Ecological Studies of the Windsor Causeway and Pesaquid Lake, 2002.

Report

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Executive Summary

An extensive study of the marsh—mudflat complex on the seaward side of the Windsor Causeway and a preliminary investigation of Pesaquid Lake were carried out during the summer and fall of 2002. The purpose of the studies was to lay the basis for an assessment of the effects of expanding the causeway to accommodate additional lanes for Highway 101, and to establish continuing monitoring of changes in the marsh and mudflat in response to the causeway and to rising sea level. Results of the study are summarized below.

1. The sediments of the Windsor Causeway tidal flat are predominately clayey silts (~68% silt and ~23% clay), with mean grain size of 23-30 μm.
2. Water contents ranged from 29.7 to 57.3% (mean ~44-46%), and organic content from 0 to 16.9% (mean 6.68 ± 5.82%). Water contents are comparable to the high values recorded by researchers in 1976-79; organic contents are higher than previous records from the Bay of Fundy.
3. An extensive array of stations was established for long term monitoring of changes to the marsh and mudflat. Station locations were surveyed in and an updated GIS database established.
4. Short-term (<4 months) monitoring of the 33 stations showed that elevation of most (27) exhibited a net increase, averaging 1.3 cm (± 1.96) by mid-October. Six stations exhibited a decrease in elevation; most of these were adjacent to tidal channels, where there was visible evidence of slumping and erosion. Stations in vegetated areas showed greatest consistency in terms of elevation; colonization by *Spartina alterniflora* typically causes stabilization of intertidal sediments.
5. Ambient sediment concentrations in flood water in the channels and over the marsh, ranged up to 1,700 mg. L^{-1} in the bore or the wave front of the advancing tide. Concentrations then declined as water depth increased. Ambient sediment concentrations in floodwater over the marsh ranged from high values of ~500 mg.L^{-1} over muddy unvegetated sites to less than 100 mg.L^{-1} at stations in the middle of the marsh. Studies of accumulation on sedimentation plates showed that an average of 7.8 mg.cm^{-2} (± 13.0) settled out during each flood tide.

6. Sediment concentrations of chlorophyll *a* ranged from 2.3 to 18.2 $\mu g.cm^{-2}$, (mean 9.8 $\mu g.cm^{-2}$). Highest values occurred on unvegetated sites bordering tidal channels, where grazing benthic invertebrates (especially *Corophium volutator*) were less abundant. Results indicate that the mudflats are biologically as rich as any previously studied in the Bay of Fundy.
7. Measurements of *S. alterniflora* height showed that the plants reached an average of 121 cm (range 49-170 cm) by the end of August. These values far exceed other salt marshes that have been studied in the Bay of Fundy.
8. Biomass of *S. alterniflora* averaged 1107 g dry $wt.m^{-2}$ (range 637-2189 $g.m^{-2}$) by the end of August. These values also far exceed those obtained in other studies of salt marshes in the Bay of Fundy. The vigorous growth of this marsh may be related a) to its high elevation, and b) to ready availability of nutrients, some of which may be supplied by the waste water outfall on the east side of the marsh. The marsh has an unusually deep (< 10 cm) surface aerobic layer. Almost all of the above ground biomass is removed by the fall die-back, and wave and ice action during the fall and winter.
9. Benthic animals are numerically dominated by the same species recorded for other Minas Basin mudflats, and for earlier studies of the Windsor mud flat: the amphipod *Corophium volutator* and the polychaete *Nereis diversicolor*. Other species include *Macoma balthica* and *Heteromastus filiformis*. Three surveys showed that benthic invertebrates are rare in areas of dense *Spartina*, and much more abundant in the unvegetated areas bordering tidal channels. Three quarters of samples in vegetated areas in early July had less than 10 organisms per sample, representing <1,300 $.m^{-2}$.
10. Replicated samples in unvegetated areas during late July showed much higher numbers, particularly of *Corophium* and *Nereis*. Samples gave estimates of *Corophium* abundance between 189 and 31,000 m^{-2}, values that are comparable to those previously obtained from Starrs Point and Avonport (Minas Basin) and Mary's Point and Dorchester Cape (Chignecto Bay), where migratory shorebirds congregate for feeding during the fall migration.

11. Non-quantitative plankton samples indicate that the plankton is dominated by copepods (especially *Pseudodiaptomus coronatus*) and the mysid shrimp *Neomysis americana*. Copepods and mysids form principal food items for many fish in Minas Basin.
12. Attempts to trap fish foraging in the Causeway Channel were unsuccessful.
13. Observations of bird use indicated that Black ducks and Herons were commonly present in the tidal channels, and greater Black-backed gulls were common foragers on the mudflats, throughout the summer. Cormorants commonly foraged in the West Channel. Most migratory shorebirds (principally Semipalmated sandpipers) seemed to forage primarily on the unvegetated areas seaward of the outflow of the St. Croix Estuary, and for only a little time on the unvegetated areas adjacent to the salt marsh. Semipalmated plovers were seen to forage on unvegetated areas near the marsh, where polychaetes were abundant.
14. In mid-August, Pesaquid Lake was a stratified impoundment, with a saline layer underlying the top 2-3 m.
15. Surface waters (0 to 2m) were relatively clear, with low turbidity (<15 NTU), relatively low pH (5.9-6.3), and high oxygen concentrations (85-100%).
16. Nitrate concentrations were very low (≤0.066 mg.L-1), providing no evidence of nutrient enrichment.
17. Deeper waters in the main channel were saline, stable and somewhat undersaturated with oxygen (< 80%), but no anaerobic waters were found.
18. Widening of the existing causeway will have negligible effects on the *physical* processes of the estuary, because the major effects have already been experienced with the original construction.
19. Expansion of the causeway will cover a small but significant part of the present mudflat and marsh, removing some of the feeding habitat for fish and birds. Estimates are that the losses will represent 9-11% of the intertidal area between the causeway and the St. Croix Estuary channel. However, continued growth of the marsh will eliminate some of the mudflat anyway.
20. Because of declines in *Corophium* populations elsewhere in the upper Bay of Fundy, there will be concerns about loss of some relatively productive areas that

have developed near Windsor as a result of the causeway. Most foraging by birds (and possibly fish?) now occurs at more distant portions of the mudflat that would not be directly involved in construction of the wider highway.

21. Widening of the causeway will have no direct effect on Pesaquid Lake. Conditions in this impoundment are largely determined by management of water levels and contaminant sources.
22. Replacement of the causeway with a bridge will bring a complex mixture of favourable and unfavourable changes.

Acknowledgements.

This study was a collaborative effort involving a number of people in addition to the ACER and Saint Mary's personnel listed in section 1.4.

We are particularly indebted to Ken Carroll and Hank Kolstee of the Nova Scotia Department of Agriculture and Fisheries for their continuing encouragement, provision of information, and logistical support. Access to storage facilities at the Control Gates office was particularly helpful. Ken Carroll also provided useful observations and information on water movements at the Causeway. During the spring of 2003, Darrel Hingley of NS Department of Agriculture and Fisheries assisted with a GPS survey of the marsh stations to improve the accuracy of the preliminary survey.

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1.0 Introduction.

The Windsor Causeway (Figure 1.1) was constructed between 1968 and 1970 to serve several purposes. It provides a major highway and railway crossing over the Avon Estuary that minimizes involvement of the Town of Windsor roads, and thus permits relatively high speed travel along Highway 101. The causeway removed tidal oscillations from the region upstream, protecting almost 1400 ha of previously dyked land from seasonal flooding. As a result, it yielded an additional 140 ha of farmland, and eliminated the need for maintenance of about 28 km of dykes (Kolstee 2002). It also created an essentially freshwater impoundment, Pesaquid Lake[1], that provides recreational and aesthetic benefits to the people of the Windsor—Falmouth area, fresh water for farming and for an important ski development, and additional water storage during high runoff events (*Ibid.*).

Construction of causeways across tidal rivers and estuaries has always caused significant change to the ecology of the system, and the Windsor Causeway is no exception (Amos 1977, Daborn 1987, Percy and Harvey 2000). Since its closure in June 1970, a saltmarsh-mudflat system has accumulated on its seaward side, whose characteristics have visibly changed during the last three decades as it became colonized by saltmarsh grasses, particularly *Spartina alterniflora*. Preliminary research in the 1970s by Amos (1977, Amos and Joice 1977) suggested that sediment was accumulating at distances up to 20 km seaward of the causeway, as a result of the decrease in tidal prism. The implication was that this would eventually cause significant shoaling of the estuary in the vicinity of Hantsport.

The marsh and adjacent mudflat attract a variety of birds for feeding and roosting purposes, including several (e.g. great blue heron, *Ardea herodias,* and double-crested cormorant, *Phalacrocorax auritus*), that feed primarily on fish. The causeway was not provided with a fishway, because it was believed that appropriate operation of the control gates would allow sufficient upstream migration of anadromous fish such as gaspereau (*Alosa pseudoharengus* and/or *Alosa aestivalis*), smelt (*Osmerus mordax*), eels (*Anguilla*

[1] Variously called Lake Pesaquid, Lake Pezaquid, Lake Pisiquid, or Pisiquid Lake.

rostrata), and even salmon (*Salmo salar*) (Sangster 1994). Some local people claim that fish passage is materially affected by the causeway, although gaspereau have been collected in lower portions of the Avon River since 1970.

Pesaquid Lake, like the headponds created by the Petitcodiac and the Annapolis Causeways, receives sediment from upstream, especially during high runoff events in the spring and fall, and possibly from tidal waters that may occasionally pass through the control gates or through apertures in the causeway itself. All these causeway impoundments have a tendency to trap such sediments, and therefore to fill in, although the rate of infilling is dependent upon the quantity of the sediment supply, and the effectiveness of flushing during strong river flow periods. In addition, Pesaquid Lake potentially receives overflow water from drainage systems in the town, and runoff from adjacent farmland that may contain fertilizers and other agricultural materials. There is an inherent potential, in such circumstances, for impounded freshwaters to become enriched with nutrients, a process known as eutrophication.

Because of the significant environmental implications of the Windsor causeway, and its long presence, a number of research studies have been conducted in the area since the mid 1970s. In general, popular opinions on the effects of the causeway are rarely based on a knowledge or assessment of the facts established by that research. Unfortunately, the research has been intermittent, often limited in scope and in time, and does not constitute a coordinated series of studies that would provide an unequivocal assessment of environmental effects. It is also true that the results have often been recorded in unpublished documents that are not readily accessible by the general public.

1.1 History of research near the Windsor Causeway.

Apart from technical investigations conducted for design of the causeway, the majority of early research was associated with concerns over the potential environmental impacts of tidal power developments in the inner Bay of Fundy (Daborn 1977). The causeways at Annapolis Royal, Moncton, and Windsor were seen as useful models for assessing the environmental implications of tidal barriers in Minas Basin, Cumberland Basin, or Shepody Bay (Amos 1977, 1987a, 1987b, Daborn 1987, Risk *et al*. 1977, Risk & Yeo 1980, Turk *et al*. 1980, Yeo 1978). Principal concerns were the effects on tidal amplitudes, on sediment distribution, and particularly on the potential that sediment accumulation resulting from barrier construction would influence the longevity or operational efficiency of a tidal power facility. Secondary concerns were related to biological resources, especially fish and birds (Daborn1977).

In 1975 and 1976, a major research program led by Carl Amos was undertaken by the Atlantic Geoscience Centre (Bedford Institute of Oceanography) to examine the dynamic forces operating in the upper Bay of Fundy. Included in this was the first detailed study of the effects of the Windsor Causeway. Direct measurements were made of the rate of sediment accretion on the Windsor mudflat during 1975 and 1976: rates ranging from 1.0 to >14 cm/month (average 5 cm/month) were calculated (Figure 1.2). The rapid rate of settlement produced a soft, muddy deposit that remained very fluid. Greatest deposition was occurring on the eastern side of the mudflat, where the sediment surface was relatively lower than other areas. At this time, the mudflat was completely separated from the causeway by a tidal channel.

As part of the same study, six bathymetric profiles were obtained at transects between the causeway and the mouth of the Avon to allow comparison with a previous survey in 1969. The results (Figure 1.3) indicated a notable shoaling in parts of the estuary which Amos and Joice (1977) estimated at < 2 m over the 9 years, extending as far as 20 km seaward. A tide gauge installed at Hantsport wharf measured smaller water heights (by up to 0.5 m) than predicted by the tide tables used by the Canadian Hydrographic Service, and this was taken as confirming evidence for the shoaling of the whole estuary since the causeway had been constructed. As part of the same study, Amos and Alföldi (1979) reported on the use of satellite imagery to permit monitoring of suspended sediments carried in the Avon Estuary.

Figure 1.1 Aerial view of the Windsor Causeway, 1981.

Figure 1.2 Map of the Windsor mudflat in 1976, showing estimated accretion rates.
(From Amos 1977, Fig. 4.)

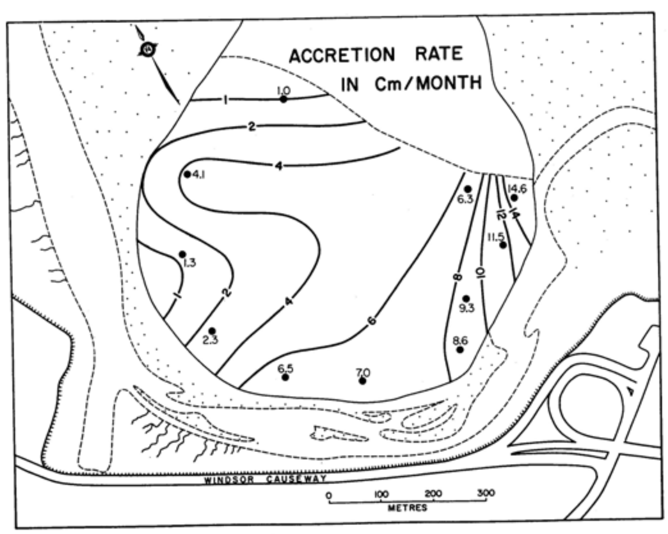
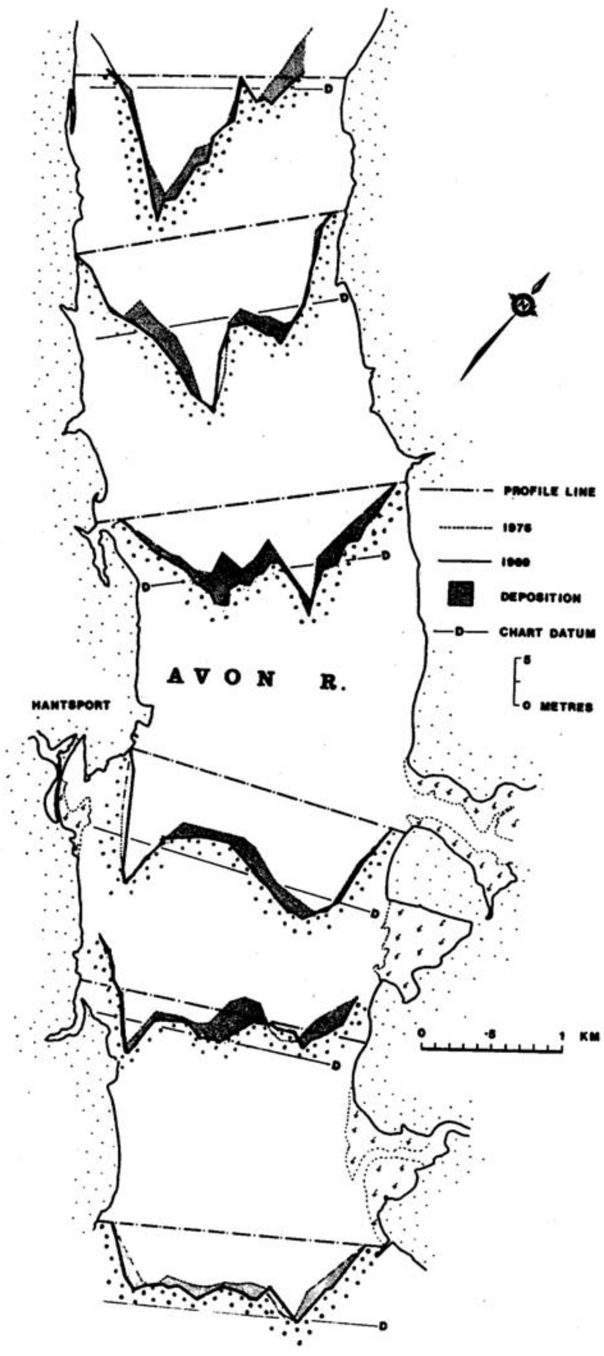


Figure 1.3 Comparison of bathymetric profiles of the Avon Estuary between 1969 and 1976. (From Amos 1977, Figure 6).



The conclusions from the projects led by Carl Amos were:

1. building the causeway in 1970 had caused the rapid and continuing deposition of sediments, most of which were derived from erosion of coastal areas in the Minas Basin or Avon Estuary, or by resuspension of deposited sediments;
2. effects were found at great distances seaward of the causeway;
3. the depositional process was continuing, and would continue, although at diminishing rates, well into the future.

During the same period (1976-79), Risk and his co-workers from McMaster University conducted studies of intertidal sediments and fauna in Minas Basin, including the Windsor Causeway. In several reports, comparisons were made between the properties of the tidal flat at Windsor, and those at a study area at Mungo Brook on the Noel Shore in Minas Basin (Risk 1977, Risk *et al.* 1977, Risk and Yeo 1980, Turk *et al.* 1980, Yeo 1978). They found that the sediments at Windsor had much higher water contents (~48%) than the Noel Shore (~30%), and higher organic content (<0.8% vs. 0.24%). Between 1976 and 1979, they found that the grain size of sediments decreased significantly (from a mean of 5.72φ to 8.69φ (i.e. from approximately 15.6 µm to 3.9 µm). Associated with this change in sediment they reported a significant decline in the abundance of the fauna.

Principal organisms encountered included the amphipod *Corophium volutator,* the bivalve *Macoma balthica*, and the polychaete worm, *Heterosmastus filiformis*. All three of these species are common dominants in intertidal mudflats of the Minas Basin, and have been subject to a good deal of research in the last 25 years. At Windsor, however, the abundance of these species was considerably lower than recorded in other study areas: e.g. *Corophium* averaged ~840 m^{-2} at Windsor, compared with ~13,000 m^{-2} at Mungo Brook (Turk *et al.* 1980), and <60,000 m^{-2} at Starr's Point, Minas Basin (Risk, *et al.* 1977, Gratto 1979, Gratto *et al.* 1983, Hicklin 1981). Curiously, in several respects, data reported in Turk *et al.* (1980) do not match other publications by the same group, which were based upon the same surveys. In particular, although the polychaetes *Nereis* spp. and *Neanthes* spp. were recorded by Yeo (1978) and Hirtle (1978) as present on the

Windsor mudflat, these were omitted from Turk *et al.* (1980). Partridge (2000) identified a number of inconsistencies in the various publications by this group.

None of these publications reported the presence of saltmarsh grasses on the mudflat; however, people began to notice the appearance of patches of marsh cord grass, *Spartina alterniflora,* during the late 1980s. Periodically, aerial photographs were taken of the mudflat by the Nova Scotia Department of Natural Resources, although these were not apparently analysed to quantify the changes in abundance of *Spartina* (Vanderkloet, pers. comm.). Rising public interest in the changes, particularly the growth of the marsh and the appearance of larger numbers of birds during the summer months, led to a report and some original observations by Sangster (1994). Sangster's report provided a review of general estuarine processes and some past research, but also included new samples of invertebrates along a south-north transect across the eastern part of the marsh (cf. Figure 1.4) collected in July 1994. Although limited in number, Sangster's samples contained consistently higher numbers of *Corophium* (1709 ± 1202 $.m^{-2}$), and *Nereis diversicolor* (693 ± 441 $.m^{-2}$), and fewer *Macoma balthica* (221 ± 104) than those reported by Turk *et al.* (1980). Sangster also made a number of estimates of shorebirds and waders visiting the flats between 8 July and 24 August 1994. This appears to be the first recorded attempt to estimate shorebird use of the Windsor marsh and mudflat complex.

Miner (1997) and Partridge (2000) investigated invertebrate abundances in two areas of the mudflat (cf. Figure 1.4) during 1996-7. The purposes of these studies were a) to examine the winter ecology of the mudflat, and particularly the effects of freezing and ice on benthic invertebrates, and b) to examine the effect of disturbance on *Corophium volutator*. Partridge (2000) monitored sediment conditions and invertebrate populations in an experimental area at the eastern border of the Windsor mudflat through the winter and spring of 1996. At this time, the Windsor mudflat was predominantly unvegetated, although there was a significant area colonised by *Spartina alterniflora* on the highest portion of the flat as well as adjacent to the causeway and dyke (Figure 1.5).

Figure 1.4. Map of the Windsor marsh—mudflat showing transects of Sangster (1994), the study areas of Partridge (2000) and Miner (1997), and the present study (2002). (Basic map provided by S. Townsend, Saint Mary's University)

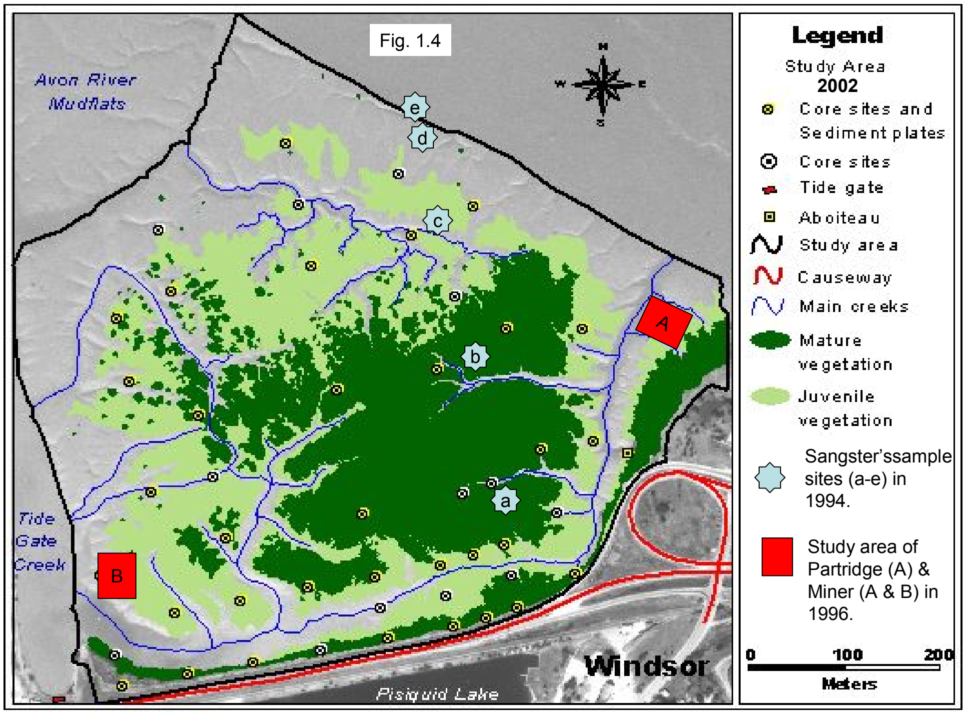


Figure 1.5. Extent of *Spartina alterniflora* on Windsor mudflat, 1996. (Source: V. Partridge).

Partridge discovered that *Corophium*, *Nereis*, and *Macoma* survived winter temperatures, but disappeared in late winter (March) following extensive ice formation and movements. Abundance values of *Corophium* during the winter were much less than 5,000 $.m^{-2}$, and often less than those of *Nereis diversicolor.* This study confirmed previous conclusions that *Corophium* numbers decline significantly over the winter months (cf. Hicklin *et al.* 1980, Möller 1986, Wilson 1989), implying that intertidal mudflats scoured extensively by ice must rebuild *Corophium* stocks during the spring and early summer by colonization from less affected areas. Miner (1997) revisited the same site as Partridge, and a new sample area on the western side of the marsh near the control gates (Figure1.4) during August 1997. Her data showed that *Corophium* numbers on the established (but unvegetated) mudflats on the eastern side were very much higher than previous studies had found (14,000-22,000 $.m^{-2}$), but no greater (~3,500 $.m^{-2}$) at the western sample area (B in Figure 1.4). Repeated disturbance by people walking over the mudflats caused a measurable decline in abundance of *Corophium*.

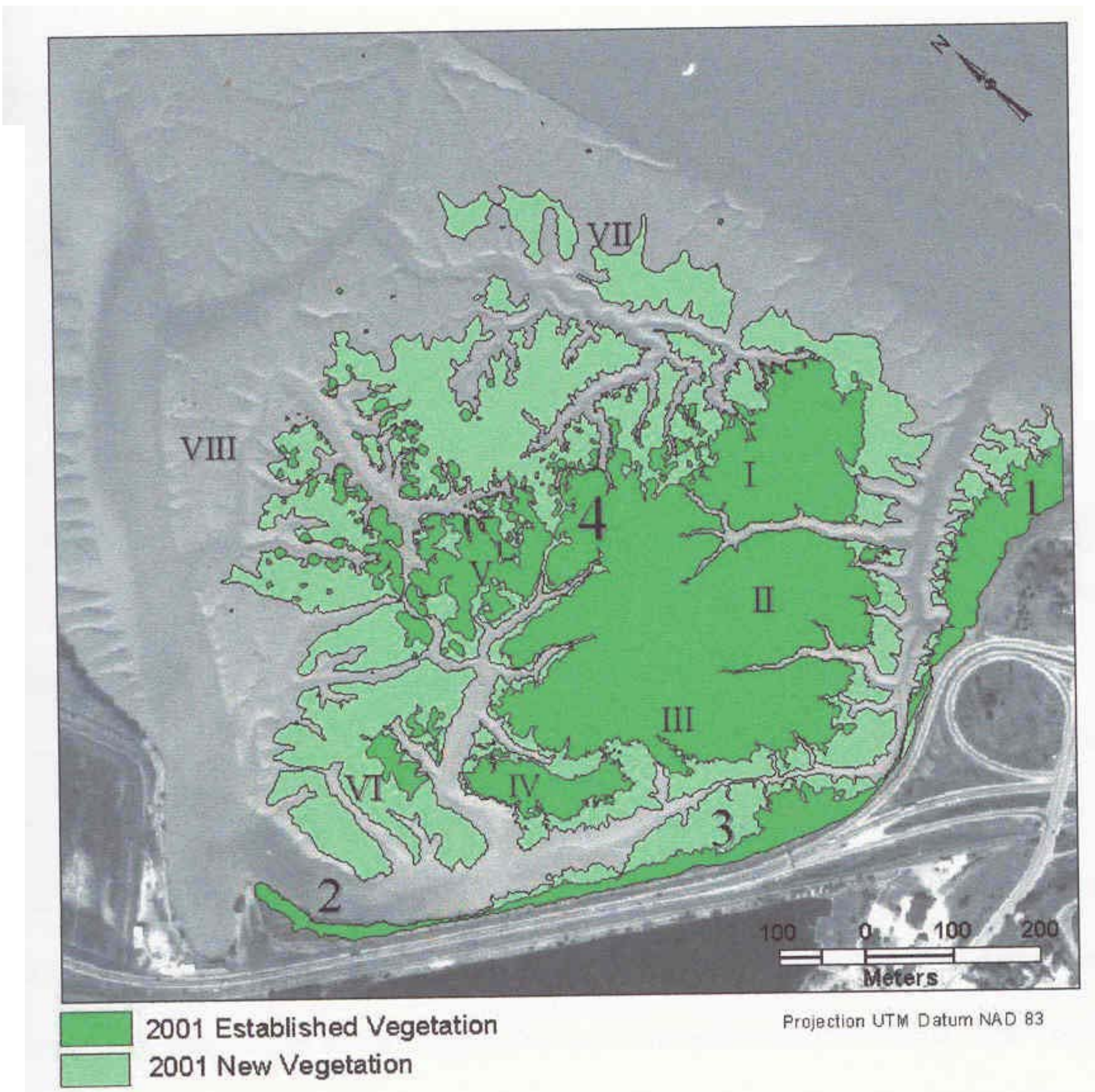
The most extensive study of the saltmarsh colonization of the areas near the Windsor Causeway was carried out by Townsend (2002). She carefully surveyed the extent of both 'established' and 'juvenile' marsh grass[2] during the fall of 2001, using differential GPS, and compared the extent of present marsh to that detectable in aerial photographs taken since 1973. Initial marsh growth was found adjacent to the dyke near the Tourist Bureau in 1973, and subsequently (1981) at the western end of the causeway. The first detectable marsh on the mudflat was apparently present as an isolated patch in 1981; it was presumably rafted in by ice. By 1992, there were more than 30 such isolated patches, probably representing several ice-rafting events. Subsequently, the established groups coalesced. During an extensive field survey, Townsend mapped out the coverage of both 'established' and 'juvenile' vegetation; her figure is shown here as Figure 1.6. Between 1995 and 2001, she calculated that the marsh grew from ~41,000 m^2 to >390,000 m^2.

[2] 'Established *S. alterniflora* colony' = "a vegetated area measuring over 2 m^2, containing mature *S. alterniflora*, possessing flowers or seedpods"; 'juvenile vegetation' = "..areas containing *S. alterniflora*, lacking flowers or seedpods, between areas of established vegetation [...] and non-vegetated mud surface, with a distribution density of more than 10 shoots per m^2." Townsend (2002) page 45.

Barring a significant environmental event, the exponential growth of *Spartina* will result in it covering almost all of the Windsor tidal flat within 5 years.

Although the research has been intermittent, and conducted for varying reasons, it constitutes an effective summary of the changes to the Windsor tidal flat over the past 3 decades. It is evident that on the seaward side of the causeway the ecosystem is still actively responding to its construction more than three decades ago. Rates of change vary

Figure 1.6 Map of established and juvenile *Spartina alterniflora,* in 2001.
(From Townsend, 2002.)



from one response to another: while the rate of sediment accumulation near the causeway (and probably further down the estuary) is relatively small now, the rate of expansion of the vegetation is very rapid, with consequences for the invertebrate fauna, and hence the vertebrates that feed in the vicinity of the marsh and mudflat.

1.2 Purpose of the 2002 study.

Plans to twin Highway 101 from the Metro area to the Annapolis Valley require modification to the crossing of the Avon Estuary at Windsor. One solution to the crossing is to expand the width of the existing causeway to accommodate an additional 2 or 4 lanes; because of local infrastructure (e.g. Fort Edward National Historic Site and the railway line), such an expansion would be most feasible on the seaward side of the existing causeway, and thus over part of the marsh-mudflat complex that has arisen there. In order to assess the environmental implications of such an expansion, recognising the long term nature of the estuary's response to natural phenomena (such as sea level rise and global climate change), it is necessary to develop a more comprehensive understanding of the dynamic processes currently under way in the Estuary. These processes respond to both short term (e.g. seasonal) and long term (multi-year) influences, including continuing rise in mean sea level. To answer both long and short term questions, it is necessary to monitor features of the marsh and mudflat in a more continuing and consistent manner than has been done in the past.

This project was designed to provide answers to the following questions:

1. What are the rates, and what is the pattern of continuing sediment deposition or erosion near the Windsor Causeway?
2. How do sediment properties related to deposition and erosion vary over the Windsor marsh-mudflat?
3. What biological resources currently exist in the marsh and mudflat?
4. To what extent are the marsh and mudflats utilised by fish and birds?
5. What biological resources will be placed at risk through expansion of the causeway?

In addressing the longer term questions, a principal objective was to establish a network of monitoring stations that will be revisited over the next few years.

1.3 Organization

The project was a collaborative effort of the Acadia Centre for Estuarine Research and the Department of Geography, Saint Mary's University. It was divided into three subprojects:

1. A study of the topography of the marsh and mudflat, the pattern of sediment characteristics and the erosional/depositional changes taking place. This subproject was led by a team from Saint Mary's University.
2. A study of biological resources of the marsh and mudflat complex, led by a team from ACER.
3. A preliminary study of Pesaquid Lake, conducted by the ACER team.

Principal funding was provided by a grant from the Nova Scotia Department of Transportation and Public Works. Additional resources were obtained from NSERC Grant No. 238447-02 to Dr. Danika van Proosdij (Department of Geography, Saint Mary's University) and from the Acadia Centre for Estuarine Research.

1.4 Personnel.

The project was jointly led by Dr. Graham R. Daborn (ACER), Dr. Michael Brylinsky (ACER) and Dr. Danika van Proosdij (Saint Mary's University).

Field and laboratory work was carried out by:

Sandi Macpherson (ACER), Kathleen Martin (ACER), Adrienne Moore (ACER), Erinn O'Toole (SMU), Leah Smith (ACER), Roxanne Struk (ACER), and Sarah Townsend (SMU). Additional field assistance was provided by Eddie Halfyard and Jonathan Lowe (ACER).

2.0 Topographic and Sedimentological Studies.

2.1 Introduction.

Tidal flats of the Minas Basin system exist in a dynamic relationship with sediments being carried in suspension by tidal water, or by ice movements in winter. Relatively new intertidal bodies, such as those created by modifications to the flow patterns in the estuary, take many years to approach an equilibrium condition. Closure of the Windsor causeway in 1970 was followed by rapid accumulation of sediments on top of the pre-existing intertidal bedforms (Amos 1977; Amos and Joice 1977). Since that time, the tidal deposit has grown, changed shape, become dissected by changes in the St. Croix Estuary channel, and has consolidated (Partridge 2000; Townsend 2002). Popular opinion has been that the deposit continues to prograde along the Avon Estuary, and causes increasing difficulty in the vicinity of Hantsport, although there is little direct evidence for this. Amos (1977), and Amos and Joice (1977) reported a net accumulation of < 2.0 m between 1969 and 1976 in the Avon Estuary up to 20 km seaward of the causeway. Information from personnel at the Fundy Gypsum Company suggests that difficulties with docking large vessels have more to do with channel migration than with net shoaling of the estuary in that region (B. Miles-Dunne—*personal communication*). Current upgrading of the facilities at Hantsport to accommodate an even larger bulk carrier (40,000 tons) indicates that the company does not anticipate insurmountable problems arising from long term effects of the Windsor Causeway.

Unfortunately, long term studies of such mudflats have not been carried out in the Bay of Fundy system in the past, and consequently it is not clear how many years are required for a disturbed system such as this to achieve equilibrium with the tidal regime.

Obvious changes have occurred in the Windsor mudflat during the last decade. These include the rapid growth of salt marsh, following its first appearance in the late 1980s (Sangster 1994; Townsend 2002), and the infilling that has taken place in the channel adjacent to the causeway. The northern extent of the intertidal flat has varied considerably over the years as a result of changes in the outflow of the St. Croix Estuary. An aerial photograph taken in 1973 indicates that the principal outflow of the St. Croix ran more or less directly across the Avon Estuary to the main thalweg of the Avon, which has commonly been on the western shore. In 1976, Amos indicated a significant outflow of the Saint Croix water was along the channel adjacent to the causeway, and then along the western side of the Avon, with a secondary pathway along the eastern side of the Avon Estuary; at this time the flat had assumed a pear shape, with its downstream (north eastern) edge defined by two channels, one oriented south to north, and the other running west to east. This configuration was present in photographs taken in 1981 and 1988, but by 1992, the main outflow channel ran roughly south to north right across the Avon. Since that time, the tip of that deposit has been cut off again as the St. Croix outflow eroded it back towards the south.

The purpose of the sedimentological studies of the Windsor marsh-mudflat complex was to address the following two questions:

a. How do sediment properties vary across the marsh-mudflat complex, both in space and in time?
b. What are the current rates of sediment accumulation or erosion?

Changes in elevation of a tidal marsh or mudflat vary according to location, tidal rhythms, proximity to tidal channels, susceptibility to wave action, ambient concentration of suspended sediments, vegetation density and structure, and local changes in sea level. Understanding these dynamic relationships requires a long time series of observations. For this purpose, an array of stations was established extending from the causeway toward the northern border of the deposit (Figure 2.1). These stations will be revisited over the coming years in order to develop a comprehensive understanding of the morphological relationships that characterise the marsh and mudflats.

2.2 Methods.

2.2.1 Establishment of Sampling Stations and GPS survey.

A total of 47 sampling stations were arranged along 10 transects oriented perpendicular to the Windsor causeway (Figure 2.1). A baseline was established approximately 2-4 m from the edge of the causeway and the start of each line marked using a wooden stake. If space permitted, a back stake was installed or another land-based marker identified, to assist in re-locating each line. A level and tripod were used to sight along the baseline and then establish each line at exactly 90^{o}. Distances between stations were measured by tape and sampling stations established at 50, 100 or 200 m intervals, depending on their location on the marsh. The length of these transects varied depending on the furthest extent of vegetation; however, the final station was always on a non-vegetated surface (i.e. seaward of the established salt marsh). The location of the sample stations was chosen to optimize the accuracy of the interpolation procedure, to create a stratified random sampling arrangement, and to provide the most comprehensive characterization of different environments within the marsh-mudflat complex. Each station was marked using a bamboo pole and flagging tape. All initial samples were collected approximately 0.5 m to the west of the sample flag; subsequent samples were obtained at the same distance in different directions to avoid resampling a disturbed surface.

The location of each station was surveyed using a Trimble Pathfinder Pro XR Global Positioning System operating in carrier phase mode. A base station was established on the geodetic benchmark located near the tide gate and the data were differentially corrected using the Pathfinder Program at Saint Mary's University. The positional accuracy of the survey was 0.4 m in the horizontal and 0.6 m in the vertical. In an effort to increase the accuracy of the GPS survey, the sedimentation stations were re-surveyed in May 2003 using a Leica SR530 dual frequency real time GPS system operated by Darrel Hingley, a survey technician with Nova Scotia Department of Agriculture and Fisheries. This instrument is capable of providing cm accuracy; the coordinate quality (mean of vertical and horizontal components) of this survey was 0.014 m.

Figure 2.1 Windsor Tidal Flat Transect Sites.

(Source: D. van Proosdij & S. Townsend).

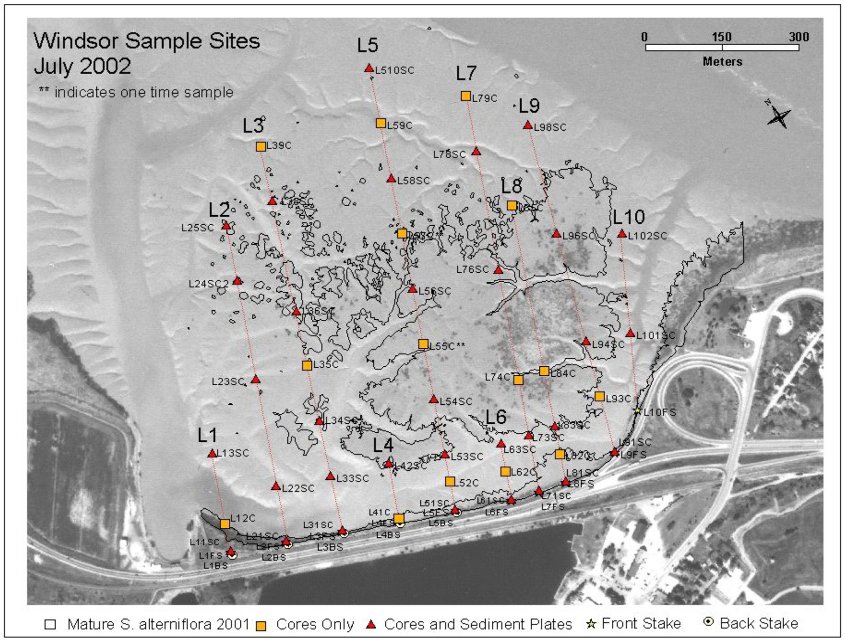
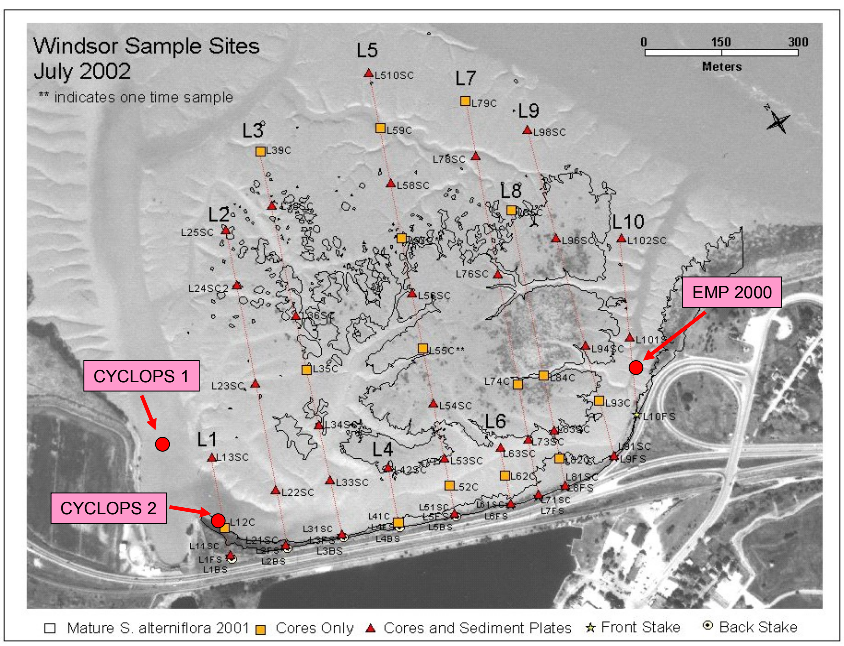


Figure 2.2 Location of Tidal Water Monitoring Sites.



2.2.2 Determination of Sediment Accretion and Erosion.

Changes in surface elevation were measured bi-weekly over the main growing season from June to October 2002 at a total of 33 sedimentation stations (stations labeled 'SC' in Figure 2.1) arranged to provide an optimal interpolation surface.

At each 'SC' station, an aluminium plate was installed 0.1 m below the marsh surface by excavating a small pit adjacent to the stake, and driving the plate beneath the undisturbed surface to the west side of the stake. Care was taken to ensure that the plate was as close to horizontal as possible. The depth of the buried plate was measured to the nearest mm at three points along its long axis using a thin, stiff rod. Any change in surface elevation between each sampling interval was determined by subtracting the measurements from the previous measurements at each point and then deriving a value for the station by averaging the three measurements. Positive values indicate sediment accretion, whereas negative values suggest erosion.

Deposition of sediment on the marsh surface during four successive tides (on 23rd and 24th July, 2002) was measured using sedimentation traps based on a design originally used by Reed (1989; Reed et al. 1997) and modified for a macrotidal environment by van Proosdij *et al*. (2002). A series of sediment traps was placed at 12 stations, arranged to give the most effective coverage. Each trap consisted of a metal frame containing a fibrous mat for support, and with a hinged lid into which 3 circles approximately 44 mm in diameter had been cut. In use, the trap was placed on the sediment surface and three pre-weighed 47 mm diam.Whatman GF/C™ filters were carefully inserted beneath the lid, which was then closed. The lid held the filters in place. When immersed in water, sediment settling from the water column accumulated on the filters. Filters were retrieved after the next high water period, and replaced three times by new pre-weighed filters, so that deposition on each of four successive tides could be calculated. Following retrieval, the filters were dried in a vacuum oven at c. 50 °C, and reweighed.

Sediment concentrations in waters flowing over the intertidal zone during high water were estimated from rising stage water samples collected in 1-litre bottles attached to a stake near the sediment trap experiments. Each bottle was fitted with a cap and two copper pipes: an inlet pipe that pointed horizontally at the level of the top of the bottle, and an exhalent pipe arranged to allow air to leave the bottle as ambient water flowed in through the inlet. Filling took approximately 1 minute once the bottle was fully immersed; once filled, the bottle did not capture any further sediment. The sediment accumulation in the bottle thus represents the ambient concentration of suspended sediments in the near surface water at that point on the marsh. Bottles were retrieved and replaced at the same time as sediment plate filters were replaced, giving samples of ambient suspended sediment concentration for each of four successive tides. Suspended sediment concentrations were determined using vacuum filtration through pre-weighed and dried 0.45 μm filters.

2.2.3 Sediment Characteristics.

Core samples were collected at each sample station to characterize the top 5 cm of the marsh surface. Sediment samples were extruded into a labeled zip lock bag or sealed sample jar. Vegetation was trimmed if present.

At each station, a modified 10 cc syringe was used to collect samples for organic matter content and water content. Samples were weighed to the nearest 0.1 mg on a precision balance, dried to a constant dry weight at 70 ^{o}C, and re-weighed to determine percent water content of the sample. The amount of organic matter was then determined using standard loss on ignition procedures. The dried sample was ashed at 500 ^{o}C in a muffle furnace to burn off all of the organic matter, cooled and re-weighed to the nearest 0.1 mg. The difference between the two weights was used to calculate the amount of organic matter in the sample.

At each station, a large, modified 160 cc syringe was used to collect a fixed volume of sediment for determination of bulk density. This sample was weighed to the nearest 0.1 mg on a precision balance, dried to a constant dry weight at a low temperature of 60 ^{o}C to prevent baking of clays, and re-weighed for wet and dry bulk densities (Lewis and McConchie, 1994).

Thirty-four aluminium cores (10 cm long, 5 cm diameter) were collected at representative stations to determine the inorganic particle size distribution of the marsh surface. These cores were processed at Mount Alison University's Wetlands Research Centre. Cores were extruded, split and sketched. The top 1 cm of the sample was removed for analysis of grain size distribution using a Coulter Laser 5000 particle size analyser. The sample was homogenized and suspended in distilled water. A total of 3 subsamples were extracted and run through the Coulter Counter which measured particles ranging in size from 0.375 to 2000 μm. The final grain size distribution was determined as the mean of the three analyses. Particle size was characterized using Folk parameters (mean, sorting, skewness and kurtosis) (Folk, 1957; Folk and Ward, 1974).

2.2.4 Interpolation of data.

All data were interpolated using Spatial Analyst Extension in ArcView GIS 3.2. Surfaces were derived from data collected in the field based on a spline interpolation algorithm using a grid cell resolution of 2 m, with the tension option, and weight of 0.1 applied to the data.

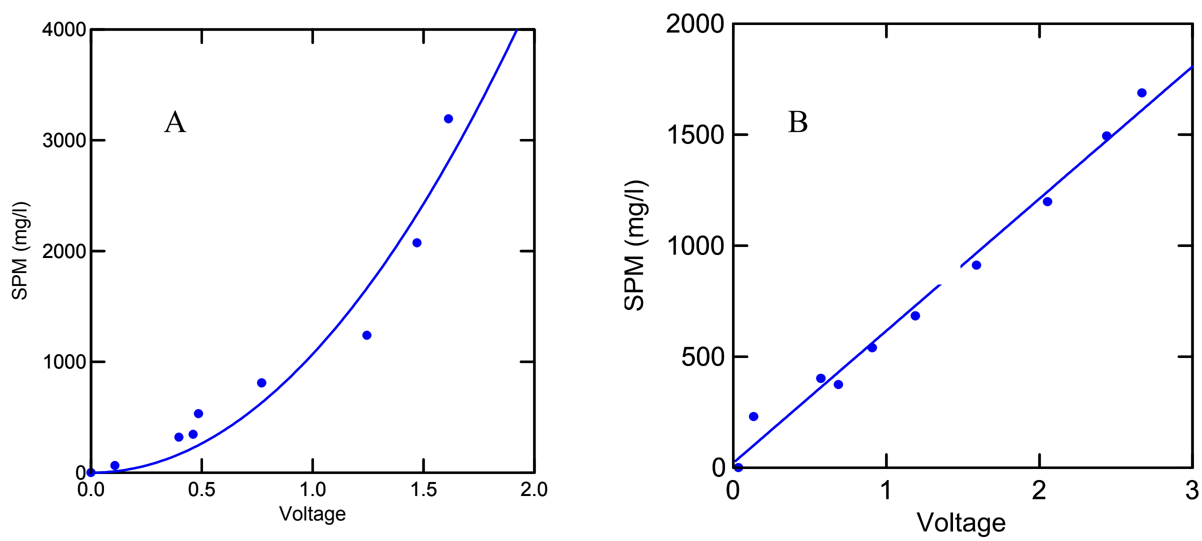
2.2.5 Tidal Water Environment.

Water temperature and salinity were monitored over several days in July at three stations in the tidal channels that bring water onto the marsh (Figure 2.2), using CYCLOPS (q.v. below), a YSI Model 6000 Multiparameter Sonde and an EMP 2000 conductivity—temperature—depth (CTD) recorder. The first station (CYCLOPS 1 in Figure 2.2) in the West Channel below the causeway control gates was occupied from 20 June to 5 July, covering 32 tides. CYCLOPS was then removed and replaced in the entrance to the Causeway Channel (CYCLOPS 2) from 21 July to 7 August, covering 37 tides. The EMP was installed on a stake in the East Channel, just above the sewer outfall, from 22 to 25 July, covering 5 tides.

Ambient Suspended Particulate Matter Concentration (SPM) measurements were carried out using CYCLOPS, a specially constructed instrument consisting of an Optical Backscatter Sensor (OBS) and data logger fitted to a tripod, and the EMP2000 CTD fitted with an OBS sensor. A sediment trap was attached to the frame of the tripod to collect sediment with which to calibrate both instruments.

Calibrations were carried out in the laboratory by submersing the instruments in a 20 litre bucket which was painted black inside and filled with tap water. Sediment collected from the sediment trap was added to the bucket in discrete steps and the OBS voltage response recorded at each step. At the same time, a 50 ml water sample was drawn from the bucket which was used to determine the absolute concentration of SPM at the time the OBS voltage was recorded. The bucket was fitted with a submersible pump to ensure that the added sediments remained suspended in the tap water. The results of the calibrations are presented in Figures 2.3A, B:

Figure 2.3 Calibration curves for OBS sensors on A. CYCLOPS, B. EMP 2000.



2.3 Results.

2.3.1 Topography and Sediment Properties.

Figure 2.4 illustrates the variation in elevation over the Windsor marsh. The highest points occur on the east side of the marsh, near the Information Kiosk, where vegetation was first observed in 1980s or along the southern end of the marsh near the causeway. The lowest stations are L3-8, L5-10 and L7-8 along the northern and western sections of the marsh surface close to the major tidal creeks or Avon River. This region is approximately 2 m lower in elevation than the highest points. This area is near the region that seems to be susceptible to erosion (see below), whereas the south, central and east sides are regions of accretion.

Figure 2.4. Topography of the Windsor Tidal Flat, June 2002.

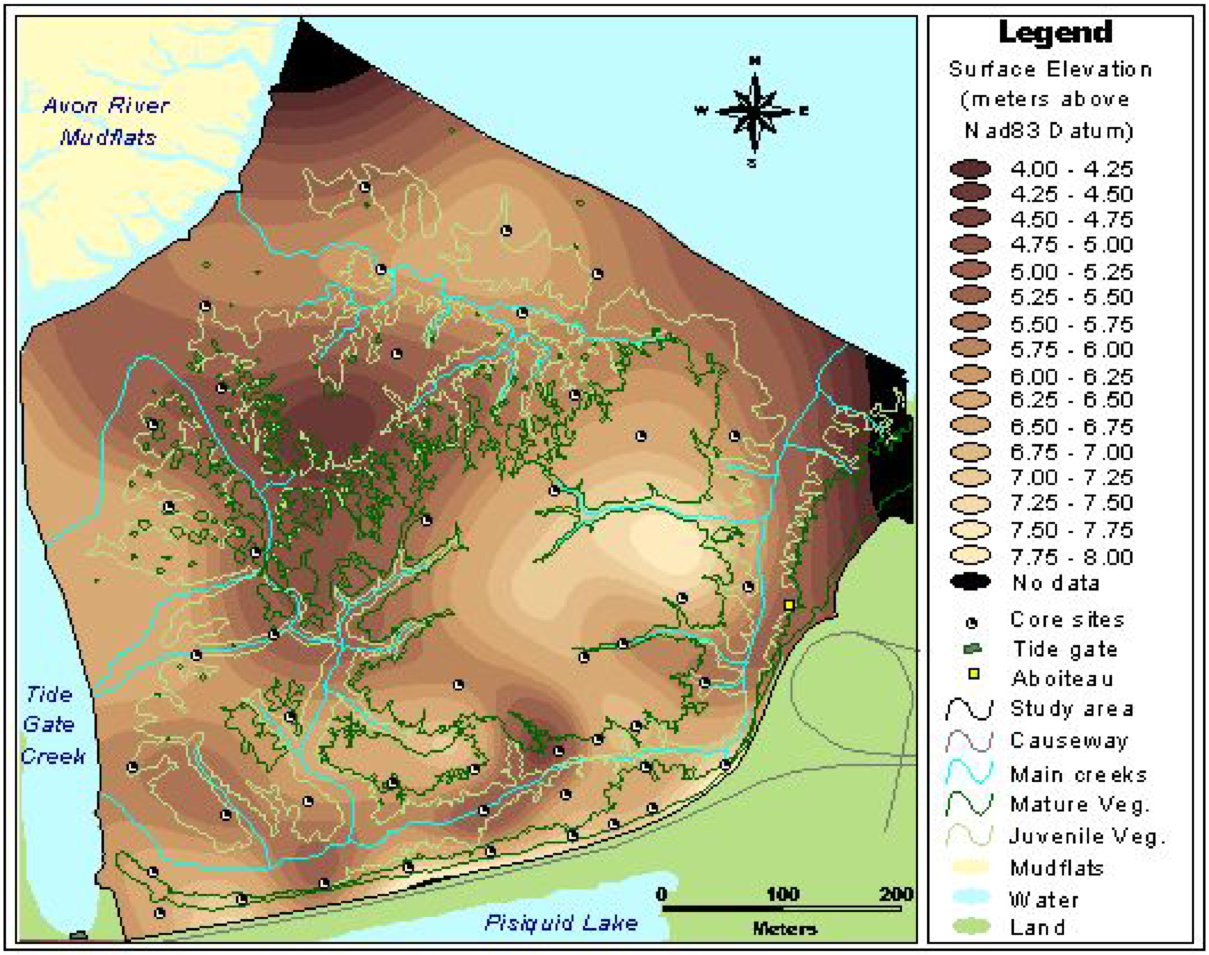
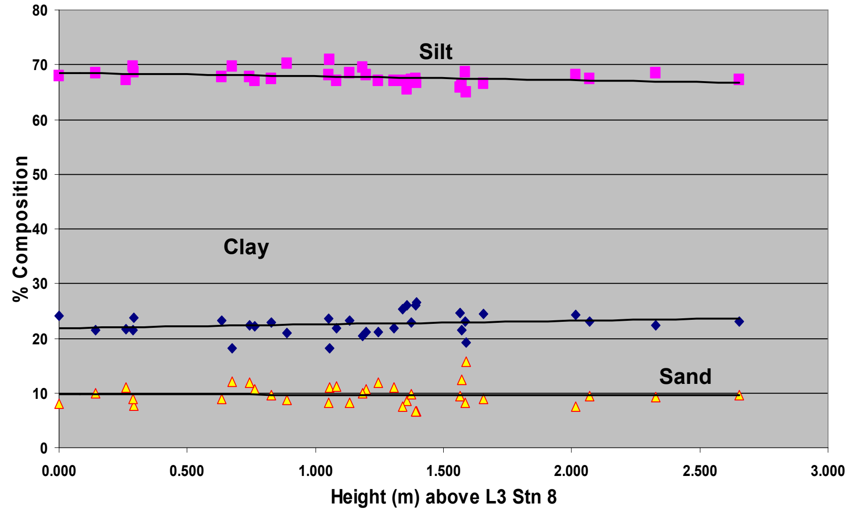


Figure 2.5. Relationship between sediment composition and relative elevation.



Deposited sediments on the Windsor marsh are generally well sorted, fine silts (67.8% ± 1.31 S.D.), with a substantial clay fraction (22.6% ± 2.04). Sands generally constituted less than 10% (Table 2.1). The clay content of these sediments is considerably higher than recorded at some other Bay of Fundy locations (e.g. Amos, 1987; Daborn *et al.* 1991; van Proosdij *et al.* 1999), although it is comparable to deposits in the Annapolis Basin (Daborn *et al.* 1995). Variation in composition is very low, and there appears to be no significant relationship between the proportion of these constituents and the variation in elevation on the marsh and mudflat (Figure 2.5).

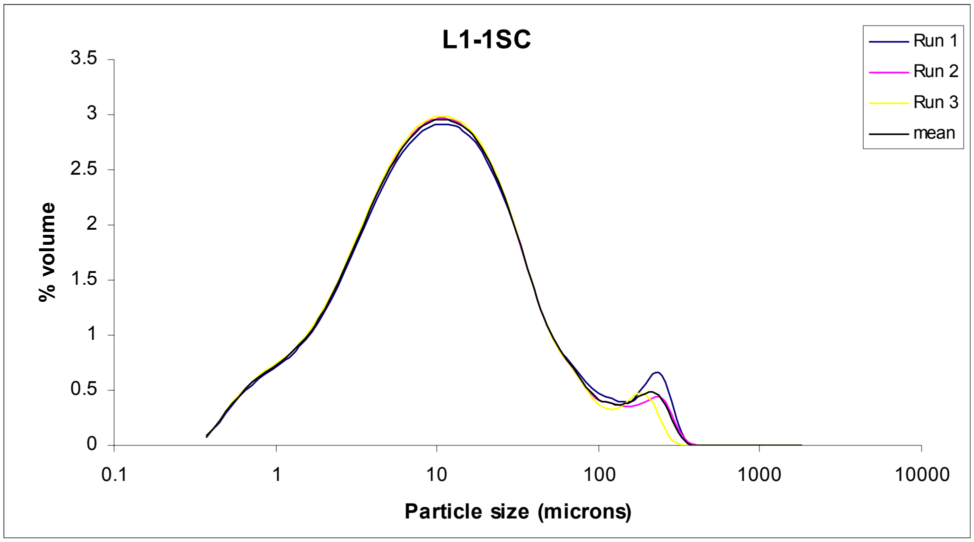
Size distribution is commonly unimodal or slightly bimodal, with principal mode(s) in the range of 9 – 30 µm (Figure 2.6; Table 2.2). Occasionally a minor additional peak occurs at c. 200 µm, representing a small component of coarse sand. Mean grain size was usually between 23 and 30 µm.

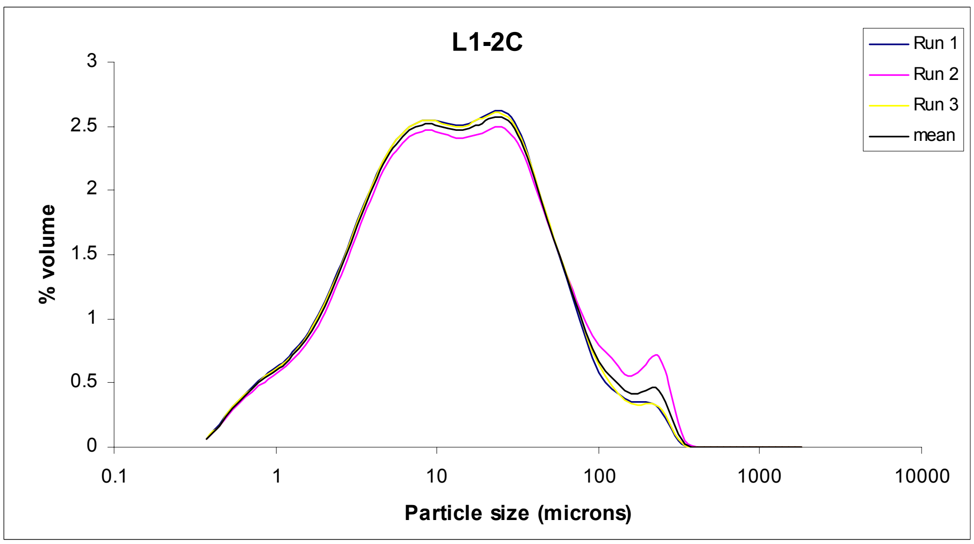
Table 2.1 Sediment Composition: June 2002

Line	Station	%clay	% silt	%sand
L1	1SC	24.53	66.57	8.91
	2C	21.51	66.15	12.35
	3SC	20.99	70.20	8.80
L2	2SC	22.22	67.04	10.74
	3SC	25.95	65.44	8.62
	4SC	22.94	67.26	9.78
	5SC	23.77	68.56	7.66
L3	1SC	23.28	67.83	8.87
	4SC	25.41	67.14	7.47
	6SC	21.70	67.32	10.98
	8SC	24.09	67.92	8.00
	9C	22.44	67.74	11.81
L4	1C	22.37	68.45	9.19
L5	2C	21.56	68.51	9.94
	3SC	26.60	66.69	6.70
	4SC	23.31	68.40	8.29
	8SC	21.40	69.66	8.92
	9C	21.85	67.13	11.00
	10SC	18.23	69.70	12.08
L6	2C	26.00	67.41	6.59
L7	1SC	24.35	68.19	7.44
	3SC	23.09	68.65	8.26
	8SC	21.13	68.13	10.74
	9C	19.24	65.04	15.73
L8	2C	24.71	65.82	9.50
	4C	20.41	69.55	10.04
	5C	23.57	68.18	8.22
L9	1SC	23.10	67.28	9.62
	3C	22.93	67.50	9.56
	4SC	23.04	67.49	9.47
	8SC	18.09	70.91	11.00
L10	1SC	21.13	67.01	11.87
	2SC	21.83	67.05	11.12
Mean		**22.63**	**67.76**	**9.67**
Standard	**Deviation**	**2.04**	**1.31**	**1.89**

There is no obvious correlation between mean grain size and the presence or abundance of vegetation (Table 2.2). However, locations with rather coarser sediment modes are often at the seaward end of long transects (e.g. L5—10; L7—8; L7—9; L9—8), or adjacent to tidal channels where stronger wave action might be anticipated (e.g. L1—2;

Figure 2.6. Selected grain size distributions.


L1-1SC
Run 1
Run 2
Run 3
mean
% volume
3.5
3
2.5
2
1.5
1
0.5
0
0.1
1
10
100
1000
10000
Particle size (microns)


L1-2C
Run 1
Run 2
Run 3
mean
% volume
3
2.5
2
1.5
1
0.5
0
0.1
1
10
100
1000
10000
Particle size (microns)

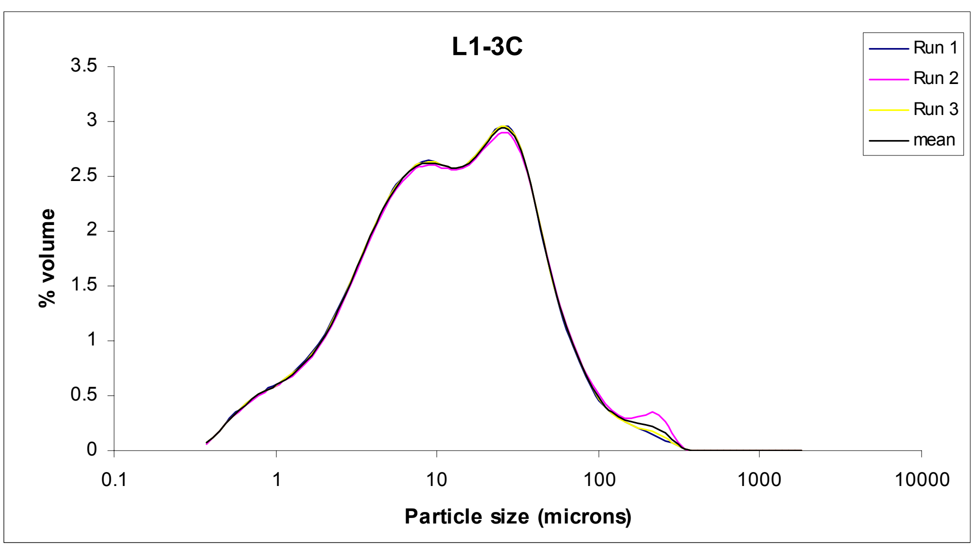
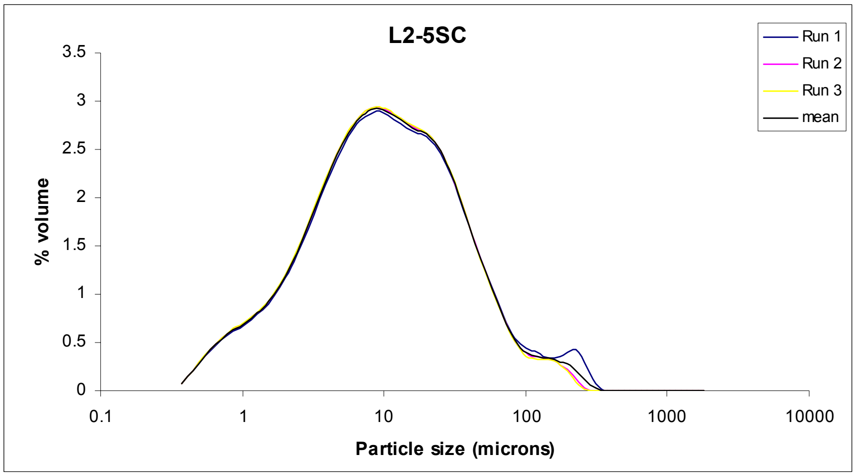
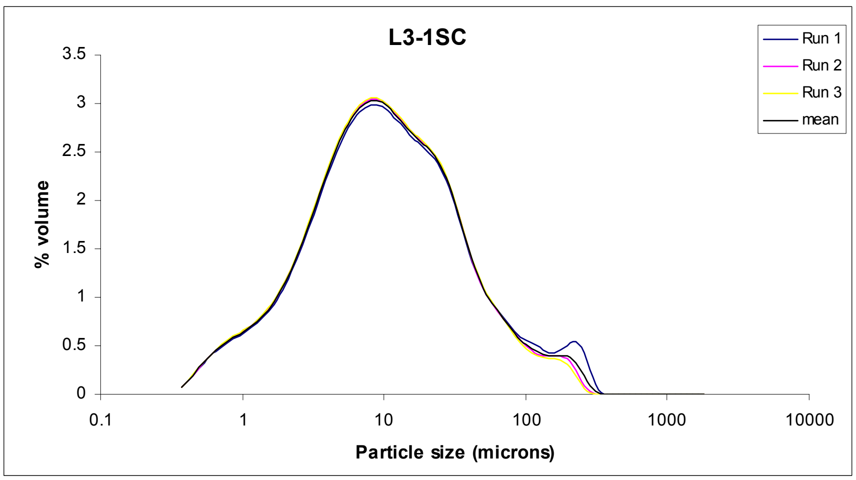

L1-3C
Run 1
Run 2
Run 3
mean
% volume
3.5
3
2.5
2
1.5
1
0.5
0
0.1
1
10
100
1000
10000
Particle size (microns)

Figure 2.6 (Cont.). Selected grain size distributions.





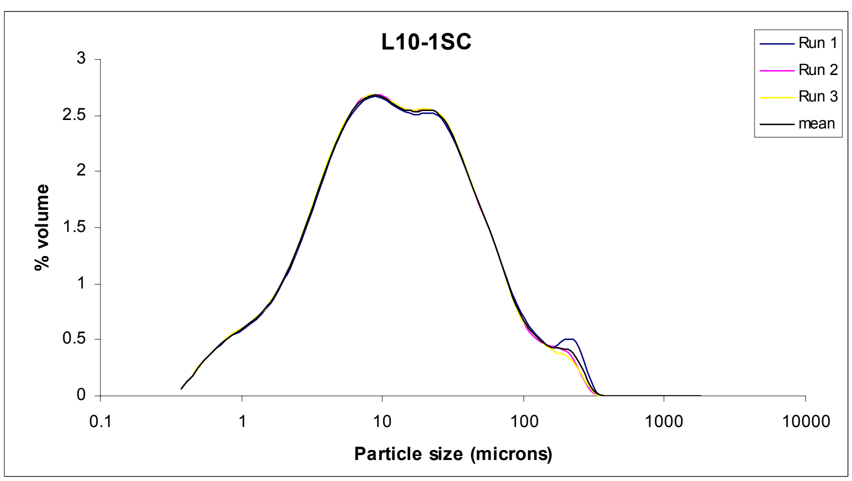


Table 2.2 Transect Stations: Vegetation & Grain Size Characteristics.

Line	Station	Sediment	Condition	Vegetative		Cover		Modal Grain	Mean Grain
		Soft	Firm	None	Scattered	Moderate	Dense	Size µm	Size µm
L1	1SC		X				X	11.29	21-26
	2C		X				X	26.14-23.81	26-30
	3SC	X			X			26.14	24
L2	1SC		X				X		
	2SC	X			X			28.7	25
	3SC	X			X				
	4SC	X					X	9.37	24
	5SC		X	X				9.37	22
L3	1SC	X		X				9.37	22
	2C	X		X				9.37	25.6
	3SC	X					X	8.54	20-24
	4SC	X			X			8.53	20-22
	5C	X		X					
	6SC	X					X	9.37	26-29
	8SC	X		X				10.29	21-23
	9C	X		X				10.29	27-29
L4	1C		X				X	18.0-19.8	22-26
	2SC	X					X		
L5	1SC	X					X		
	2C	X		X				10.0-22.0	24-26
	3SC	X					X	8.54	17-22
	4SC		X				X	10.29	21-25
	6SC	X					X		
	8SC	X			X			10.29	22-26
	9C	X			X			10.29	25-28
	10SC	X		X				28.7	27-30
L6	1SC		X				X		
	2C	X			X				
	3SC	X			X				
L7	1SC		X				X	9.37	19-24
	3SC	X			X			16.4-18.0	21-26
	4C		X				X		
	6SC	X				X			
	8SC	X			X			18.0-19.6	25-29
	9C	X		X				31.5	29-32
L8	1SC	X					X		
	2C	X					X	9.37	23-25
	3SC	X			X				
	4C	X		X				11.29	24-27
	5C	X					X	8.54	21-25

Table 2.2. (Cont).

Line	Station	Sediment	Condition	Vegetative		Cover		Modal Grain	Mean Grain
		Soft	Firm	None	Scattered	Moderate	Dense	Size µm	Size µm
L9	1SC		X			X		9.37	23-26
	3SC	X		X				9.37	23-26
	4SC	X					X	9.37	22-27
	6SC	X					X		
	8SC	X		X				26.14	27-30
L10	1SC	X			X			9.37	26-29
	2SC	X		X				9.37	26-29

L1—3; L4—1). In these circumstances, finer sediments may be more inclined to winnow away, and thus become part of the ambient suspended sediment load, rather than remaining deposited.

Two independent analyses of sediment water content were obtained from samples collected in late June. Water contents ranged from c. 30-56%, with a mean of c. 45% (± 5.5) (Table 2.3). The distribution pattern of water content (Figure 2.7) shows a mixed relationship with vegetative cover. In areas of salt marsh that have been established longest, water content tended to be a little lower than in areas of relatively new vegetation, or unvegetated areas at lower elevation.

Water content is a seasonally varying parameter (cf. Anderson 1983); consequently, values later in the summer would have been somewhat lower as less frequent flooding and strong evaporative losses during warm summer days (especially on neap tides when low water is near mid-day) led to significant drying and cracking of exposed sediment (Figure 2.8). In vegetated areas, however, the sediment surface remained relatively more moist than unvegetated areas even in late July and August.

These values are significantly higher than other records for the Bay of Fundy (see Table 2.4); however, water content is greatly influenced by sediment characteristics, and is generally higher in sediments with greater clay content, such as those of the Windsor Tidal Flat.

Figure 2.7 Interpolated distribution of % water in surficial sediments of the Windsor Tidal Flat, June 2002.

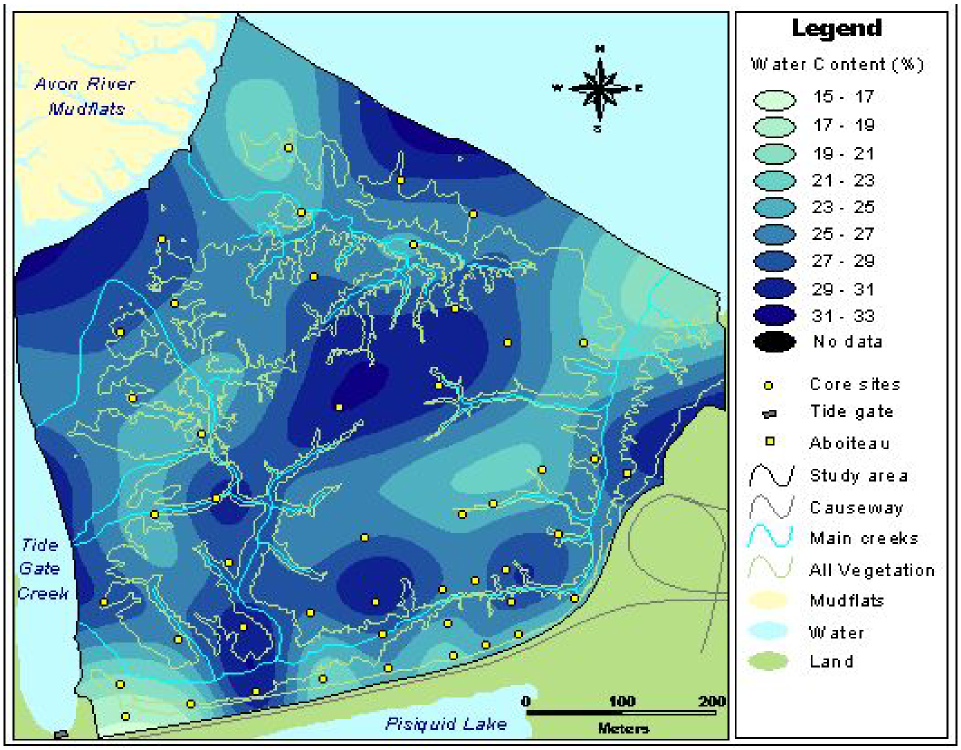


Figure 2.8. Cracked surface of exposed sediment, July 2002.

Table 2. 3. Windsor Transect stations: bulk density, water and organic content of surficial sediments.

Station	EASTING	NORTHING	Water content	Bulk density	Organics
	(m NAD83)	(m NAD83)	(%)	(g/cm3)	(%)
L11SC	409569.801	4983210.223	29.66	1.03	6.60
L12C	409560.284	4983259.035	33.74	0.99	5.41
L13SC	409537.589	4983385.212	47.43	0.83	5.95
L21SC	409667.277	4983228.348	34.23	1.01	5.43
L22SC	409649.127	4983326.830	45.93	0.73	-
L23SC	409613.704	4983516.839	42.39	0.81	4.32
L24SC2	409581.283	4983693.512	44.60	0.77	5.06
L25SC	409562.380	4983792.305	44.94	0.88	13.24
L31SC	409765.312	4983247.202	53.51	0.63	6.79
L32C	409649.13	4983326.83	56.26	0.63	5.30
L33SC	409745.260	4983344.729	50.03	0.80	6.13
L34SC	409725.060	4983443.329	45.54	0.88	5.63
L35C	409704.740	4983541.450	49.61	0.77	5.18
L36SC	409684.278	4983638.901	47.32	0.61	3.78
L38SC	409643.356	4983835.398	47.00	0.73	5.31
L39C	409623.041	4983933.024	48.58	0.75	12.96
L41C	409864.865	4983266.027	38.24	0.85	5.67
L42SC	409846.052	4983366.426	47.97	0.69	5.95
L51SC	409963.303	4983284.803	44.01	0.75	6.91
L52C	409953.963	4983333.811	48.28	0.67	6.21
L53SC	409944.588	4983382.983	50.14	0.79	0.00
L54SC	409926.169	4983481.357	46.95	0.75	13.79
L56SC	409888.510	4983678.669	57.30	0.53	5.97
L58SC	409851.768	4983876.444	48.40	0.68	16.56
L59C	409833.437	4983974.728	47.19	0.60	0.17
L510SC	409813.112	4984072.808	37.33	1.00	3.68
L61SC	410061.318	4983302.737	39.71	0.80	6.61
L62C	410052.235	4983352.595	43.62	0.75	6.07
L63SC	410043.520	4983402.363	47.33	0.72	6.18
L71SC	410109.443	4983317.655	42.51	0.80	4.80
L73SC	410091.716	4983416.202	43.93	0.87	5.33
L74C	410074.068	4983515.511	41.32	0.86	5.90
L76SC	410038.496	4983712.839	50.63	0.76	6.33
L78SC	409999.810	4983924.721	43.73	0.77	2.68
L79C	409981.839	4984023.409	50.47	0.67	4.16
L81SC	410156.636	4983334.744	41.49	0.79	5.99
L82C	410147.224	4983383.715	48.67	0.71	5.69
L83SC	410137.936	4983433.543	49.95	0.69	5.72
L84C	410119.270	4983531.644	38.11	1.08	7.30
L85C	410063.265	4983827.140	48.25	0.83	4.47

Table 2.3. (Cont).

Station	EASTING	NORTHING	Water content	Bulk density	Organics
	(m NAD83)	(m NAD83)	(%)	(g/cm3)	(%)
L91SC	410242.290	4983387.971	50.52	0.48	5.59
L93C	410216.951	4983486.235	47.39	0.72	2.98
L94SC	410191.653	4983584.255	41.98	0.74	5.53
L96SC	410141.294	4983777.878	49.81	0.67	6.44
L98SC	410090.990	4983971.750	47.76	0.70	5.26
L101SC	410270.133	4983599.743	45.69	0.79	3.79
L102SC	410254.661	4983777.783	48.13	0.50	4.98
		mean	**45.69**	**0.76**	**5.95**
		max	**57.30**	**1.08**	**16.56**
		min	**29.66**	**0.48**	**0.00**

Table 2.4. Summary of sediment percent water content values reported for sites located within the upper Bay of Fundy.

Sample Date	Site	Percent Water Content			Reference
		N	Mean	Range	
19 to 21/06/02	Windsor	46	44.1	34.2-55.8	This study
08/76	Windsor	20	47.5	-	Turk et al. 1980
07-08/77	Windsor	60	47.9	-	Turk et al. 1980
05-07/78	Windsor	80	44.3	-	Turk et al. 1980
17/07/79	Windsor	16	48.6	-	Turk et al. 1980
04/07/78	Pecks Cove	3	17.8	17.2-18.4	Hicklin et al 1980
04/07/94	Pecks Cove	3	34.3	32.-34.3	Shepherd et al. 1995
05/09/78	Grande Anse	4	20.5	16.8-22.2	Hicklin et al 1980
05/07/94	Grande Anse	4	36.0	34.8-38.0	Shepherd et al. 1995
15/05/78	Marys Point	4	18.4	17.5-19.5	Hicklin et al 1980
16/0694	Marys Point	4	30.8	27.0-34.7	Shepherd et al. 1995
20/06/94	Kingsport	4	216	18.7-25.2	Shepherd et al. 1995
20/06/94	Porters Point	3	30.8	30.4-31.2	Shepherd et al. 1995
21/06/94	Avonport	4	24.4	16.6-31.6	Shepherd et al. 1995
11/07/89	Starrs Point	1	35.0	-	Daborn 1991
22/06/94	Starrs Point	7	25.4	18.9-31.0	Shepherd et al. 1995
23/06/94	Evangeline	4	27.0	18.0-33.9	Shepherd et al. 1995
26/06/78	Minude	3	19.6	18.0-20.5	Hicklin et al 1980
27/07/94	Minude	3	37.9	34.5-40.1	Shepherd et al. 1995
27/06/78 to 08/08/78	Kingsport	5	49.3	44.0-57.7	MacKinnon and Walker 1979
27/06/78 to 08/08/78	Grande Pre	5	45.2	41.1-54.0	MacKinnon and Walker 1979

Bulk density is a useful index of the degree of consolidation of a sediment, as well as its composition. Bulk density of samples taken in late June from 47 sites ranged from 0.48 to 1.03 $g.cm^{-3}$ (Table 2.3). There is, as expected, a strong correlation between bulk density and water content (Figure 2.9). Interpolation of these point values indicates that higher bulk density values occur in older established parts of the marsh, where the sediment has had a longer time to consolidate, or near the causeway and dyke (Figure 2.10), and somewhat lower values in wetter localities at lower elevations.

Organic content of the surficial sediments ranged from 0 to 16.9%, with an average value of 6.68% (± 5.82). The pattern of distribution of surficial organic contents is shown in Figure 2.11. There is no correlation between the organic content and bulk density values of surface sediments (r^2 = 0.058). Similarly, there is no correlation between the surficial sediment water content and its organic content (r^2 = 0.022). A comparison of these values with other studies is presented in Table 2.5.

Figure 2.9 Relationship between bulk density and water content of surficial sediments, Windsor Tidal Flat, June 2002.

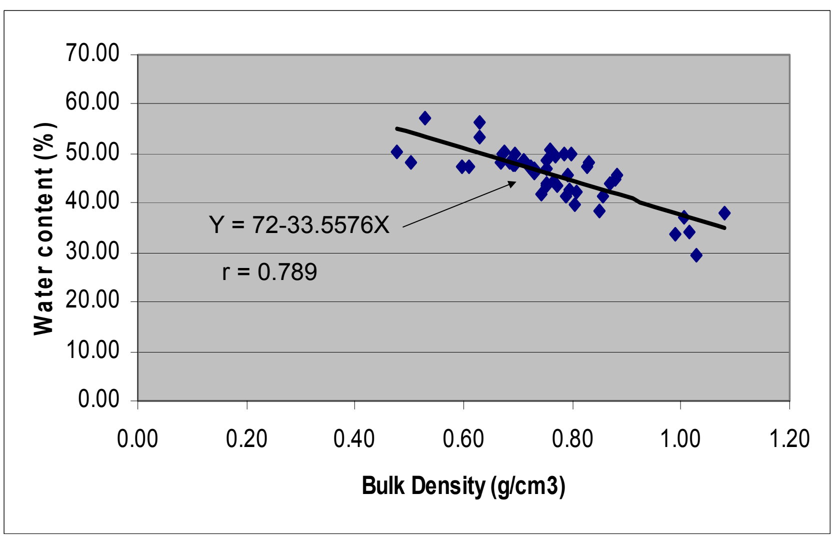


Figure 2.10. Interpolated distribution of bulk density of surficial sediments of the Windsor Tidal Flat, June 2002.

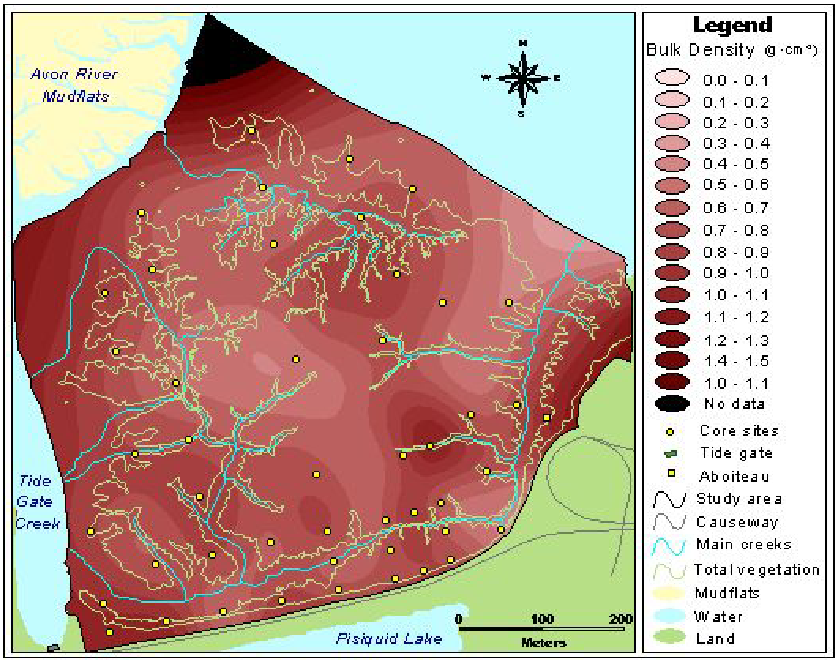


Figure 2.11. Interpolated distribution of % organic matter values in surficial sediments of the Windsor Tidal Flat, June 2002.

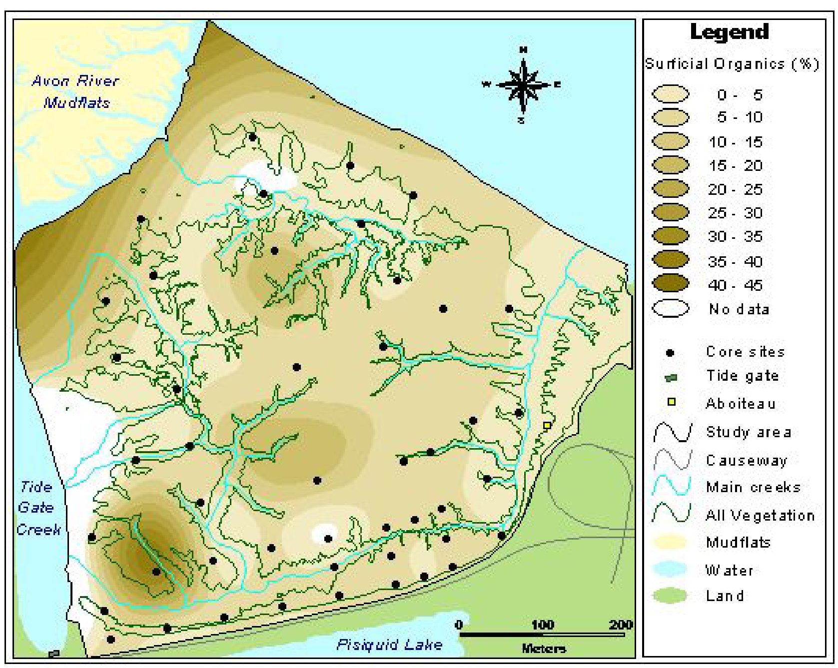


Table 2.5. Summary of sediment percent organic content values reported for sites located within the upper Bay of Fundy.

Site	Percent Organic Content			Reference
	N	Mean	Range	
Windsor	44	5.8	0.0 -16.6	This study
Windsor*	30	0.8	-	Turk et al. 1980
Dorchester Cape	-	4.2	-	Murdoch et al. 1986
Wood Point	-	4.4	-	Murdoch et al. 1986
Kingsport	9	4.2	2.6-6.6	MacKinnon and Walker 1979
Grande Pre	5	2.0	1.6-2.4	MacKinnon and Walker 1979
Starrs Point	-	-	0.6-3.5	Daborn et al. (1991)

*Analysis based on a carbon analyzer which consistently gives lower values than the loss on combustion technique used in this study.

2.3.2 Sediment deposition and erosion.

Depth of sediment overlying aluminium plates buried at 33 stations[3] between 19 and 20 June, 2002, was measured at biweekly or monthly intervals until mid-October 2002, to monitor changes in bed level resulting from accretion or erosion. For consistency, measurements were made by the same operator wherever possible. These stations are essentially permanent, and will be revisited in future years to continue monitoring of changes to the marsh and mudflat. The stations will continue to be monitored at monthly intervals (when free of ice), until June 2003; then seasonally for the next 2 years, and then annually in summer.

Results from the present summer are summarised in Figure 2.12 (A-H), and an interpolation of the net changes over the summer and fall is shown in Figure 2.13. Negative values are indicative of decreases in bed level (i.e. erosion), except during the first measurements where an apparent decrease in depth of the plate may be attributable to some settlement following the establishment of the plate. After some preliminary settling, most stations exhibited a net increase in elevation over the 4 months of record, with a few (6) showing a net decrease. Average net change was 1.30 cm (± 1.96 S.D.). Some of the greater increases occurred at intermediate stations of the longer transects

[3] All stations labelled 'SC'.

(e.g. L3-6, L5-6, L7-6, L9-6), with the largest net decreases occurring at the most seaward stations (e.g. L3-8, L5-10, and L7-8) or adjacent to an actively moving channel (e.g. L1-3). Recent slumping was observed at places in each channel.

Figure 2.12. Changes in elevation at transect stations of the Windsor tidal flat, June-October 2002.

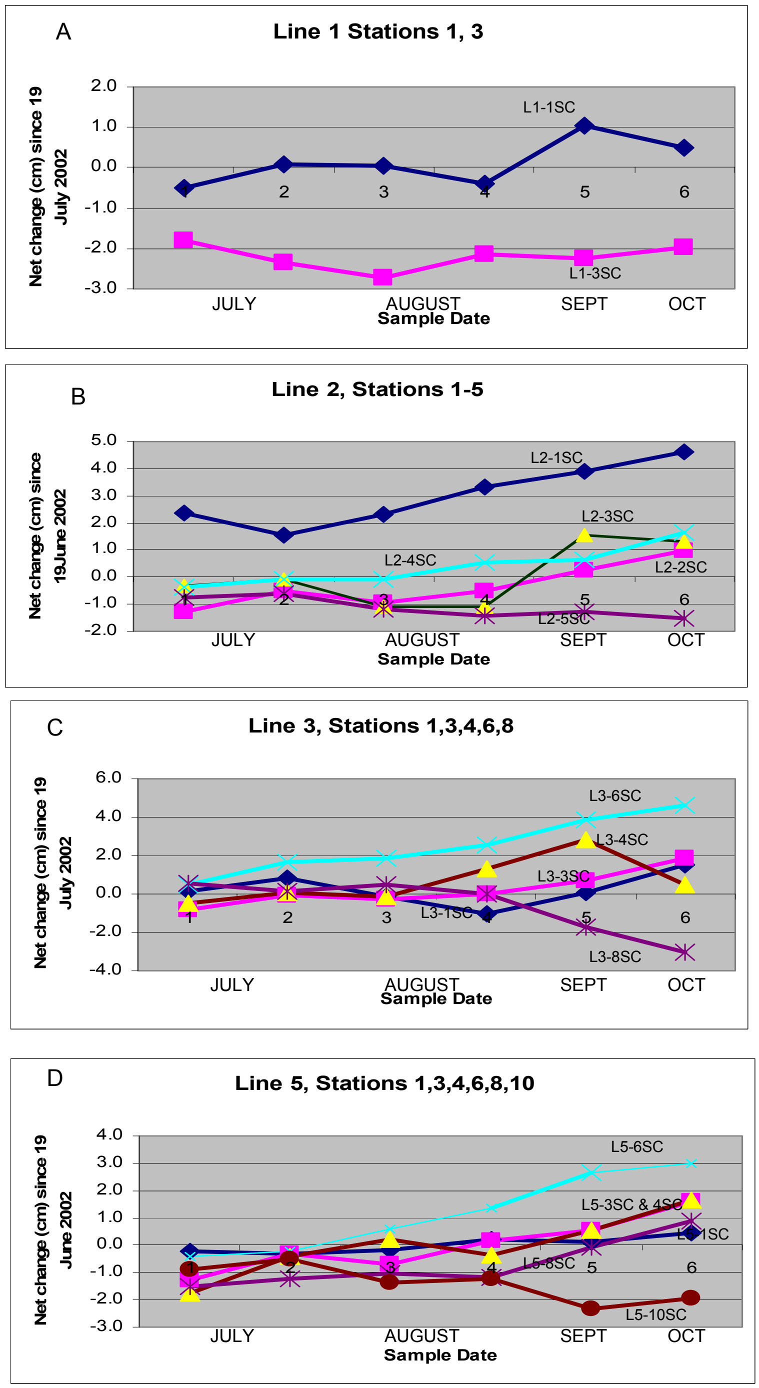
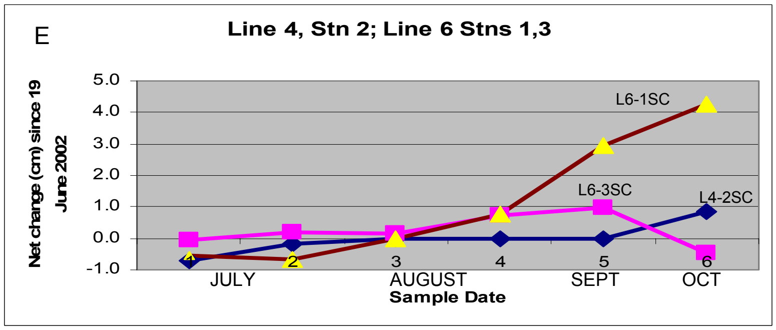
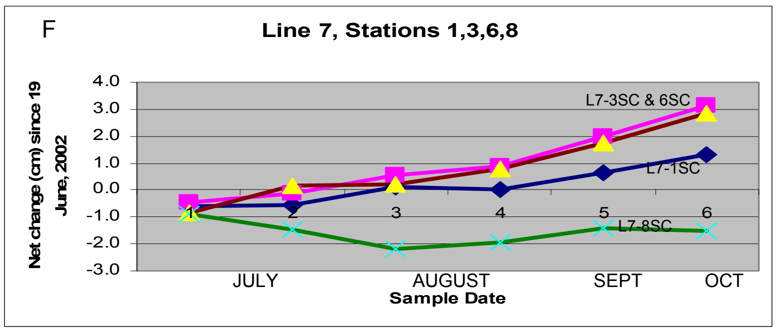
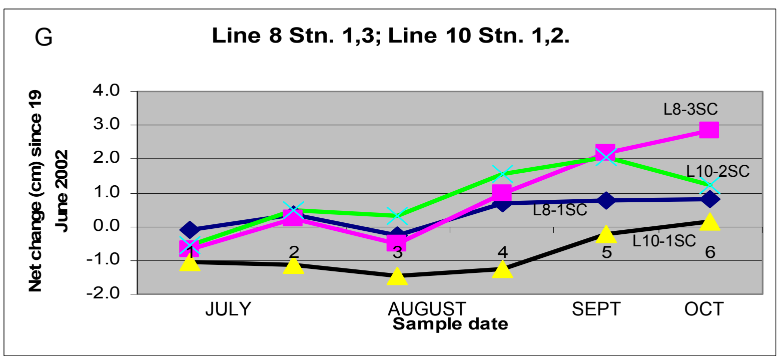


Figure 2.12 (Cont.)







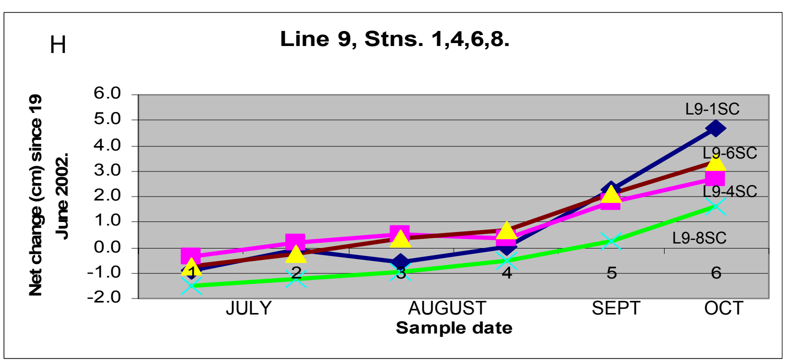
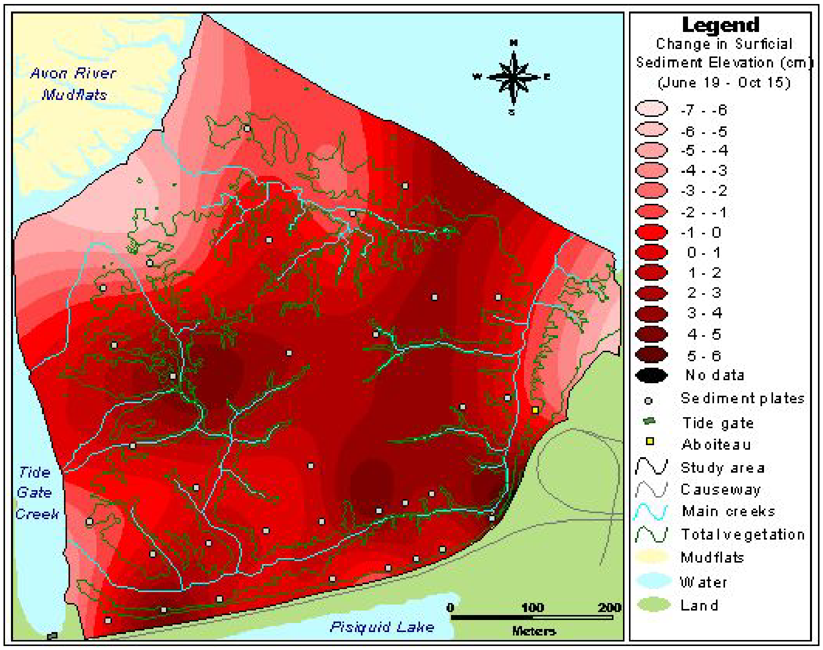


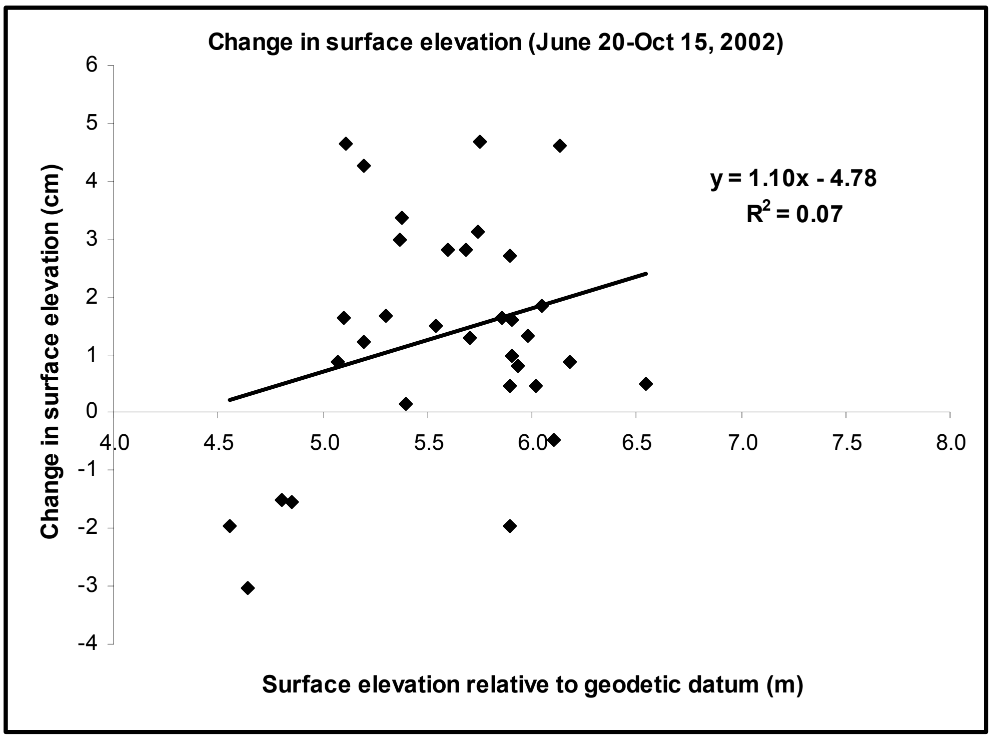
Figure 2.13. Interpolated pattern of net changes in sediment elevation of Windsor Tidal Flat, 19 June to 15 October, 2002.



Accretion of sediment in a salt marsh or a mudflat results partly from settling of suspended sediments when the marsh or mudflat is flooded. Rates of deposition depend upon a number of factors, including: ambient suspended sediment concentration; water column turbulence; density and baffling effects of salt marsh flora; wave action; the frequency and length of time inundated; and the cohesive nature of deposited sediments. The interpolation shown in Figure 2.13 shows that greatest deposition was not always associated with lower elevations, as might occur if the length of time and depth of water over the site constituted the principal control on sediment deposition. In fact, there is no significant correlation (r^2 = 0.07) between the elevation of a site and the amount of sediment deposited over the 4 months of the study (Figure 2.14). The trend line shown in Figure 2.14, which seems to imply a positive relationship between elevation and deposition (i.e. that more sediment was accumulated at higher elevations) becomes almost horizontal if only two stations (L3-8SC and L9-1SC) are removed from the analysis.

It should be noted however that the negative (erosional) values illustrated in Figure 2.13 close to the Information kiosk are simply an artifact of the interpolation procedure and do not reflect processes operating in this region since sedimentation stations were not established.

Figure 2.14: Relationships between elevation and sediment accumulation on Windsor Tidal flat, June – October 2002.



To complement the monitoring of bed levels, direct measurements of sediment deposition were made using sedimentation plates over four successive tides on 23rd and 24th July. Sediment deposition data were recalculated to give an estimate of the amount of sediment deposited during the flooding tide, and then interpolated for the whole of the study area. The mean rate of sediment deposition (7.8 ± 13.0 mg cm^{-2} TC^{-1}) is slightly higher than studies in the Cumberland Basin (van Proosdij *et al.,* 2001; Davidson-Arnott *et al*., 2002). Analysis of the data is continuing.

Suspended particulate matter (SPM) concentrations were estimated from water samples collected in bottles attached to stakes near each sedimentation plate during the four high tide sedimentation experiments. Suspended sediment concentrations ranged from c. 40 $mg.L^{-1}$ to > 550 $mg.L^{-1}$ (Table 2.5). In general, suspended sediment concentrations were higher in the more seaward stations of Line 5 (L5-6, -8, -10) than at other stations

Table 2.6 Suspended sediment concentrations of flooding waters, 23-24 July.

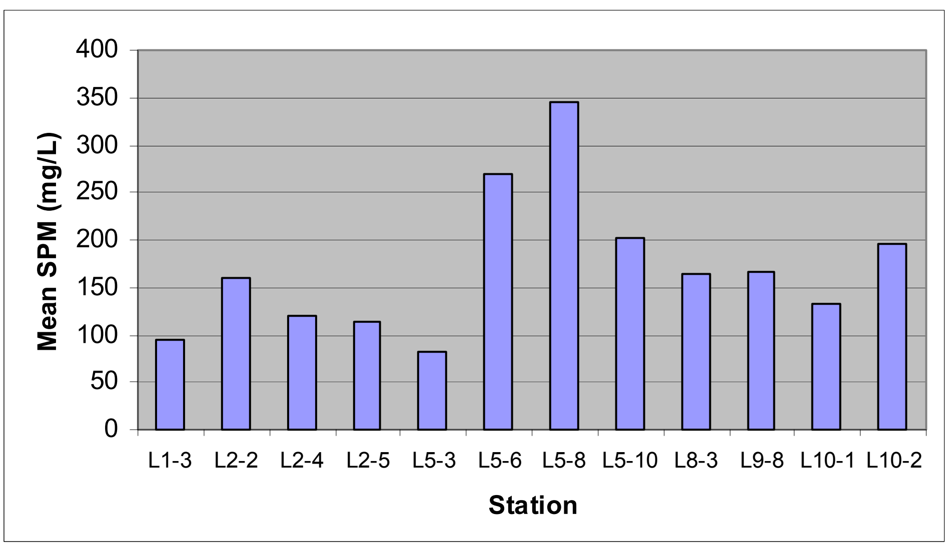
Date & Tide	Station ID	Volume (ml)	Mass filter (g)	Filter + sediment (g)	Mass sediment (g)	[SPM] (mg/L)
23 a.m.	L1-3sc	512	0.4147	0.4395	0.0248	48.44
23 p.m.	L1-3sc	516	0.3891	0.4211	0.032	62.02
24 a.m.	L1-3sc	513	0.5527	0.643	0.0903	176.02
24 p.m.	L1-3sc	521	0.5231	0.5723	0.0492	94.43
23 a.m.	L2-2sc	531	0.3927	0.4457	0.053	99.81
23 p.m.	L2-2sc	519	0.403	0.459	0.056	107.90
24 a.m.	L2-2sc	518	0.5251	0.6218	0.0967	186.68
24 p.m.	L2-2sc	511	0.5232	0.647	0.1238	242.27
23 a.m.	L2-4sc	410	0.3992	0.4415	0.0423	103.17
23 p.m.	L2-4sc	412	0.4059	0.4525	0.0466	113.11
24 a.m.	L2-4sc	396	0.5165	0.5539	0.0374	94.44
24 p.m.	L2-4sc	420	0.5235	0.5945	0.071	169.05
23 a.m.	L2-5sc	512	0.3997	0.4845	0.0848	165.63
23 p.m.	L2-5sc	516	0.3964	0.4304	0.034	65.89
24 a.m.	L2-5sc	518	0.5522	0.5861	0.0339	65.44
24 p.m.	L2-5sc	513	0.5235	0.6062	0.0827	161.21
23 a.m.	L5-3sc	501	0.3857	0.4226	0.0369	73.65
23 p.m.	L5-3sc	516	0.4014	0.434	0.0326	63.18
24 a.m.	L5-3sc	509	0.5248	0.5702	0.0454	89.19
24 p.m.	L5-3sc	507	0.5171	0.5675	0.0504	99.41
23 a.m.	L5-6sc	507	0.4056	0.5402	0.1346	265.48
23 p.m.	L5-6sc	515	0.3942	0.5399	0.1457	282.91
24 a.m.	L5-6sc	500	0.5212	0.6728	0.1516	303.20
24 p.m.	L5-6sc	504	0.5215	0.634	0.1125	223.21
23 a.m.	L5-8sc	519	0.3891	0.5206	0.1315	253.37
23 p.m.	L5-8sc	516	0.4063	0.5232	0.1169	226.55
24 a.m.	L5-8sc	515	0.5214	0.6816	0.1602	311.07
24 p.m.	L5-8sc	60	0.5223	0.5576	0.0353	588.33
23 a.m.	L5-10sc	522	0.4024	0.4934	0.091	174.33
23 p.m.	L5-10sc	515	0.3858	0.4764	0.0906	175.92
24 a.m.	L5-10sc	514	0.5214	0.628	0.1066	207.39
24 p.m.	L5-10sc	505	0.5212	0.6493	0.1281	253.66
23 a.m.	L8-3sc	508	0.3883	0.535	0.1467	288.78
23 p.m.	L8-3sc	561	0.3946	0.4519	0.0573	102.14

Table 2.6 Suspended sediment concentrations of flooding waters, 23-24 July.

Date & Tide	Station ID	Volume (ml)	Mass filter (g)	Filter + sediment (g)	Mass sediment (g)	[SPM] (mg/L)
24 a.m.	L8-3sc	512	0.5271	0.6025	0.0754	147.27
24 p.m.	L8-3sc	506	0.5216	0.5817	0.0601	118.77
23 a.m.	L9-8sc	534	0.3903	0.4643	0.074	138.58
23 p.m.	L9-8sc	524	0.4028	0.4959	0.0931	177.67
24 a.m.	L9-8sc	519	0.5224	0.6218	0.0994	191.52
24 p.m.	L9-8sc	522	0.528	0.6101	0.0821	157.28
23 a.m.	L10-1sc	512	0.3893	0.4571	0.0678	132.42
23 p.m.	L10-1sc	526	0.3992	0.4685	0.0693	131.75
24 a.m.	L10-1sc	529	0.5219	0.6003	0.0784	148.20
24 p.m.	L10-1sc	524	0.5168	0.5789	0.0621	118.51
23 a.m.	L10-2sc	528	0.3936	0.4537	0.0601	113.83
23 p.m.	L10-2sc	523	0.4092	0.5478	0.1386	265.01
24 a.m.	L10-2sc	517	0.5184	0.6473	0.1289	249.32
24 p.m.	L10-2sc	517	0.5184	0.5982	0.0798	154.35

(Figure 2.15). These three stations, and L10-2, which also has relatively higher SPM concentrations, are on or near the unvegetated area of the mudflat. Floodwaters rising onto the tidal flat from the channels have relatively much higher concentrations (cf. Section 2.3.3), but it is apparent that concentrations fall as the water advances through the marsh.

Figure 2.15 Mean suspended sediment concentrations of flood water, 23-24 July 2002.



2.3.3 Tidal Water Environment.

Topographic changes in a salt marsh or an intertidal mudflat are intricately related to the properties of the water that inundates them. The capacity of moving waters to carry materials in suspension is related to the velocity of movement, the turbulence of that movement, and the nature of the material that is available for transport in suspension (Dyer 1986). The relationship between tidal movements and sedimentary deposits is a dynamic one: if velocity and/or turbulence of moving water decreases, its capacity to carry materials in suspension is decreased, and excess becomes deposited; conversely, if moving water carries less than its capacity of suspended material, it will probably capture available sediment from a marsh or mudflat, causing erosion. An example of the latter is available in the Annapolis Estuary (Daborn *et al.* 1995).

The Windsor marsh-tidal flat complex has changed considerably over 32 years, eroding in some areas and accreting in others. In order to understand these changes, it is necessary to know the properties of the water that advance onto the marsh.

Suspended sediment concentrations at Cyclops 1.

CYCLOPS 1 was deployed in the West Channel, below the control gates from 20 June to 5 July 2002. Results are given in Figure 2.16.

As the bore entered the channel, suspended sediment concentrations rose to well above 1,300 $mg.L^{-1}$, and occasionally to nearly 1,700 $mg.L^{-1}$. As water level rose, and turbulence decreased, the concentration of sediments in suspension in near bottom waters fell to <200 $mg.L^{-1}$. The turbulence associated with the tidal bore clearly causes resuspension of deposited material from the floor and sides of the channel. When water movements decrease towards high tide, however, sediments settle through the water leading to stratification in the water column.

Figure 2.16. Suspended sediment concentrations (SPM) at CYCLOPS 1, 20 June -5 July 2002.

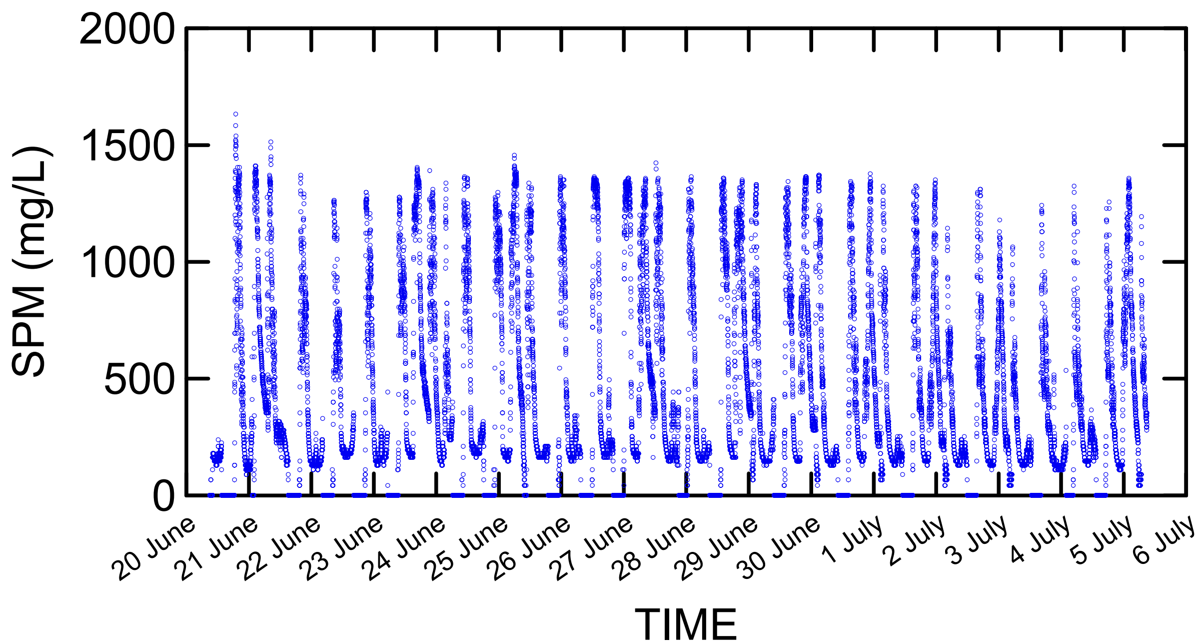
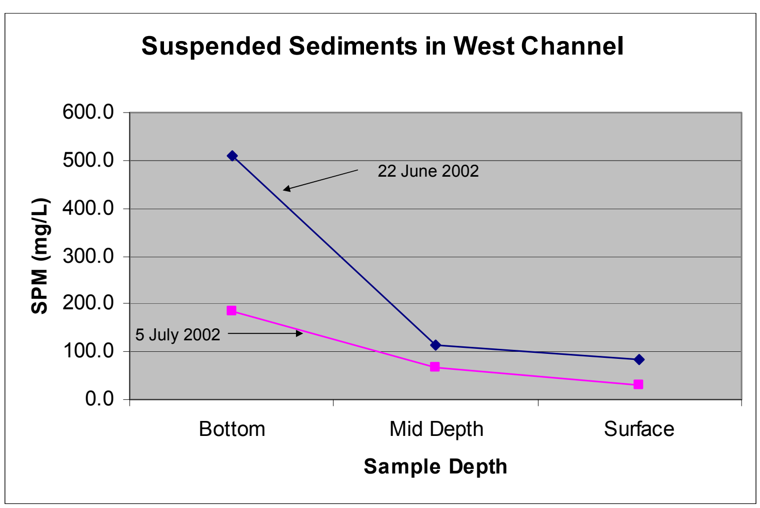


Figure 2.17 shows data from water samples taken in the West Channel near the time of high water on 22 June and 5 July. SPM concentrations were relatively low (< 100 mg.L^{-1}) at the surface, and increased with depth. On 22 June, the deepest sample showed > 500 mg.L^{-1}, whereas on 5 July, bottom waters were < 200 mg.L^{-1}.

Figure 2.17. Suspended sediments in West Channel near high water.



The differences in concentration of ‘bottom water’ may result from differences in actual sampling depth, or in the strength of the bore, but may also be influenced by temporal changes in ambient suspended sediment concentrations. The tidal range on 5 July was 12.1 m, compared with 8.6 m on 22 June (Appendix 1).

Water temperature, salinity and suspended sediments at Cyclops 2.

The second deployment of CYCLOPS and the YSI sonde was in the entrance to the Causeway Channel (cf. Figure 2.2). The location of CYCLOPS 2 was considerably above the level of CYCLOPS 1; as a result, the instrument was only immersed for approximately 3.5 hours in each tidal cycle (Figure 2.19)[4].

Water temperature and salinity at CYCLOPS 2 varied little (Figure 2.18). Water temperature averaged 19.6 °C and ranged between 18.1 and 23.7 °C. Salinity averaged 26.6 ppt and ranged between 25.6 and 28.0 ppt, which are typical of values from the more offshore areas of the Minas Basin. Presumably the large quantity of freshwater that is occasionally sluiced from Pesaquid Lake during the ebb tide becomes thoroughly mixed with seawater in the Avon Estuary before being returned on the next flood. Consequently, the water that enters the Causeway Channel, and therefore inundates the marsh from the southern end, exhibits relatively high salinity.

Suspended sediment concentrations at CYCLOPS 2 showed notably lower values than at CYCLOPS 1, and the pattern was much less consistent than in the West Channel. Except for a single tide on 21 July, most of the highest readings were <1000 $mg.L^{-1}$ (Figure 2.20). During late July and early August, SPM values were very much lower than before, generally <200 $mg.L^{-1}$. The remarkable decline in SPM values in this series between 22 July and 7 August is unlike anything that we have recorded elsewhere in estuaries of the Maritimes. On face value, these records indicate that water flooding into the Causeway Channel during mid-summer carried much lower SPM concentrations than

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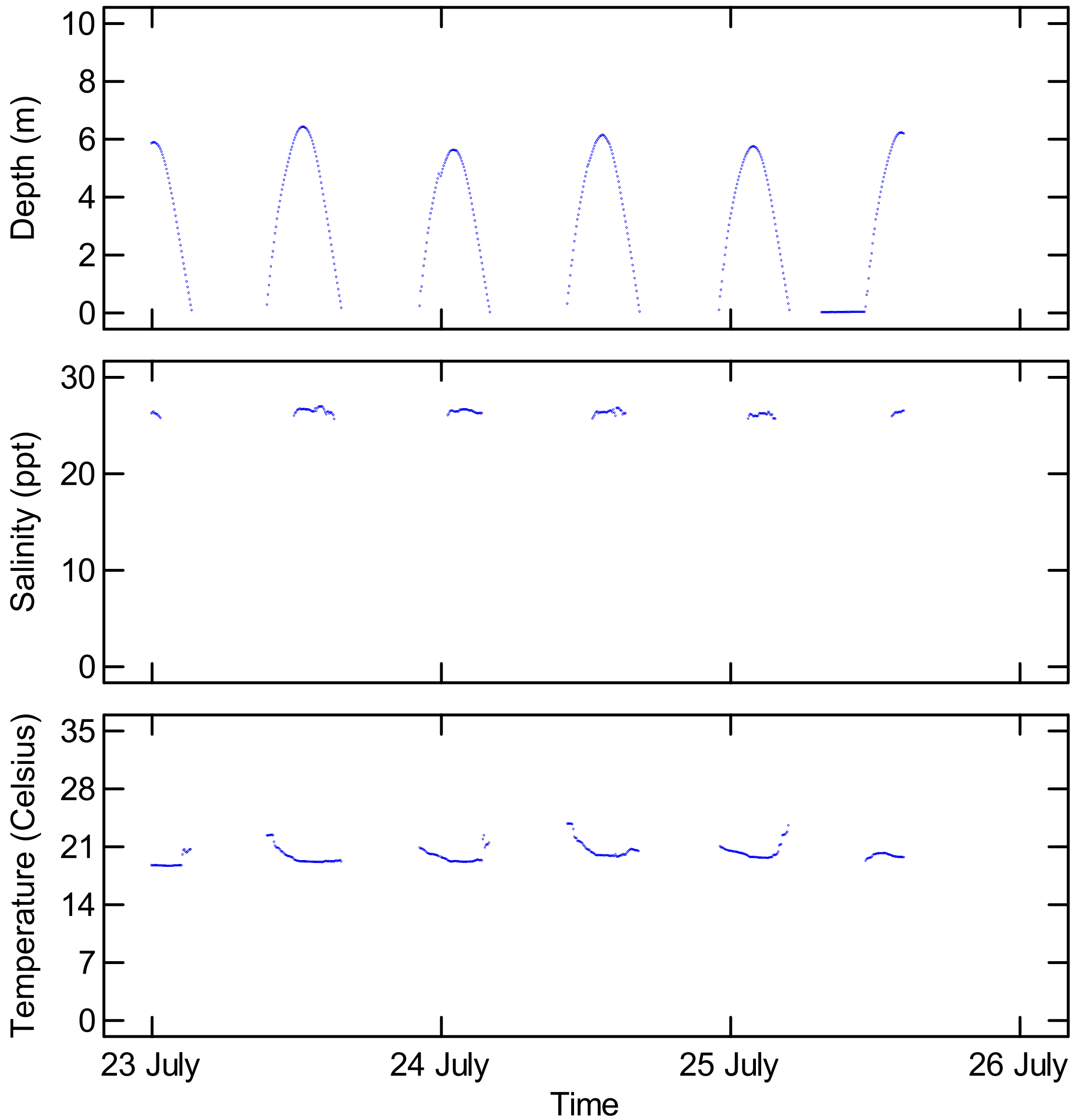
[4] Because spurious readings may occur when the instruments have become exposed on the falling tide, the data for Figure 2.18 have been edited to show only real values during immersion.

previously found in the West Channel, or during 23- 25 July in the East Channel (see below). At present, the CYCLOPS 2 SPM results are unexplained.

Figure 2.18. Water temperature, salinity and depth at CYCLOPS 2, 23-26 July, 2002.



Water temperature, salinity and suspended sediments in the East Channel.

The EMP 2000 was deployed in the East Channel, just upstream from the sewer outfall pipe from 23 – 25 July during the sediment flux measurements described in Section 2.3.2 above. Results are shown in Figure 2.21.

Figure 2.19. Immersion of CYCLOPS 1 & 2 in relation to high water.
(Tide records for 24 July courtesy of K. Carroll).

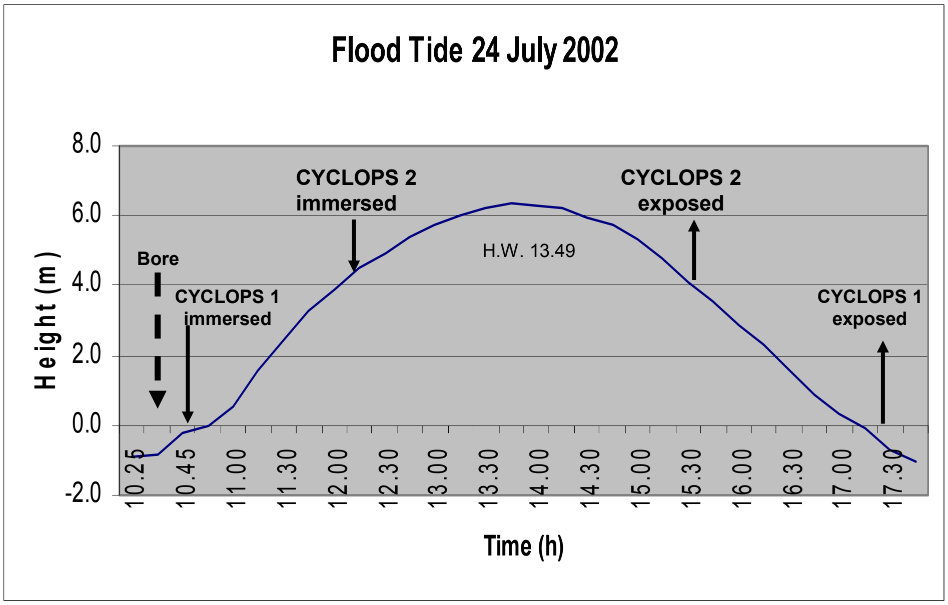


Figure 2.20. Suspended sediment concentrations (SPM) at CYCLOPS 2, 20 July -7 August, 2002.

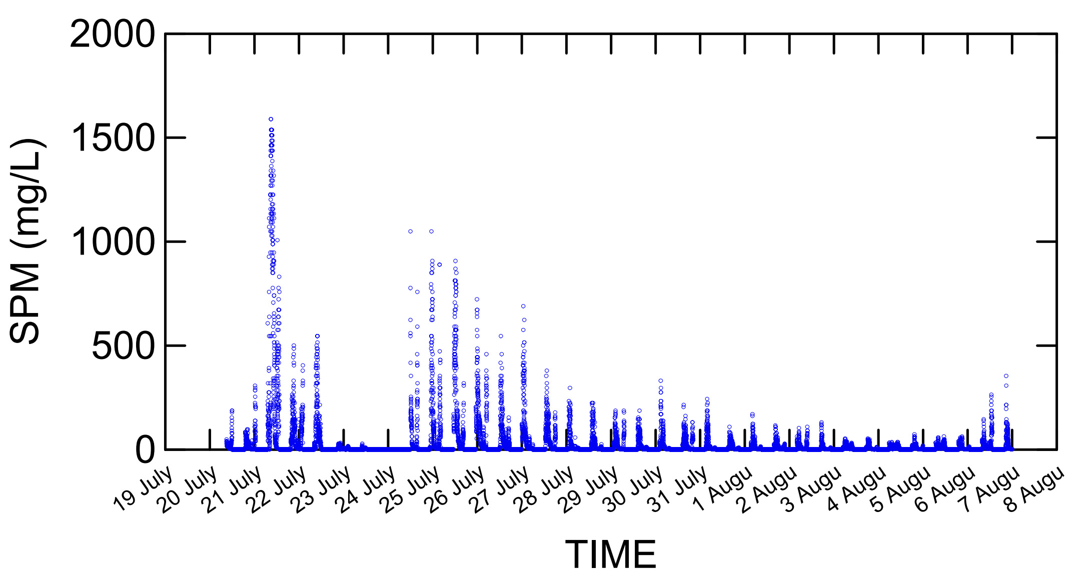
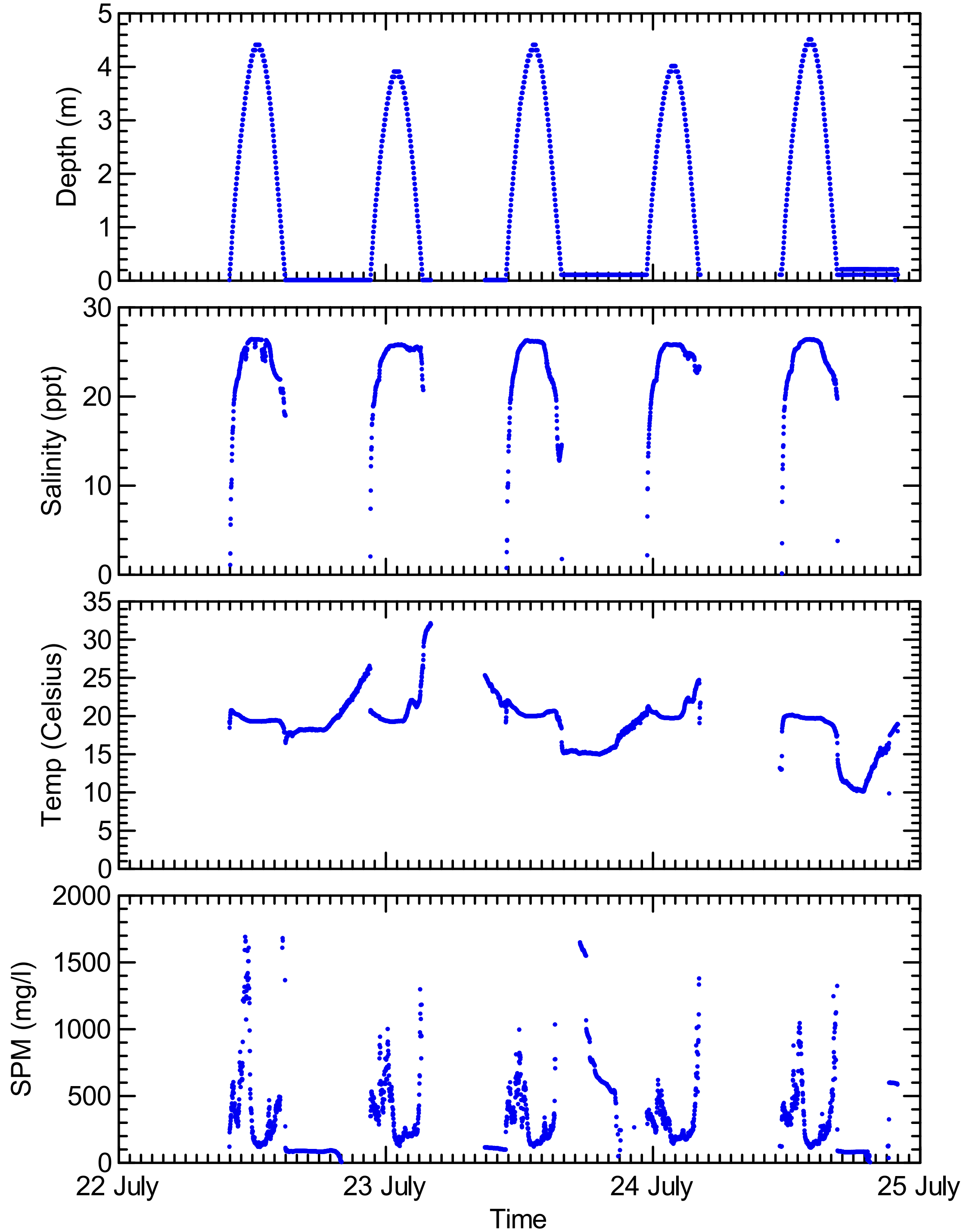


Figure 2.21. Water temperature, salinity, depth and SPM in the East Channel, 23-26 July 2002.



Salinity at the EMP site ranged from 0 to 28 ppt, rising with the increasing depth of immersion. The very low salinity values during the early flood indicate that freshwater flowing from the sewer outfall under the highway on-ramp is initially pushed back towards the marsh without being fully mixed into the advancing seawater. This channel is relatively deep, and hence sheltered from wind effects during the early flood. Water temperature varied from ~8 to >30 ^{o}C during the deployments, the very high value on 23rd corresponding to the highest air temperature (33.5 ^{o}C) of the month (Appendix 2). Because of extensive heating of exposed mudflats during the low tide, water over the marsh tends to follow the air temperature fairly closely during summer. The first water to enter the East Channel carried high SPM levels, reaching more than 1,500 mg.L^{-1}, comparable to the flood waters of the bore. Concentrations then declined as depth increased, but rarely fell below 200 mg.L^{-1}. This channel is relatively narrow, with muddy, unvegetated sides, so that wave action at any stage of the tide causes resuspension of settled material. On the falling tide, the last water to leave the channel is also high in suspended particulate matter, with values between 1,000 and 1,500 mg.L^{-1}. During this short deployment, little evidence of human activity was noted; at other times, mud-sliding down the steep banks near the Visitors' Centre causes substantial disturbance of deposited sediments that may be transported onto the marsh with the next flood tide.

2.4. Summary.

The sedimentological studies conducted in 2002 were designed to provide information on a) the characteristics of the deposit that has accumulated since closure of the Causeway, and b) the short-term changes and interactions governing accretion and erosion of the marsh—mudflat complex. Results can be summarized as follows:

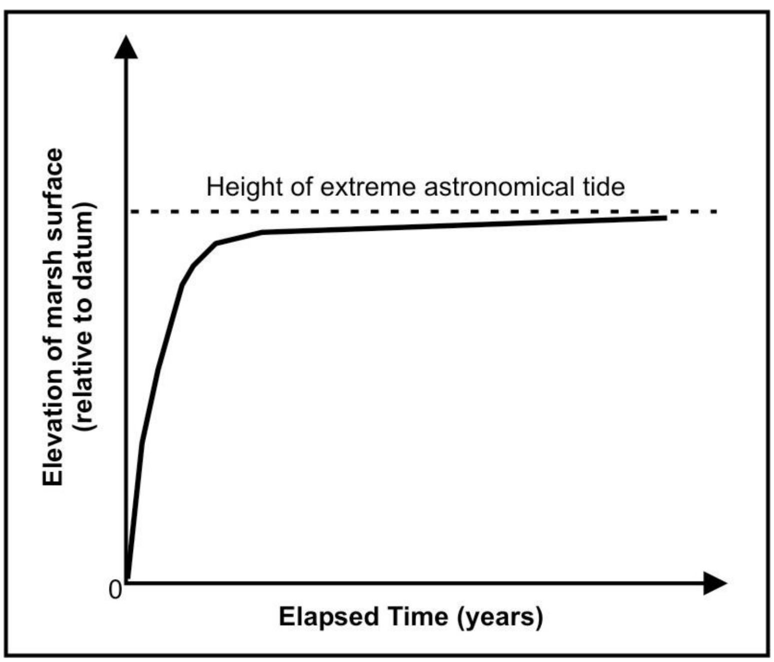
23. The sediments of the Windsor Causeway tidal flat are predominately clayey silts (~68% silt and ~23% clay), with mean grain size of 23-30 µm.
24. Water contents ranged from 29.7 to 57.3% (mean ~44-46%), and organic content from 0 to 16.9% (mean 6.68 ± 5.82%). Water contents are comparable to the high

values recorded by researchers in 1976-79; organic contents are higher than previous records from the Bay of Fundy.

25. An extensive array of stations was established for long term monitoring of changes to the marsh and mudflat. Station locations were surveyed in and an updated GIS database established.
26. Short-term (<4 months) monitoring of the 33 stations showed that elevation of most (27) exhibited a net increase, averaging 1.3 cm (± 1.96) by mid-October. Six stations exhibited a decrease in elevation; most of these were adjacent to tidal channels, where there was visible evidence of slumping and erosion. Stations in vegetated areas showed greatest consistency in terms of elevation; colonization by *Spartina alterniflora)* typically causes stabilization of intertidal sediments.
27. Ambient sediment concentrations in flood water in the channels and over the marsh, ranged up to 1,700 $mg.L^{-1}$ in the bore or the wave front of the advancing tide. Concentrations then declined as water depth increased. Ambient sediment concentrations in floodwater over the marsh ranged from high values of ~500 $mg.L^{-1}$ at the edges of the marsh (over muddy unvegetated sites) to less than 100 $mg.L^{-1}$ at stations in the middle of the marsh. Studies of accumulation on sedimentation plates showed that an average of 7.8 $mg.cm^{-2}$ (± 13.0) settled out during each flood tide. Analysis of these data is continuing.

Results from this study emphasize the highly dynamic nature of this marsh – mudflat complex more than 3 decades after completion of the Causeway. Models of mudflat/ saltmarsh evolution developed for macrotidal systems in the United Kingdom (e.g. Pethick, 1981; Allen, 1990) can well be applied in some form to the Windsor mudflat/marsh complex. The rate at which a mudflat / marsh builds up is theoretically a function of the rate of inorganic sedimentation, organic (peat) production, rate and trend of change in sea level and the rate of long term compaction. Figure 2.22 illustrates that the rates of sedimentation during the early stages of marsh evolution are very rapid, supporting early observations by Amos, 1977. However, over time, as the mud consolidates and the vegetation becomes established, these rates of sedimentation will decrease as the marsh surface rises up within the tidal frame, 'fed' by fewer and fewer tides laden with suspended sediment. Eventually the marsh will build to a stable elevation that is less than that of the extreme tide (Figure 2.22). It is likely that the Windsor mudflat/ marsh complex is presently around the midpoint of the upward trajectory. The rates of sedimentation measured in this study indicate that the marsh is still accumulating sediment quite rapidly and will keep pace with rising sea levels. In addition, *Spartina alterniflora* continues to colonize the mudflat surface at a rapid rate (Townsend, 2002) and will do so until all of the available mud substrate has been covered. At the periphery of the mudflats, however, especially along some channel sides, erosion is occurring at intervals, resulting in the slumping and remobilization of sediments.

Figure 2.22: Model of evolution of mudflat / marsh surface modified from Allen, 1990. Curve depicts elevation of the surface relative to geodetic datum over time.



The high organic content of the sediments indicates that the marsh is unusually rich. Some of the organic material may be derived from effluent from the Town of Windsor, which empties into the East Channel, and may then be redistributed across the marsh by the flooding tide. However, biological studies (cf. section 3) show that both the marsh and mudflats are highly productive. It is these resources that may be impaired by further expansion of the Causeway on the seaward side.

3.0 Biological Studies.

3.1 Introduction.

Early research following the construction of the Windsor Causeway emphasized the relatively inhospitable environment that was being created (e.g. Risk *et al.* 1977, Turk *et al.* 1980). By comparison with the rich marshes and mudflats of other parts of the Minas Basin, the Windsor mudflat harboured few organisms, and was clearly much less productive. Since the sediments have stabilized (especially with colonization by *Spartina),* and the mudflat began to be transformed into a salt marsh, the biological characteristics have also changed dramatically. For most casual observers, the growth of the new marsh and the appearance of large numbers of shorebirds during late summer have been visible evidence of the continuing development of the Windsor mudflat.

Before 1604, salt marshes were extensive throughout the upper Bay of Fundy. However, it has been estimated that approximately 80 percent of the original Bay of Fundy salt marshes have been lost as a result of extensive dyking, much of which was carried out in the upper reaches of the Bay by the original Acadian settlers (Gordon and Cranford 1994). The present day extent of salt marsh within the Minas Basin is about 2700 ha, probably <15% of the pre-Contact area.

Salt marshes are typically categorized as either high or low marsh. High marsh occurs above the mean high water level and consists largely of marsh hay, *Spartina patens,* although several other salt tolerant plants are also present. Low marsh is typically present between mean high water and the high water level of neap tides. It is composed almost exclusively of marsh cord grass, *Spartina alterniflora*. The development of high marsh along the present Windsor mudflat is confined to a narrow zone adjacent to the seaward side of the causeway. Most of the Windsor marsh consists of low marsh plants. Within the Bay of Fundy region low marsh vegetation typically begins to grow in early spring and dies off in late fall. During winter much of the dead and decaying surface vegetation is removed by extensive ice scouring (Gordon *et al.* 1985).

Salt marshes are among the world's most productive ecosystems and are considered to be extremely valuable. In addition to contributing organic matter to marine food webs, they are sometimes grazed on directly, particularly by water fowl (Van Zoost 1969). They also play other important roles such as providing habitat and nursery areas for various organisms and in contributing to the stabilization of shorelines.

The fate of organic matter produced by salt marshes varies according to the geomorphologic and physical characteristics of the marsh (Odum *et al.* 1976). Salt marshes occurring in areas of high tidal amplitude, and which are also relatively exposed to the sea, tend to export most of their production. In contrast, those that occur in areas of low tidal amplitude, have extensive development of tidal creeks, and are protected from the open sea by structures such as offshore barrier islands, tend to retain most of their production. They may even capture organic matter derived from neighbouring shorelines or marshes as detritus is brought onto the marsh with the flood tide. Bay of Fundy marshes fall into the first category (i.e. organic matter exporters) and the low marshes export most of their production (Morantz 1973; Smith *et al.* 1980; Gordon *et al.* 1985; Gordon and Cranford 1994). As a result, Bay of Fundy salt marshes are considered to play a significant role in contributing organic matter to the lower benthic intertidal and offshore pelagic detrital food webs.

Proposals to expand the causeway to accommodate twinning of Highway 101 inevitably raise the issue of important estuarine resources that may be affected. Because of the intermittent nature of research in the past, there are few data relating to biological characteristics of the present marsh—mudflat complex. The purpose of biological studies carried out during the summer of 2002 was to provide baseline information for a subsequent assessment of the ecological implications of expanding the causeway. Principal foci were on the marsh plants, particularly *Spartina alterniflora,* and on the benthic invertebrates that form the food for fish and birds. The microscopic plants (i.e. microflora -- mainly diatoms and blue-green algae), which often play a significant role in the stabilization of sediments (Decho 1990, Patterson and Daborn 1991, Daborn *et al.*

1993) were not explicitly examined, however measurements of chlorophyll *a* in surficial sediments may be used as an indicator of the productivity of microscopic forms.

Although preliminary attempts were made to assess the presence and activities of fish and birds, lack of time and sampling difficulties rendered the results of limited value.

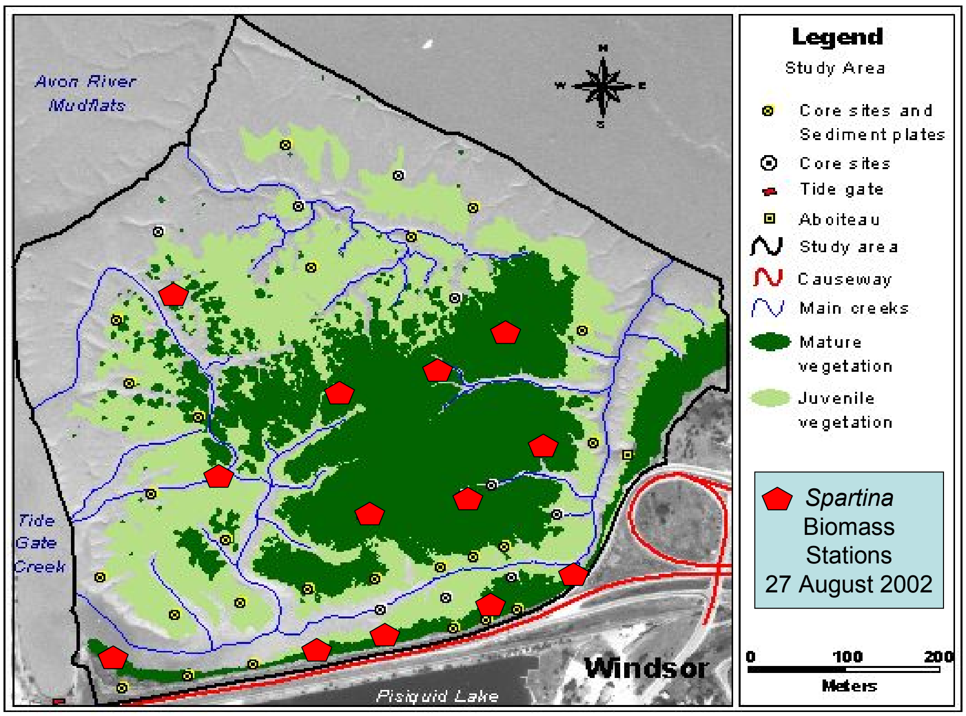
3.2 Methods.

Samples for sediment chlorophyll *a* content, an estimate of benthic diatom abundance, were collected with a 1.2 cm diameter syringe modified to sample the upper 5 mm of sediment. Samples were stored frozen in scintillation vials until analysis. Chlorophyll was extracted by adding 15 ml of 90% acetone to the vial, shaking vigorously by hand, and allowing extraction to proceed for 24 hr in the dark under refrigeration. The sample was then centrifuged at 2400 rpm for three minutes and the supernatant transferred to a 1 cm path length cuvette. Measurements of absorbance were made at wavelengths of 665 ηm for chlorophyll, and 750 ηm for turbidity before and after acidification with 0.1 ml of 10% HCl. Chlorophyll *a* concentration was calculated from absorbance according to the equations presented by Lorenzen (1967).

Sampling of the principal vegetation was aimed at determining the productivity of this relatively new marsh. Experience from previous work by the Saint Mary's team had indicated that plant growth was especially vigorous on this marsh compared with other Bay of Fundy marshes (Townsend 2002).

Changes to the vegetation were monitored at two week intervals during the growing season. Mean height of the vegetation was determined to the nearest 0.5 cm using a meter stick at each sedimentation station at bi-weekly intervals. In October, the overall standing crop biomass was determined by removing all *Spartina* from within a 20 cm by 20 cm square deposited randomly near each of 13 selected sites (Figure 3.1). All removed material was placed in a labeled zip lock bag, and weighed in the laboratory. Following drying to constant weight, the samples were reweighed. Vegetation density was determined through a stratified random sampling design. The number of stems (determined at ground level) located within five randomly chosen 20 cm by 20 cm grids within a 1 m^2 quadrat were counted at each selected station when sediment cores were collected. The total number of stems obtained from the smaller grids was multiplied by 5 to obtain an estimate of stem density over one square meter.

Figure 3.1. Sample stations for biomass estimates of *Spartina alterniflora,* August 2002.

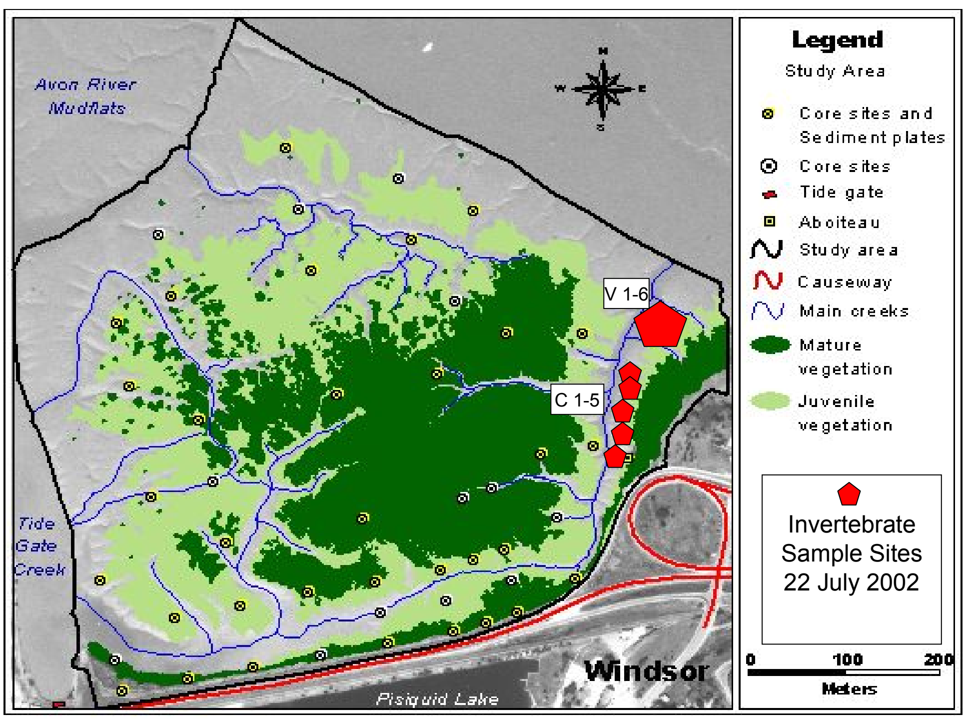


Samples of benthic invertebrates were taken on three separate occasions during July using hand-held core samplers. On 4-5 July, large core samplers (9.8 cm diam., 75.44 cm^2) were used to obtain a single sample at each transect station. The core was driven by hand as deep as possible into the substrate at a location approximately 0.5 m south of each marker stake. Each sampler was provided with a serrated metal edge, which, when rotated, cut through the plant roots; often a sharp knife was then required to sever roots that extended below the full depth of penetration of the sampler. All contents of the core were removed to a labeled bag, returned to the laboratory, and washed carefully through a

250 µm sieve. Invertebrates were sorted from the mass of plant material remaining, stored in ethanol, identified to at least family level, and enumerated under a microscope.

On 22 July, a second series of samples was taken in unvegetated areas at the east side of the marsh—mudflat. Each of these samples was taken with a small core sampler (4.8 cm diam.; 26.42 cm^2), inserted to a maximum depth of 12 cm. Three random core samples were taken at each of six sites (V1-6) in the area previously studied by Partridge (2000); three replicate samples were also taken at each of 5 sites (C1-5) located along the bank of the East Channel, up to the vicinity of the sewer outfall. Locations are indicated in Figure 3.2. Each sample was stored separately in a labeled plastic bag, carefully washed through a 250 µm sieve, sorted, preserved and processed as the other core samples.

Figure 3.2. Invertebrate sample stations in the East Channel, 22 July 2002.

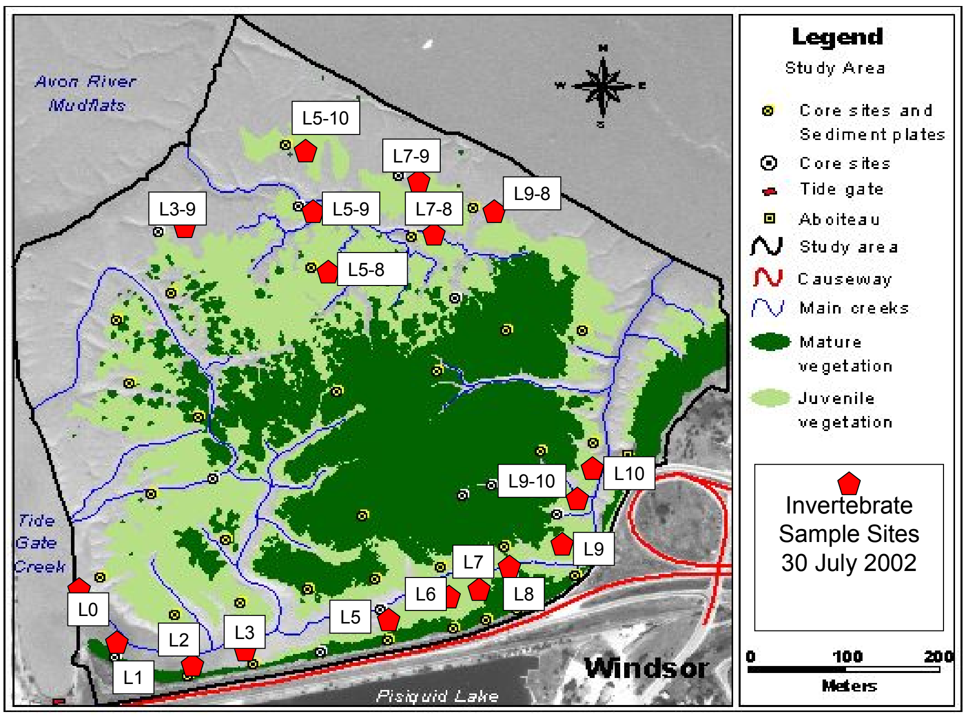


On 30 July, a third series of replicated small core samples was taken at unvegetated stations throughout the marsh, along the channel adjacent to the causeway (the Causeway

Channel), and along the East channel south of the sewer outfall (Figure 3.3). These samples were processed in the same way.

Two non-quantitative plankton hauls were taken in the West Channel (below the control gates) on 22 June and 19 July, using a 0.6 m diam. net fitted with 150 µm mesh. Samples were preserved in 10% formalin for identification in the laboratory.

Figure 3.3. Invertebrate sample stations, 30 July 2002.



Three separate attempts were made to trap fish in the Causeway Channel in July and August, using a combination of seines and trap nets. Because of difficulties with high water velocity and the steep side of the channel, a seine proved ineffective. Similarly, a trap net set in the Causeway Channel at high tide on 7 August failed to capture any fish.

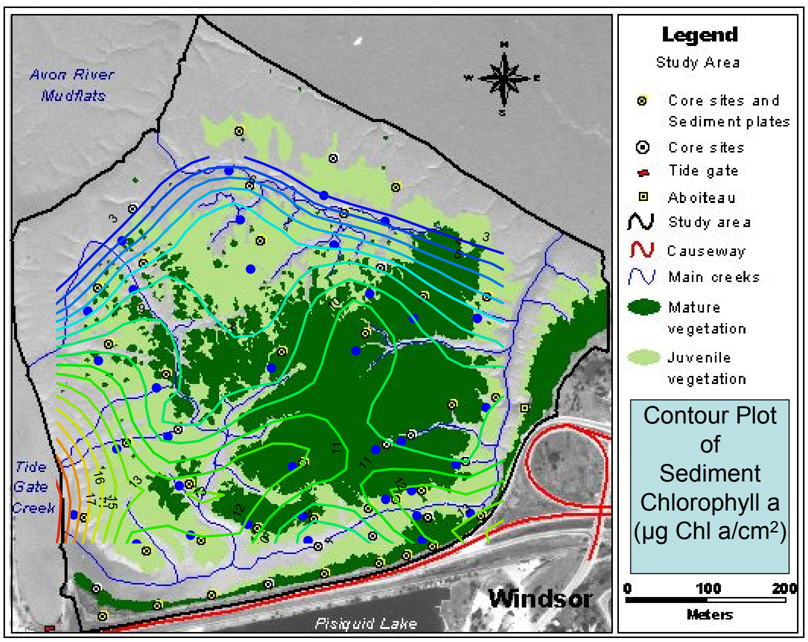
Observations of bird presence on the marsh and mudflats were made throughout the summer. A specific survey of bird use and activity was carried out by two teams of observers on 2 August, during the falling tide. Observers were located on the eastern dyke near the Tourist Information Centre, and on the western side of the West Channel.

3.3 Results.

3.3.1 Chlorophyll *a*.

Sediment chlorophyll *a* concentrations ranged from 2.3 to 18.2 $\mu g.cm^{-2}$, with a mean of 9.8 $\mu g.cm^{-2}$ (Table 3.1). Distribution pattern of the chlorophyll over the marsh and mudflat is shown in Figure 3.4.

Figure 3.4. Contour plot of chlorophyll *a* concentrations in sediments of the marsh and mudflats.



Highest values were encountered on the western side of the flat, intermediate values on the main portion of the marsh, and lower values on the unvegetated areas to the north. These high chlorophyll values indicate that deposited sediments in the Windsor marsh and mudflat probably contain active and productive microflora. Chlorophyll values vary in relation to the abundance of microscopic algae that are present, which is determined by the amount of light and nutrients available for production, and the abundance of animals (e.g. *Corophium volutator*) that may graze on the diatoms. Low values of chlorophyll in

Table 3.1. Summary of sediment chlorophyll *a* and marsh biomass characteristics of the Windsor marsh—mudflat complex.

Station Number	UTM Easting (NAD)	UTM Northing (NAD)	Sediment Water Content (%)	Sediment Organic Content (%)	Sediment Chlorophyll *a* Content (μg/cm^2)	Salt Marsh Grass Biomass (g/m^2)
L1-1SC	409569.80	4983210.22	35.0	6.6	13.8	-
L1-2C	409560.28	4983259.04	35.4	5.4	-	1355.5
L1-3SC	409537.59	4983385.21	41.7	6.0	18.2	-
L10-1SC	410270.13	4983599.74	40.4	3.8	10.7	-
L10-2SC	410254.66	4983777.78	48.8	5.0	7.3	-
L2-1SC	409667.28	4983228.35	34.2	5.4	10.1	-
L2-2SC	409649.13	4983326.83	46.2	-	7.5	-
L2-3SC	409613.70	4983516.84	44.3	4.3	14.0	-
L2-4SC	409581.28	4983693.51	40.9	5.1	12.0	-
L2-5SC	409562.38	4983792.31	41.3	-	5.2	-
L3-1SC	409765.31	4983247.20	55.7	6.8	7.8	-
L3-3SC	409745.26	4983344.73	43.7	6.1	12.2	-
L3-4SC	409725.06	4983443.33	47.3	5.6	16.9	1108.9
L3-5C	409704.74	4983541.45	47.0	5.2	3.9	-
L3-6SC	409684.28	4983638.90	42.0	3.8	10.9	723.2
L3-8SC	409643.36	4983835.40	48.4	5.3	9.6	-
L3-9C	409623.04	4983933.02	43.5	13.0	3.6	-
L4-1C	409864.87	4983266.03	39.6	5.7	12.5	929.4
L4-2SC	409846.05	4983366.43	44.2	5.9	14.3	-
L5-10SC	409813.11	4984072.81	37.5	3.7	4.2	-
L5-1SC	409963.30	4983284.80	43.2	6.9	9.6	1070.3
L5-2C	409953.96	4983333.81	49.5	6.2	4.4	-
L5-3SC	409944.59	4983382.98	44.2	0.0	6.8	-
L5-4SC	409926.17	4983481.36	48.6	13.8	14.8	2485.9
L5-6SC	409888.51	4983678.67	49.7	6.0	7.8	768.3
L5-8SC	409851.77	4983876.44	43.8	16.6	5.7	-
L5-9C	409833.44	4983974.73	47.0	0.2	11.4	-
L6-1SC	410061.32	4983302.74	41.3	6.6	4.9	-
L6-2C	410052.24	4983352.60	42.0	6.1	-	-
L6-3SC	410043.52	4983402.36	44.8	6.2	-	-
L7-1SC	410109.44	4983317.66	46.4	4.8	10.1	2340.1
L7-3SC	410091.72	4983416.20	41.2	5.3	12.7	-
L7-4C	410074.07	4983515.51	39.9	5.9	10.9	1546.3
L7-6SC	410038.50	4983712.84	47.7	6.3	11.4	743.2
L7-8SC	409999.81	4983924.72	44.8	2.7	7.0	-
L7-9C	409981.84	4984023.41	47.7	4.2	2.3	-
L8-1SC	410156.64	4983334.74	41.3	6.0	11.7	-
L8-2C	410147.22	4983383.72	45.9	5.7	15.1	-
L8-3SC	410137.94	4983433.54	49.4	5.7	18.2	-
L8-4C	410119.27	4983531.64	42.9	7.3	5.7	-
L8-5C	410063.27	4983827.14	46.6	4.5	11.7	-
L9-1SC	410242.29	4983387.97	43.7	5.6	13.8	1144.1
L9-3C	410216.95	4983486.24	44.6	3.0	6.5	-
L9-4SC	410191.65	4983584.26	45.4	5.5	-	799.5
L9-6SC	410141.29	4983777.88	46.5	6.4	8.3	1328.7
L9-8SC	410090.99	4983971.75	46.0	5.3	3.6	-

unvegetated areas correspond to high numbers of *Corophium* at the time of sampling. Although variable, the range and maximum chlorophyll concentrations rank among the highest that have been recorded for mudflats in the inner Bay of Fundy (Table 3.2).

Table 3.2. Summary of sediment chlorophyll *a* values reported for sites located within the upper Bay of Fundy.

Sample Date	Site	Chlorophyll a (µg/cm^2)			Reference
		N	Mean	Range	
19 to 21/06/02	Windsor	42	9.8	2.3 – 18.2	This study
16/05/96	Windsor	72	3.9	2.3 - 6.9	Partridge (2000)
21/02/96	Windsor		4.2		Partridge (2000)
03/06/96	Windsor	16	2.8	1.1 - 6.1	Partridge (2000)
01/07/77	Pecks Cove	-	7.0	-	Hargrave *et al.* 1983
01/07/77	Anthony Park	-	10.0	-	Hargrave *et al.* 1983
07/89	Starrs Point	-	3.0		Daborn *et al.* (1991)

There is no correlation between chlorophyll values and the organic matter content of the sediment (r^2 = -0.38), because the latter is largely attributable to detritus (dead organic matter) derived from marsh plants.

3.3.2 *Spartina alterniflora.*

During the course of the summer, height of *Spartina* stems was recorded at the same time as sediment plate depths and samples. In mid-June, *S. alterniflora* plants were between 8 and 50 cm in height (ave. 31 cm); by late August, the vegetation had reached heights ranging from 49 to 170 cm (average 121 cm) (Figures 3.2 and 3.3). These values far exceed other records for salt marshes in the upper Bay of Fundy (Table 3.3).

Table 3.3. Summary of maximum height of salt marsh (*Spartina alterniflora*) reported for sites located within the upper Bay off Fundy.

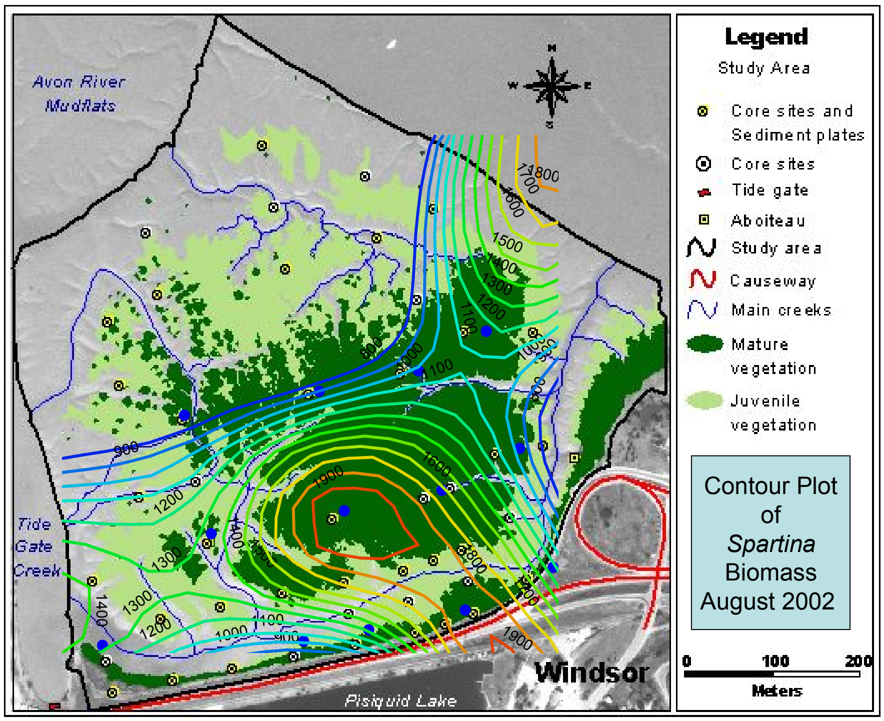
Site	Height (cm)	Comments	Reference
Windsor	121 (49-170)	Mean and range	This study
Grande Pre	35 (28-42)	Mean and Range	Cranford *et al.* 1989
Kingsport	39-69	Range	Smith *et al.* 1980
Grande Pre	84-112	Range	Smith *et al.* 1980
Wolfville	43	Mean of 24 Samples	Gross *et al.* 1991

Figure 3.5. View of Windsor marsh looking northwestward, 15 July 2002.

Figure 3.6. View of Windsor marsh looking northward, 15 August 2002.

Estimates of the biomass of *Spartina alterniflora* were made on the basis of samples at 13 selected stations across the marsh (cf. Figure 3.1 above). An interpolation of the distribution of *Spartina* biomass over the marsh is shown in Figure 3.7.

Figure 3.7. Contour plot of *Spartina alterniflora* biomass on the Windsor marsh, August 2002. (Units are g dry weight.m^{-2})



Maximum biomass was encountered at stations on either side of the Causeway Channel, where the marsh has been established for the longest time, and the elevation is higher than elsewhere. Although the number of sample stations is small, and probably does not adequately represent the variation in biomass occurring on the marsh as a whole, the results represent the highest values recorded so far for a marsh in the Bay of Fundy.

The annual above ground net production of *S. alterniflora* along the Atlantic coast of North America ranges between about 500 and 2000 g dry wt m^{-2} (Marinucci 1982). Numerous studies carried out within the upper Bay of Fundy have reported annual productivities ranging from about 270 to 600 g dry wt per m^2 (Morantz 1973; Smith *et al.* 1980; Gordon *et al.* 1985).

Although the productivity of the Windsor salt marsh was not measured in this study, the estimates of late summer biomass provide a rough estimate of production for comparison with other studies.[5] The biomass attained in late August is considerably greater than the maximum biomasses measured in other low salt marshes within the upper Bay of Fundy (Table 3.4). This is also true of the maximum plant height (Table 3.3 and see Figure 3.6).

Table 3.4. Summary of maximum above ground salt marsh (*Spartina alterniflora*) biomass reported for sites located within the upper Bay off Fundy.

Site	**Biomass (g dry wt m^{-2})**		**Reference**
	Mean	**Range**	
Windsor	1107	637 – 2189	This study
Cumberland Basin	563	-	Gordon *et al.* 1985
Anthony Park	389	-	Hargrave *et al.* 1983
Pecks Cove	235	-	Hargrave *et al.* 1983
Grande Pre	300	-	Cranford *et al.* 1989
John Lusby Marsh	483	-	Morantz 1976
Kingsport	120	473 - 609	Smith *et al.* 1980
Grande Pre	160	684 - 816	Smith *et al.* 1980

The reason for the high biomass measured in this study is difficult to determine based on present data. The factors considered to be most important in controlling salt marsh growth are length of growing season (Turner 1976), nutrient limitation, especially nitrate (Gallagher 1975), depth and duration of inundation (Gordon *et al.* 1985) and sulfide toxicity (Howes *et al.* 1981.) Wiegert *et al.* (1983) point out that some of these factors (nitrate limitation and sulfide toxicity) are largely a result of anaerobic conditions. Under these conditions sulfide builds up and nitrate regeneration by sediment microorganisms is very slow. The importance of nitrogen availability in the production of Minas Basin salt marshes was demonstrated in a study by Smith *et al.* (1980) in which nutrient enrichment

[5] This would be a minimum estimate because salt marsh continues to grow into early fall, and because the loss of material resulting from the shedding of leaves during the growing season is not accounted for.

of salt marsh sediments by the addition of ammonium nitrate resulted in productivity increases of more than 80 percent.

The Windsor mudflat has two characteristics that may explain the large biomass of low marsh. Older marshes typically have a shallow aerobic layer near the surface, often less than 1 cm thick, (Anderson and Hargrave 1984), whereas that of the Windsor marsh is deep; secondly, most of the low marsh has been established at a relatively high elevation within the intertidal zone.

The depth of the sediment anaerobic layer underlying the area in which biomass estimates were made was exceptionally deep, averaging 11.8 cm, making it doubtful that sulfide toxicity is important in limiting growth. In addition, biological remineralization of organic nitrogen to nitrate is likely much more rapid than it would be under anaerobic conditions.

The high elevation of the salt marsh results in it being exposed for a relatively long period of time and therefore it is not subject to the light limitation and higher rates of leaf loss that occur in salt marsh located at low elevations of the intertidal. The spatial distribution of biomass (Figure 3.7) indicates the importance of elevation as the greatest biomass was attained within areas of the salt marsh having the highest elevation and nearest to the high tide level. The proximity of the salt mash to a storm sewer outflow suspected of carrying some untreated sewage (which typically has high nitrate concentrations) may be another factor contributing to the high biomass levels.

Whatever the reasons are for the exceptionally vigorous growth of *S. alterniflora* in this marsh, most of the above-ground biomass is removed from the site during the winter months as a result of die-back and ice effects. Figure 3.8 shows the marsh in late December, before the winter ice had really developed. Figure 3.9 shows that much of the marsh cord grass stems have been broken off and piled as an extensive deposit along the sides of the causeway. All of this material will eventually become fragmented, dispersed, and decayed, contributing to the food web of the Avon Estuary.

Figure 3.8. Windsor marsh looking westward from the Information Centre, 23 December 2002**.**

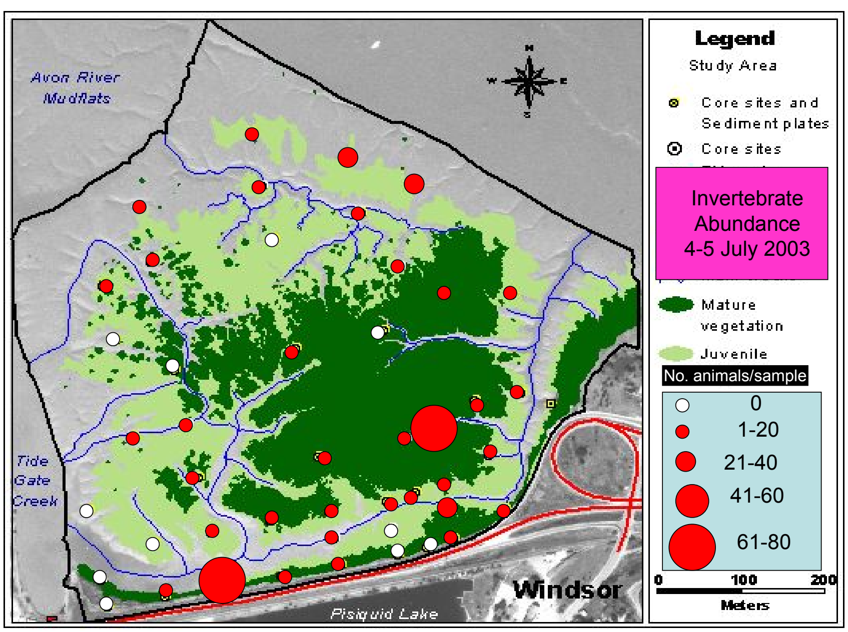
Figure 3.9. *Spartina alterniflora* detritus against the Windsor Causeway, 23 December 2002**.**

3.3.3 Benthic invertebrates.

As with most intertidal flats of the inner Bay of Fundy, the fauna of the Windsor tidal flat exhibits little diversity at any given site, often being dominated by a small number of species, each of which may nonetheless be extremely abundant. Principal species encountered in the samples were the amphipod *Corophium volutator,* the polychaete worm *Nereis diversicolor*, and the bivalve *Macoma balthica.* These are the same species recorded by Risk and his co-workers (Risk *et al* 1977, Turk *et al.* 1980), and by Partridge (2000). It is probable that other species, particularly the polychaetes *Heteromastus filiformis* and *Manayunkia aestuarina*, were also present, but these are small or thin worms that are difficult to sort from samples containing a great deal of root material. Consequently, these other, smaller species may have been present. Identification below the family level of the polychaetes has not yet been completed.

Results of the preliminary survey of invertebrates at transect stations conducted in early July are shown in Figure 3.10. Symbols indicate the total number of organisms recovered

Figure 3.10. Invertebrate distributions at transect stations, 4-5 July 2002.



from the large sampler (area 75.44 cm^2)[6]. Most samples contained few (<10) to no animals, especially in densely vegetated areas (Figure 3.11); where large numbers of animals were present, the station was located on a muddy, unvegetated site, usually near one of the tidal channels, and the dominant organism was *Corophium volutator.*

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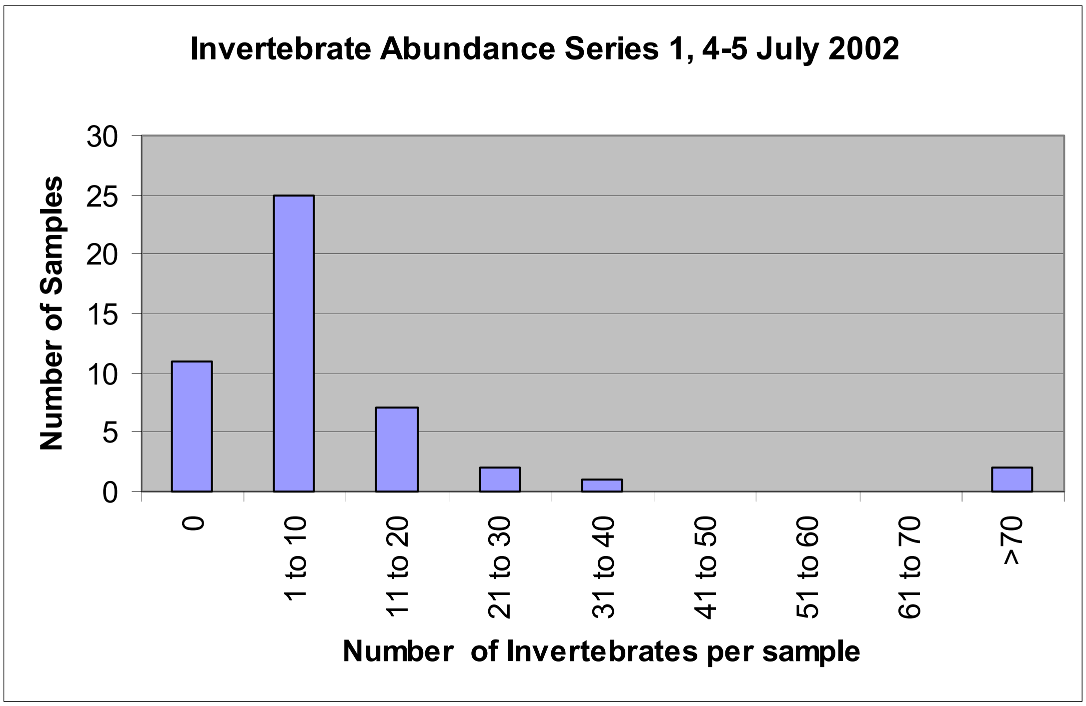
Figure 3.11. Frequency of capture of invertebrates at transect stations, 4-5 July 2002.



The results clearly illustrate that benthic invertebrates are absent or very uncommon in the presence of dense *Spartina alterniflora.* Because the transect stations were laid out primarily to permit study of the growing marsh, two additional series of collections were made in areas that were unvegetated, particularly along the sides of the East and Causeway Channels, and at transect stations on the northern edge of the marsh. In these series a smaller sampler was used[7], and 3 replicate samples taken at each site. Results are shown in Figures 3.12 to 3.16.

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[6] Estimates of the abundance of animals per square metre may be obtained by multiplying the number captured by 132.6.

[7] Area of small sampler was 26.42 cm^2. Estimates of the abundance of animals per square metre may be obtained by multiplying the number captured by 378.5.

Figure 3.12. Invertebrate distributions at East Channel sites, 22 July 2002.

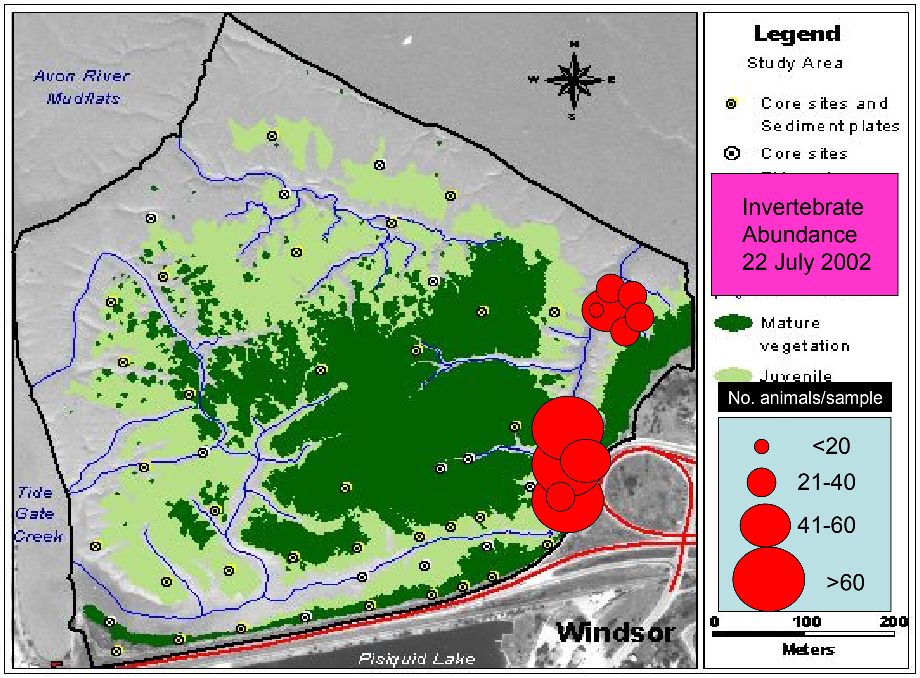


Figure 3.13. Invertebrate distributions at East and Causeway Channel sites, 30 July 2002.

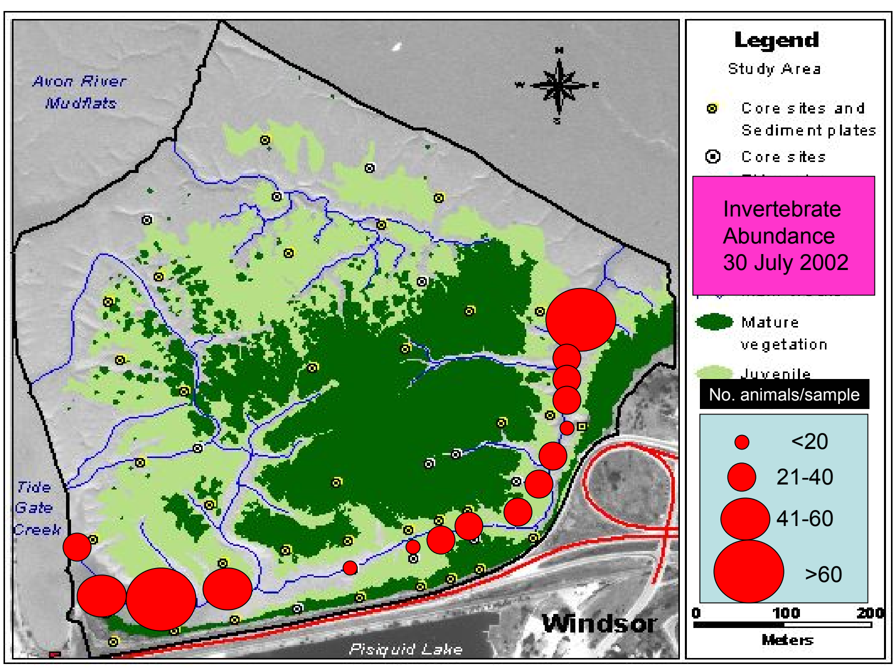
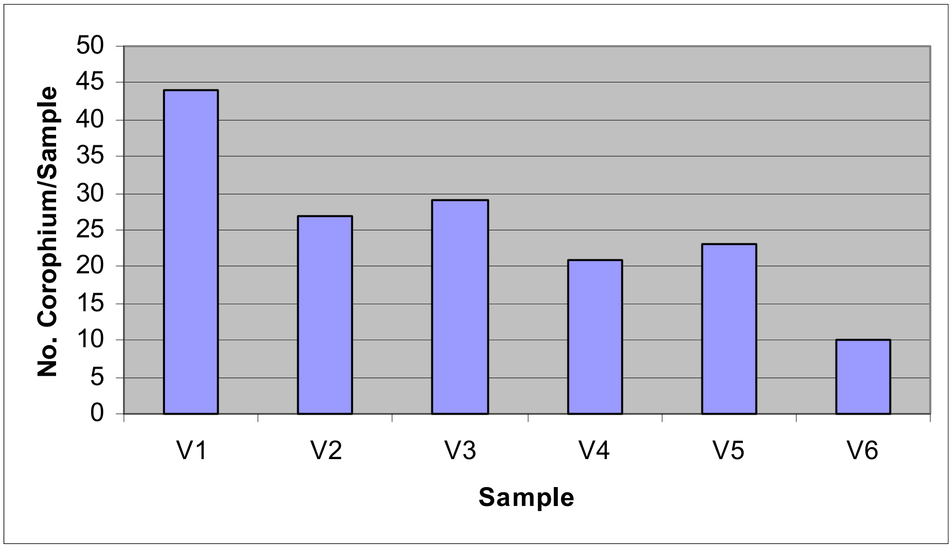
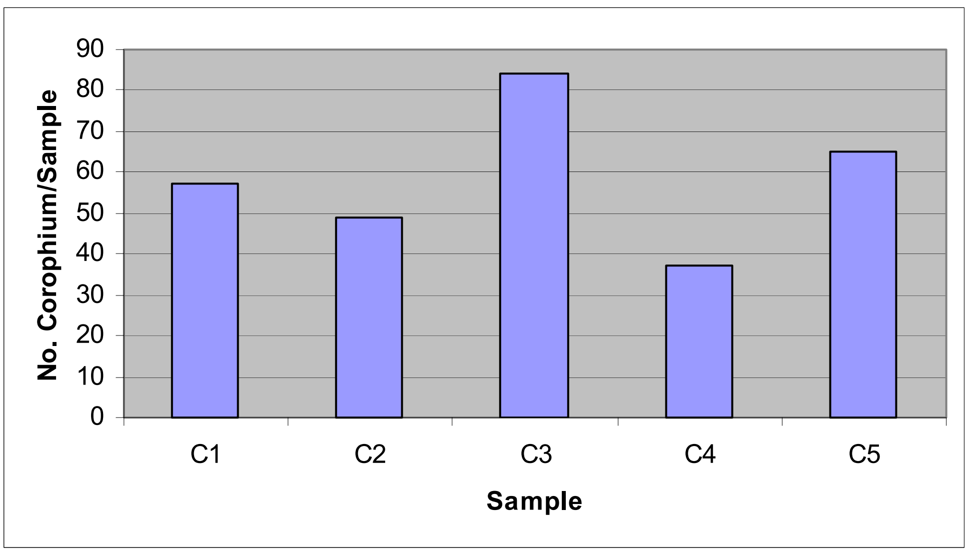


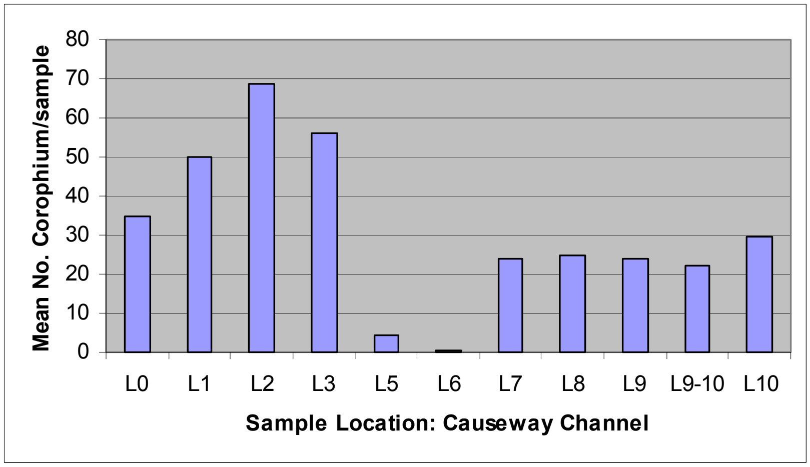
Figure 3.14. Abundance of *Corophium volutator* at sites near the East Channel, 22 July 2002.

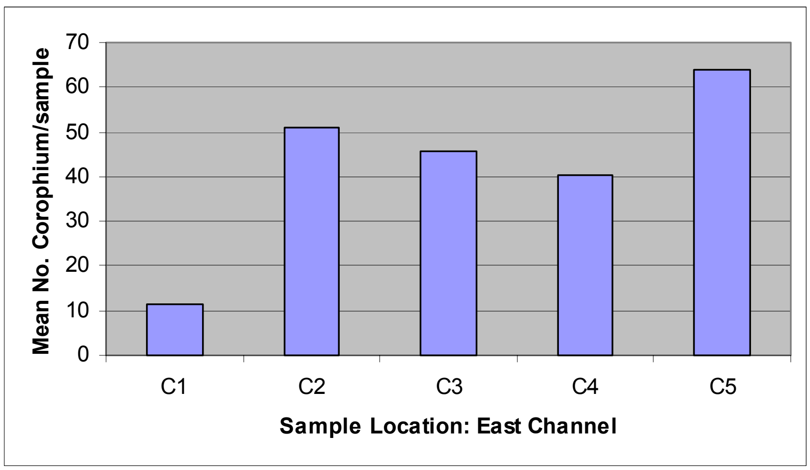




The fauna of the mudflats of the East Channel is dominated by the amphipod *Corophium volutator*. Numbers of *Corophium* in the samples of 22 July from the study area of Partridge (2002) (see Figure 3.2) represent abundances in the range of 3,000 – >16,000 *Corophium* per square metre. Estimates from the inner portion of the East Channel are even higher: 14,000 – 31,000 /m^2. In addition to the *Corophium*, there were several hundred polychaetes, particularly *Nereis* spp. in samples from Partridge's study area.

Figure 3.15. Abundance of *Corophium volutator* at sites in the Causeway and East Channels 30 July 2002.

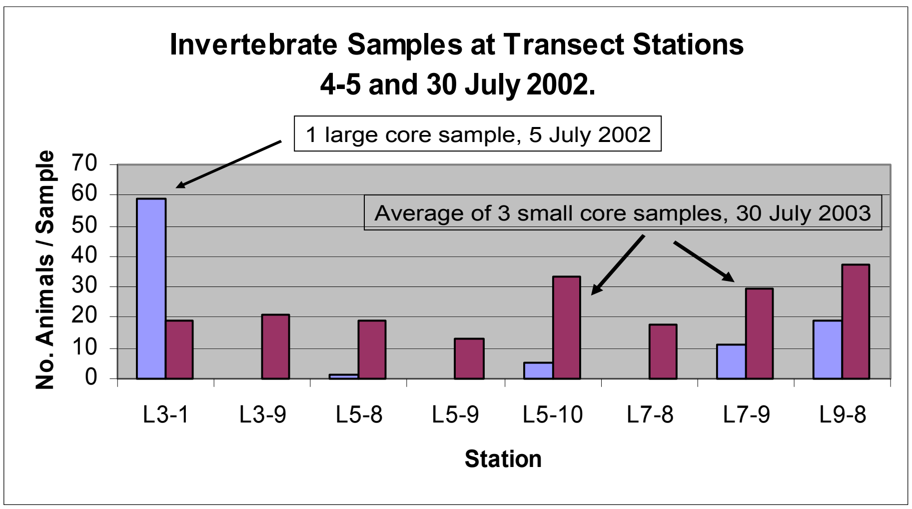




In the extensive series of samples on 30 July, similar high numbers of invertebrates, mainly *C. volutator*, were found in the channel sides and muddy areas of the Causeway and inner East Channels (Fig. 3.15). Samples in the Causeway Channel were taken between the regular transect stations, all but one of which is in a vegetated area. The numbers of *Corophium* ranged from 189 to >25,000 /m^2, the lowest numbers occurring at sample sites between Stations 1 and 2 of Line 6. In this area, which represents almost the highest point between the East and Causeway Channels, the surface was unvegetated, and the mud tended to dry out quickly and crack during exposure.

The large numbers of invertebrates collected in late July contrast with the very low numbers obtained from samples at all transect stations in early July. That the difference is not solely a function of vegetated cover is shown by comparison of the invertebrate numbers collected at northern transect stations that are unvegetated. This is shown in Figure 3.16.

Figure 3.16. Abundance of *Corophium volutator* at unvegetated transect sites of the Windsor salt marsh, 5 and 30 July 2002.



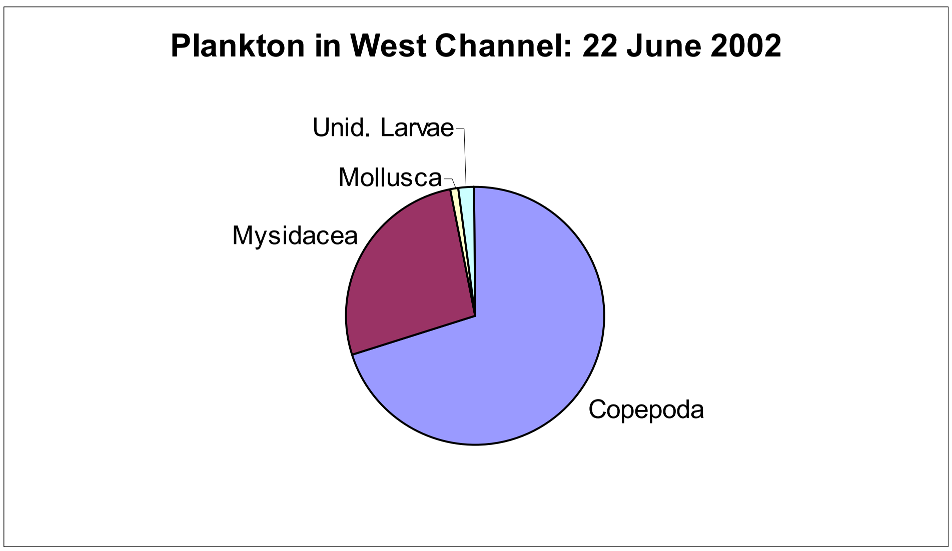
Except for station L3-1, replicated small core samples at the end of July produced much larger numbers of invertebrates than the single large core taken at the beginning of the month. These results suggest that the principal cause is recruitment of animals, particularly *Corophium,* during the month. This corresponds well to the seasonal pattern of occurrence of *Corophium* that has been identified by previous workers.

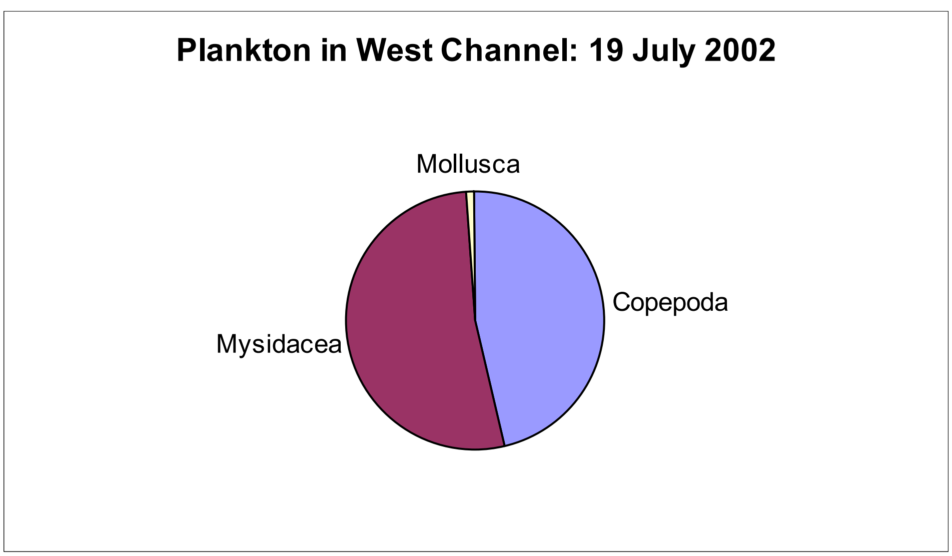
The conclusion from these investigations is that invertebrate abundance is particularly high in the muddy channels that are frequently flooded, and is generally low in densely vegetated areas. Significant changes in abundance occur during the summer months in relation to breeding cycles of dominant animals, and these are probably patterns that affect the foraging behaviour of many fish and birds.

3.3.4 Plankton.

Plankton tows were carried out at high tide in the West Channel on two occasions. The samples were non-quantitative, but demonstrate that the plankton fauna is dominated by relatively few species. Results are shown in Figure 3.17.

Figure 3.17. Plankton of the Avon Estuary.





Because of the presence of many immature forms, species identification is difficult and time-consuming. For this reason, data are presented as relative abundance of the major taxa present, primarily crustaceans (mysid shrimp and copepods), and some mollusk (clam) larvae. The most abundant organism in the June sample was the copepod *Pseudodiaptomus coronatus,* which is a common dominant in many turbid portions of the inner Bay of Fundy. Other copepods were *Eurytemora herdmani,* and *Acartia* spp. In July, the sample was dominated by the mysid shrimp *Neomysis americana*. A variety of larval stages of polychaetes and mollusks were also present, but represented very small fractions of the sample (<2%) compared with the larger crustaceans.

Neomysis and *Eurytemora* are among the most important pelagic food of fish in Minas Basin (Redden 1986, Redden and Daborn 1991, Stone and Daborn 1987). It is expected that the West Channel provides a rich feeding ground for fish during high tide periods, and the presence of large numbers of fish-eating birds suggests that many fish are taking advantage of it.

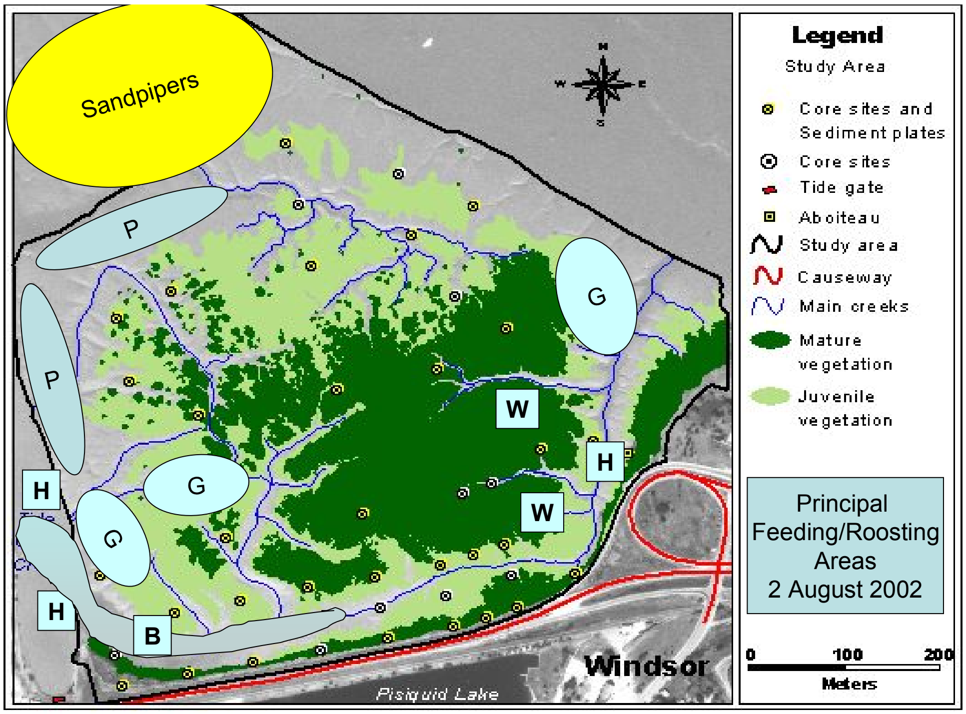
3.3.5 Fish and Birds.

Attempts to catch fish entering the Causeway Channel using seine and trap nets were completely unsuccessful. Only one eel (*Anguilla rostrata)* was obtained in three attempts. Sampling was made difficult by the steep southern side of the Causeway Channel, which prevented pursing of the seine, and the trap net could not be set up before the falling tide caused it to stream out near the surface. This investigation needs to be repeated, preferably using an array of experimental gill nets and trap nets.

It cannot be concluded, however, that fish do not forage in the Causeway Channel as well as the West Channel. The latter commonly had a number of cormorants and Great blue herons actively hunting during both rising and falling tides, and these were not seen entering the Causeway Channel, perhaps because both species are susceptible to human disturbance.

On 2 August, teams of observers were established on the dyke near to the Information Bureau and at the west side of the West Channel to observe the use of the marsh and mudflat by birds. Results are summarized in Figure 3.18, and team observations recorded in Appendix 3.

Figure 3.18. Use of Windsor marsh—mudflat complex by birds, 2 August 2002.



[Symbols: B= Black duck; G=Black-backed gull; H=Blue heron; P=Semipalmated plover; W= Willet].

Throughout the summer, the most common birds seen on the marsh itself were Greater black-backed gulls (*Larus marinus* –G in Fig. 3.18). These were numerous, often seen roosting on the exposed mudflats, particularly in stable unvegetated areas on the west side, and around the mouth of the East Channel. They were frequently observed foraging on the mudflats, but it was not possible to determine their prey; it was most likely *Nereis* spp. Fecal waste from roosting gulls was abundant in open areas on the west side, and probably contributes significantly to the nitrogen and phosphorus available. Black ducks (*Anas rubripes* –B in Fig. 3.18) were also common in the mouth of the East and Causeway Channels throughout the summer and fall. This species feeds on material at the water surface, and sometimes forages by burrowing into soft sediments. Black ducks are common in the channels during the fall, and probably benefit from the vast quantity of seeds released by *Spartina*. A pair of Willets (*Catatrophorus semipalmatus* –W in Fig.

3.18) was frequently disturbed on the eastern side of the marsh, and probably had nested there.

Great blue herons (*Ardea herodias* – H in Fig. 3.18) were commonly present and apparently foraging at the water's edge in all three channels. On most days 3 or 4 individuals could be seen, but on at least one occasion there were at least 6. Herons are easily disturbed, and tended to leave the area as soon as people began to move near the marsh. Double-crested cormorants (*Phalacrocorax auritus*) were almost always present in the West Channel, and often seen foraging, especially during the rising tide. They were rarely observed to move far into the Causeway Channel, although since they are also easily disturbed, presence of observers might have deterred them from doing so.

During the 2 hours following high tide (08.05) on the 2nd of August, the observer teams kept track of large numbers of foraging shorebirds, particularly the smaller 'peeps' and larger plovers. Most flocks recorded as 'peeps' were predominately Semipalmated sandpipers (*Calidris pusilla*), although other sandpipers may have been present. At the beginning of the ebb tide, a large group of several thousand 'peeps' was roosting at the edge of the marsh just below the dyke on the west side of the West Channel. As the tide fell, this flock moved onto the newly-exposed mudflats on either side of the West Channel, and then spread out over the northern part of the mudflat as this became exposed. Approximately 1 hour after high water, all the 'peeps' had moved over from the west side of the West Channel to the unvegetated areas of the tidal flat. On the east side, a few small flocks (<50) sandpipers were seen foraging near the sewer outflow in the East Channel, but by an hour after high water these birds had all moved to join others at the northern edge of the mudflat. Approximately 1.5 hours after high water, almost all of the 'peep' flocks had moved again, across the outflow of the St. Croix estuary to the muddy, unvegetated extension of the Causeway mudflat that has become separated by the outflow channel of the St. Croix. This is an area that we have been unable to sample for safety reasons. However, the concentration of shorebirds in that area for the rest of the low tide period suggests that it may have high densities of *Corophium.*

The only plover recognized was the Semipalmated plover (*Charadrius semipalmatus* –P in Fig. 3.18), which was observed in small groups throughout the eastern and western sides of the marsh. This species spread out and remained for much of the falling tide in high elevation, but muddy areas of the marsh. These correspond to areas that have fairly large numbers of the polychaete *Nereis*.

These limited observations confirm those of Sangster (1994) and others that the marsh—mudflat complex is used by migratory shorebirds as a feeding area. However, it seems probable that the principal foraging area is now further downstream, away from the causeway, and in the extension of this deposit that lies on the seaward side of the St. Croix outflow. Few shorebirds were seen foraging in the Causeway Channel, unlike previous years. This may be because of the higher human activity during the summer of 2002, but it also may be that the effective foraging areas are decreasing as the marsh continues to grow.

3.4 Summary.

The principal objective of these biological studies was to determine what biological resources are currently associated with the Windsor marsh and mudflat that would be affected by expansion of the Causeway to accommodate more lanes on Highway 101. It appears that this new marsh is among the most vigorous and productive of salt marshes, and that animal populations associated with the mudflats are changing as the marsh expands. Results are summarized below:

1. Sediment concentrations of chlorophyll *a* ranged from 2.3 to 18.2 $\mu g.cm^{-2}$, (mean 9.8 $\mu g.cm^{-2}$). Highest values occurred on unvegetated sites bordering tidal channels, where grazing benthic invertebrates (especially *Corophium volutator*) were less abundant than at other unvegetated sites. Results indicate that the mudflats are as rich as any previously studied in the Bay of Fundy.
2. Measurements of *Spartina alterniflora* height showed that the plants reached an average of 121 cm (range 49-170 cm) by the end of August. These values far exceed other salt marshes that have been studied in the Bay of Fundy.

3. Biomass of *S. alterniflora* averaged 1107 g dry wt.m^{-2} (range 637-2189 g.m^{-2}) by the end of August. These values also far exceed those obtained in other studies of salt marshes in the Bay of Fundy. The vigorous growth of this marsh may be related a) to its high elevation, which means light is abundantly available (i.e. shading by turbid water during flooding does not make light a limiting factor for growth), and b) ready availability of nutrients, some of which may be supplied by the waste water outfall on the east side of the marsh. The marsh has an unusually deep (< 10 cm) surface aerobic layer. Almost all of the above- ground biomass is removed by the fall die-back, and wave and ice action during the fall and winter.
4. Benthic animals are numerically dominated by the same species recorded for other Minas Basin mudflats, and for earlier studies of the Windsor mud flat: the amphipod *Corophium volutator* and the polychaete *Nereis diversicolor*. Other species include *Macoma balthica* and *Heteromastus filiformis*. Three surveys showed that benthic invertebrates are rare in areas of dense *Spartina*, and much more abundant in the unvegetated areas bordering tidal channels. Three quarters of samples in vegetated areas in early July had less than 10 organisms per sample, representing <1,300 animals.m^{-2}.
5. Replicated samples in unvegetated areas during late July showed much higher numbers, particularly of *Corophium* and *Nereis*. Samples gave estimates of *Corophium* abundance between 189 and 31,000 .m^{-2}, values that are comparable to those previously obtained from Starrs Point and Avonport (Minas Basin) and Mary's Point and Dorchester Cape (Chignecto Bay), where migratory shorebirds congregate for feeding during the fall migration.
6. Non-quantitative plankton samples indicate that the plankton is dominated by copepods (especially *Pseudodiaptomus coronatus*) and the mysid shrimp *Neomysis americana*. Copepods and mysids form principal food items for many fish in Minas Basin.
7. Attempts to trap fish foraging in the Causeway Channel were unsuccessful.
8. Observations of bird use indicated that Black ducks and Great blue herons were commonly present in the tidal channels, and Greater black-backed gulls were common foragers on the mudflats, throughout the summer. Cormorants

commonly foraged in the West Channel. Most migratory shorebirds (principally Semipalmated sandpipers) seemed to forage primarily on the unvegetated areas seaward of the outflow of the St. Croix Estuary, and for only a little time on the unvegetated areas adjacent to the salt marsh. Semipalmated plovers were seen to forage on unvegetated areas near the marsh, where polychaetes were abundant.

4.0 Pesaquid Lake Study.

4.1 Introduction.

Construction of the Windsor Causeway in 1970 created a predominantly fresh water impoundment known as Pesaquid Lake[8]. Water level in the lake is normally maintained at 9.0 feet by operation of the causeway gates, but in anticipation of heavy rainfall or snow melt, the level is lowered to provide sufficient water storage when high tides prevent release of water from the lake (Kolstee 2002). Periodically, the level is lowered for other reasons, including a spring time lowering to prevent erosion of upstream banks during thawing, and for maintenance work at the causeway gates (*Ibid.*).

The periodic lowering of water levels reveals a soft sediment bottom, particularly near the eastern end of the causeway. Local reports also suggest that there has been significant shoaling in the upper portions of the headpond, and extensive growth of aquatic vegetation in areas that were apparently deeper and unvegetated prior to causeway construction. Creation of an impoundment in a macrotidal system frequently produces two important results:

1. if salt water is trapped or able to penetrate above the dam, this will commonly remain layered beneath the overlying (less dense) fresh water because the tide is no longer present to mix fresh and seawater as in the natural estuary;
2. lack of water movement and flushing in the lake leads to a tendency to accumulate sediment and nutrients. In extreme cases, the impoundment can become enriched with nutrients (i.e. eutrophic), with consequent development of excessive growths of algae, and loss of oxygen in deeper water.

Both of these consequences represent negative effects on fish habitat and other amenity value (e.g. recreation). However, other than periodic monitoring of water quality (fecal coliform bacteria) by the Town of Windsor, there appears to have been no systematic study of Pesaquid Lake since it was formed. The lake has become a base for aquatic recreation, and an important aesthetic asset in relation to waterfront development.

[8] Variously called Lake Pesaquid, Lake Pezaquid, Lake Pisiquid, or Pisiquid Lake.

The purpose of the preliminary survey of the lake described below was to obtain some baseline information that might address the issues of water quality and habitat conditions in the impoundment.

4.2 Methods.

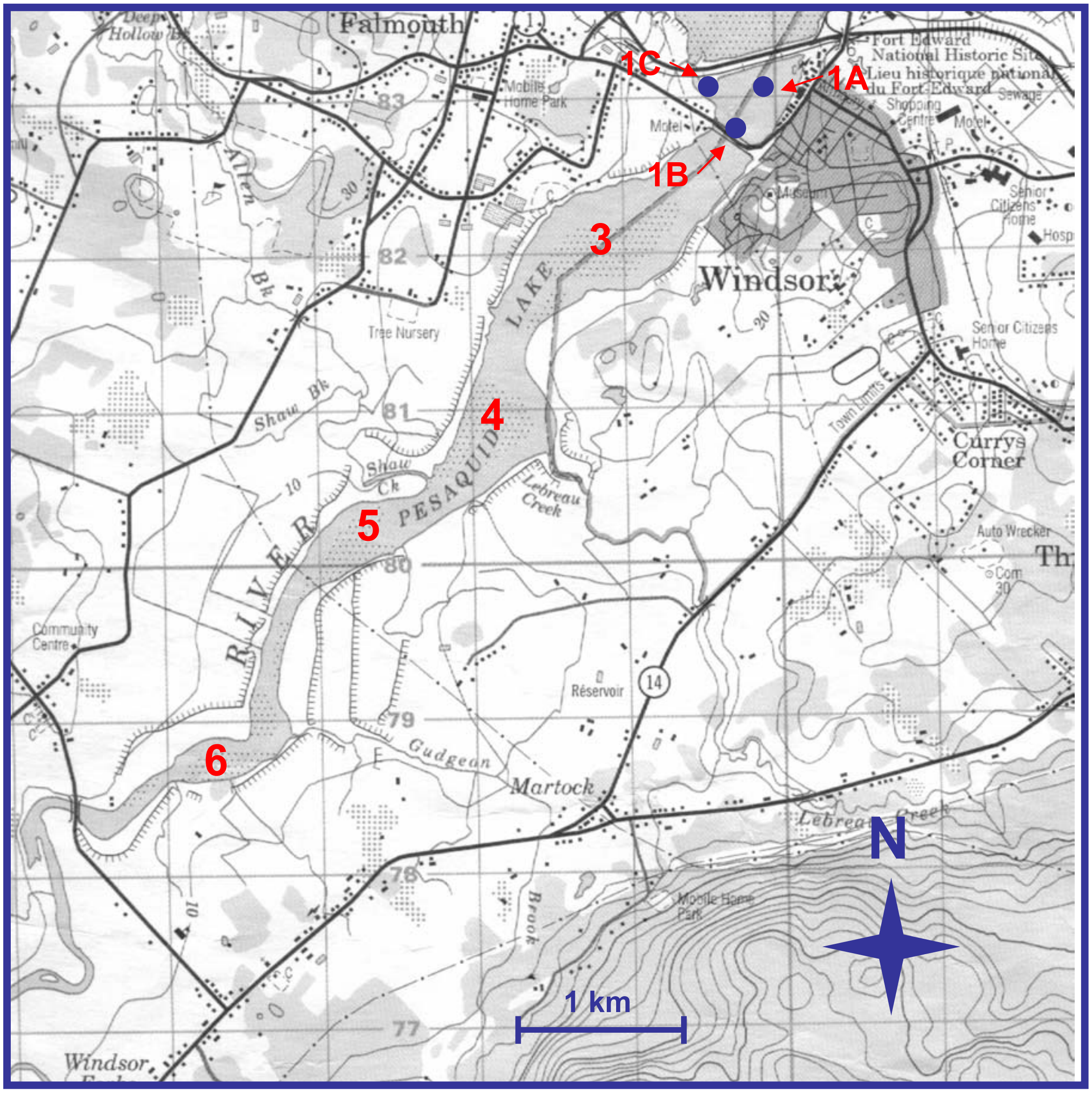
A preliminary survey of water quality within Pesaquid Lake and the Avon River was carried out on 14 August 2002. Water quality samples were collected at six stations, three within the headpond and three at stations located further upstream within the main branch of the Avon River (Figure 4.1).

Water temperature and conductivity depth profiles were measured using a YSI Model 33 SCT meter. Dissolved oxygen profiles were obtained using a YSI Model 95 Dissolved Oxygen meter. Water transparency was measured using a 20 cm diameter Secchi Disk. True color was determined after filtering through Watman GF/C filters, using the platinum-cobalt standard procedure as described in the Environment Canada Analytical Methods Manual (1979).

Total suspended particulate matter (SPM) determinations were made by filtering 1 litre water samples through pre-combusted Watman GF/C glass fibre filters and oven drying the filters at 60-70 ºC to a constant dry weight. Suspended particulate inorganic matter (SPIM) was determined after combustion of the filters at 500 ºC for 3 hr and reweighing the filters. Suspended particulate organic matter (SPOM) was determined as the difference between total particulate matter and particulate inorganic matter.

Samples for nitrate determination were collected in 500 ml acid washed bottles and refrigerated until analysis. Nitrate concentration was determined using the procedure for low nitrate concentration described in the HACH (1988) Water Analysis Handbook.

Figure 4.1. Sampling stations in Pesaquid Lake and the Avon River, August 2002.



Samples of bottom sediments were taken with an Ekman Grab. Each sample was stored in a plastic bag, sieved through a 250 μm sieve, fixed in formalin, and sorted in the laboratory. Identification of the organisms present is continuing.

4.3 Results.

Water quality results obtained from the survey are given in Table 4.1.

Throughout the headpond and river, at least the top 2 metres of water were fresh, with conductivities <300 µmhos.cm; for stations 3-6, freshwater was recorded from the surface to the bottom. At stations 1B and 1C, however, conductivity became sharply higher below 4 m, approaching values typical of the nearby sea (29,500 µmhos.cm, ≈28 ppt), indicating that in the main channel there is a wedge of salt water underlying the fresh surface water. At least in the channel, the headpond is stratified. This salt wedge probably does not penetrate much beyond the new road bridge. Evidence provided by the operators of the control gates indicates that one of the gates malfunctioned on 9th August, less than a week before the survey. It is possible that the salt wedge seen on the 14th was formed at that time (K. Carroll, pers. com.).

Surface water temperatures were relatively warm, from 26.5 to 27.5 ^{o}C, a reflection of the extremely high air temperatures (33.9 ^{o}C) on that day (cf. Appendix 2). The deeper saline water was cooler than the surface (by 6-7 ^{o}C), which increases the density difference, and the stability of the stratification.

Secchi Disk values were about 2 m, indicating that sufficient light exists for growth of plants at depths of approximately 5 m throughout the headpond. In the upper stations, the disk was still visible when it lay on the bottom.

Dissolved oxygen values were high at the surface, generally close to full saturation (100%). At depth, however, oxygen concentrations were somewhat lower, corresponding to 60 to 75%. Such a decline is rather typical of stratified estuaries, because deeper water cannot be re-oxygenated unless it is brought into contact with the air. In the absence of vertical mixing, which is caused by tide or wind, this does not happen.

Table 4.1. Summary of water quality data collected from Pesaquid Lake and the Avon River, 14 August 2002.

Station	Northing	Easting	Secchi Depth (m)	Depth (m)	Temp (°C)	Conductivity (µmhos/cm)	Dissolved Oxygen (mg/L)	Dissolved Oxygen Saturation (%)	SPM (mg/L)	Turbidity (NTU)	Nitrate (mg/L)	pH
1A	4982999	409872	1.9	0.0	26.5	200	7.8	96.8				
"	"	"		1.0	25.5	190	7.9	94.6	2.86	13.80	0.059	6.3
"	"	"		2.0	24.5	220	7.2	85.4				
"	"	"		3.0	23.0	430	7.4	85.1				
1B	4982826	409805	2	0.0	27.5	180	8.0	98.2				
"	"	"		1.0	27.0	178	7.9	98.2	2.77	5.01	0.066	6.2
"	"	"		2.0	22.9	492	7.3	87.1				
"	"	"		3.0	21.2	1700	5.5	63.0				
"	"	"		4.0	21.5	5500						
"	"	"		4.5	20.0	29500						
"	"	"		5.0	20.0	29500	6.1	75.6				
"	"	"		5.5	20.0	29500						
1C	4983009	409609	1.9	0.0	27.5	200	8.0	108.0				
"	"	"		1.0	27.0	208	7.8	97.1	2.80	11.30	0.049	6.1
"	"	"		2.0	25.0	199	7.8	94.6				
"	"	"		3.0	22.5	600	6.0	68.6				
"	"	"		3.5	21.9	810						
"	"	"		4.0	21.1	1490	6.4	71.1				
"	"	"		4.5	21.0	2010						
"	"	"		5.0	21.0	4000						
"	"	"		5.2	21.0	5210						
3	4982158	409111	> bot	0.0	27.5	108	8.0	98.7				
"	"	"		1.0	26.0	130	7.8	94.3	3.51	13.50	0.052	6.1
"	"	"		1.5	25.0	130	7.7	93.1				
4	4981059	408278	> bot	0.0	27.0	102	7.9	97.1				
"	"	"		1.0	26.0	100	7.8	96.2	4.29	1.56	0.052	6.1
"	"	"		2.0	24.5	120	7.6	92.5				
5	4980277	407368	> bot	0.0	27.5	99	7.8	96.2				
"	"	"		1.0	26.0	95	7.7	93.8	6.01	10.10	0.059	5.9
"	"	"		1.5	26.0	95						
6	4978427	405132	2.4	0.0	26.5	48	7.9	96.6				
"	"	"		1.0	25.0	49	7.4	87.5	4.91	3.51	0.052	6.0
"	"	"		2.0	24.5	49	7.2	85.4				
"	"	"		2.5	24.5	49						

Turbidity was generally very low in surface water (< 15 NTU, Table 4.1). Nitrate levels were also extremely low (well below the Canadian Drinking Water Standards), indicating that there is no evidence of excessive nutrient run-off into the river or the headpond.

4.4 Summary.

Contrary to some expectations, this initial survey of Pesaquid Lake has shown that water quality in the surface waters is relatively high. There was little indication of excess nutrients or algal growth as commonly afflicts impoundments that are surrounded by agricultural or residential areas. Results are summarized below.

1. In mid-August, Pesaquid Lake was a stratified impoundment, with a saline layer underlying the top 2-3 m.
2. Surface waters (0 to 2m) were relatively clear, with low turbidity (<15 NTU), relatively low pH (5.9-6.3), and high oxygen concentrations (85-100%).
3. Nitrate concentrations were very low ($\leq$0.066 mg.L^{-1}), providing no evidence of nutrient enrichment.
4. Deeper waters in the main channel were saline, stable and somewhat undersaturated with oxygen (< 80%), but no anaerobic waters were found.

5.0 Ecological Implications of Expanding the Windsor Causeway

Preliminary plans for twinning Highway 101 include expansion of the width of the Windsor Causeway to accommodate an additional 2 or 4 lanes. Because of infrastructure limitations, such expansion is feasible only on the seaward side of the existing structure, and would be designed to decrease the sharp curve at the western end. The construction would therefore cover part of the marsh and tidal channel adjacent to the existing causeway. The present study was designed, in part, to provide information relevant to an assessment of the ecological implications of such an expansion. It was also the first step in a planned long term monitoring of continuing evolution of the marsh—mudflat complex that resulted from construction of the original causeway.

Assessment of the ecological implications of expanding the causeway needs to address

1. the effects on physical processes of the estuary below the causeway;
2. the effects on biological processes and resources; and
3. the effects on Pesaquid Lake and the Avon River.

It is also necessary to consider the potential effects of global environmental changes, particularly sea level rise, and the frequency of extreme weather events, such as storm surges.

An alternative solution to the crossing issue, favoured by some local interest groups, is complete removal of the existing causeway and its replacement by a bridge of sufficient capacity to accommodate a four lane highway and the existing railway. While this alternative was not the subject of the 2002 study, the results provide information that is relevant to that issue.

5.1 Effects of causeway expansion on physical processes of the Avon Estuary.

It seems to be a common (public) perception that expansion (i.e. widening) of the existing causeway would initiate a significant change to the physical dynamics of the Estuary similar to construction of the original causeway. This is not probable. The major effect of the original construction in 1970 was a significant reduction in the tidal prism and consequent reduction in velocity and turbulence of tidal waters. These changes resulted in the progressive accumulation of deposited sediment that has given rise to the present marsh and mudflat complex. Widening the causeway would have a negligible effect on the tidal prism, because the expansion of the marsh and mudflat has itself reduced the volume of water able to move in the Avon Estuary.

Continued development of the marsh seems likely to favour the infilling of the Causeway Channel, a drainage channel that runs parallel to the causeway, which was kept open by tidal flows[9], until the late 1980s. Eventually the marsh would be expected to grow completely up to the present causeway, thus almost eliminating the mudflats that currently remain as part of the Causeway Channel.

5.2 Direct and Indirect Impacts of Expanding the Windsor Causeway

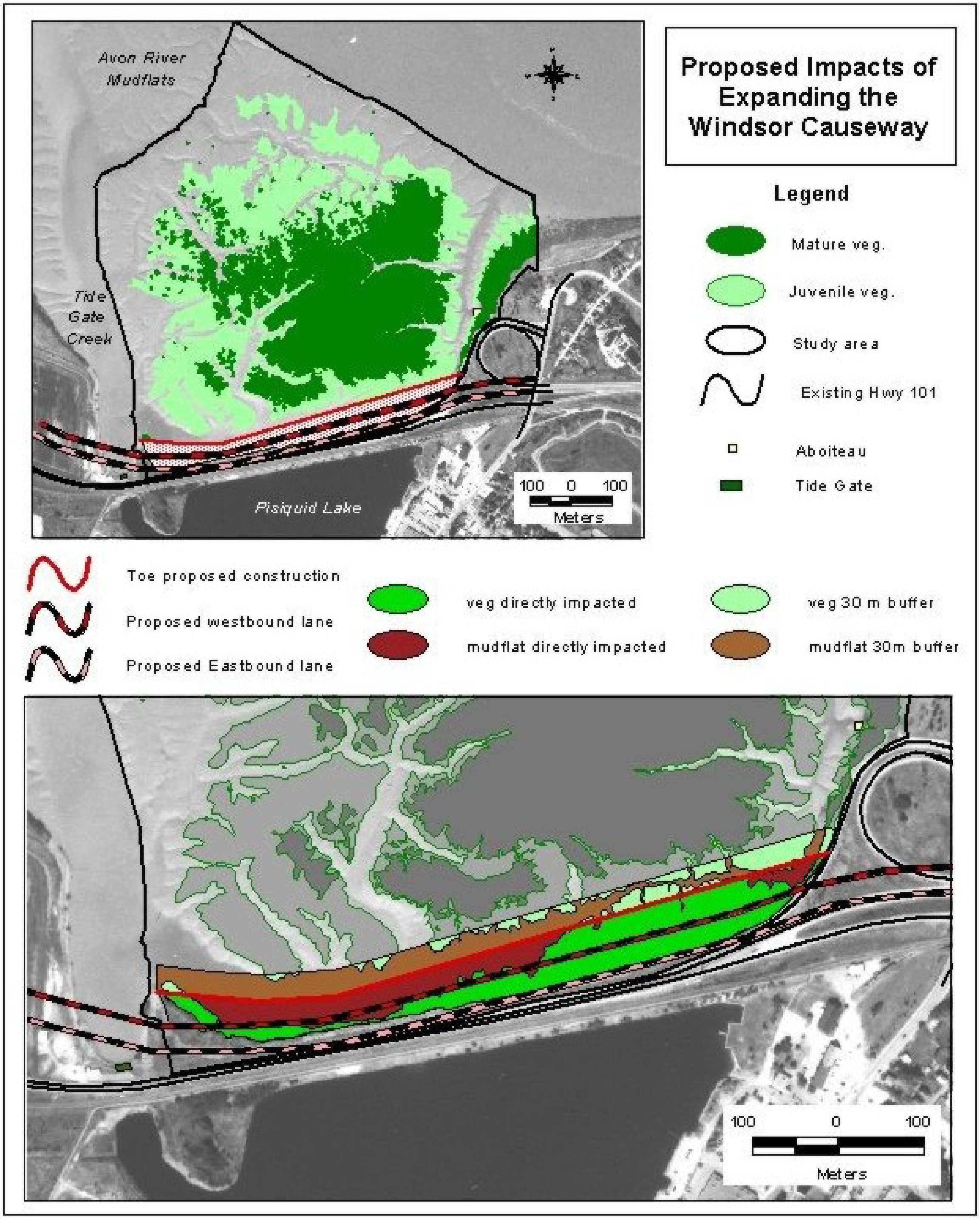
Expansion of the causeway as presently contemplated, would involve construction over a small but significant fraction of the marsh and mudflat that lies adjacent to the causeway (cf. Figure 5.1).

The areas of intertidal habitat that would be directly and indirectly impacted by the expansion of the 101 Highway were determined using ArcView 3.2 with Spatial and Image Analyst Extensions and a paper CAD survey supplied by the Nova Scotia Department of Transportation and Public Works. The location of the proposed lanes and new toe of the causeway were manually digitized on a rectified aerial photograph. The areas of vegetation and mudflat impacted by the expansion were derived using geoprocessing techniques and the GPS vegetation survey data conducted by Saint Mary's University in 2001.

Table 5.1 summarizes the area of intertidal habitat that will be directly or indirectly impacted by the construction process. Areas of intertidal habitat located landward of the

[9] And possibly some seepage through the causeway prior to infilling.

Figure 1: Estimated 'footprint' of the Windsor Causeway following expansion associated with 'twinning' of Highway 101.[10] Vegetation areas derived from Townsend, (2001).



[10] Note that the location of the proposed lanes is only an approximation of their position on the marsh surface.

proposed toe were assumed to be completely removed or buried during the construction process. A 30 m buffer was added seaward of the proposed toe location to represent vegetation and mudflat areas likely to be indirectly impacted by the construction process (e.g. debris, heavy machinery, etc.). Table 5.1 also includes calculations for a 50 m construction buffer.

Table 5.1. Estimates of the amount of intertidal habitat directly or indirectly impacted by proposed expansion of the Windsor Causeway. [11]

Existing Habitat within Study Area	**Area (m^2)**	**Area (acres)**
Saltmarsh Vegetation	397,515	98
Mudflat	327,717	81
Total Intertidal Habitat	725,232	179

Analysis of Habitat Impacts from Construction Process					
Habitat	**Direct (m^2)**	**30 m buffer (m^2)**	**50 m buffer (m^2)**	**Total (with 30 m buffer)**	**Total (with 50 m buffer)**
Vegetation	24,284	8,057	19,148	32,342	43,432
Mudflat	13,852	15.973	20,860	29,826	34,712
TOTAL (in m^2)	38,136	24,031	40,008	62,167	78,144
TOTAL (in acres)	9	6	10	15	19
% of existing vegetation.	6	2	5	8	11
% of existing mud	4	5	6	9	11
% of total intertidal	5	3	6	9	11

Currently there are approximately 725,230 m^2 (179 acres) of intertidal habitat within the study area. The construction of the additional eastbound and westbound lanes would result in a direct loss of approximately 5% of the total intertidal habitat (6% of all saltmarsh vegetation and 4% of all mudflat area) (Table 5.1). An additional 3% of the

[11] (Direct impacts represent areas completely removed and indirect impacted areas represented as habitat located within a 30 m or 50 m zone adjacent to the proposed location of the toe of the new causeway. Existing saltmarsh habitat determined from a fall 2001 survey by Townsend (2002).

total intertidal habitat available would be indirectly impacted (based on a 30 m buffer) by the construction process. In total, approximately 8% of the total intertidal habitat (8% of all saltmarsh vegetation and 9% of all mudflat area) will be directly or indirectly impacted by expansion of the Windsor Causeway. If a 50 m construction buffer were used, this value raises the impact footprint to approximately 11% of the total intertidal habitat within the study area.

5.3 Effects of causeway expansion on biological processes and resources of the Avon Estuary.

As described in this report, the salt marsh appears to be one of the most productive (on a unit area basis) in the Bay of Fundy, and possibly in North America. Although there is no evidence that the marsh cord grass is grazed directly by any organisms, the above ground production is largely sheared off in winter, and in fragmented form represents a considerable contribution of organic material to the estuarine ecosystem. In addition, the large seed production of *Spartina alterniflora* (cf. Figure 5.2) is probably utilized by Black ducks and other waterfowl.

The evidence from this study indicates that the Windsor marsh is unusual in the very low abundance of benthic animals in areas where the *Spartina* is particularly dense. The mudflats, however, harbour relatively large numbers of *Corophium volutator* and *Nereis diversicolor*, and smaller numbers of the bivalve *Macoma balthica* and other polychaetes. These muddy areas are potentially good feeding grounds for fish and birds. *Corophium volutator* is a species of great significance to the inner Bay of Fundy ecosystem. It is often a numerically dominant organism, and constitutes a major food item for most fish species (Gilmurray and Daborn 1981, Imrie and Daborn 1981, Dadswell *et al.* 1984a, b, Stone and Daborn 1987) and migratory shorebirds (Hicklin 1981, Hicklin *et al*. 1980). In recent years, there has been great concern about declining numbers of *Corophium* in areas such as Starrs Point and Johnson's Mills that used to be major feeding grounds (Shepherd *et al.* 1995).

Figure 2. *Spartina* seed detritus along the Windsor Causeway, 23 December 2002.

It appears that the Windsor mudflats have become relatively attractive to shorebirds, and the data obtained in this study indicate that abundance of *Corophium* in the muddy areas surrounding the new marsh is comparable to that in other favoured feeding areas in years past.

Construction over the mudflat and marsh adjacent to the causeway will therefore entail loss of about 10% of the potential foraging habitat for both fish and birds in the area adjacent to the causeway. The data at hand, however, suggest that the major foraging area for shorebirds may be on the distant mudflats beyond the St. Croix Estuary channel. This has not been surveyed, but the absence of marsh grass and the apparent use of that area by 'peeps' rather than the mudflats and channels nearer the causeway suggest that there may be large abundances of *Corophium volutator* there. The principal users of the marsh and mudflats nearer to the causeway appear to be plovers, herons, Black duck and gulls.

Information about fish usage of the channels and mudflats is absent. It would be expected, however, that a number of species -- especially Atlantic silverside (*Menidia menidia)*, tomcod (*Microgadus tomcod)*, and winter flounder (*Pseudopleuronectes* *americana*) -- would visit these channels on the rising tide (Dadswell *et al.* 1984a, b). Given the limited area of the mudflats of the Causeway Channel, its loss would be of little significance to the foraging area available to fish. It should also be noted that continued growth of the marsh is expected to diminish the area of mudflat remaining near to the causeway, and hence in the region that would be covered by its expansion.

5.4 Effects of causeway expansion on Pesaquid Lake.

Other than direct construction activities, expanding the causeway will have no significant effect on the present condition of Pesaquid Lake, provided there are no changes to the current pattern of water level modifications. Although an impoundment such as this has the potential to become eutrophic as a result of nutrient enrichment, and to trap sediments, lowering the water storage capacity, these will not change just because the causeway has been widened. There is potential, however, that construction would increase the mobility of deposited sediments, leading to greater accumulation of sediment in the headpond if these are able to pass upstream during construction. These additions to the sediment deposits of the headpond would probably be very small compared with the amount that has accumulated since original construction of the causeway more than 3o years ago.

The present study included a single limnological survey of the lake, conducted in August when it was expected that conditions might be most degraded: high temperatures and low flushing would lead to declines in oxygen availability in deeper waters, and any nutrient enrichment would lead to high growth of phytoplankton. While there was some depletion of oxygen in deeper waters, because of the stratification, there was no evidence of anaerobic conditions. Similarly, water clarity remained high, and nitrogen concentrations were extremely low. The absence of a well developed benthic community is most likely due to periodic incursions of salt water through the causeway. It is apparent that a small salt wedge existed in the headpond at the time of the survey, but we do not know how persistent this feature is. It is possible that the salt wedge is eliminated during periods of high river flow, and then re-established if salt water is able to seep back through the causeway[12]. Most benthic organisms are either adapted to fresh water or to relatively saline water. Periodic oscillations between fully fresh to almost full strength sea water tend to eliminate the vast majority of long-lived species such as clams or insects. A periodically stratified estuary is one of the most difficult habitats for benthic animals. This seems to be the reason for the almost complete absence of benthic animals in the samples taken in August, although a more extensive survey is required.

A further consideration for planners is the potential implications of longer term global environmental changes, such as sea level rise, and the increased frequency of extreme events. The orientation of the Avon Estuary does not leave it particularly susceptible to strong wave action at the causeway, and as the marsh and mudflat continue to evolve, they act as a 'soft' shoreline barrier that would minimise effects of major storms that could be significant in other parts of the Bay of Fundy system. It seems probable that, left unchanged, the marsh will continue to trap sediment and rise with rising sea level, maintaining its dynamic equilibrium with tidal flows. Construction of a wider causeway will not change that.

A greater concern may be associated with the prospective increase in extreme precipitation events. At the present time, cooperation between Nova Scotia Power Inc. (which impounds and stores water upstream for hydroelectricity generation), and the Nova Scotia Department of Agriculture and Fisheries (which manages water levels in Pesaquid Lake), is usually able to accommodate release of large quantities of water downstream. However, there is concern that in recent years a considerable amount of sediment has accumulated in Pesaquid Lake because it is not being flushed out effectively. This limits the capacity of the impoundment to store water, and while there have been few instances in recent years where problems were encountered, the difficulty will only increase if extreme events do become more frequent as predicted, and the headpond volume is not maintained or increased.

[12] There is some indication that portions of the causeway may still be somewhat porous, allowing salt water to penetrate the structure during high spring tides (K. Carroll, *pers. com*). Because of its density, it would tend to settle below the fresh water from the river.

5.5 Implications of Causeway Removal.

Although not the subject of the present study, the possibility of removing the existing causeway and replacing it with a bridge has been raised. There is a growing interest in removing causeways that were constructed in the 1960s and 1970s in order to reverse the negative impacts that such obstructions have created. These effects include: reduced lengths of tidal rivers; stratification of upstream impoundments; changed freshwater discharges; elimination of salt marshes; sediment deposition upstream and/or downstream of the barrier; elimination of migratory fish stocks or impedence of movement because of anaerobic barriers; eutrophication of upstream freshwaters; reduced nutrient exchange with coastal waters; retention of contaminants and harmful bacteria; loss of tidal bores and other tourist attractions; and changes to groundwater (cf. Wells 1999). Concern about the negative effects of causeways in tidal areas has become enhanced in recent years by greater recognition of the role that salt marshes may have played in the ecology of coastal waters. It is estimated that, since 1604, more than 80% of the salt marshes in the Bay of Fundy have been lost through dyking and causeway construction, with undetermined effects on the productivity of coastal ecosystems. There is considerable public interest in the recovery of some of these lost marshes achieved by reopening tidal restrictions. The benefits of barriers, which usually provided the rationale for their construction, include: flood control; cost-effective transportation; increased land for agriculture and residential/industrial development; and some forms of recreation.

If the Windsor Causeway were to be removed and replaced by a bridge, allowing free flow of water past the Town of Windsor, the consequences would not be trivial. There would be potential benefits, including recovery of migratory fish stocks that have been reduced in size since causeway construction. The hazards of impounding water that is contaminated by residential and agricultural waste will be diminished because of the capacity of an estuarine system to process organic matter, including fecal bacteria and pathogens. Eventually there might be the development of marsh and mudflat systems in the area that is currently a freshwater impoundment, and this might well change local wildlife diversity. Ironically, removal of this causeway would probably eliminate what appears to be one of the most productive marshes in the Bay of Fundy system; normally construction of tidal barriers is associated with a loss of salt marshes.

It should be noted, however, that knowledge of estuarine systems, particularly of macrotidal estuaries like the Bay of Fundy, is not sufficient to forecast the rate at which the system will evolve following removal of the causeway. It is most likely that the current marsh—mudflat system that has grown up since the construction of the causeway will begin to erode as tidal flows increase. Unless there is dredging to increase the cross-sectional area at the level of the present causeway, erosion of the marsh and mudflat is likely to be a slow process at first. It may take a number of years before sufficient erosion has taken place to significantly increase the flow of tidal water into what is now the headpond.

The fate of the sediment eroded from the marsh and mudflat is also uncertain. In general, estuaries tend to move sediments in a landward direction, because velocities on the flood tend to be higher than those on the ebb. Consequently, some sediment accumulation may be concentrated upstream, while another fraction of the several million tonnes that have settled there since 1970 may be distributed downstream or into the St. Croix estuary. There is, in fact, no guarantee that all of the existing mud and marsh will ever be removed: there was an intertidal bar in that place prior to construction of the causeway.

At all events, it will be many years before a stable dynamic system is re-established.

5.6 Summary.

Consideration of the ecological implications of expanding (widening) the present causeway involves a) the effects on physical processes; b) the effects on biological processes and resources; and c) the effects on Pesaquid Lake.

1. Widening of the existing causeway will have negligible effects on the *physical* processes of the estuary, because the major effects have already been experienced with the original construction.

2. Expansion of the causeway will cover a small but significant part of the present mudflat and marsh, removing some of the feeding habitat for fish and birds. Estimates are that the losses will represent 9-11% of the intertidal area between the causeway and the St. Croix Estuary channel. However, continued growth of the marsh will eliminate some of the mudflat in the vicinity of the causeway anyway.
3. Because of declines in *Corophium* populations elsewhere in the upper Bay of Fundy, there will be concerns about loss of some relatively productive areas that have developed near Windsor as a result of the causeway. Most foraging by birds (and possibly fish?) now occurs at more distant portions of the mudflat that would not be directly involved in construction of the wider highway.
4. Widening of the causeway will have no direct effect on Pesaquid Lake. Conditions in this impoundment are largely determined by management of water levels and contaminant sources.
5. Replacement of the causeway with a bridge will bring a complex mixture of favourable and unfavourable changes.

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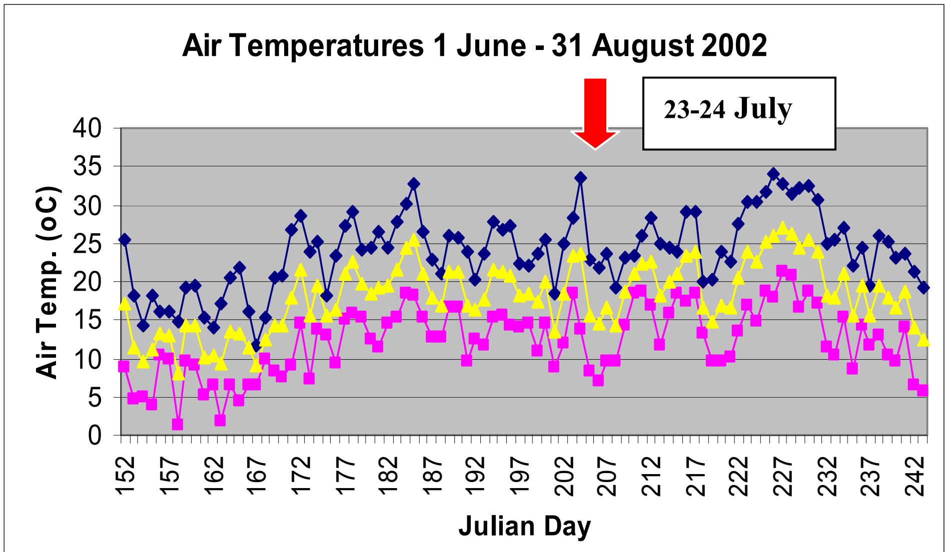
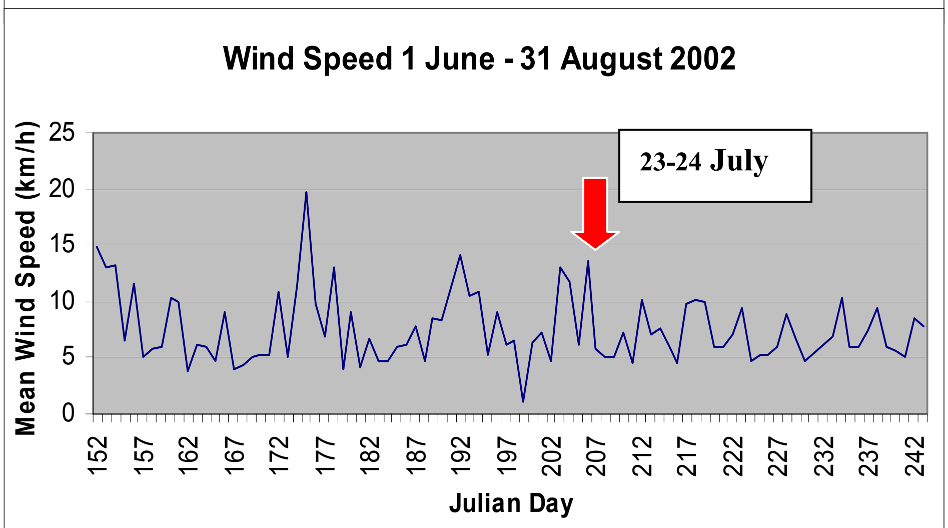
7.0 Appendices.

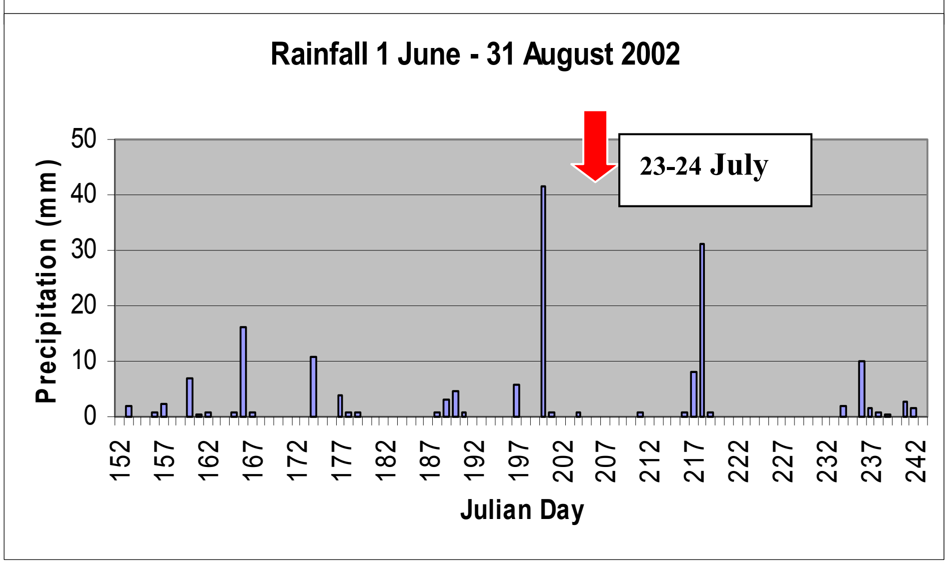
Appendix 1. Tidal forecasts for Hantsport, May – August 2002.

(Source: Tides and Currents™, Nautical Software Inc.)

Appendix 2. Weather data for Kentville, 1 June-31 August 2002.







Appendix 3. Observations of birds on the Windsor marsh and mudflat, 2 August 2002.

Time	West Team	East Team
08.45	8 Black Duck in Causeway Channel	15 'peeps' feeding below outfall pipe in East Channel.
	2 Herons disturbed on west shore of the West Channel; flew across the channel to the northern part of the main mudflat.	15 gulls on East Channel, marsh side.
08.50	Large flock of several thousand 'peeps' spreading over mudflat on west side of West Channel; many closest to edge of falling water. Did not see where they came from, but might have been roosting near the dyke. Not all feeding: some just appear to be resting and preening.	Solitary heron feeding below outflow pipe, on marsh side of East Channel. 21 willets on marsh side of East Channel near outfall pipe.
08.55	Most of the 'peeps' flew across the West Channel as soon as the northwest point of the mudflat became exposed; commenced feeding intensively. Approximately 12 plover feeding near the end of Transect Line 3.	Flock of ±50 'peeps' flying northwestward toward Estuary. Approx.25 gulls seen on northern end of mudflat, south side of St. Croix outflow.
09.02	A new small flock of 'peeps' arrived flying in from the south, along the West Channel. Joined the main flock on the northwest point.	2 gulls remain near outfall pipe
09.07	Several hundred feeding 'peeps' remain on the enlarging mudflat on the west side of the West Channel, where main flock had been previously. About 30-35 plover feeding on the east side of the West channel, near an isolated patch of *Spartina*.	
09.10	Merlin flew along West Channel from south to north.	
09.13	Almost all of the 'peeps' have now moved over to the east side of the West Channel, leaving 20-25 plover foraging along the water's edge.	10 plover feeding near northern end of mudflat, adjacent to St. Croix outflow.
09.30	Only 3 plover now feeding on the east side of the West Channel; most of the others (about 30-40) have concentrated in the tidal channel that drains the	2 cormorant flying east over end of East Channel Large flock of 'peeps' flying northwestward to

	mudflat into the West Channel.	Estuary
09.40	Almost all ‘peeps’ have moved out of sight, having flown across the main outflow channel of the St. Croix.	
09.45	Team moved up to the 101 on-ramp near the treatment plant from which we could see the far mudflats. Almost all the ‘peeps’ have moved over to the north side of the St. Croix channel, leaving a scattered few on the south side mudflats. Most of the plover that can be seen are on the south side of that channel, but have now dispersed beyond our range of view.	