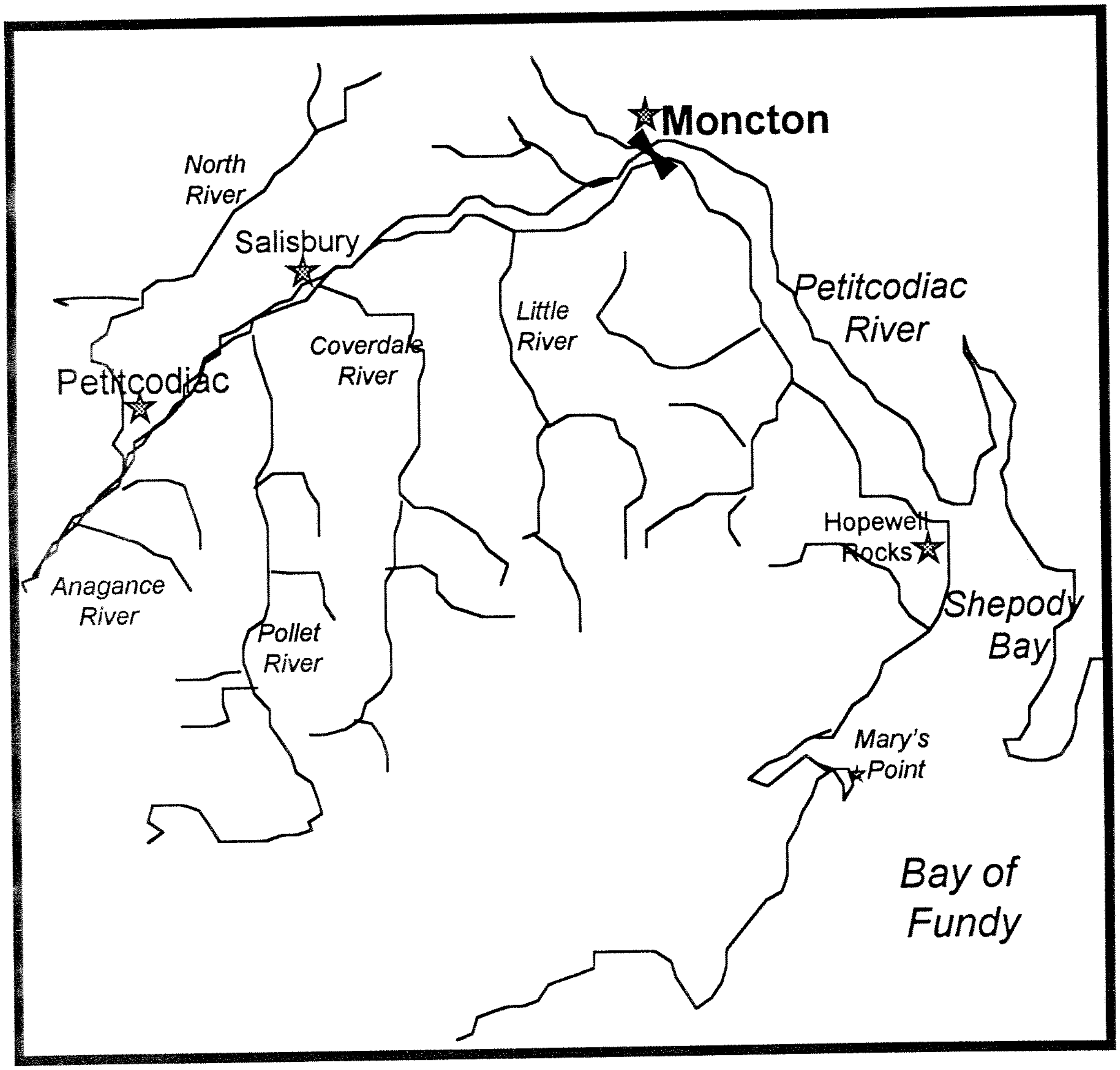

Figure 1c. A map of the area showing the main Petitcodiac River tributaries and the location of the Moncton causeway (adapted from the Ecoversite site map (1998)).

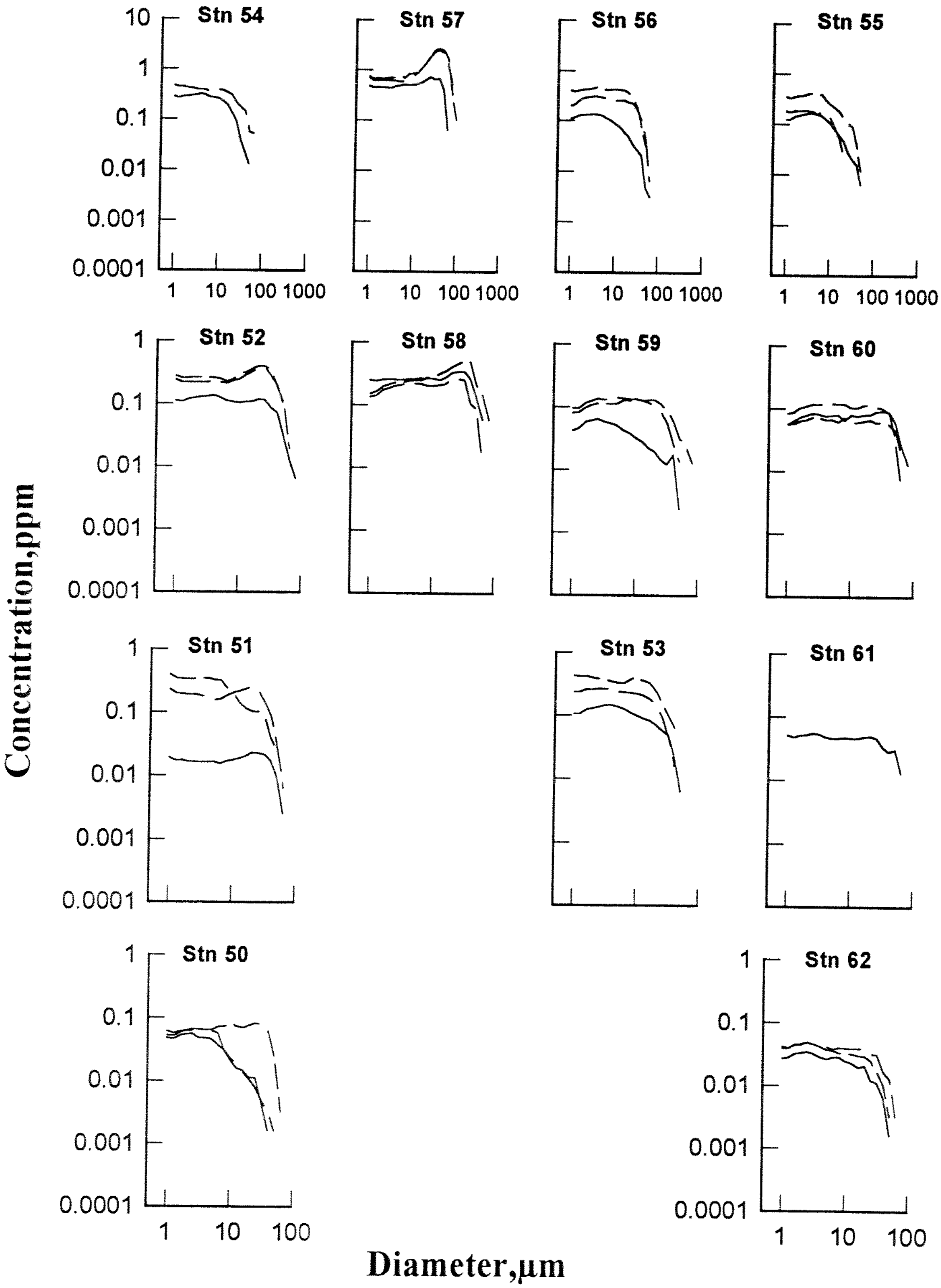

Figure 2a. Disaggregated grain size distributions for Inorganic SPM, Shepody Bay, 1977.

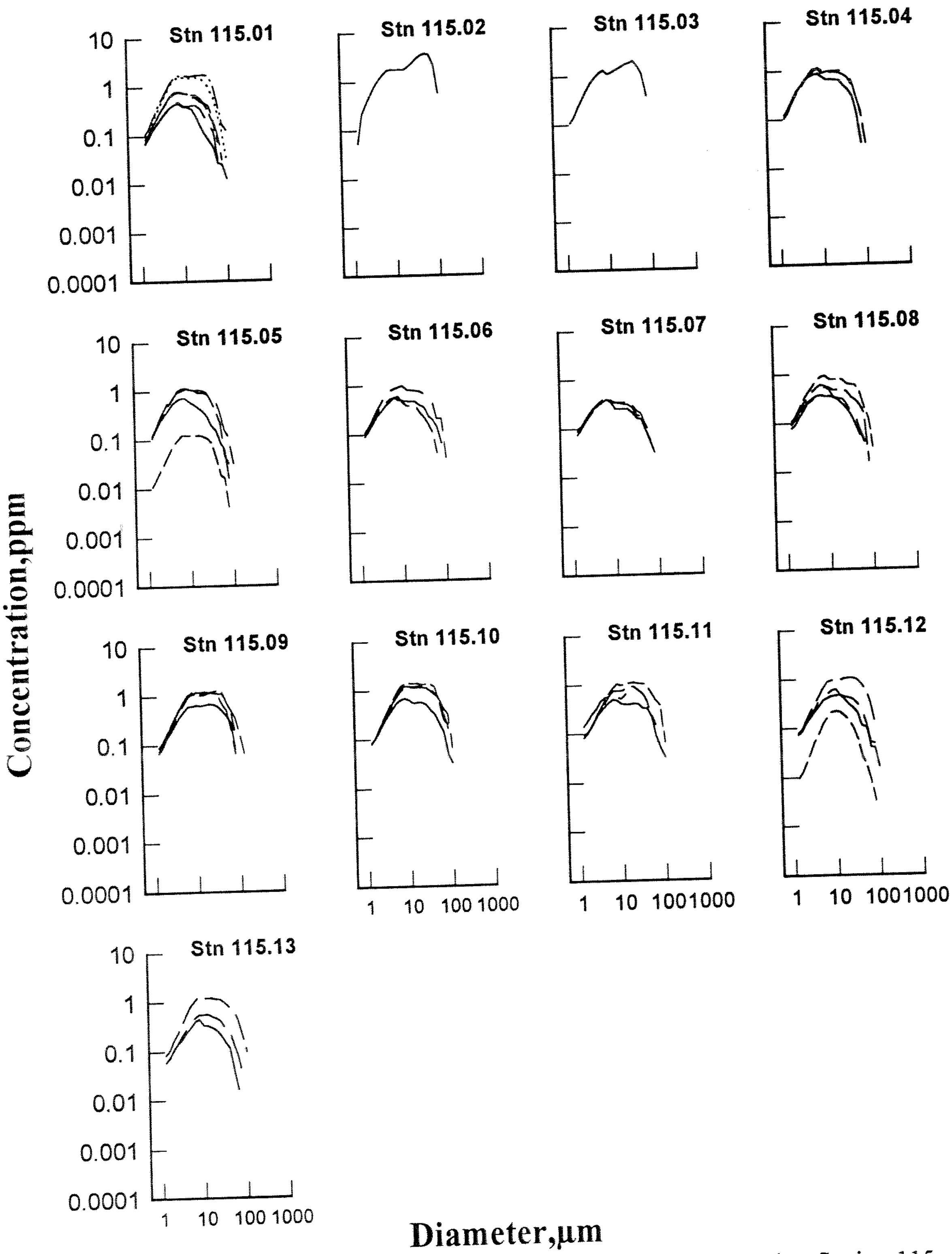

Figure 2b. Disaggregated grain size distributions for Inorganic SPM, at Anchor Station 115, Shepody Bay, 1977.

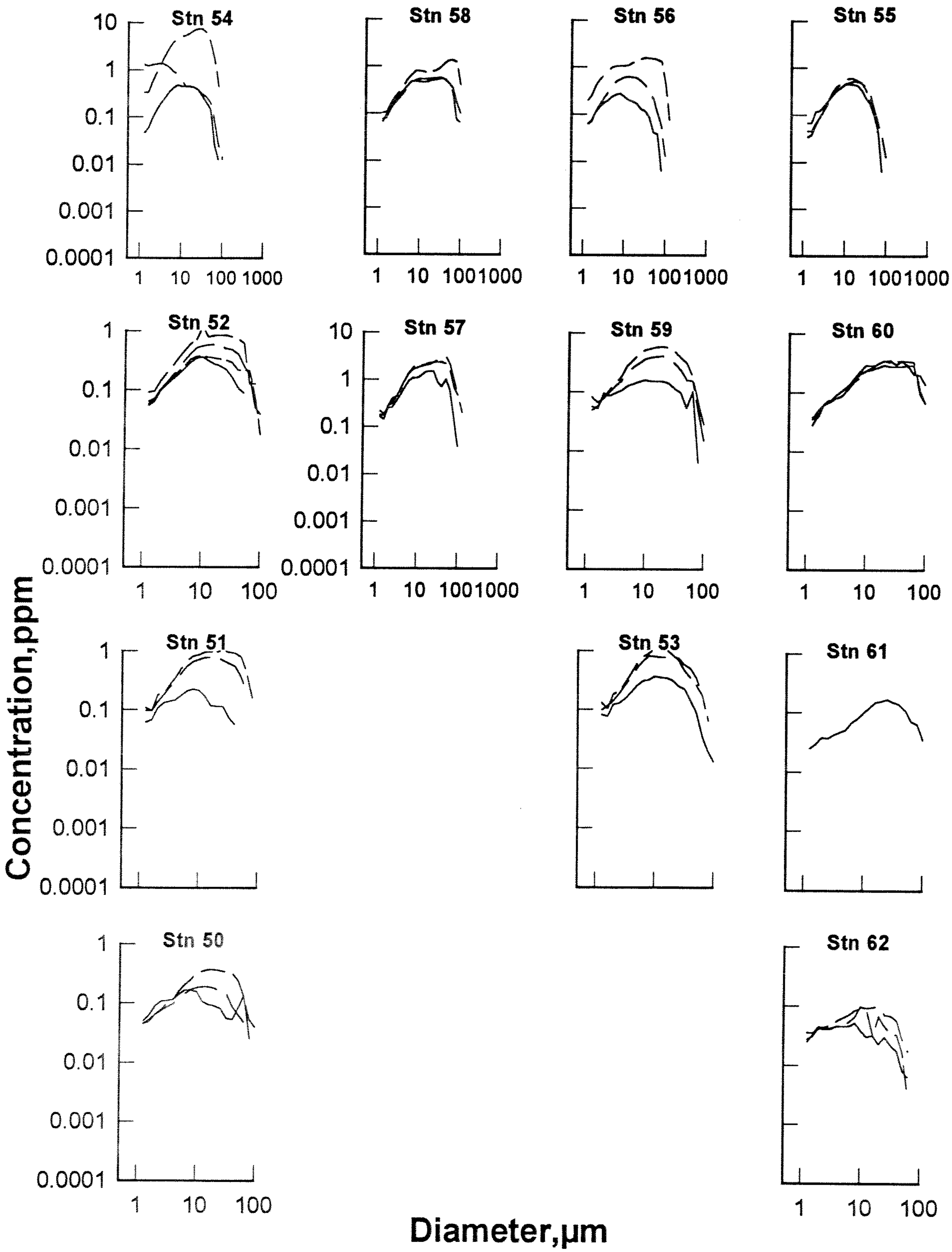

Figure 3a. Disaggregated grain size distributions for Total SPM, Shepody Bay, 1977.

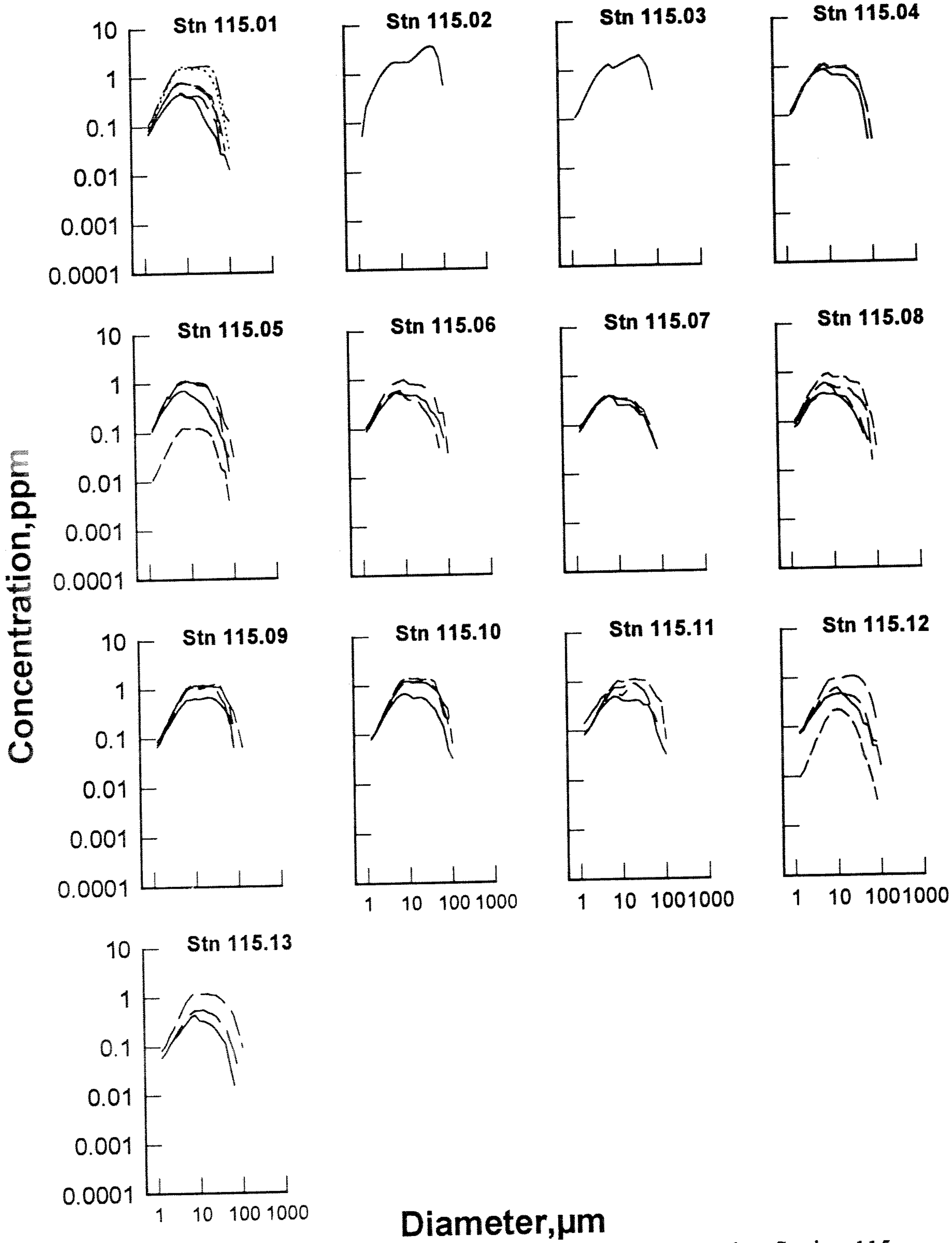

Figure 3b. Disaggregated grain size distributions for Total SPM, at Anchor Station 115, Shepody Bay, 1977.

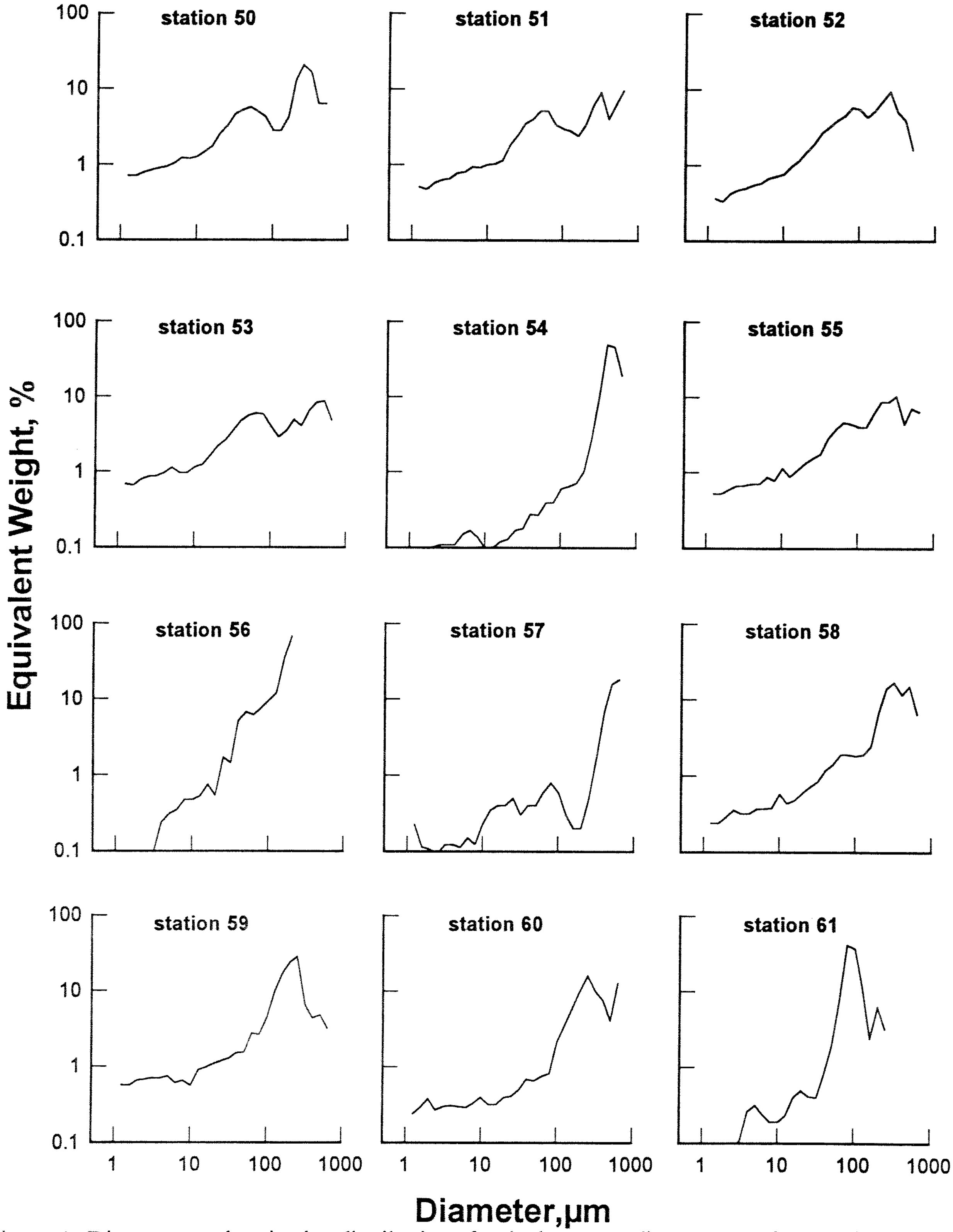

Figure 4. Disaggregated grain size distributions for the bottom sediments at various stations in Shepody Bay, 1977.

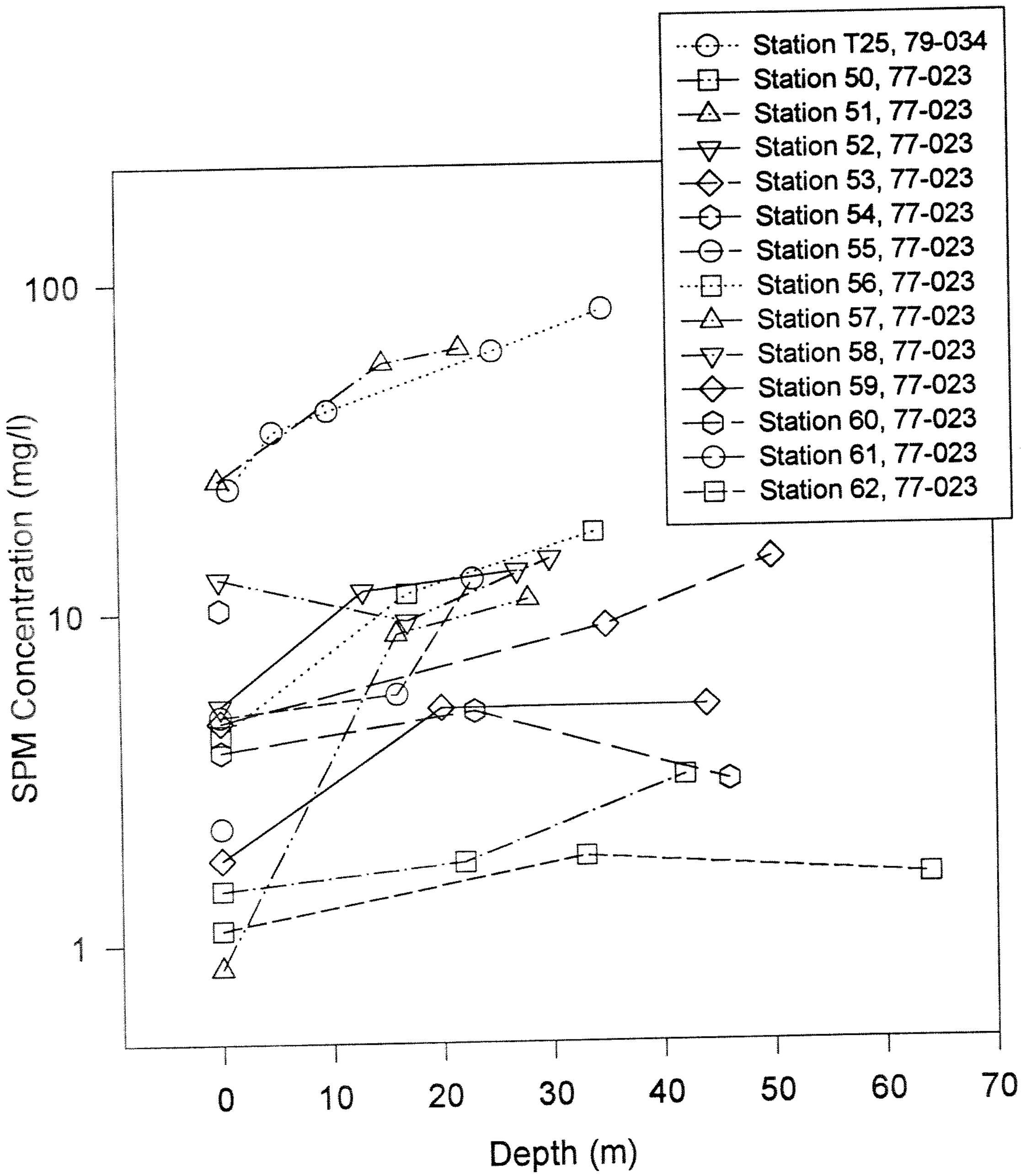

Figure 5. Inorganic SPM values for various stations calculated from filter values, processed by a Coulter Counter TAII.

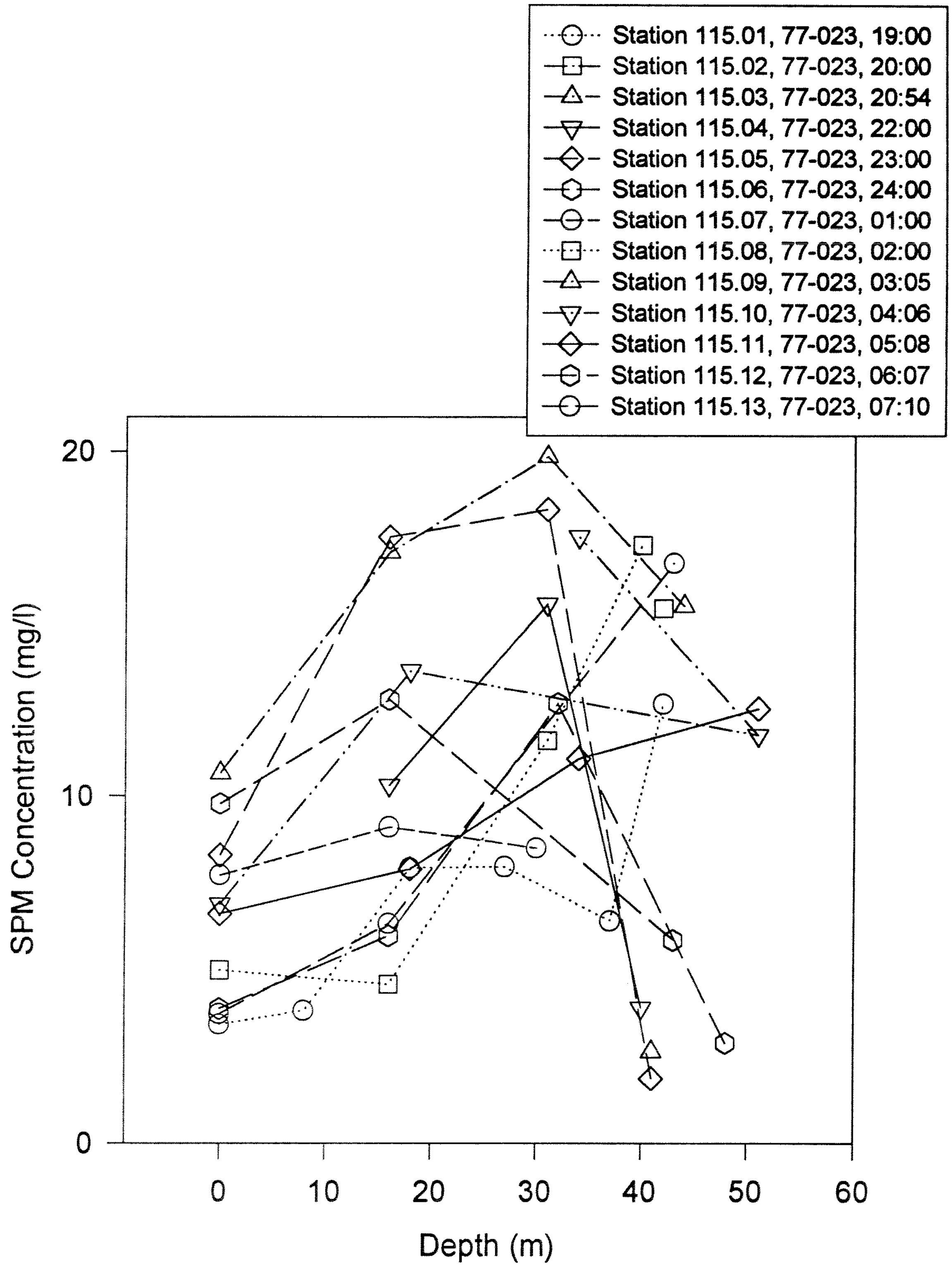

Figure 6. Inorganic SPM values for Anchor Station 115 calculated from filter values, processed by a Coulter Counter TAII.

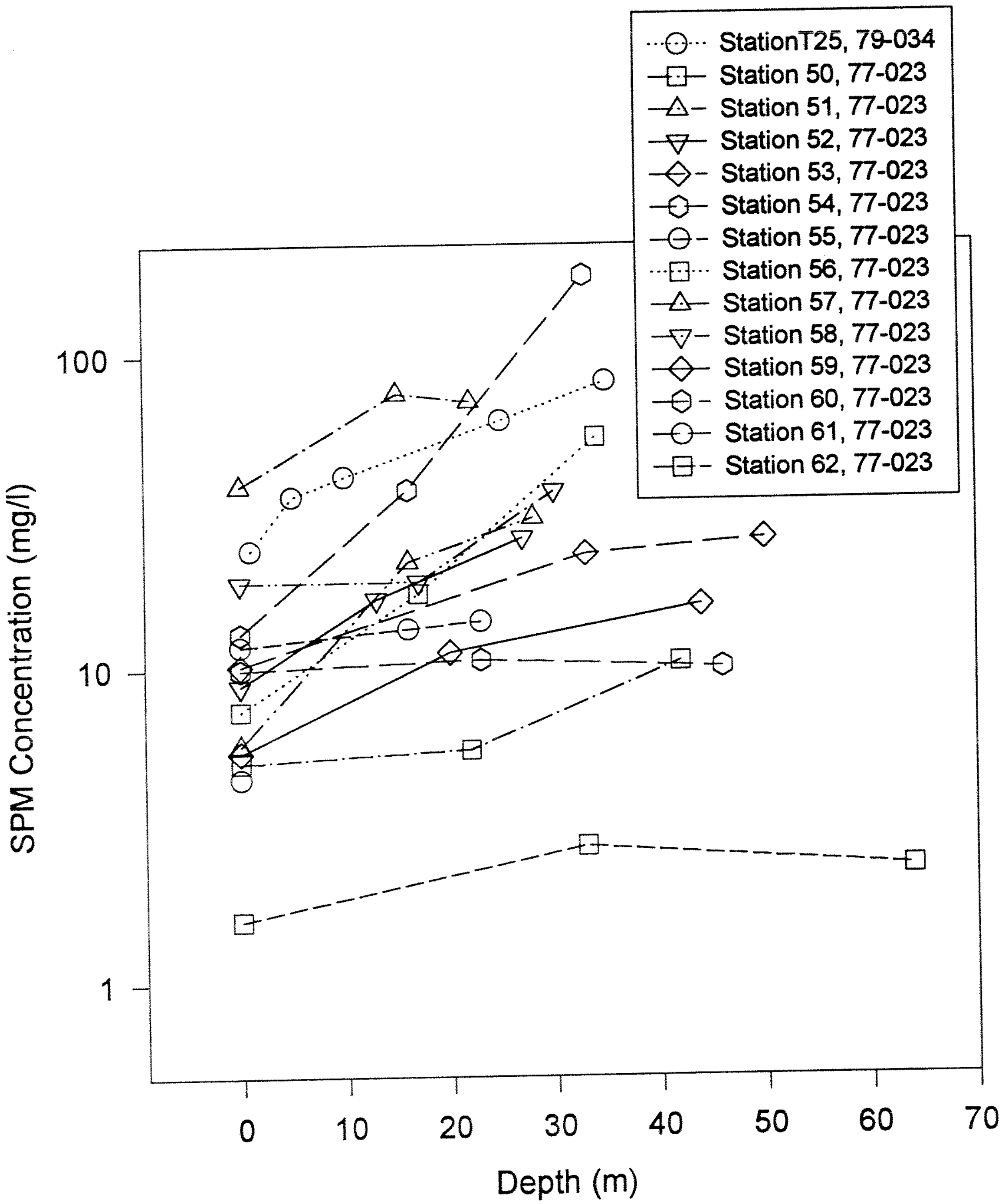

Figure 7. Total SPM values for various stations calculated from raw water samples, processed by a Coulter Counter TAII.

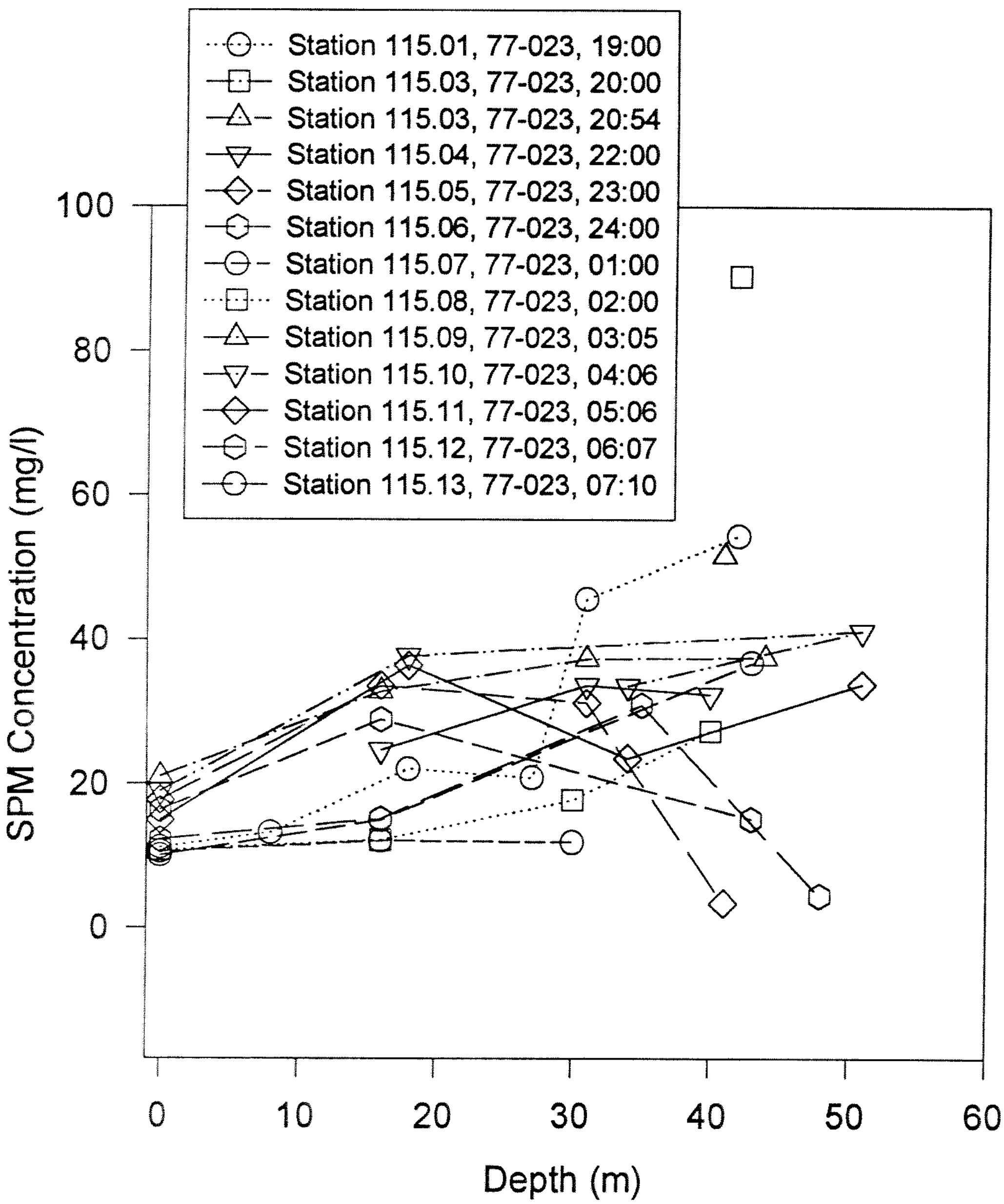

Figure 8. Total SPM values for Anchor Station 115 calculated from filter values, processed by a Coulter Counter TAII.

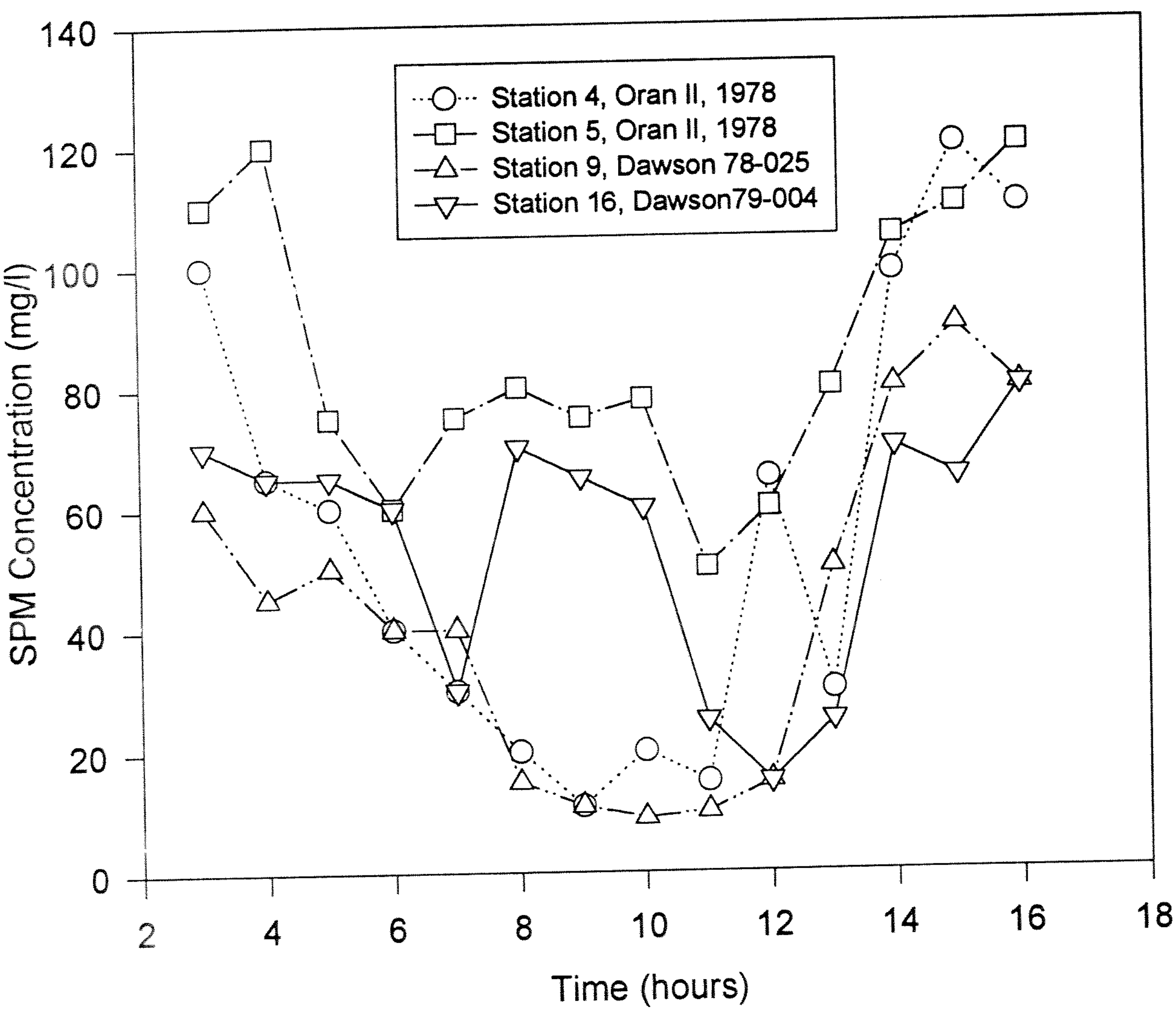

Figure 9. SPM concentrations in the surface waters of Petiticodiac River/Shepody Bay.

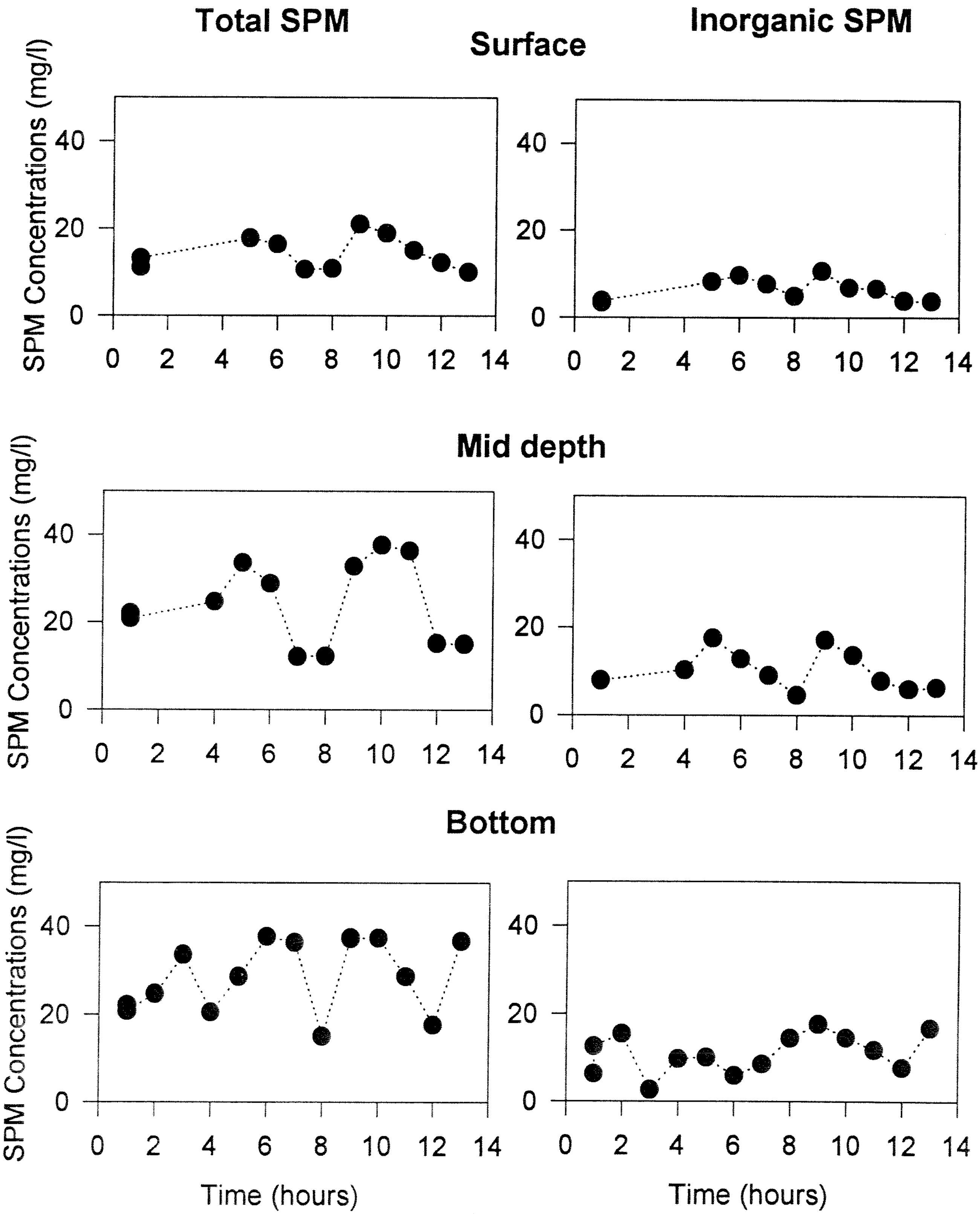

Figure 10. SPM concentrations for each cast plotted at Anchor Station 115.