CHARACTERIZATION OF SEDIMENT IN THE SALMON RIVER ESTUARY

by

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ABSTRACT

Truro, Nova Scotia, Canada located at 45 ^{0} 21' north and 63 ^{0} 16' west is at the head of Cobequid Bay on the Bay of Fundy which has some of the worlds highest tides and is known for its tidal bores.

The purpose of this study is the characterization of the intertidal sedimentary environment of the Salmon River Estuary by examining the amount of suspended sediment in the water column, the occurrence of the sediment deposits, its particle size and the amount deposited within the estuary itself. Measurements were taken during the monthly sequence of high tides for sediment accumulations at three locations, for water column sediment concentrations at four locations and the sediment concentrations calculated for the depths sampled. Tidal heights were measured continuously at the seaward end of the study area by a Campbell Scientific Sonic Ranger.

Seasonally the sediment deposits within the estuary were found to restrict the estuary discharge channels and remained until freeze up. The sediment concentrations within the water column were classed as fluid mud. Particle sizes characterizing the competence of the tidal intrusions into the estuary were predominately silt at the landward locations changing to fine sand at the seaward locations.

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CHAPTER 1- INTRODUCTION and LITERATURE REVIEW

1.1 Introduction

The Bay of Fundy between Nova Scotia and New Brunswick divides into two major branches, (i) the Chignecto Bay and (ii) the Minas Basin. Located between latitudes 45^0 00' and 45^0 30' and longitudes 63^0 15' and 64^0 30' the Bay of Fundy is known for its high tides and occurrences of tidal bores at the head of each branch. The entire Bay of Fundy is classified as macro-tidal due to its tides being > 4 m in height (Amos, 1978a in Gordon et al., 1985). Other features that support this classification are the lack of barrier islands and the presence of sandbars 1-5 km in length (Middleton, 1977). Minas Basin has at its head the Cobequid Bay and at the headwaters of the Cobequid Bay is the town of Truro, located at the head of the Salmon River Estuary.

The tidal waters of the upper bay have a characteristic brown color due to sediment within the water column which can be attributed to a combination of the geology, geological history and tides of the Minas Basin and Cobequid Bay. Tidal water influxes during the summer months deposit sediment within the channels of the Salmon River estuary and from personal observation these deposits exhibit evidence of reducing estuary channel discharge capacities.

The town of Truro is one of five designated Flood Risk Areas under the Canada-Nova Scotia Flood Damage Reduction Program undertaken in the 1980's by federal and provincial governments (Service Nova Scotia and Municipal Relations, 2000). It is the only designated area which is identified because of its high potential for flood damage located on the Bay of Fundy. Therefore evidence of any estuary discharge channel restrictions and its duration may have some influence on this desgination.

1.2 Objectives

The purpose of this study is the characterization of the intertidal sedimentary environment of the Salmon River Estuary showing that the tidal intrusions of the silt laden water over the summer months significantly restricts river channel cross sectional areas and that the characteristics of the suspended material changes both temporally and spatially. Figure 1 shows the location of Truro at the head of the Minas Basin and

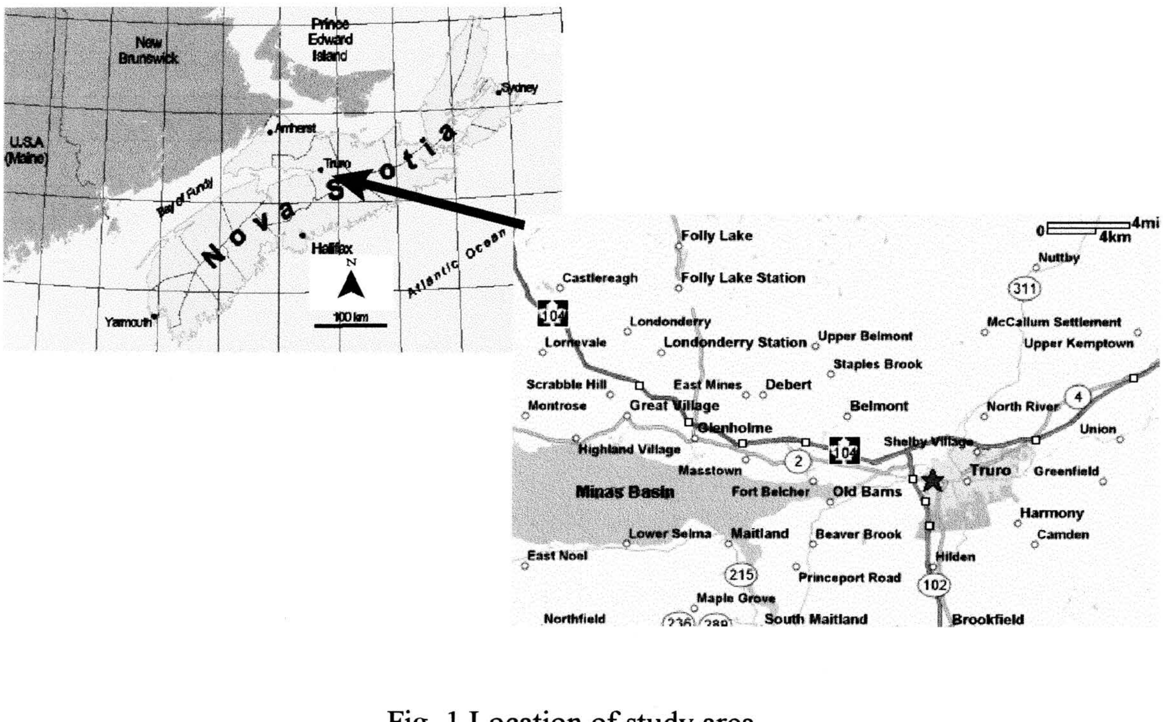

Fig. 1 Location of study area

Cobequid Bay. The study area is a 4.8 km section of the Salmon River Estuary that encompasses a section of the North River and the Salmon River. This section of estuary is intersected by three bridges which form the boundaries of the study area. The study objectives are to examine four locations, Sampler A at 141 m, Sampler B at 2502 m, Sampler C at 4542 m and Sampler D at 4819 m upstream from the lower boundary of the study area over a two year period during the summer months. Measurements at these locations will include; (i) sediment concentrations in the water column within specific ranges of depth from the water surface, (ii) particle size distribution of the collected suspended material at the four sites, (iii) the net deposition of sediment at 0 m, 4542 m and 4819 m, (iv) tidal peak ranges at 0m, the lower boundary of the study area and, (v) electrical conductivity (EC) and pH determinations at the four sites to assess salt water intrusion or fresh water runoff.

1.3 Literature Review

1.3.1 Geological History of Minas Basin and Cobequid Bay

The geology of Cobequid Bay and Minas Basin consists of Pleistocene deposits of glacial till and fluvial outwash underlain by a bedrock of Triassic sandstone and volcanic rock intrusions (Roland, 1982). Over 13,000 years ago the Minas Basin and Cobequid Bay were covered with ice that scoured the underlying land and caused the land mass to sink. After the ice melted, the land rebounded upward until approximately 4,000 years ago when the land started subsiding again. Current estimates place this downward sinking of the Minas Basin and Cobequid Bay at 15 cm per century (Roland, 1982). Coupled with a rise in sea level of 15 cm per century the relative change increases on average 30 cm per century (Grant, 1975). Yet the Minas Basin and Cobequid Bay's relative sea rise is lower when compared to rates reported by Day et al., (1999) for other estuaries in the world such as the Nile River Delta's rate of 50 cm and the Mississippi River Delta's rate of 100 to 120 cm per century.

1.3.2 Tides and Currents

When the sun and moon are in alignment, as when the moon is in its new or full moon phase, an extra high tide (spring tide) occurs. An extra low tide called a neap tide occurs when the sun and moon form a right angle triangle with the earth during the first and last quarter phases of the moon. For the Bay of Fundy the maximum yearly tidal range occurs when the sun passes the earth's equator in the spring and the minimum occurs in the autumnal passage of the sun through the equator.

Due to the elliptical orbit of the earth around the sun and elliptical orbit of the moon around the earth a tidal maxima occurs every 18.6 y when the sun and moon align as close as possible (Minister of Supplies and Services Canada, 2001). After this, the tidal ranges decline for 9.3 y before starting to increase for the next 9.3 y (Roland, 1982). This tidal maxima last occurred in 1998 and we are now in the declining stage of the 18.6 y cycle.

The Minas Channel leading to the Minas Basin is scoured twice daily by the movement of water through the 5 km wide channel with a mean velocity of 16 km h^{-1} (Roland, 1982) and Amos (1978b) reported that the Minas Basin has 15.3 km^3 of water which drains during tidal fluxes and exposes approximately 306 km^2 of mudflats. These twice daily flows of water produce currents in the Minas Basin and Cobequid Bay. Counterclockwise tidal current patterns have been determined from various drift bottle studies, as reported by Pelletier and McMullen (1970), performed in 1922, 1950, 1959 and 1969 indicating that the north side of the Minas Basin has a weaker tidal current than the tidal current traveling along the south side moving towards the head of the Cobequid Bay.

Tidal bores occur when the incoming tide, known as the flood tide, reaches the mean sea level elevation and a shoal area at the same time, and the leading edge of the tide encounters friction from the bed of the bay. When this friction is large enough it causes the downstream side of the flood tide to rise faster than the leading edge, which then materializes as a tidal bore. If this shoal area is long enough in length the tidal bore height increases producing a wave form shown in Fig. 2, which will continue to move upstream ahead of the flood tide (McIntyre and Desplanque 1959).

These tidal bores traveling over the flat expanses of the Minas Basin and Cobequid Bay stir up silt and clay deposited on the bottom from the previous tide and move these materials landward with the greatest silt loading of the water column occurring at mid-flood and mid ebb tide (Amos, 1977). Due to the fact that the most

Fig. 2 Tidal bore in the Lower Truro area (reproduced by permission of NSDAF).

sediment is carried in both directions by the mid-tidal currents and the flood tidal current being the stronger, deposition of sediment is in the form of beds at the mouths of estuaries. These beds are not planar, due to the motion of the suspended materials, and Yalin (1973) reported they are usually depicted by sand waves which the next incoming bore has an opportunity to resuspend and move even further landward. Dyer (1976) reported that over time this acceleration and deceleration of currents may produce a hysteresis effect for sediment transport.

1.3.3 Sediment sources and features within Minas Basin and Cobequid Bay

There are considered to be four major sources of sediment within the Basin and Bay and listed in their order of sediment contribution are: cliff erosion, open sea 25 to 50 % of cliff, river erosion 0.004 % of cliff and seabed erosion which is < 0.004 % (Amos, 1977). The relative change in sea level due to land subsidence and mean sea level rise suggest coastal erosion (Middleton, 1977) of the Minas Basin and Cobequid Bay as a major source of sediment.

Aerial photo analysis over numerous years have shown a great deal of variability in estimating shoreline erosion rates in the Minas Basin. Generally shoreline erosion rates were initially estimated to be in the order of approximately 200 cm y^{-1} along the Minas Basin coastline (Middleton, 1977). Palmer and Beanlands (1977) reported rates of shoreline erosion from Burncoat Head to the mouth of the Shubenacadie River along the southern shore of the Minas Basin and Cobequid Bay are in the order of 5 - 10.5 cm y^{-1}. One area in Cobequid Bay from Burncoat Head to Selma had erosion rates in the order of 65 - 105 cm y^{-1} with the average over twenty-six years being 50 cm y^{-1} (Amos, 1977). Daily erosion rates at Old Barns, Cobequid Bay, measured by GPS surveying equipment (D. Hingley, personal communication, 2002), of the foreshore during a 56 d period in 2002 were 17 - 148 cm d^{-1}. The foreshore is a region of sediment deposits from the floor of the bay to a height of 4.3 m, in this area, where salt tolerant plants have established themselves at the higher elevation. These erosion rates can translate into total sediment inputs of 3.8×10^{6} m^3 y^{-1} (Amos, 1977), 4.8×10^{6} m^3 y^{-1} (Middleton, 1977) and to 6.1×10^3 m^3 d^{-1} in the Old Barns area (personal communication with D. Hingley, 2002), moving headwards based on tidal current studies into the Cobequid Bay.

Pelletier and McMullen (1970) described the western part of Minas Basin as having large areas of relatively coarse sediment while the eastern side of the Minas Basin has relatively fine sediment with scattered patches of coarse sediment. The sorting of the sediment material tends to increase in the central part of the Minas Basin compared with near shore areas and estuaries which have poor to moderately sorted sediments (Pelletier and McMullen, 1970).

There are three recognized major sediment features evident within the Minas Basin and Cobequid Bay. They are the rock platform, sand sediment feature and mud sediment feature. The rock platform is characterized by a steep wave cut platform which is 2 km wide at the mouth of the Cobequid Bay. This platform as reported by Middleton (1977) is itself covered with gravel and mud deposits.

The sand sediment feature is characterized by large bed forms which are commonly asymmetrical in cross section and occur parallel to tidal currents over a substrate of gravel. This gravel can overlay geologically older sand deposits which have in-filled channels cut into bedrock or they may overlay the much older Triassic sandstones. These bars are described by Middleton (1977) as being up to 3 km long and 5 -15 m thick and are separated from each other by the major tidal channels of the bay. The large sand bars subdivide into a megaripple relief that has the shape of ripples 2 - 8 m long and 0.3 - 0.5 m high superimposed upon the larger sand bed form. Dalrymple et al., (1978) reported the sand sediment features found within the Cobequid Bay have sediment sand diameters ranging from 0.125 - 1.6 mm (fine sand to very coarse sand) with the majority being between 0.25 - 0.5 mm (medium sand). These authors also found that sand ripple bed forms only occurred when the mean sand size was less than 0.25 mm (fine sand) and the estimated average corresponding tidal velocity was 0.75 m s^{-1}.

The last major sediment feature according to Middleton (1977) is the mud sediment feature which are sediment particle sizes less than 0.10 mm found at the upper tidal reaches of the Minas Basin and Cobequid Bay. The upper tidal reaches have extensive salt marsh areas which were dyked for agricultural production initially by the Acadians and maintained after the Acadian Expulsion by the Loyalist settlers. A Federal-Provincial agreement for the reclamation of the marshlands under The Maritime Marshland Rehabilitation Act, Chapter 61 of the Statues of Canada of 1948 , in the interests of agriculture and community welfare required the Government of Canada to do all necessary engineering services (Canada Department of Agriculture, Maritime Marshland Rehabilitation Act, 1949). Part of those engineering services was testing of the soil bearing capabilities at potential construction sites. Therefore at various marsh surface levels along the Cobequid Bay, particle size analysis by the Canada Department of Agriculture Soil Mechanics Division showed the average sand size to be 0.05 to 0.10 mm (very fine sand) in size(Canada Department of Agriculture Soil Mechanics Division, 1955).

1.3.4 Estuaries

Estuaries are described in various ways such as a water passage where the tide meets the current of a stream (Websters, 1981) or as a semi-enclosed coastal body of water which has an unrestricted connection to the sea (Luketina, 1998). Both describe an estuary, but estuaries occur all over the world under different climatic conditions. Those in the southern hemisphere can experience an extended dry period where the fresh water flow can cease and the estuary can be closed off from the sea (Elliot and McLusky, 2002) and in comparison McLusky and McIntyre (1995) describe European and North American estuaries as having more annual rainfall and being open to the sea all year round.

Researchers have refined the description by using estuary morphology, hydraulics and sediment transport trends (FitzGerald et al., 2002) coupled with either biological, chemical or physical characteristics to describe an estuary. Using the geometry of the estuary, Ippen (1966) states where an estuary meets a river channel, the geometry of the channel can either be of uniform width and depth to combinations of exponentially or linearly varying width or depth.

Hydrological characteristics include the height of the tide, either micro, meso, or macro, as well as the shape of the estuary itself. If the ratio of tidal amplitude is greater than the channel depth the river channel is then tidally dominated (Davis, 1978). FitzGerald et al., (2002) in an investigation along the New England coast characterized riverine associated inlets, as estuaries which are periodically dominated by fresh water discharges. Tidally dominated channels are characterized by tides entering the channel acting as a wave progressing in the landward direction and then eventually being extinguished by the bottom friction (Godin, 1999). These wave amplitudes tend to have a short duration flood tide followed by a longer duration ebb tidal outflow (Davis, 1978). A result of this tidal time profile is that the flood tide is associated with bedload transport while the ebb tide is associated with suspended sediment transport. These estuaries are often characterized by a bell or funnel shaped mouth and the channel width and depth decrease progressively landward (Davis, 1978).

Chemical and physical characteristics used to describe estuaries are the saltwater to freshwater gradients. Mann and Lazier (1996) describe two isohaline types, one where at the interface of the fresh and saltwater, mixing is not vigorous, allowing the freshwater to push the saltwater front back and a layer of freshwater lies over the saltwater, which is called a wedge type. The other type is where the salt and freshwater mixing is such that there are no wedges. Instead of the isohaline gradient being in the vertical direction it is horizontally in the longitudinal direction (Ward, 1976). Davis (1971) further describes specific estuary water mixing as being homogeneously or heterogeneously mixed either in the vertically or horizontally direction.

1.3.5 Sediment movement

Tidal currents carrying sediment tend to vertically grade the sediment material since transport is accomplished by traction and suspension (Fig. 3) and this transport moves in two directions, flood and ebb according to Frey and Basan (1978).

Depositions of sediment occur over different time scales which can be from seconds to seasons (Christie et al., 1999) due to local hydraulic conditions, such as tidal

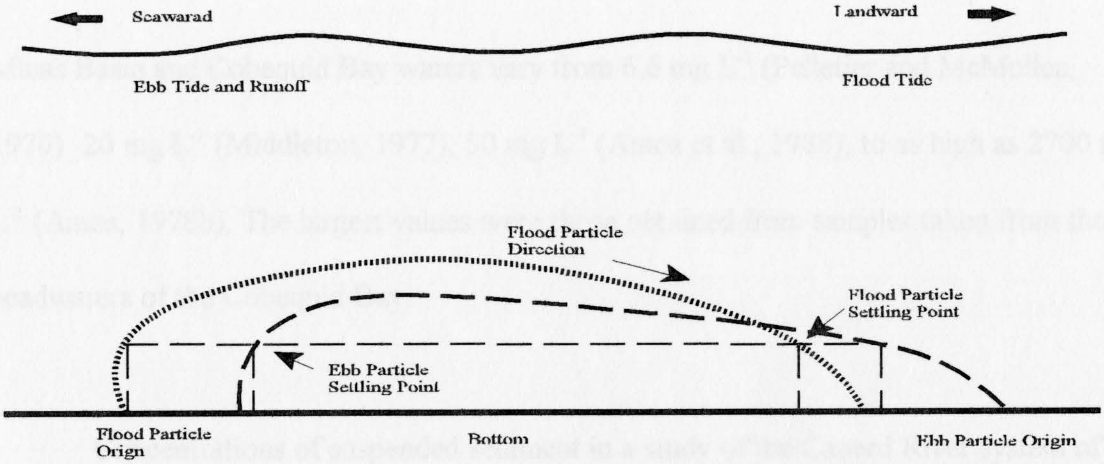

Fig. 3 Movement of sediment due to tidal flows (modified from Davis 1971 schematics).

currents and river runoff volumes, influencing the amount of sediment moving within the estuary (Ariathurai and Krone, 1976). Sediment movement is partitioned into two broad groups: suspended load or bedload.

Sediment suspension occurs when the particle is dislodged from the bottom (Jago and Mahamed, 1999) and involves two lifting processes, one due to pressure differences produced by gradients in velocity and the second due to upward turbulent velocities occurring close to the bottom (Briggs, 1978). Once suspended, less energy is required to maintain the particle in suspension. Suspended sediment load is the amount of material suspended in the water column due to current velocities and the effect of particle buoyancy within the medium. Pitty (1971) reports that these particles are usually less than 0.14 mm in diameter. Suspended sediment is usually determined from water samples taken during high tide at various depths of the water column. Reported suspended sediment loads of the

Minas Basin and Cobequid Bay waters vary from 6.6 mg L^{-1} (Pelletier and McMullen, 1970), 20 mg L^{-1} (Middleton, 1977), 50 mg L^{-1} (Amos et al., 1988), to as high as 2700 mg L^{-1} (Amos, 1978b). The largest values were those obtained from samples taken from the headwaters of the Cobequid Bay.

Concentrations of suspended sediment in a study of the Canard River system of the Minas Basin showed a classic suspension concentration profile which is low suspended sediment concentrations at the surface and higher concentrations at the bottom. Daborn and Pennachetti (1979) reported the surface modal particle sizes were 10 -16 μm while those from the bottom are usually > 20 μm. The bottom samples were several magnitudes of concentration higher than the upper samples revealing a stratified water column concentrations of suspended sediment indicative of bedload transport (more likely a fluid mud in this setting)(Eagleson et al., 1966).

The Cornwallis River located in the same general area as the Canard, was sampled from the mouth of the river to its upper reaches (11 km upstream) and revealed increasing sediment concentrations and decreasing sediment size ranges (Daborn and Pennachetti, 1979). At the mouth where the tidal influence was the greatest the sediment concentration was 50 mg L^{-1} and all particle sizes were < 280 μm while at the upstream end the suspended sediment concentration was 4500 mg L^{-1} and the particle sizes were < 40 μm (Daborn and Pennachetti, 1979).

Bed load (again, a fluid mud) is that material located at or near the bottom of the water column that does not become suspended but flows with the prevailing current and can be transported as individual particles or as a mass of particles. Transportation is usually by traction due to pressure gradients caused by suction forces from turbulent velocity which lifts the particle (Brooks et al., 1997). Traction starts when the oscillating turbulent flow allows the liquidization of the particle layer on the bottom surface and its resuspension into the water column and when the turbulent flow becomes insufficient the suspended particle will settle to the bottom (de Wit and Kranenburg, 1997). This turbulent flow value according to Ariathurai and Krone (1976) may also be identical for the erosion of the sediment depending upon the bottom characteristics of the channel.

1.3.6 Sediment settling parameters

The amplitudes of tidal intrusion or freshwater runoff can affect the speed at which a particle can settle to the bottom of the estuary. The settling velocity of suspended sediment depends on the particle size of the material and the density of the medium in which it is suspended.

The sediment concentration per depth of water column will indicate the vertical profile of the medium, but the size of a particle can be a changing parameter since flocculation can occur within the water column. Flocculation occurs when two particles with different electrical charges come into contact with each other and bond together into a larger particle. These bonds can be electrically strong or weak depending upon the electrical characteristics of the two particles and the electrical charge of the surrounding particles. Eagleson et al., (1966) reported that flocculation is associated with clay materials, salt concentrations and some types of metal oxides all under 2 μm in size. Tidal estuaries are known to have salinity gradients which effect the rate of flocculation and the diameter of available sediment sizes attainable before tidal currents change direction (Guan et al., 1998).

Other factors influencing the settling velocity are the concentration of the lower elevation suspended sediment being higher than the concentration above it hindering the settling velocity of the particles from the surface due to collisions between particles (Ariathurai and Krone, 1976). The maximum amount of sediment that can settle out in a tide is the amount in the water column between tidal direction changes at the mid-tide due to the tidal currents being the lowest at this tidal position (Frey and Basan, 1978). Ariathurai and Krone (1976) also report that sediment settling velocities in an estuary are found to change with changing tidal amplitude.

1.3.7 Electrical conductivity and pH

Variation in salinity can be clearly identified in analysis of the tidal cycle versus the depth data of the tidal range with the greatest range being measured during Spring and Neap tides (Christie et al., 1999). There has been found, in other estuaries, a direct correlation between the electrical conductivity of the water, the density of the medium (Horne, 1969) and the presence of saltwater within the system (Fettweis et al., 1998 and

Lauff, 1967). Burton and Liss (1976) found that the electrical conductivity increases with higher seawater intrusion and the pH would be expected to decrease with more freshwater runoff in the estuary.

1.3.8 Sediment classification

The US Army Coastal Engineering Research Center (USACERC, 1977) reported there are two classification systems used to determine the sizes of sediments, and they are the Unified Soil Classification based on the a classification system used by engineers, and the Wentworth Classification based on a classification system used by geologists. In the analysis of sediments, the material in estuaries varies from coarse materials such as stone to the finer sand, silt and clay particle sizes. The majority of particles in this estuary are small and a graphic method to clearly distinguish between the smaller particles utilizes a negative log transformation of the particle sizes. In the Wentworth Classification System each size class is divided into class intervals which are related to each other by a ratio of $1{:}2^{1/2}$ based on the fact each interval is twice the preceding interval and one half the succeeding interval (Griffiths, 1967). The diameter of sand is near lognormal and the negative log 2 transformation happens to coincide with the size limits of sand in the Wentworth Classification (Krumbein, 1936 in USACERC, 1977). The negative log value is used since it will give a whole number value for finer particles (Royce, 1970) which can then be used for describing the distribution of the particles by their mean, median and standard deviation (USACERC, 1977).

1.4 Summary

Geologically the Minas Basin and Cobequid Bay consisting of glacial tills underlain by Triassic sandstones lends itself to being easily erodible. With the tides in the Minas Basin as high as 15 m and numerous tidal bores occurring in the area the ability to move the erodible material is evident within the system. Erosion rates of 65 to 105 cm y^{-1} (Amos, 1977) from the cliffs surrounding the Minas Basin and on land located near mean tidal elevations in Cobequid Bay erosion rates of 17 to 148 cm d^{-1} (D. Hingley personal communique) ensures adequate material is available for suspension within the tidal water column.

The Salmon River Estuary is located at the head of the Cobequid Bay so the movement of tidal sediment tends to be in a landward direction. The period between flood tide and ebb tide, called slack tide, is where the tidal currents are minimized and allows some of the tidally suspended sediment to settle to the estuary bottom before ebb tidal currents can remove it.

Electrical conductivity and pH parameters demonstrate the temporal and spatial extent of the tidal intrusions and the estuary watershed runoff events when they occur. By using a standardized sediment classification system called phi, a log transformed mm size, it will assist in quantifying the spacial variability of the sediment in the estuary.

CHAPTER 2- RESEARCH METHODS

2.1 Introduction

The Town of Truro is bordered on one side by a dyked estuary subject to semi-durinal tidal intrusions from the Minas Basin. Similar to all urban areas, pressure to utilize all land within a civic boundary for commercial or residential development is prevalent. It is known that the tidal influxes are significant enough to affect the Salmon River Estuary hydrologically but does the sediment in the tidal water have any affect on the estuary?

Locally tidal high heights are taken from the calculated tidal highs based on a primary reference port in St. John, N.B. (Minister of Supply and Services, 2000) which is over 300 km away. The ability to be able to accurately measure the tidal high water elevations in the Truro area by the Sonic Ranging Sensor (Campbell Scientific, 1994) can give some comparisons of the elevations to the closest primary reference port. The ability to relate these tidal elevations on a geodetic basis allows the comparison of the tide height to any point within the estuary and to the bottom elevations of deposited sediment. The tides are measured in 15 min. intervals allowing a profile of the incoming tide to be compiled to show if the tide is a predominantly flood tide. Flood tides are incoming tides which are of a shorter time duration than the ebb tide and have a characteristic faster vertical rise than the ebb tidal vertical drop. This profile could show if the tide in Truro is a predominantly flood tide, which would infer that the incoming tide is pumping sediment into the estuary.

Tidal bores are the front of a water wave traveling in an landward direction the same as the incoming tide. These bores can cause loosely consolidated bottom sediments to become resuspended and Truro is known for having a tidal bore occurring just before each tidal influx. The second year of the study the Sonic Rangers measurements of the tidal profile were changed from 15 min. intervals to 1 min. intervals to profile the tidal bores.

If the tides are pumping sediment into the estuary the particle sizes and location of these sizes along the estuary would give an indication of the tidal currents competency. Water currents are known to be able to move sediment, but the competency of the current to move sediment is usually determined in laboratories since the ability to measure all water currents within a reach is not easily accomplished. Sediment concentrations within the water column during just the monthly high tide sequence can determine how far the tidal intrusions inundate the estuary and whether the sediment is stratified within the water column itself due to a high sediment concentration.

Electrical conductivity and pH measurements can determine the temporal and spatial extent of the tidal or watershed runoff events during a monthly high tide sampling period. Annually the Salmon River Estuary's hydrological environment changes due to lower rainfall events with wider temporal occurrences of significant rain events during the summer.

sediment. Initially the estuary channel in the spring is assumed to be at its maximum discharge capacity and as the summer progresses the deposits of sediment occurring affect this discharge capacity. Sounding measurements from three sites along the estuary will help determine the spatial and temporal parameters of the bedload accumulations.

2.2 Materials and methods

2.2.1 Site Selection

The location for this study is 4.8 km in length and encompasses the tidal portions of the North and Salmon Rivers, Truro, Nova Scotia. The total watershed area upstream from the Veterans Memorial Highway is 669.5 km^2 (Reid, 1973). Three bridges form the boundaries of the study area (Fig. 4) and they are located where the Veterans Memorial Highway (Site 1) crosses the estuary, where the North River Bridge (Site 2) crosses the North River and where the Park Street Bridge (Site 3) crosses the Salmon River. These sites were chosen because they all are within the tidal extent of the river system. Site 1 always had tidal incursions while at Sites 2 and 3 the number of tidal incursions diminished as the season progressed. These incursions declined in number due to a number of factors such as, lower than expected tidal height, higher fresh water runoff which masked the tide or the channel was restricted to such an extent that tidal waters did not reach these sites.

The estuary study area is enclosed along its length by dykes on either side and at

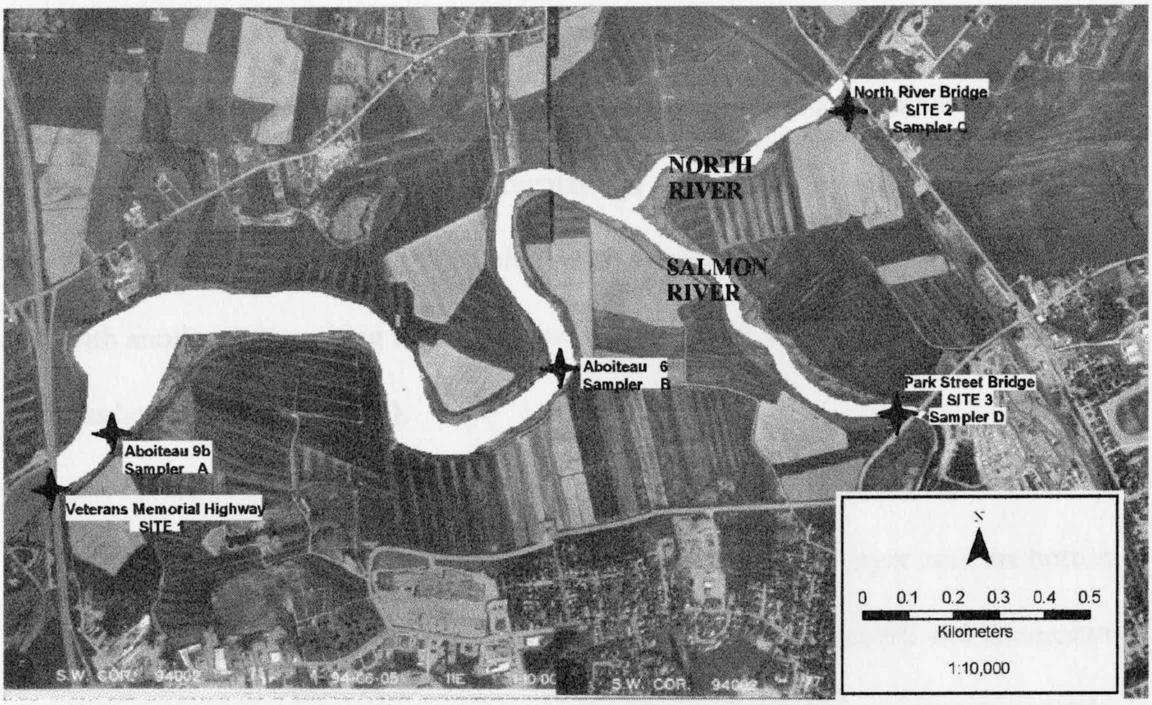

Fig. 4 Aerial view of the study area showing four sampler locations and three bridge sites forming the boundaries of the study area which is outlined in white.

3.6 km upstream from the Veterans Memorial Highway (Site 1) the confluence of the North River estuary channel and Salmon River estuary channel occur, a further 0.9 km upstream of this confluence on the North River channel a highway bridge (Site 2) crosses the estuary and at 1.2 km upstream the Salmon River channel another bridge (Site 3) spans the estuary.

2.2.2 Measuring sediment deposits

As evidenced by the consequences of the Windsor Causeway construction the amount of sediment material in the Minas Basin tidal system is large in volume and changes to the tidal flow regime can move copious amounts landward. A mudflat started to form downstream of the structure and six years later was 1.8 x 10^6 m^3 according to Amos (1977). The mouth of the Avon River 20 km away had a net accumulation across the channel of 2 m and Amos (1977) estimated the volume of sediment required to do this was 80 x 10^6 m^3. The amount of this volume that was supplied by suspended sediment was 5 % with another 1 % coming from shoreline erosion while 94 % came from the Minas Basin as bedload (Amos, 1977).

Le Normant (2000) defines fluid mud as a dense sediment layer near the bottom which is able to flow horizontally and this mud layer according to deWit and Kranenburg (1997) has a large impact on the estuarine environment. Given the opportunity to settle and consolidate on the bottom, this fluid mud layer, could be used as a measure of the rate of bedload deposits within the estuary.

If the study area is considered to be a closed system where the bedload entering from the downstream end (Site 1) is transported temporally and spatially to the landward Sites 2 and 3 then this transport rate could be defined as the unit width cross section per unit time similar to a sediment transport rate as defined by Dyer (1976).

The three bridges, at the boundaries of the study area, were surveyed and cross sections of the river were taken on the same day using a Leica T 1000 Total Station to determine geodetic elevations. This allowed the measurements from the top of each bridge railing posts to be correlated to the other bridges, to the tidal elevations recorded at Site 1 and established a base line at each bridge from which the estuary bottom elevations could be calculated. Taking measurements in the order of the site numbers and using the bridges themselves as a baseline for the geodetic elevation of the estuary channel allowed cross sections of the estuary to be done similar to using a boat or surveying the estuary bottom repeatedly over the course of the study as is the normal practice. From abutment to abutment, Site 1 is 189 m long at elevation 14.1 m ,the posts are 2.36 m apart and the estuary channel width is 139 m, Site 2 is 56 m long at elevation 14.5 m, the posts are 2.34 m apart and the estuary channel width is 40 m and Site 3 is 90 m long at elevation 15.1 m, the posts are 2.36 m apart and the estuary channel width is 54 m. The bridge crossing the estuary at Site 3 was constructed in an arc and therefore the actual elevation was chosen as the height of the first rail post on the North side of the bridge.

Estuary changes in bottom elevation due to sediment deposits were taken with a 30 m tape attached to a 64 mm polyethylene rope with a 9 kg weight at the end of the rope. The weighted line was lowered from each rail post over the estuary channel, such that the weighted line was perpendicular to the estuary bottom, and the measurements taken from the top of the rail posts to the nearest 13 mm. Because the estuary bottom during low ebb tidal flows has the characteristics of fluid mud, the weight only rested on the bottom momentarily. Utilizing the surveyed elevations of each rail post as a base elevation, the estuary channel elevation below each post could be calculated. Differences between consecutive measurements as the season progressed showed the net sediment deposition, erosion and the channel restriction.

Deposited sediment is the sediment remaining in the estuary channel after deposition or erosion by the tides or runoff. Measurements were taken a minimum 6 hrs after the high tide and the measurement intervals for deposited sediment from Site 1, 2 and 3 were performed during year 1 on a monthly basis and during year 2 were increased in frequency to just before sediment sampling and just after sediment sampling. The increased frequency during the second year was an attempt to capture more of the sediment deposits variability profile present within the estuary system.

The river discharge was not specifically measured, but it can be related to rainfall data. Rainfall data was obtained from a weather station approximately 800 m upstream of Site 3 during year 1 and a second weather station 5 km due north of the same location in year 2.

2.2.3 Suspended sediment sampling

Uncles et al.,(2000) found that there was a seasonal and spatial variability both vertically and longitudinally of suspended sediment concentration within and between different estuaries. To compare different estuaries, they sampled the water column 1 h prior to slack water during low fresh water runoff.

The suspended sediment sampling of this study is just before slack tide and is in ranges of depth from the water surface due to the design of the water sampler the variability of the tidal ranges and the estuary infilling at the landward sampler locations. The sampling platforms were designed to open when the tide peaks causing a float to trip and allowing water into the individual 50 mL sample vials, which are equally spaced at 0.59 m along the sampling platforms. If the tidal influx was lower or higher than predicted from the St. John tidal charts, then the sample collected would not be at the expected depth but would be within the 0.59 m spacing.

Sampling is also limited to the ice free and frost free time of year, since the sediment samplers are not heated and would freeze, unable to take any samples. Thirty year precipitation normals show that seasonal precipitation is highest in the fall and winter (Environment Canada, 2004) therefore runoff from the watersheds entering the estuary during this time period tends to erode the sediment deposits present within the estuary otherwise the sediment deposits will accumulate.

Tidal water enters the estuary on a semi-durinal sequence over a seasonal time period and therefore the sediment loading of the estuary is expected to be quite variable temporally and spatially. To determine if there is a vertical and longitudinal variability in suspended sediment concentration along the estuary sampling was undertaken at four locations. The four sampling locations were established at the following distances upstream of Site 1, Sampler A was 141 m upstream at NSDAF aboiteau 9b , Sampler B was 2.5 km upstream at NSDAF Aboiteau # 6 , Sampler C was 4.5 km upstream at Site 3 and Sampler D was 4.8 km upstream at Site 4. The locations for the Samplers A, B, C and D were chosen for accessability and degree of stable anchoring needed for the sampler platform. Samplers A and B are in areas where the greatest depth of water occurred due to vigorous tidal intrusion and river runoff and required a more secure mounting site. Sampler A was located close to the sonic ranger, a water level measuring device, and always had a water depth at slack tide > 2.4 m while Sampler B was located where the majority of the time a water depth at slack tide was > 1.8 m. The secure mounting sites were aboiteaux maintained by the Nova Scotia Department of Agriculture and Fisheries (NSDAF) as part of their Land Protection Marsh Maintenance Program. Samplers C and D were located in areas of tidal intrusions which rarely had slack water depths greater than 1.2 m and were mounted on posts. All samplers were attached with 64 mm poly rope to either a buried 40 cm x 1.5 cm drift pin or nailed with four fencing nails to a 20 cm x 20 cm timber. Samplers A and B were dislodged from their secure mounting sites once and Samplers C and D were upset twice. Sampler C during one upset broke its 64 mm poly rope anchor which has a breaking strength of 759 kg.

Measuring the deposited sediment of the estuary from the three bridges crossing the estuary and sampling the water column just before slack tide would allow the determination of the sediment load within the water column. The water column sediment load would then be an indication of the sediment fluxes available since an increased column load would infer increased bed loading and increased tidal energy. This also would be based on the assumption that all of the material settling from the suspended sediment load would be settled into the bedload zone during the time period during slack tide, since when the tide turned the ebb velocity would erode any material not already consolidated to the bottom from the bedload zone.

A study performed on the Cornwallis River (Daborn and Pennachetti, 1979), which empties into the Minas Basin, found that the vertical suspended sediment profiles were not homogeneous. A reason for this could be, that in various estuarine studies Zimmermann-Timm (2002) found the sinking rates of aggregates ranged from 1 to 665 m d^{-1} and that the settling velocity is reduced after a critical concentration threshold is reached.

The sediment samplers were designed to capture the sediment profile in the vertical direction by obtaining the first sample from within 30.5 cm of the water surface and thereafter at 61.0 cm intervals to a maximum depth of 2.4 m at samplers A and B and 1.8 m at Samplers C and D. Each sampler platform (Fig. 5) consisted of a Fisherbrand 50 mL plastic vial placed vertically along a 5 cm x 10 cm board called a mounting board and held in place by electrical conduit brackets. These samplers have a rubber stopper placed in the mouth of the vial connected to an small elbow shaped bronze welding rod which is then crimped fitted, using aluminum cable crimps, to a longer connecting bronze welding rod. These bronze rods can then be crimped together to increase the number of samplers on each mounting board.

The tripping mechanism for the sampler is a toilet bowl float 30.5 cm above the first vial opening when the flood tide exerts enough pressure on the float to pull the connecting the rods upward allowing tidal water to enter all of the vials at once. Another float was needed since bedload deposits restricted sampler mounting board depth and not

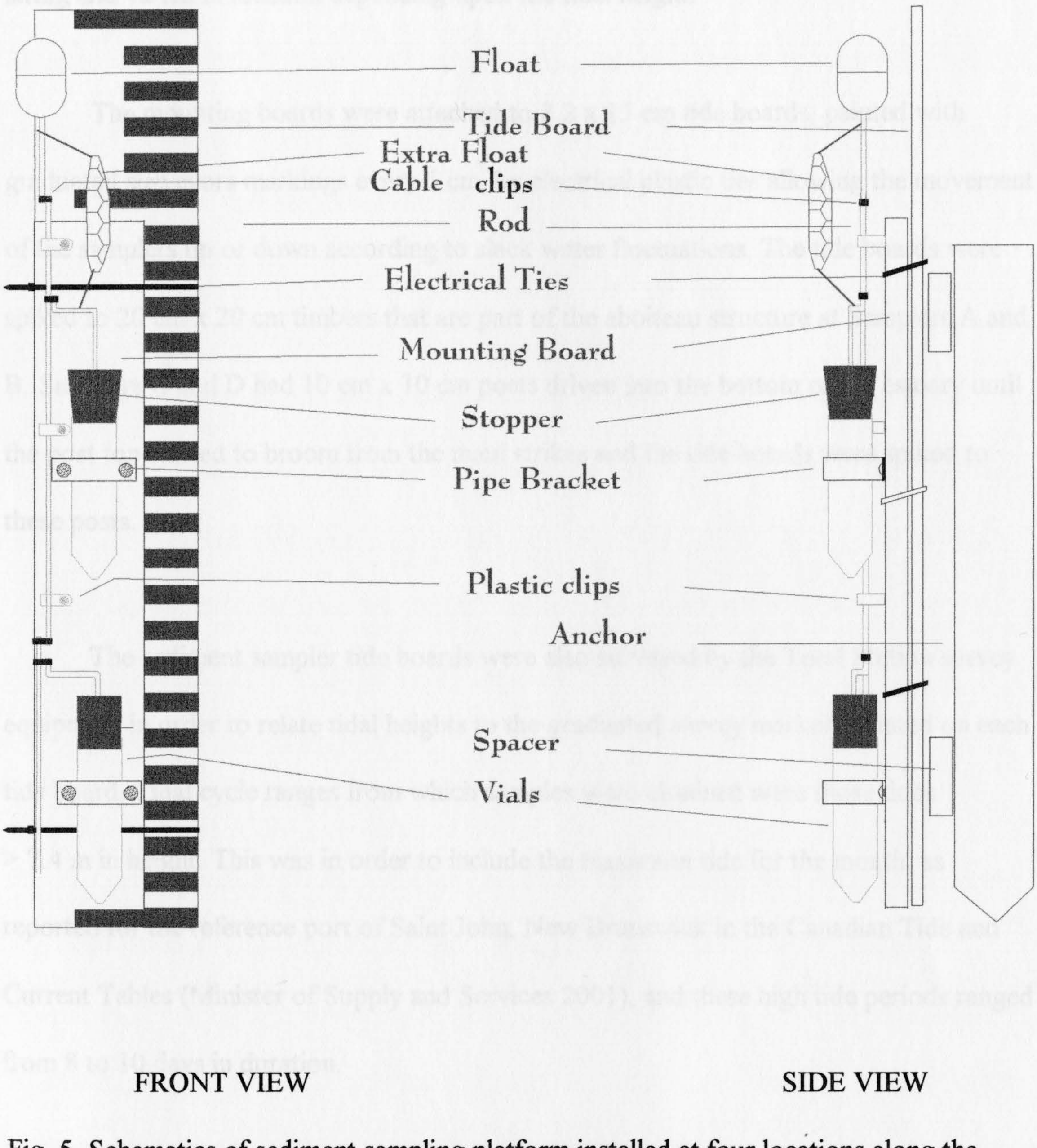

Fig. 5 Schematics of sediment sampling platform installed at four locations along the estuary showing the sample vial attachment to graduated tide board, stopper opening mechanism and float to lift stoppers at high slack tide.

all of the tides could reach the upper float. This extra float was foam insulation used to seal cracks around windows in a 15 cm diameter cylinder by 25 cm long around a nylon string and varied in location depending upon the tidal height.

The mounting boards were attached to 2.2 x 15 cm tide boards, painted with graduated surveyors markings every 5 cm, by electrical plastic ties allowing the movement of the samplers up or down according to slack water fluctuations. The tide boards were spiked to 20 cm x 20 cm timbers that are part of the aboiteau structure at Samplers A and B. Samplers C and D had 10 cm x 10 cm posts driven into the bottom of the estuary until the post top started to broom from the maul strikes and the tide boards were spiked to these posts.

The sediment sampler tide boards were also surveyed by the Total Station survey equipment in order to relate tidal heights to the graduated survey markers painted on each tide board. Tidal cycle ranges from which samples were obtained were those tides > 7.4 m in height. This was in order to include the maximum tide for the month, as reported for the reference port of Saint John, New Brunswick in the Canadian Tide and Current Tables (Minister of Supply and Services 2001), and these high tide periods ranged from 8 to 10 days in duration.

Climatological factors can depress or increase the expected tide or fresh water runoff heights and the use of electrical ties allowed one to obtain samples at a depth for a given expected tidal intrusion. A select series of samples over the complete study area were left unstopped for selected tides to determine the total amount of suspended material present in the flood tidal water. Differences in the suspended sediment concentrations between open vials and closed vials will give an indication of the % of suspended material available for deposition on the flood tide. At the time of collection all vials were sealed with twist on caps and stored at room temperature for further analysis in the laboratory.

2.2.4 Electrical conductivity and pH

Wenner and Geist (2001) indicated that a salinity profile is a reflection of the estuaries hydrography and habitat. By analyzing the salinity on a tidally averaged basis some long term estuarine characteristics may be identified (Uncles, 2002). Increasing salinity was found to decrease the size of suspended aggregates in a study by Zimmermann-Timm (2002) and the particle sizes were less than or equal to 150 μm diameter and spherical in shape.

Once the estuary is dominated by the tidal regime a freshwater runoff event may not show a change in electrical conductivity since the event may just be flushing accumulated salinity therefore the pH value may show when such an event is occurring. Values of pH according to Wenner and Geist (2001) should be within the range of 6.0 to 8.5 for a healthy estuary system and the measurement of this parameter can give insight on the influence of the salt water and fresh water sources.

The EC and pH of the samples collected in 2000 were analyzed during the winter while the ones collected in 2001 were analyzed within 24 h of collection. Samples were not stirred excessively since it was found that samples with a sediment concentration greater than 30 g L^{-1} the probes were fouled. The increased frequency of the EC and pH measurements were done in 2002 in order to determine if small scale rain events could be detected.

Electrical conductivity was determined using a Radiometer Conductivity Meter CDM2e by the following procedure. The probe was calibrated with distilled water and then enough of the sample was decanted into a smaller vial in order to cover the probe and a reading in mmhos was taken. The probe was then rinsed with distilled water and placed in a beaker with enough distilled water to cover the probe until the next measurement.

The pH of samples was determined using the Oaktron pH/mV/^{0}C meter. The samples were decanted into 50 mL beakers and the pH probe inserted into the medium. After waiting for the reading to stabilize on the digital readout it was recorded and the probe rinsed with distilled water for the next sample.

2.2.5 Sediment particle size analysis

Fine sands were found to be transported by fast tidal currents in many estuaries if they fringed a macro-tidal sea (Jago and Mahamod, 1999) such is the case in the estuary under study. The suspended sediment concentrations are an indication of the amount of material entering the estuary. Determining the suspended sediment concentration at the different sampler locations can show when and where the estuary is dominated by either the tidal or fresh water regime. In late spring the tidal intrusion will increase in dominance due to lower fresh water runoff and the sediment concentration will move longitudinally up the estuary. A large fresh water runoff would move the sediment within the system downstream and the sediment concentration would reflect this occurrence.

The vertical suspended sediment profile of the water column will reflect the stratification of the water column. A Chesapeake Bay study showed different suspended sediment concentrations near the bottom but the surface concentrations were unaffected by changes in tidal heights (Uncles, 2002). Overall, the greater the concentration the more of the material is available for deposition.

The sediment concentration is measured from samples by a gravimetric method where samples for the suspended sediment concentration were weighed on a Sartorius balance scale model ± 0.001 g. A disposable aluminum dish is preweighed and 10 mL of a stirred and shaken sample is pipetted ± 0.0001 mL into the dish, the pipette is then rinsed with distilled water into the tin to get all of the residue from the sides of the pipette. The dish is dried for a minium of 24 h at 105 ^{0} C in a Fisher ISO Temperature Oven 100 Series Model 1166 and after drying the dish is cooled and reweighed. The weighed value represents the amount of suspended sediment on an oven- dried basis in the water column at that particular depth and location along the estuary.

Some samples were collected without stoppering and the values obtained from these open vial samples represent all of the suspended sediment before slack water in that particular tide. The difference between the open values and closed values indicates the amount of material settling towards the bedload zone.

Particle size analysis of the clay, silt and sand percentages within the water column were completed for selected tidal samples in order to determine the spatial and temporal differences of particle size distributions within the study area. Suspended sediment concentrations may be equal at different samplers but the particle composition might differ depending upon the hydrological energy needed to transport different sized particles. Organic matter content of the samples are assumed to be low in content and therefore particle sizes of the suspended sediment are determined by a modified procedure used by NSAC Soil Analytical Laboratory (Brewster, 2001). Complete sample sets of the water column profile for individual samplers were selected for particle size analyses. Each sample vial of the set was stirred, shaken and rinsed with distilled water into a 400 mL beaker, pre-weighed on a Sarotrius Balance Scale to 0.0 g ± 0.001. In order to determine the base weight of the various mineral fractions the composite sample was placed in a Fisher Isotemp 100 Series drying oven for a minium 36 h at 105 ^{0}C, cooled in a desiccator, reweighed, and the sediment weight determined by subtracting the pre-weighed beaker weight from the dried weight. To disperse the flocs and clods within the composite sample it was mixed with 10 mL of Calgon® dispersing agent premixed at 50 mL to 1 L of distilled water and 100 mL of distilled water, allowed to soak for 1 h, restirred and rinsed into a Hamilton Beach milkshake cup filled with distilled water to a preset level and mechanically stirred for 5 min on the Hamilton Beach milkshake blender. The dispersing agent is used to separate particles so that the flocs formed would not occur and those that had occurred would be deflocculated. The shaken composite was wet sieved thru a 270 mesh sieve (53 μm) in a funnel over a KIMAX TC 20 ^{0} C 1205 mL sedimentation cylinder. The captured material in the mesh sieve is the sand and silt component of the composite sample and is rinsed repeatedly until no coloration is observed in the rinse water going into the sedimentation beaker and then placed in a preweighed aluminum dish for drying in the oven for a minium of 24 h.

Sedimentation cylinders are used to calculate the clay portion of the sediment sample and do this by being filled to the 1000 mL level, covered with a watch glass and placed in a water bath to sit for 24 h. Twenty four hours later once the water bath temperature became a constant 20 ^{0} C, the sedimentation cylinders contents at 1 min intervals between cylinders, were mixed for 2 min using a custom made plunger, covered with a watch glass and allowed to sit undisturbed for 4.5 to 6.5 h to allow the clay portion of the composite sample to start settling. The time of mixing was also recorded so that samples are taken later in the day at the same time intervals as the mixing by pipetting a 20 mL $\pm$ 0.01 sample from a set depth into a pre-weighed dish and placed in the drying oven for a minium of 24 h. For the pipette analysis method which is based on Stokes Law the resistance a fluid would exert on a spherical shaped particle equals the effect of gravity on that particle and therefore the settling velocity of the particle would be constant. The theory has merits for particles smaller than small sand 0.053 mm or 3 ϕ (Royce, 1970).

The dried sample was then cooled in the desiccator, reweighed and the 20 µm clay portion determined from the resultant weight.

The sand and silt content was determined by transferring the captured sediment in the sieve to a pre-weighed aluminum dish using distilled water and dried for 24 h in the drying oven, cooled in the desiccator and reweighed to determine the total sand and silt weight. The dried material was then placed in a set of preweighed (6 cm diameter) US Standard Sieve Series ASTM E-11 Specifications by Dual Manufacturing Company and arranged in the following sequence from the top to the bottom: 2.00 mm, 1.00 mm, 0.500, 0.250 mm (60 mesh), 0.150 mm, 0.106 mm (140 mesh), 0.053 mm (270 mesh) and pan. A cover was placed over the top sieve and the sieves shaken in a Humbolt Testing Equipment Laboratory sieve-shaker for 15 min. After being shaken the pans were individually reweighed and the portion of material in each pan recorded. These recorded weights were then used to calculate descriptive statistics and the % of fine gravel (2.00 mm), very coarse sand (1.00 mm), coarse sand (0.500 mm), medium sand (0.250 mm), fine sand (0.150 mm), and very fine sand (0.106 and 0.053 mm). The silt % is calculated by subtracting the clay (< 0.002 mm) % and gravel plus sand % from 100 with the silt content % being the remainder.

2.2.6 Tidal ranges

The rates at which sedimentation occur within this type of estuary varies due to tidal fluctuations. The Minas Basin is semi-durinal it is known to have varying tidal amplitudes on a bi-weekly basis (Allen et al., 1976). Within the Cobequid Bay itself, Humphrys et al., (1977) reported that the major energy contributor to the tidal amplitude is the lunar effect which contributes up to 95 % of the total tidal energy resulting in a higher than average series of monthly tides each month. Tidal heights for the Bay of Fundy are published by the Federal Department of Fisheries and Oceans on an annual basis and are mainly for shipping purposes. Daily times of high and low water heights are given for reference ports and other locations called secondary reference ports around the bay (Minister Supply and Services Canada, 2001) and the closest reference port to Truro is Saint John, New Brunswick. The tidal heights in these publications are defined as the vertical distance of the tide between the surface of the sea and chart datum for those ports and in those ports not navigable at low water it would be where the vessel would rest its keel on blocks or mattresses (Minister Supply and Services Canada, 2001).

The effects of the weather can cause differences between predicted and observed tidal range and are mainly the effects of barometric pressure and wind direction (Minister Supply and Services Canada, 2001). A low pressure may cause a rise in sea level as much as 0.3 m , which if coupled with a wind in the direction of the tidal flow the tidal difference between the predicted in Saint John and Truro can be greater (Minister Supply and Services Canada, 2001). Saint John is approximately 350 km from Truro and the closest secondary port is Burncoat Head 40 km away therefore there is no accurate tidal information available for the Truro area from the Department of Fisheries and Oceans.

Tidal flood and ebb tidal cycles are currently being recorded by the NSDAF where the Veterans Memorial Highway (Highway 102) crosses the Salmon River Estuary. Tides are measured by utilizing a Campbell Scientific SR50 sonic ranger, (Fig. 6) which works on the principle of emitting a sound wave and measuring the time it takes for the wave to return to the emitter. Based on the time lag the height of the ground or tide is determined from a set reference and each reading is calibrated for temperature in order to overcome atmospheric noise. The sonic ranger was mounted under the bridge and the readings were collected every 60 s and averaged every 15 min until being stored in a Campbell Scientific CR 10 data logger and is accurate plus or minus 0.4 % of the distance to the target surface which in this case was 3.6 cm. The accuracy of the sonic ranger can then be utilized to determine the river bed height or river height during the ten days of suspended sediment sampling.

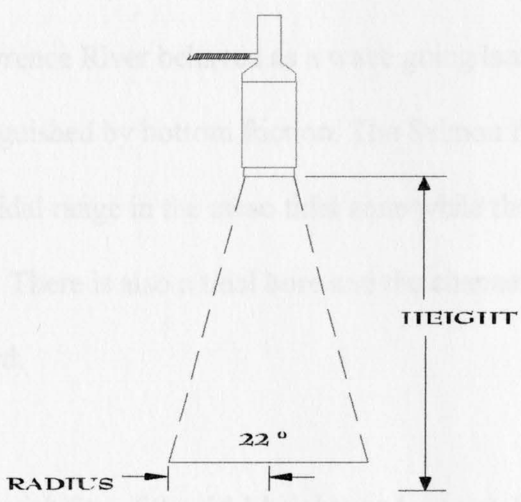

Fig. 6 Sonic Ranger operational schematics showing direction of mounting towards water.

CHAPTER 3 - RESULTS AND DISCUSSION

3.1 Suspended sediment

Displaying the sediment concentration profile vertically will indicate the amount of settling occurring during each tidal influx. The difference in sediment concentration between the depths sampled represented the rate of settling, since the incoming tide is assumed to be well mixed. Longitudinal sediment concentration differences are considered to represent the stratification of the water column and indicate the tidal influxes of sediment for each tide. Each sample is a temporal and spatial record of the changes occurring within the estuary.

The Minas Basin is classified as a hyper tidal (Uncles et al., 2000) water body due to tidal ranges in excess of 6 m in height occurring at Burncoat Head. The Salmon River Estuary is at the head of the Minas Basin and the mean tidal highs for 2000 and 2001 were 2.1 m ± 0.9 and 1.9 m ± 1.0 making this a mesotidal area. Godin (1999) found that a tide entering the St. Lawrence River behaved as a wave going landward, becoming distorted and eventually extinguished by bottom friction. The Salmon River Estuary reflects this by having a measured tidal range in the meso tidal zone while the Minas Basin and Cobeqiud Bay are macro tidal. There is also a tidal bore and the channel width and depth diminishes as one goes landward.

Due to the variability of the tidal heights and estuary bedload accumulations, samples were collected from the surface and proceeded downward, segmented into 0.59 m depth increments. A sample collected from the water surface 0 m to 0.59 m deep was labelled as being 0.0 m, the next sample label would be 0.6 m ranging in depth from 0.60 m to 1.19 m , a 1.2 m sample label covers 1.20 m to 1.79 m depth and so forth until the maximum sample collected 1.80 m to 2.39 m in depth was labelled 1.8 m. Not all of the sampler platforms collected samples from the maximum sampler depth due to the estuary shallowing in the landward direction, Samplers A and B collected samples from the maximum depth while the maximum sample depth at Samplers C and D was 1.79 m (labelled 1.2 m). Sediment concentration samples were collected within 5 d either side of the monthly peak tide as predicted from the Canadian Tide and Current Tables (Minister of Supply and Services, 2000 and 2001).

Jiménez and Madson (2003) state in a study of sediment transport, a key variable is the velocity of sediment settling when sediment suspension is the dominant process. Tidal currents are evident in the Salmon River Estuary, by the occurrence of a tidal bore, and sediment will be in suspension as long as current velocity overcomes the factors controlling particle settling. Mitchell et al., (1999) refers to work done by Mehta (1993) that the amount of settling taking place depends upon the concentration of sediment and the length of time a mud bank is submerged.

Expected sediment profiles could possibly show some stratification of sediment in the water column, compared to the vertical mixing evident before high water, similar to what Uncles and Stephens (1999) found during their study of the Ouse Estuary in the UK.

This stratification can be due to the effect of gravity on particle settling rates with the largest concentration of large grains near the bottom and decreasing sediment size and concentration occurring towards the surface (Carson and Kirkby, 1972).

Some tidal predictions were equal in magnitude for consecutive tides and led to an evaluation of the sampler operation. Tidal currents into the estuary stir up bottom sediments and keep them in suspension as long as the particle velocity overcomes the factors controlling particle settling. Therefore all samples collected just before the peak flood tide should have less sediment concentration than samples collected over the complete tidal cycle since some settling would have occurred before the flood tidal peak due to diminishing current velocities. Collecting samples from the days of predicted equal tidal magnitudes, one day the sampler being left open for the complete tidal cycle and the following day the sampler was set for normal sampling operation, allowed an evaluation of the sampler operation. Each pair of days the normally collected sample and the unstoppered sample were considered a set for evaluation of the sediment sampler. Over the two years of the study forty-two sets were collected in this manner, but only thirteen sets had complete sample collections from each sampler location. All unstoppered sample sediment concentrations were greater than the normally collected sample and ranged from 13 % to 112 % greater in sediment concentration with the mean being 66 % greater. This indicates the samplers worked as designed and collected samples during the period between peak current velocity and slack water at high tide and that the normally collected samples on average represented 60 % of the sediment available from the complete tidal cycle and the remaining suspended load was on its way to the bottom of the water column.

In order to determine if successive tidal magnitudes were equal, a comparison of the tidal elevation recorded by the sonic ranger, and the elevation at each samplers tide board was made. If successive tidal elevation measurements at the sonic ranger and sampler tide boards were equal then the tide was considered to be of equal magnitude over the complete study area for both of those days. Unfortunately the predicted successive equal tidal elevations did not transpire into actual tides of equal magnitude at the sonic ranger and the sampler tide boards. The variability inherent in the successive tidal influxes may be attributed to changes in barometric pressure and wind direction (Minister of Supply and Services, 2000 and 2001).

In order to facilitate discussion on samples from different years the following syntax will be utilized. Sampler A, 2000 and Sampler D, 2001 will be printed as Sampler A-00 and Sampler D-01. The words calender days will be abbreviated as CD and Samplers C and D will be referred to as landward samplers.

Annually using the coefficient of variation (cv), the lowest dispersion (Table 1) occurs at Samplers A and B and the highest at Samplers C and D. Samplers C-00 and D-00 are 1.8 times more dispersed than Samplers A-00 and B-00 while during 2001 the same samplers were 1.3 times more dispersed than Samplers B-01 and A-01.

Table 1 Annual coefficient of variation at each sampler.

Year	Sampler A	Sampler B	Sampler C	Sampler D
2000	0.77	0.84	1.58	1.56
2001	0.81	0.81	1.13	1.25

Longitudinally in the estuary Fig. 7 shows the relative dispersion of the sediment within the water column during 2000 for all four samplers at the 0.6 m sample depth.

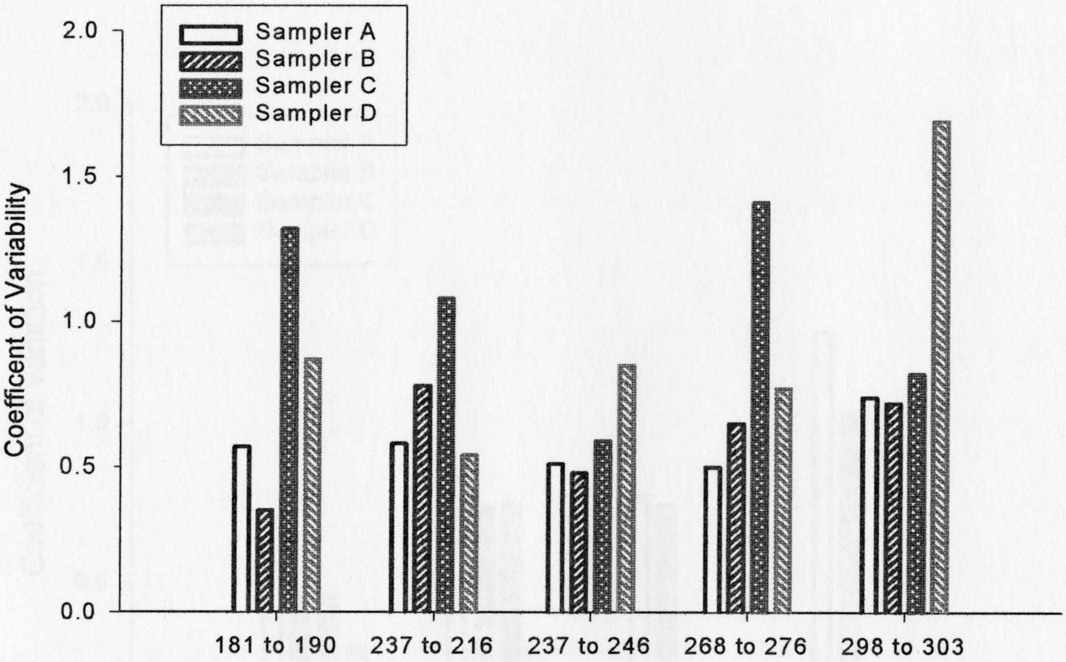

Fig. 7 Dispersion (coefficient of variability) at 0.6 m sampling depth in 2000 between the four sampler locations along the estuary. Seasonally the dispersion varies between samplers with Sampler D-00 showing the greatest dispersion during CD 298-303.

There is an increase in the coefficient during CD 268 to 276 indicating sediment concentration fluctuations occurring at this time of the year. A similar trend, not shown, occurred during CD 258 to 265, 2001. Calendar days 237 to 246, 2000 has the lowest dispersion evident during the year again this occurred during CD 229 to 238 in 2001 (not shown) indicating a less dispersed sediment concentration fluctuations within the estuary on an annual basis.

Comparison of the sediment concentration dispersion during a sampling period is shown in Fig.8 during CD 170 to 178, 2001. The higher values of the coefficient of

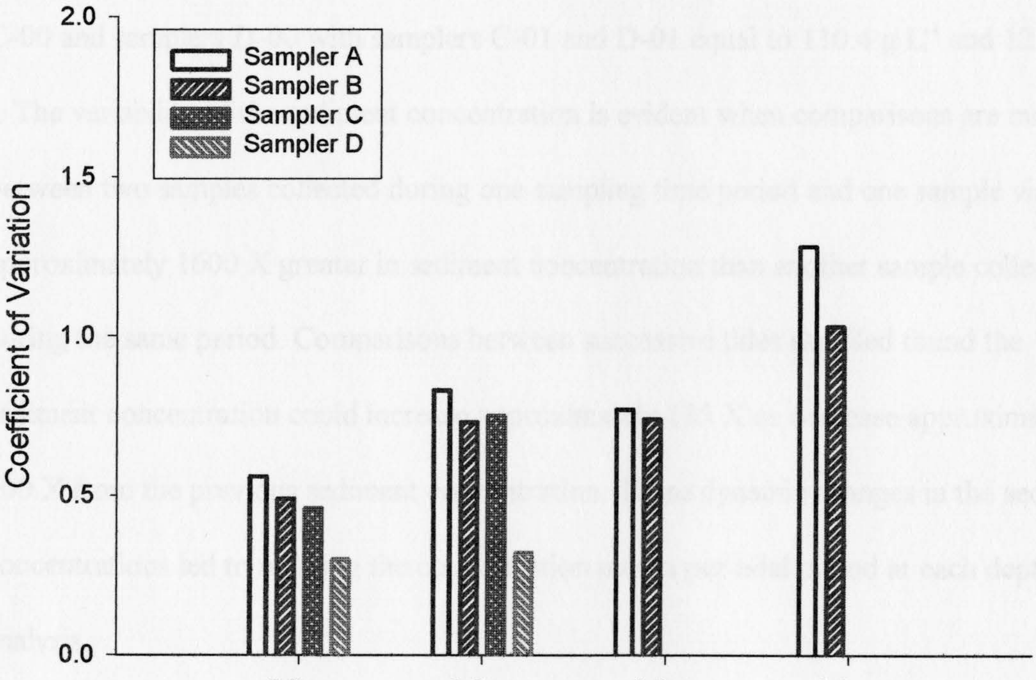

Fig. 8 Dispersion (coefficient of variability) by sampler at different depths during CD 170 to 178, 2001. Sampler D has low variability compared to the other samplers ,a less dynamic location hydrologically while at the 1.8 m depth for Samplers A and B the dispersion is the greatest.

variation are evident at the deeper sampling depth levels which, during this time frame, indicates more variation in the concentration is occurring near the bed load area of the estuary.

Annually the sediment concentrations ranged from 0 g L^{-1} to 706.6 and 0.0 g L^{-1} to 946.3 g L^{-1} during 2000 and 2001 respectively but the mean concentrations were 172.1 g L^{-1} for Sampler A-00 and 177.6 g L^{-1} for sampler A-01. The highest sediment concentrations were 185.5 g L^{-1} for Sampler B-00 but Sampler B-01 only had a value of 146.1 g L^{-1}. The lowest mean concentrations were 72.2 g L^{-1} and 75.6 g L^{-1} at Samplers C-00 and samplers D-00 with samplers C-01 and D-01 equal to 110.4 g L^{-1} and 121.0 g L^{-1}. The variability of the sediment concentration is evident when comparisons are made between two samples collected during one sampling time period and one sample vial was approximately 1600 X greater in sediment concentration than another sample collected during the same period. Comparisons between successive tides sampled found the sediment concentration could increase approximately 135 X or decrease approximately 100 X from the previous sediment concentration. These dynamic changes in the sediment concentrations led to utilizing the concentration means per tidal period at each depth for analysis.

Suspended sediment load is described as that material suspended and transported by fluids while bedload is transported in fluids by the processes of saltation, sliding and rolling (Syren, 1990). This concentration can vary greatly between estuaries and can be attributed to seasonal and tidally generated horizontal and vertical gradients (Uncles et al., 2000). Hydrological processes (Nino and Garcia, 1998), (Hodgkins et al., 2003) along with gravity and current velocity determine the maximum particle size that can be suspended and differentiating between the suspended load and bedload can be difficult. Guan et al., (1998) suggest that turbulence will collapse by viscous effects if the sediment concentration is greater than 20 g L^{-1}. LeNorment (2000) described, when modelling sediment transport in the Loire Estuary, fluid mud 0.5 m to 2.0 m thick and having concentrations between 50 g L^{-1} to 200 g L^{-1} being able to move horizontally due to gravity, hydrostatic forces or overlying water currents and sediment concentrations greater than 250 g L^{-1} as moving as a viscous fluid.

The sample data were checked for normality using the Kolmogrov-Simirnov test at $\alpha = 0.05$, constant variance and independence using Minitab (Minitab Student Edition Release 12, Minitab Statistical Software, State College, Pa.). The above assumptions were violated and the data was transformed into the natural log for two reasons. Reimann and Fitzmoser (1999) found that the log transformation is: i) the most common transformation in geochemical and environmental data sets and ii) the transformation allows the distributions to be more graphically symmetrical (Krumbein and Graybill, 1965).

Table 2 shows the sediment concentration in natural log (e) units for individual stations, depths and years of sampling. Suspended sediment concentrations have been measured in rivers up to 1 g L^{-1} (Zimmermann-Timm, 2002) and as high as 3.5 g L^{-1} in Shepody Bay and Cumberland Basin (Uncles et al., 2000). Ross (1988) in deWit and Kraenburg (1997) observed that liquefaction of mud and a net current resulted in a large horizontal transport of the fluid mud. The definition of fluid mud being greater than of 20 g L^{-1} utilized by Guan et al., (1998) and < the 250 g L^{-1} value used by LeNormant (2000) was adopted in this study and therefore 61 % and 64 % of all sediment concentrations collected in 2000 and 2001 respectively were in this range and should be considered 'fluid mud'. Converting the fluid mud value of 20 g L^{-1} into the natural log value $e = 2.99$ reveal that Samplers C and D at the 0 m depth (Table 2) for both years were < the 2.99 value. Between 20 % and 24 % of the sediment concentrations were > 250 g L^{-1} in 2000 and 2001 which according to LeNorment (2000) makes mud act as a viscous fluid. Therefore the Salmon River Estuary tended to be fluid mud during the study and mean sediment concentrations increased downward from the surface indicating possible sediment size stratification within the water column.

Sediment stratification can also be abetted within the water column due to aggregation of the particle as it settles towards the bottom of the estuary. There are several methods (Brinke, 1993) for this to occur and they are: (i) adsorption of the sediment particles by organic polymers from microorganisms , (ii) salt flocculation where the fresh water mixes with the salt water and (iii) organisms forming pseudo facies.

From Table 2 the standard deviations of sediment concentrations diminish the

Table 2 Sample numbers, means and variances at different depths over 2000 and 2001.

Year	Sampler	Depth (m)	Count (n)	Mean Conc. $(e)^{low}_{high}$	Std. Dev. $(e)^{high}_{low}$
2000	A	0.0	55	3.96	0.73
		0.6	59	4.81	0.77
		1.2	48	5.20	0.70
		1.8	28	5.52	0.47
2001	A	0.0	62	3.75	0.82
		0.6	68	4.71	0.70
		1.2	62	5.10	0.47
		1.8	55	5.31	0.31
2000	B	0.0	53	3.72	1.19
		0.6	57	4.81	0.80
		1.2	48	5.30	0.74
		1.8	29	5.70	0.48
2001	B	0.0	59	3.98	0.83
		0.6	62	4.80	0.78
		1.2	60	5.02	0.73
		1.8	30	5.50	0.89 [a]
2000	C	0.0	44	2.06	1.78
		0.6	31	4.04	1.22
		1.2	6	5.77	0.67
2001	C	0.0	48	2.88	2.40
		0.6	28	4.96	1.09
		1.2	4	5.10	0.34
2000	D	0.0	50	1.92	1.74
		0.6	39	3.86	1.61
		1.2	13	5.07	1.13
2001	D	0.0	50	2.82	2.19
		0.6	39	4.30	2.45
		1.2	7	5.63	0.82

a Sampler B-01 variability at the 1.8 m depth was the only concentration that did not follow the expected trend and did not diminish.

deeper the sample is collected yet increase the further landward the sample is collected, indicating less variability in concentrations going downward from the water surface but more variability at the landward sampler locations of the estuary. There was only one depth level where the decrease in variability did not diminish the lower the sample is from the surface and it was Sampler B-01 at 1.8 m. Examination of each sample collected at Sampler B at 1.8 m during this sampling period did not reveal why the trend of decreasing sediment concentration variability was different at this depth. In analysis of tidal sediment concentrations Bryce et al., (1998) found that this variability was due to reworking of the bedload material by either the tide or river. In this study the standard deviations tend to be larger at the surface of the water column and furthest into the estuary where more dynamic hydrological events can take place.

Mean natural logs of sediment concentrations were plotted (Fig. 9) for Sampler D-00 and Sampler A-01 at specific depths after being transformed, using the Lowess Method, which is a weighted linear regression commonly used to smooth data sets. The horizontal lines reflect the variability represented in Table 2 and when deflections of the lines are compared in a horizontal direction Sampler D shows much greater variability than Sampler A, a reflection of a more dynamic hydrological environment in the landward sampler.

Uncles (2002) in a review of estuary research found that energetic currents can cause stratified layering shown in Fig. 8. At the lower end of the estuary Sampler A-01 there is a definite similarity between the sediment concentrations at the 0.6 m and 1.2 m depths. A two sample t test of the means for Sampler A-01 during CD 200 to 209 between the 0.6 m and 1.2 m depths revel that at $\alpha = 0.05$ ($p = 0.98$) indicating there is no significant difference between both sediment concentrations. A p value = 0.61 occurred for the t test of the means at $\alpha = 0.05$ between the two sediment depth bands during sampling period CD 283 to 289 indicating in this case that the 1.2 m increased vertically in depth during both these sampling periods.

Within each depth band there were significant and non significant differences in sediment concentration between subsequent sampling periods. In Table 3 the two sample t test at $\alpha = 0.05$ of consecutive sampling periods revealed that between CD 200 to 209 and CD 229 to 238 seven out of twelve possible samples along the estuary were significantly different. The p values for Samplers C-01 and D-01 at the 0.0 m depth were 0.02 and 0.04, at the 0.6 m depth Samplers A-01, B-01, and C-01 were 0.03, 0.01 and 0.02 respectively and Sampler A-01 at the 1.2 m and 1.8 m depths had p values of 0.01 and 0.03. All of the significantly different Sampler A-01 and B-01 values decreased in concentration from the previous value while the other Samplers C-01 and D-01 increased in concentration a symptom of tidal pulsing. There is another sampling period which had six out of twelve samples significantly different and that is between CD 258 to 265 and 283 to 289. The opposite occurred during this series of samples at Sampler A-01 since the significant differences were increases in sediment concentration as was Sampler B-01

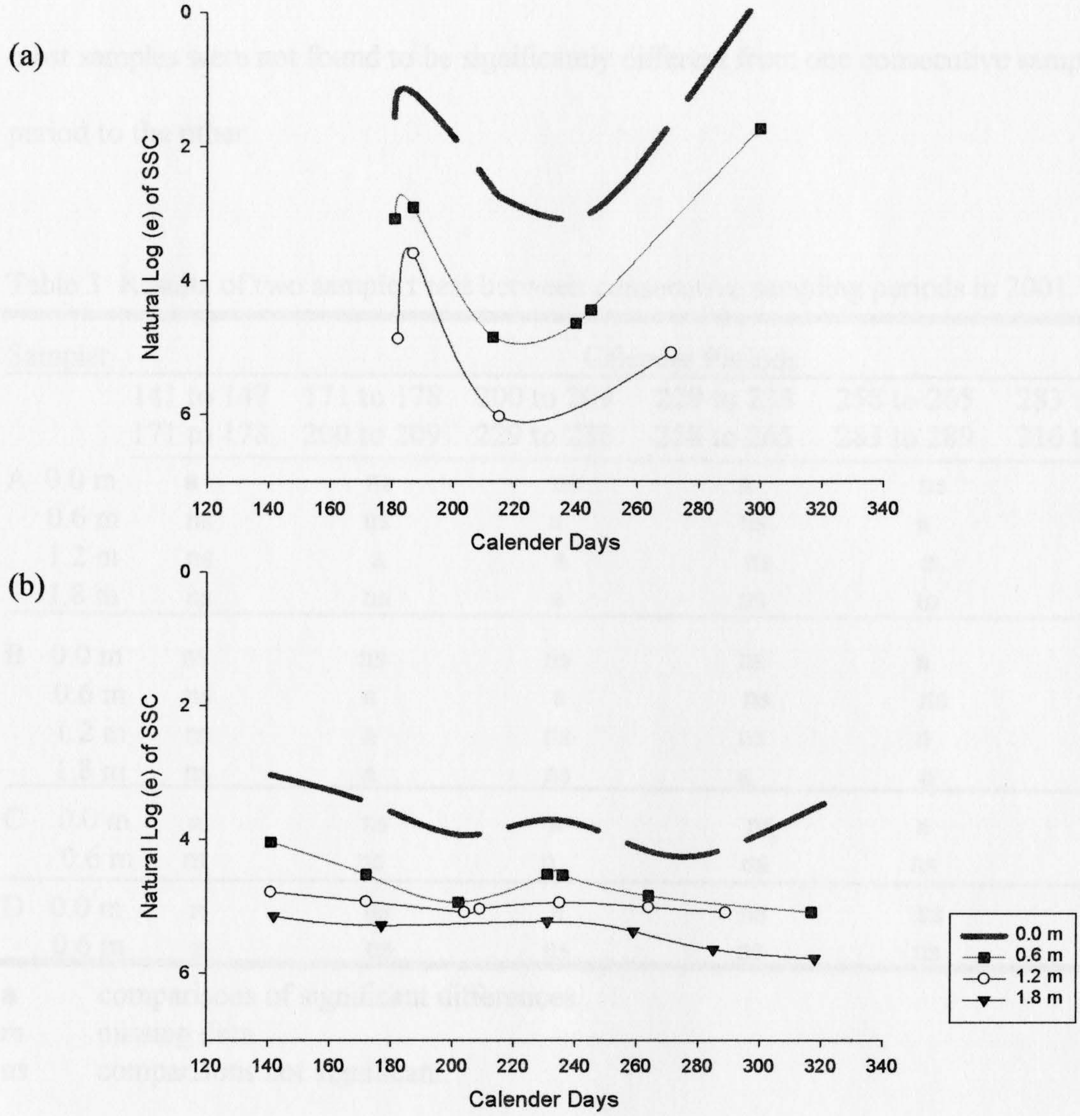

Fig 9 (a) Sampler D-00 showing stratification of sediment concentrations and the variability at each depth.
(b) Sampler A-01 showing stratification of sediment concentrations and the variability at each depth.

at the 0.0 m depth while all other three significant differences had the sediment concentration decrease, a sign of a runoff event within the watershed. During 2000 the most samples were not found to be significantly different from one consecutive sampling period to the other.

Table 3 Results of two sample t test between consecutive sampling periods in 2001.

Sampler		Calender Periods					
		141 to 147 171 to 178	171 to 178 200 to 209	200 to 209 229 to 238	229 to 238 258 to 265	258 to 265 283 to 289	283 to 289 316 to 321
A	0.0 m	a	ns	ns	a	ns	a
	0.6 m	ns	ns	a	ns	a	ns
	1.2 m	ns	a	a	ns	a	ns
	1.8 m	ns	ns	a	ns	m	m
B	0.0 m	ns	ns	ns	ns	a	a
	0.6 m	ns	a	a	ns	ns	a
	1.2 m	ns	a	ns	ns	a	ns
	1.8 m	ns	a	ns	a	a	a
C	0.0 m	a	ns	a	ns	a	ns
	0.6 m	m	ns	a	ns	ns	m
D	0.0 m	a	ns	a	ns	ns	a
	0.6 m	a	ns	ns	ns	ns	ns

a comparisons of significant differences.
m missing data.
ns comparisons not significant.

Using a two sample t test at $\alpha = 0.05$ it was found that sediment concentration means at Sampler A-01 at depths 0.6 m, 1.2 m and 1.8 m were not significantly different between the first sampling period and the last sampling period of the year even though there was a increase in sediment concentration at these depths in the order of 21 % for the 0.6 m depth, 2 % for the 1.2 m depth and 10 % for the 1.8 m depth. For two years of the study, 67 % of all depths sampled had initial sediment concentration levels that were lower than or equal to those collected at freeze up, an indication of fall runoff events.

In Fig 10, since similar results occurred each year, different years are depicted showing the spatial characteristics of the sediment concentrations at each of the four depths sampled at sampler locations A, B. C and D. The greatest sediment concentration variability is at the landward Samplers C and D and at the depths closest to the surface. The 0.0 m depth graph shows at the start of sampling that Sampler B-01 was equal to the sediment concentration at Sampler A-01, gradually increased beyond Sampler A-01 and eventually ended the season equal in concentration to Sampler A-01. A two sample t test of the means at $\alpha = 0.05$ shows there is no evidence of a significant difference between Samplers A-00 and B-00. At the landward end of the study area Sampler D during both years exceeded the sediment concentrations at Sampler C a reflection of there being more tidal occurrences due to a lower geodetic elevation at this location. A one way analysis of variance of Samplers A, B, C and D (2001) at the 0.0 m depth for sampling periods CD 229 to 238 and 258 to 265 at $\alpha = 0.05$ shows there is no evidence of there being any significant differences between them, with p values of 0.13 and 0.21 respectively. This indicates that the estuary at the 0.0 m depth is almost uniform in sediment concentration during this period of the season.

At the 0.6 m depth Sampler B-00 sediment concentration is greater than Sampler A-00 and this is similar to the pattern revealed by data collected in 2001 (not shown). A two sample t test at $\alpha = 0.05$ indicated that there was no point where Sampler B-00 was significantly different than Sampler A-00 with p values ranging from 0.54 to 0.83 over

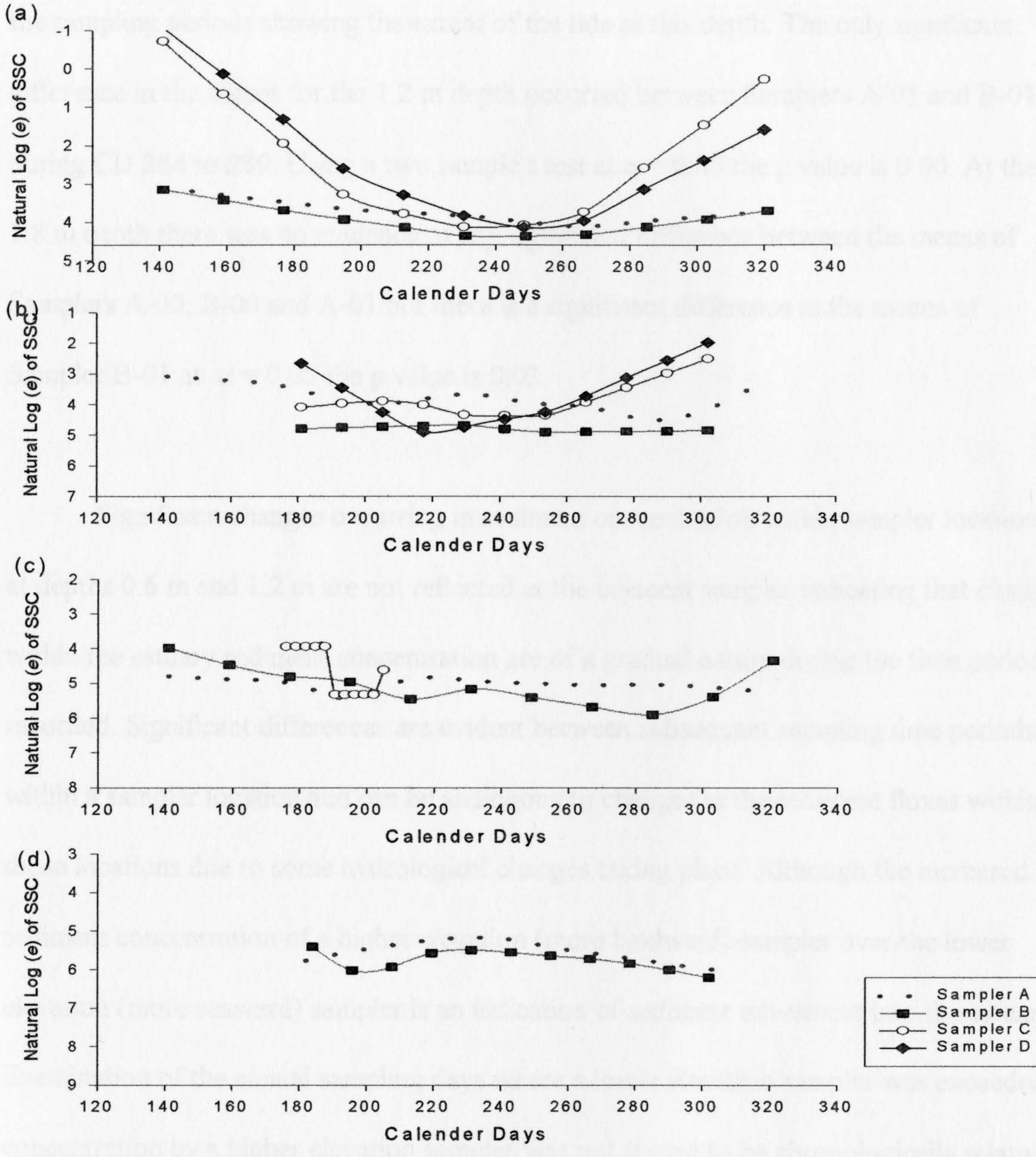

Fig. 10 (a) Sample depth 0.0 m with Samplers A-01, B-01 ,C-01 and D-01 showing longitudinal changes within the estuary.

(b) Sample depth 0.6 m with Samplers A-00, B-00 ,C-00 and D-00 showing longitudinal changes within the estuary.

(c) Sample depth 1.2 m with Samplers A-01, B-01 ,C-01 and D-01 showing longitudinal changes within the estuary.

(d) Sample depth 1.8 m with Samplers A-00, B-00 ,C-00 and D-00 showing longitudinal changes within the estuary.

the sampling periods showing the extent of the tide at this depth. The only significant difference in the means for the 1.2 m depth occurred between Samplers A-01 and B-01 during CD 284 to 289. Using a two sample t test at $\alpha = 0.05$ the p value is 0.00. At the 1.8 m depth there was no evidence of any significant difference between the means of Samplers A-00, B-00 and A-01.but there is a significant difference in the means of Sampler B-01 at $\alpha = 0.05$ the p value is 0.03.

Significant changes occurring in sediment concentration within sampler locations at depths 0.6 m and 1.2 m are not reflected at the adjacent sampler indicating that changes within the estuary sediment concentration are of a gradual nature during the time periods recorded. Significant differences are evident between subsequent sampling time periods within a sampler location and can be analogous to changes in the sediment fluxes within those locations due to some hydrological changes taking place. Although the increased sediment concentration of a higher elevation (more landward) sampler over the lower elevation (more seaward) sampler is an indication of sediment movement into the estuary. Examination of the annual sampling days where a lower elevation sampler was exceeded in concentration by a higher elevation sampler was not shown to be chronologically related.

To visualize the amount of suspended sediment moving within the estuary the total suspended loads for CD 254, 2000 and CD 287, 2001 were calculated using the following assumptions: (i) the estuary bottom gradient is uniform longitudinally, (ii) the water surface is considered to be level and (iii) the sediment concentration at each sampler location can be averaged with the adjacent sampler location. The width of the estuary channel is approximately 94.1 m wide (Maritime Marshland Rehabilitation Agency, 1959) at Sampler B and in 2000 digitizing of the dyke maps along the estuary channel give estuary widths in this area of 78.6m to 102.4 m. Therefore the sampler located further downstream, at the lower elevation, would have a sample from a deeper depth than the sampler located at a higher elevation and the deeper sample is considered to feather out to the higher elevated sampler location. The amount of sediment suspended within the water column on CD 254 with a 8.1 m tidal height is 76,581.5 m^3 and for the tidal height 8.2 m later in the day it is 75,376.0 m^3. The sediment in the estuary for CD 287 was 81,327.1 m^3 for a 8.3 m tide and increased to 152,859.7 m^3 for the 8.4 m tide later in the day showing a movement of the bedload in the estuary.

A number of things were discovered while collecting sediment concentration samples within the estuary. The tidal influx has approximately 40 % of the total sediment suspended on its way to the estuary bottom by the time slack tide is reached. The more variable sediment concentrations are located at the surface of the water column and at the landward locations and the estuary over the season tended to be stratified in sediment concentration vertically and greater than 20 g L^{-1} for most of the season. The sediment concentration at the start of the season and end of the season tended to be the same even though the sediment concentration significantly increased during the season showing that the hydrological conditions within the estuary were similar. Changes in sediment concentration could be quite dynamic without the influence of precipitation as shown when the sediment concentration for 1 d with two tides was estimated and the succeeding flood tide increased the sediment concentration within the estuary by 1.9 x.

3.2 Sediment deposits

There is 40 % of the suspended sediment on its way to the estuary bottom and the effect this has on the estuary drainage channel characteristics is very important. Fluid mud is known to reduce bed turbulence (deWitt and Kranenburg, 1997) and there is evidence that this can be accomplished with sediment concentrations as low as 20 g L^{-1} (Guan et al., 1998). The occurrence of slack water in the Salmon River Estuary coupled with high sediment concentrations makes sediment available for deposition, similar to conditions over an intertidal mudbank (Mitchell et al., 1999). The net rate of deposition onto the estuary bed varies depending upon the sediment concentration, slack water residence time, watershed runoff and sediment settling rate. Erosion of this newly settled material can depend upon the ebb tidal current (Christie and Elliot, 1998), watershed runoff volumes or bottom exposure time to the sun and air which can consolidate the material.

In order to determine bed erosion or deposition Christie et al., 1999 measured the actual bed level changes on a macro tidal mudflat. The three bridges, (Site 1) the 102 Highway, (Site 2) North River, and (Site 3) Park Street, are at the extreme edges of the study area and perpendicular to the estuary flow. Repeated cross sections portray channel bottom changes (Cooper, 2002) due to deposition or erosion of sediment which can be converted to sediment area changes per each measurement. The actual measurements, called soundings, were taken at each evenly spaced bridge rail post to the bottom of the estuary with a 10 kg weighted 30 m measuring tape at low tide. Subtracting the height of the bridges above the ground level at each bank from the soundings allows one to calculate the channel depth and water depth for each measurement. The bridges were also surveyed to their geodetic elevations using a total station survey equipment in order to correlate all the bridge elevations to each other.

Cross sections in 2000 taken at intervals ranging from 27 to 40 d apart showed sediment deposits fluctuated greatly. In order to better quantify estuary sediment deposits at each of the three cross section sites, soundings were increased in frequency to just before and after sediment concentration sampling. Figure 11 shows the channel cross section at Site 2 which is not representative of a typical estuary channel but is a constructed channel, excavated and diked by the Nova Scotia Department of Environment in the early 1970's to minimize damage from increasing flood events due to ice jams. The maximum channel depth line represents the maximum sounding recorded at each rail post over the two year study and is assumed to represent the maximum channel discharge area available while the minium channel discharge area for each year of the study is represented by the two upper lines of the graph. The difference between the sediment deposited 2000 , 2001 lines and the maximum channel depth is equal to the annual change in deposition, similar changes were recorded at Sites 1 and 3 (not shown). The calculated channel areas in Table 4 represent the minium and maximum areas available for channel discharge

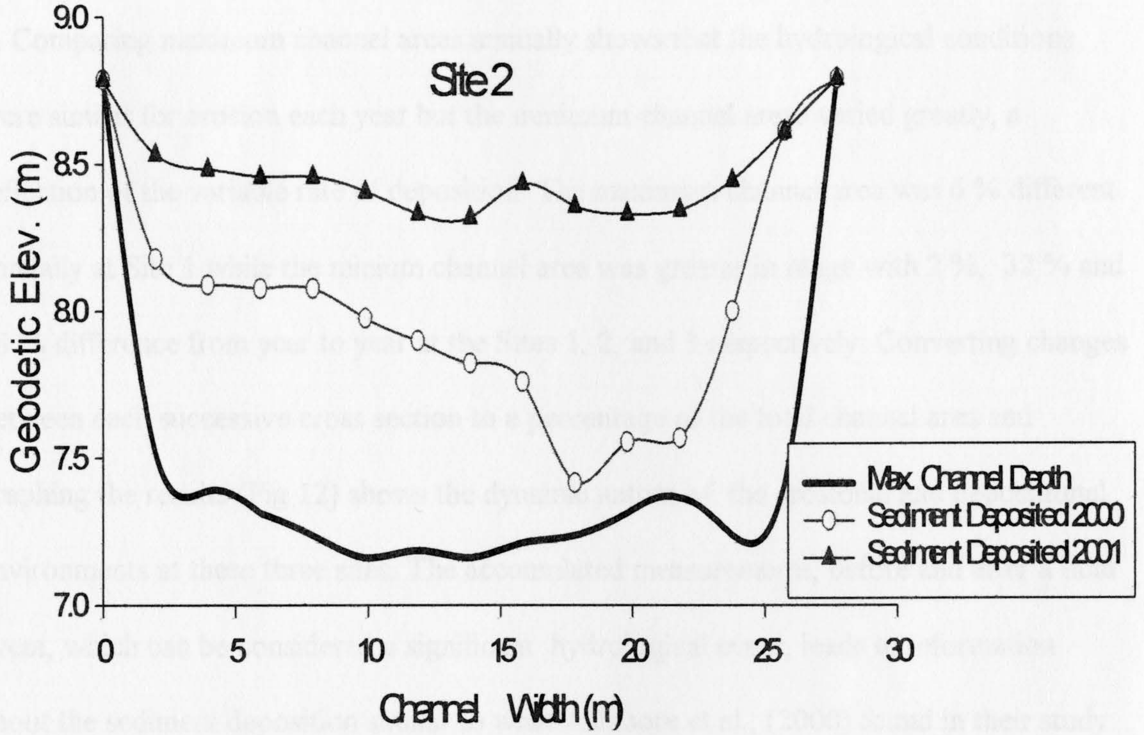

Fig. 11 Maximum and minium channel discharge areas, looking landward towards the watershed, recorded at Site 2 for 2000 and 2001.

annually for each site. The two year maximum channel area possible is calculated by using the maximum soundings recorded over two years at each rail posts. There is a loss in

Table 4 Calculated cross sectional areas showing available channel discharge areas.

		2000		2001	
	Max. 2y Area (m^2)	Max. Area (m^2)	Min. Area (m^2)	Max. Area (m^2)	Min. Area(m^2)
Site 1	543.1	478.5	285.1	507.1	290.8
Site 2	116.1	103.9	75.5	104.8	62.0
Site 3	77.5	60.3	43.8	63.1	29.6

channel area at all of the sites and these reductions are substantially greater at Sites 2 and 3. Comparing maximum channel areas annually shows that the hydrological conditions were similar for erosion each year but the minimum channel areas varied greatly, a reflection of the variable rate of deposition. The maximum channel area was 6 % different annually at Site 1 while the minium channel area was greater in range with 2 %, 32 % and 18 % difference from year to year at the Sites 1, 2, and 3 respectively. Converting changes between each successive cross section to a percentage of the total channel area and graphing the results (Fig 12) shows the dynamic nature of the erosional and depositional environments at these three sites. The accumulated measurements, before and after a tidal event, which can be considered a significant hydrological event, leads to information about the sediment deposition similar to what Ashmore et al., (2000) found in their study of river erosion. The estuary channels at the start of the season has sediment deposits occupying a small portion of the discharge channel area and steadily fills in the discharge channel area as the summer progresses. Depending upon runoff, the deposits increase in area, Site 1 peaking after Sites 2 and 3 (Fig. 11), until later in the season when rainfall seasonally increases and the deposit area declines but not to its original area, before freeze up. At the end of the 2000 sampling season there was 33 %, 17 % and 25 % of the channel discharge area occupied by sediment deposits at Sites 1, 2 and 3 respectively. This increased to 41 %, 34 % and 34 % at the end of 2001 a reflection of the different climatic conditions between the two years. The maximum channel area occupied by the sediment deposits annually was as

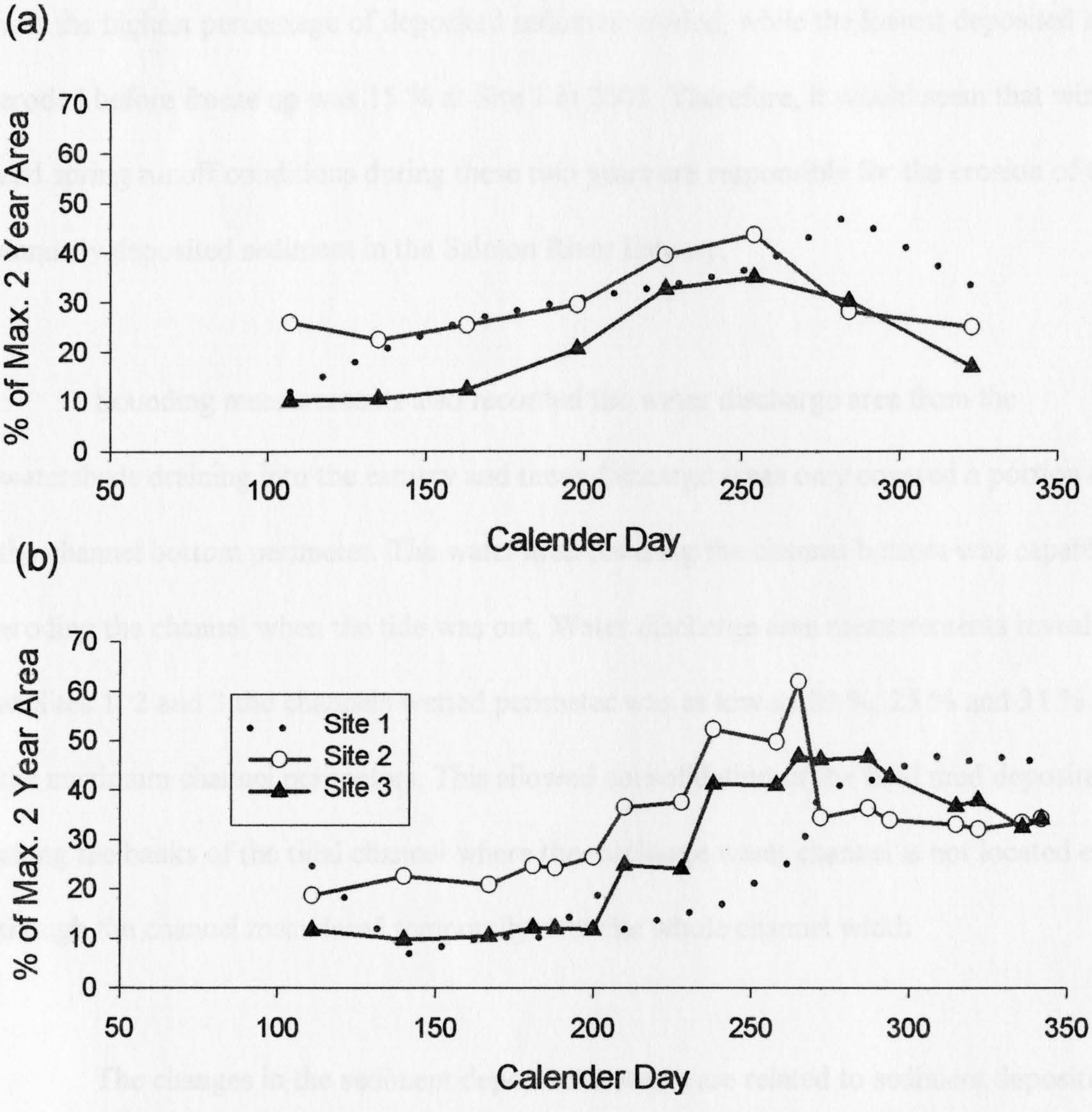

Fig 12 (a) % changes in the sediment deposit areas of the three Sites during 2000 using the 2 year maximum cross section depth as being equal to 100 percent of channel discharge area.
(b) % changes in the sediment deposit areas of the three Sites during 2001 using the 2 year maximum cross section depth as being equal to 100 percent of channel discharge area.

high as 48 %, 35 %, and 45 % in 2000 and 48 %, 47 %, and 62 % in 2001 for the Sites 1, 2 and 3 an indication of tidal pulsing of sediment into the estuary. By the time of freeze up in 2000 at Site 2, 51 % of the total sediment deposited that season had been eroded, which was the highest percentage of deposited sediment eroded, while the lowest deposited area eroded before freeze up was 15 % at Site 1 in 2001. Therefore, it would seem that winter and spring runoff conditions during these two years are responsible for the erosion of the annually deposited sediment in the Salmon River Estuary.

Sounding measurements also recorded the water discharge area from the watersheds draining into the estuary and these discharge areas only covered a portion of the channel bottom perimeter. The water area covering the channel bottom was capable of eroding the channel when the tide was out. Water discharge area measurements reveal that at Sites 1, 2 and 3 the channels wetted perimeter was as low as 20 %, 25 % and 31 % of the maximum channel perimeters. This allowed consolidation of the fluid mud deposited along the banks of the tidal channel where the discharge water channel is not located even though the channel meandered temporally over the whole channel width.

The changes in the sediment deposit elevations are related to sediment deposition and erosion rates (Table 5) which can be estimated by dividing the differences in subsequent sediment deposit areas by the width of the discharge channel and then dividing that resultant averaged height by the number of days between measurements. Using a two sample t test of the means between consecutive measurements there were no significant differences in sediment deposit rates over the two years. The variable sounding measurements intervals during 2001 showed differences in sediment deposition and erosion rates since there was a 5 fold increase at Site 1 over the 2000 deposition rates and a 4 fold increase in deposition rates for Site 3. During 2000 the maximum deposition rate was 1.7 cm d^{-1} over 28 d at Site 3 while Site 1 had a rate of 1.5 cm d^{-1} and Site 2 was 1.0 cm d^{-1}.

Table 5 Calculated deposition and erosion rates for Sites 1, 2 and 3. (Negative values indicate erosion)

Year	Calender Days	Site 1 (cm d^{-1})	Site 2 (cm d^{-1})	Site 3 (cm d^{-1})
2000	135	1.3	- 0.3	0.0
	163	1.0	0.2	0.1
	198	0.5	0.3	0.7
	226	1.0	1.0	1.7
	254	0.5	0.3	0.2
	284	1.5	-1.1	-0.4
	323	-1.6	-0.2	-0.8
2001	140	-2.6	0.3	-0.2
	167	0.6	-0.1	0.1
	181	-1.0	0.6	0.3
	200	2.2	0.2	-0.1
	210	-3.4	2.1	3.1
	228	0.8	0.1	-0.1
	258	1.8	-0.3	-0.1
	265	1.3	3.6	2.0
	272	8.6	-8.1	-0.3
	287	0.3	0.3	0.1
	315	1.0	-0.3	-0.8
	322	-2.1	-0.3	0.4

Annually averaged erosion rates were the greatest at Site 1 at 1.6 cm cm d^{-1} and 1.1 cm d^{-1} and 0.8 cm d^{-1} for Sites 2 and 3. The maximum erosion rate was 7 X greater during one seven day measurement interval in 2001 over the 2000 rates at Site 2. Figure 13 shows the changes in deposition and erosion for the three Sites during 2001.

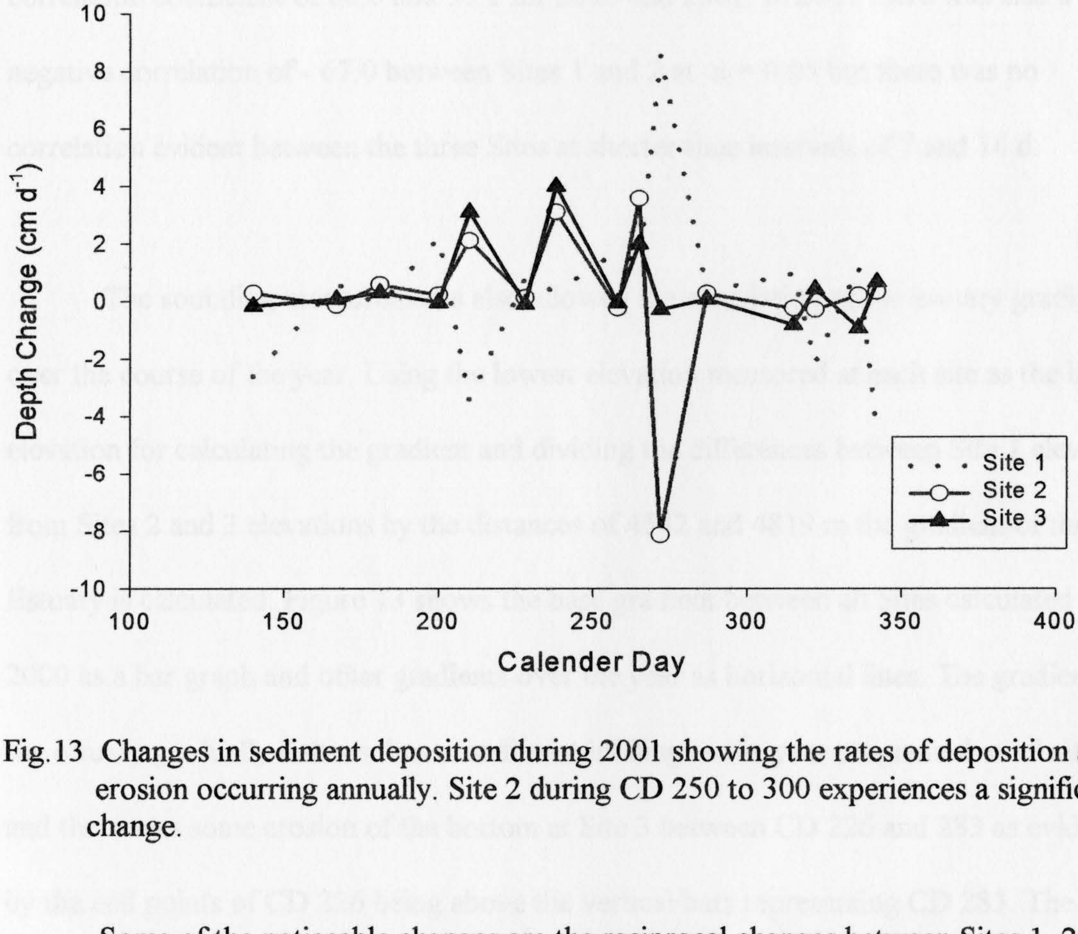

Fig.13 Changes in sediment deposition during 2001 showing the rates of deposition and erosion occurring annually. Site 2 during CD 250 to 300 experiences a significant change.

Some of the noticeable changes are the reciprocal changes between Sites 1, 2 and 3 on CD 225, 2001 and the extreme differences between Sites 1 and 2 on CD 265. The extreme changes between Sites 1 and 2 on CD 265 was due to an unrecorded rain event in the watershed antedotal evidence from locals in the area recorded a 152 mm rainfall. The maximum rate of deposition for 2001 was 8.6 cm over 7 d for Site 1 corresponding to a

8.1 cm erosion rate at Site 2 while the Site 3 rate of deposition peaked at 4.0 cm for 10 d compared to 3.1 cm at Site 2. Erosion rates for Site 3 peaked at 0.9 cm d^{-1} over 10 d and the highest Site 1 erosion rate was 4.8 cm over 6 d. Correlation analysis done for both years show at $\alpha = 0.05$ there is a strong correlation between Sites 2 and 3 with a correlation coefficient of 80.6 and 55.1 for 2000 and 2001. In 2001 there was also a negative correlation of - 67.0 between Sites 1 and 2 at $\alpha = 0.05$ but there was no correlation evident between the three Sites at shorter time intervals of 7 and 14 d.

The sounding measurements also allowed the calculation of the estuary gradient over the course of the year. Using the lowest elevation measured at each site as the base elevation for calculating the gradient and dividing the differences between Site 1 elevation from Sites 2 and 3 elevations by the distances of 4542 and 4819 m the gradient of the Estuary is calculated. Figure 13 shows the base gradient between all Sites calculated in 2000 as a bar graph and other gradients over the year as horizontal lines. The gradient of the estuary gradually flattens due to sediment infilling as the year progressed at all sites and there was some erosion of the bottom at Site 3 between CD 226 and 283 as evidenced by the end points of CD 226 being above the vertical bars representing CD 283. The graph reveals that the gradient at Site 1 has the maximum gradient change between CD 107 and 163 while the maximum gradient changes at Sites 2 and 3 occur between CD 163 and 226. The minium gradient in Fig.14 occurred on CD 283 between Sites 1 and 3 and was 0.11 m km^{-1} while the gradient between Sites 1 and 2 was 0.43 m km^{-1} during the same period. The maximum gradient occurred at CD 107 with 1.41 m km^{-1} between Sites 1 and 2 and

0.95 m km^{-1} between Sites 1 and 3 in 2000 . Comparing 2000 to 2001 reveals the minium gradient measured was 0.02 m km^{-1} between Sites 1 and 3 and 0.40 m km^{-1} between Sites 1 and 2 on CD 336 (2001) while the

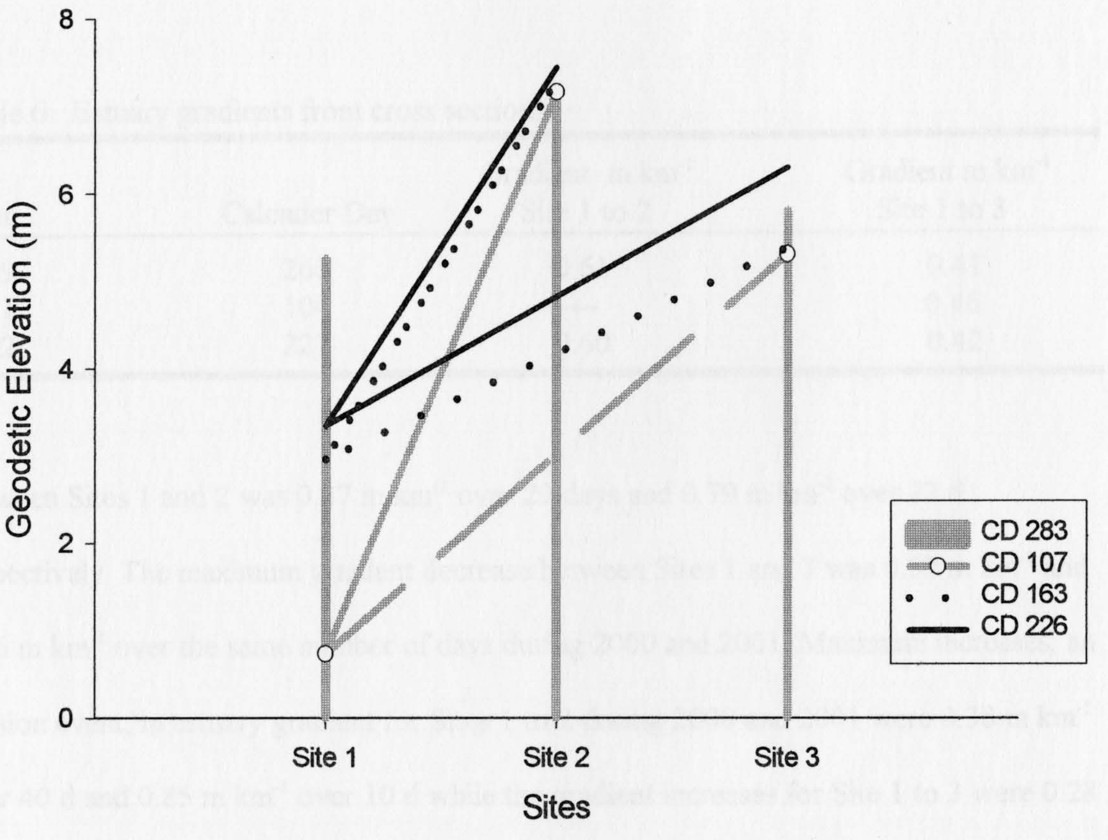

Fig 14 Estuary gradient for various CD in 2000.

maximum gradient measured was 1.41 m km^{-1} on CD 210 (2001) and between Sites 1 and 3 and 1.93 m km^{-1} between Sites 1 and 2 on CD 180 (2001). Historically the gradient of the estuary in Table 6 as measured by Maritime Marshland Reclamation staff in 1969 and 1971 and the Nova Scotia Department of Fisheries in 2002 reveal that the estuary gradient annually is stable.

There are runoff events and infilling events that can dramatically change the estuary gradient. In 2000 and 2001 the maximum gradient decrease, an infilling event,

Table 6 Estuary gradients from cross sections.

Year	Calender Day	Gradient m km^{-1} Site 1 to 2	Gradient m km^{-1} Site 1 to 3
1969	260	0.61	0.41
1971	104	-----	0.46
2002	227	0.60	0.42

between Sites 1 and 2 was 0.47 m km^{-1} over 29 days and 0.79 m km^{-1} over 22 d respectively. The maximum gradient decrease between Sites 1 and 3 was 0.52 m km^{-1} and 0.76 m km^{-1} over the same number of days during 2000 and 2001. Maximum increases, an erosion event, in estuary gradient for Sites 1 to 2 during 2000 and 2001 were 0.38 m km^{-1} over 40 d and 0.85 m km^{-1} over 10 d while the gradient increases for Site 1 to 3 were 0.28 m km^{-1} and 0.94 m km^{-1} over the same time periods. The amount of sediment deposited and removed on an average daily basis between sounding measurements at the deposited sediment level in volume terms can be estimated. The sediment deposition rate on a daily basis for a 0.76 m km^{-1}, decrease in gradient, over 22 d is equal to 357.91 m^{-3} d^{-1} of material deposited within the estuary between Sites 1 and 3. The erosion rate, increase in gradient, of 0.94 m km^{-1} over 10 d between Sites 1 and 3 in 2001 is equal to 437.13 m^{-3} d^{-1} eroded on an volume basis.

Due to the malfunction of the sonic ranger during the second year of the study, tidal bottom elevations recorded at Site 1 during 2000 and 2001 by the sonic ranger were not available from CD 86 to CD 200 for analysis.

Other data sets collected in 1998 and 1999 by the NSDAF at the same site were available for analysis and Fig 15 shows four years of estuary bottom elevations. For

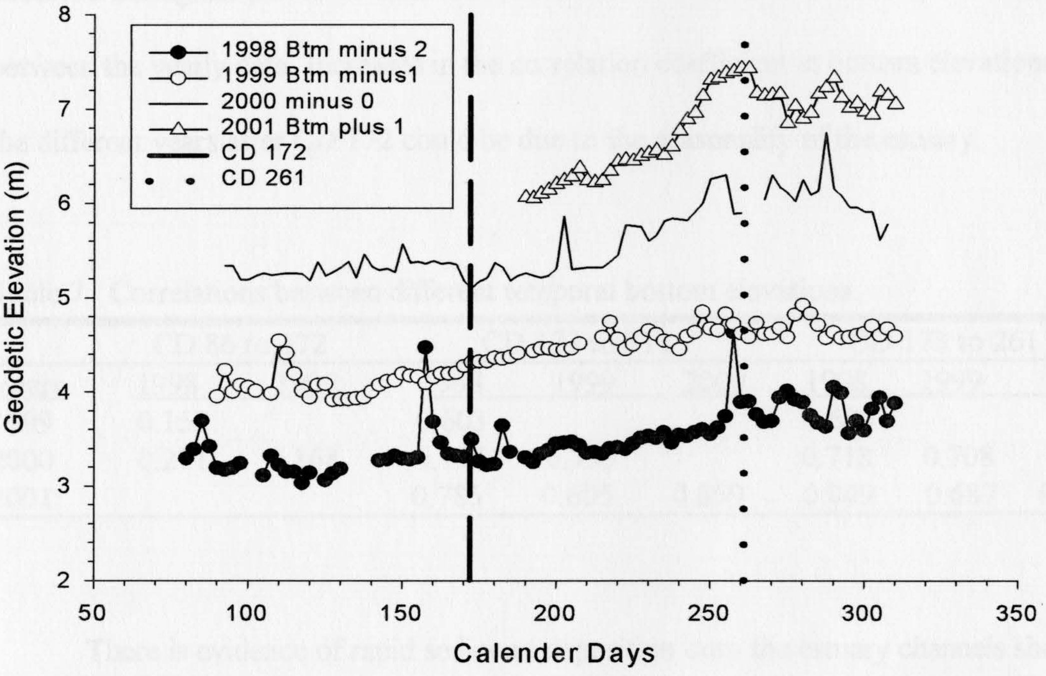

Fig. 15 Annual bottom elevations at Site 1 over a 4 year period showing the rise in gradient.

clarity the yearly data was separated on the graph by adding (or subtracting) a value from each of the data points. An annual rising trend is evident after CD 172 and peaks at around CD 261. The data sets were divided into two halves on either side of CD 172 and correlations between the two halves examined. Then data sets were further divided into pre CD 172, CD 173 to 261 and CD 261 to 311.

There is no correlation between 1998, 1999 and 2000 bottom elevations before CD 172, but there is strong correlation after this date from CD 173 to 311. Further analysis in 28 and 29 day intervals from CD 172 reveal that the correlation increases to a maximum value during CD 172 to CD 261. Peaks in the data values are rain events that occurred during the period of data collection. Table 7 shows the results of correlations between the yearly data. Increases in the correlation coefficient in bottom elevations for the different years after CD 172 could be due to the seasonality of the estuary.

Table 7 Correlations between different temporal bottom elevations.

	CD 86 to 172		CD 173 to 311			CD 173 to 261		
Years	1998	1999	1998	1999	2000	1998	1999	2000
1999	0.158		0.603			0.633		
2000	0.271	0.168	0.735	0.733		0.718	0.708	
2001			0.785	0.605	0.859	0.849	0.687	0.927

There is evidence of rapid sediment deposition onto the estuary channels shown by the diminished channel discharge areas over a relatively short time span of 235 d in 2001. The sediment deposits as a percentage of the channel discharge area increases during the season and is not removed before freeze up in early winter. Sediment deposit elevations can change quickly as shown by the rates of elevation changes of deposition and erosion at the different sites in excess of 8.0 cm d^{-1}. Another result of the sediment deposits is the gradient of the estuary channel gradually flattens due to deposition.

Cross sections of the estuary at the 3 Sites showed dramatic changes in sediment deposit and erosion rates over a short time period. Annual deposits of sediment were shown to be able to occupy 68 % of the available estuary discharge channel that were not completely eroded by freeze up thus restricting the estuary discharge channel. Low tide watershed discharge was covering only 30 % of the discharge channel perimeter leaving the remainder to consolidate between tidal influxes. The maximum sediment deposition rate was 8.6 cm d^{-1} while the maximum erosion rate was 8.1 cm d^{-1}. Using 4 y of channel bottom elevations it was discovered that the estuary after CD 172 seasonally increases its sediment deposit rate until later in the year.

3.3 Particle size analysis

Currents within the water column have the ability to move sediment in the estuary both through suspension and by saltation . The flood tides and ebb tides create currents strong enough to move sediment within the estuary and at different times of the year the predominate direction is in the landward direction. By examining the sediment size of all of the samples mixed together for the different sampler locations the competence of the currents can be depicted temporally.

Sampler locations in the study area going landward in the estuary is Sampler A, Sampler B, Sampler C on the North River branch and Sampler D on the Salmon River branch. Box plots (Fig.16) with the percentage clay, silt and sand at each sampler over 2001 are displayed. The larger the box height the higher the variability of the percentages

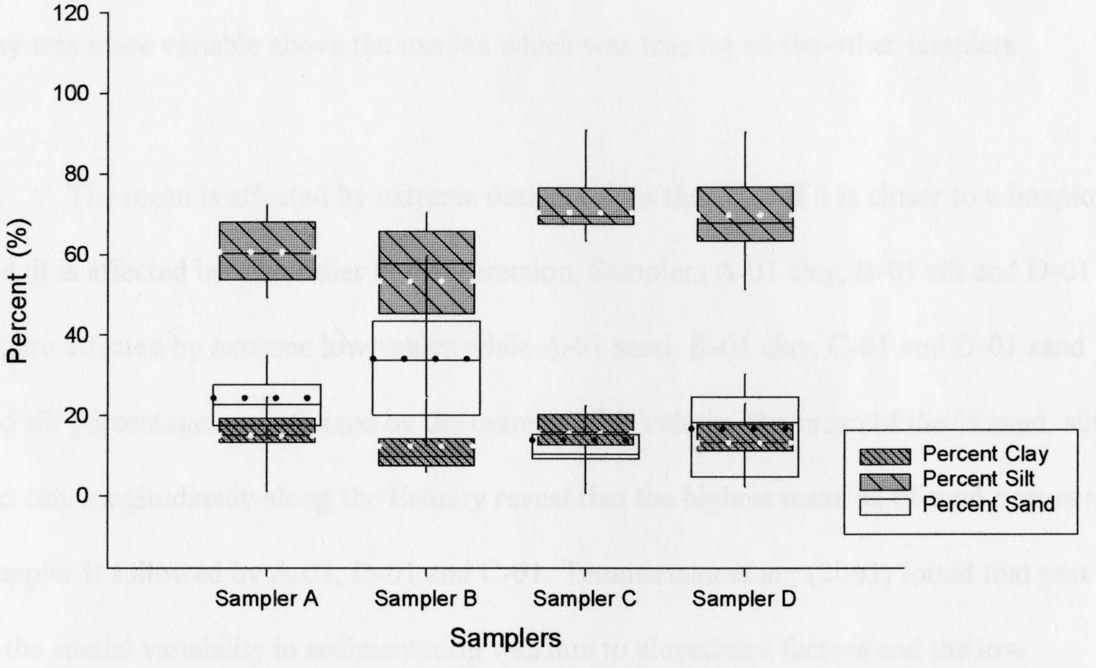

Fig. 16 Box plots of sand, silt and clay percentages for 2001 showing overlap of quartiles for clay and sand at Samplers A, C and D.

of clay, silt and sand collected. Therefore at Sampler B-01 sand had the largest dispersion followed by silt and then clay. Sampler D-01 followed the same trend but variability of each component percentage was smaller relating the hydrological conditions at each location with Sampler D-01.

The boxplots are divided by a solid line, the median, of the percentages and a row of dots represent the mean. Where the mean and median are at the mid point of the boxplot at Sampler A-01 silt the % values follow a normal distribution. The median is the area of the distribution where the number of values collected are 50 % above this or below this value. If one end of the boxplot is closer to this median line the other part of the distribution accounted for more of the variability at that sample location. Sampler D-01 clay was more variable above the median which was true for all the other samplers.

The mean is affected by extreme outlier values therefore if it is closer to a boxplot end, it is affected by the outlier in that direction. Samplers A-01 clay, B-01 silt and D-01 silt are affected by extreme low values while A-01 sand, B-01 clay, C-01 and D-01 sand and silt percentages are affected by the extreme high values. The mean of the % sand, silt and clay longitudinally along the Estuary reveal that the highest mean % of sand occurs at Sampler B followed by A-01, D-01 and C-01. Temmerman et al., (2003) found that part of the spatial variability in sedimentation was due to elevational factors and the low variabilities of Sampler C-01 reflects this. The % of silt is highest at Sampler D-01 and then C-01, A-01, B-01. The clay content was variable over the two years but at Sampler B it was consistently lower than elsewhere along the estuary. This spatial variability is expected (He and Walling, 1998) due to sediment transport erosion and deposition dynamics.

Table 8 shows the mean percentages for various particle sizes at each sampler. There is significant difference using a two sample t test between the percentage of sand (0.053 mm to 1.00 mm) at Sampler B-01 and all other Samplers with p values = 0.01 for Sampler A-01, and p = 0.00 for Samplers C-01 and D-01.Sampler B-00 also was significantly different from the other 2000 samplers with p values of 0.00 for all two

Table 8 Mean percentages of sands, silt and clay for different Samplers.

	% Coarse and Medium Sand	% Fine Sand	% Very Fine Sand	% Sand	% Silt	% Clay
2000						
Sampler A	1.67	1.00	22.52	25.64	55.88	18.46
Sampler B	0.67	0.64	38.42 [a]	40.19 [a]	48.37	11.47
Sampler C	0.77	0.57	11.52	10.29	62.29	27.38
Sampler D	0.53	0.56	17.74	19.05	65.86	15.07
2001						
Sampler A	1.39	0.73	23.37 [a]	26.07	60.53	13.39
Sampler B	1.24	0.97	35.17 [a]	37.97 [a]	50.23 [a]	11.65
Sampler C	1.50	0.68	13.24	15.88	68.50	15.46
Sampler D	0.89	0.60	16.57	18.53	69.61	11.84

a significantly different from all other Samplers.

sample t tests. In a study of suspended sediment concentrations by Sichingabula (1998), particles ranging in size from 0.062 mm to 2 mm were found to be transported by intermittent suspension or saltation and that these particles were entrained from the bed after scouring. Therefore the maximum sand % at Sampler B is indicative of the location in the estuary where the energy of the flood tide and currents are balanced by the ebb tide and runoff currents for these sized particles.

Upon analyzing the different sand fraction % it is evident that there is no significant difference between any of the other samplers for fine gravel and very coarse sand, coarse and medium sand, and fine sand but Sampler B is significantly higher for the % of very fine sand (0.106 to 0.053 mm) for both years from the rest of the samplers and at $\alpha = 0.05$ with p values of 0.02, 0.00 and 0.000 for Samplers A-01, C-01 and D-01 respectively. Sampler A-01 (Table 8) is also significantly different in very fine sand % from all other samplers with p values of 0, 0, and 0.02 for Samplers B-01, C-01 and D-01 respectively. This size of sand is also the majority of the sand %, which is different from the dominant size 0.25 mm to 0.50 mm that Dalrymple et al., (1978) found in Cobequid Bay, again showing that the hydrological competence of the tide to transport material diminishes in the landward direction. The geodetic elevation of Sampler C would limit the amount of sand transported to this location unless it was coming from the watershed itself which is not evident from these measurements.

Using a two sample t test at $\alpha = 0.05$ the % of silt at Sampler A-00 was not significantly different from Sampler C-00 and Sampler D-00 ($p = 0.05$) and Sampler B-00 was significantly lower than Samplers C-00 ($p=0.01$) and D-00 ($p=0.00$). During 2001 there was significantly higher percentage of silt at Samplers C-01 and D-01 than at Samplers A-01 and B-01, for Sampler A-01 compared to Samplers C-01 ($p = 0.03$) and Sampler D-01 ($p = 0.03$), and for Sampler B-01 compared to Samplers C-01 ($p = 0.00$) and D-01 ($p = 0.00$). An explanation for this might be that the competence of the tidal flood is such that it can pump the finer sized silt (0.002 mm to 0.053 mm) component into the landward areas of the estuary. As confirmation, using a two sample t test at $\alpha = 0.05$ on the sorting coefficient of the samplers shows that Samplers A and B are not significantly different from each other nor are samplers C and D, but the landward Samplers C and D are better sorted than Samplers A and B for both years of the study. Other factors affecting the silt content could be similar to what Uncles and Stephens

(1999) found in tidal sediment fluxes in England, where between 97 to 100 % of the micro flocs surviving sampling and sediment analysis were less than 0.063 mm in size.

The clay % using a two sample t test is not significantly different at $\alpha = 0.05$ for any of the samplers which is expected since the particle size is most likely to remain in suspension throughout the system. This is different than what Sichingabula (1998) found in the Fraser River in British Columbia, a river dominated system where the sediment as it traveled downstream had the mean sand content decrease and the clay content increase.

Figure 17 displays for one day each sediment concentration components (sand, silt and clay) at the sampler locations averaged over the total depth sampled on a m^{-1} basis. Typically the lower elevation Samplers A and B have higher sediment concentrations which are correlated with the their higher sand and silt content changing as the sampler is located more landward and higher in elevation. Based on a classification of sediments by Folk (Royce, 1970) the downstream sediment is a silty sand and changes to a silt classification at the landward sampler locations. This silty sand classification based on the ratio of the two components has ramifications on the stability of the deposited sediment. Yamamuro and Lade (1999) found that the increase in fines (defined as particles less than 0.074 mm) to a sand size would increase the potential for liquidization of the material at certain static pressures. The deposition of this silty sand creates a silt sand structure that can be highly compactable where the smaller soil particles would slide into voids between the lager particles. This would give the sediment better stability at compression, however

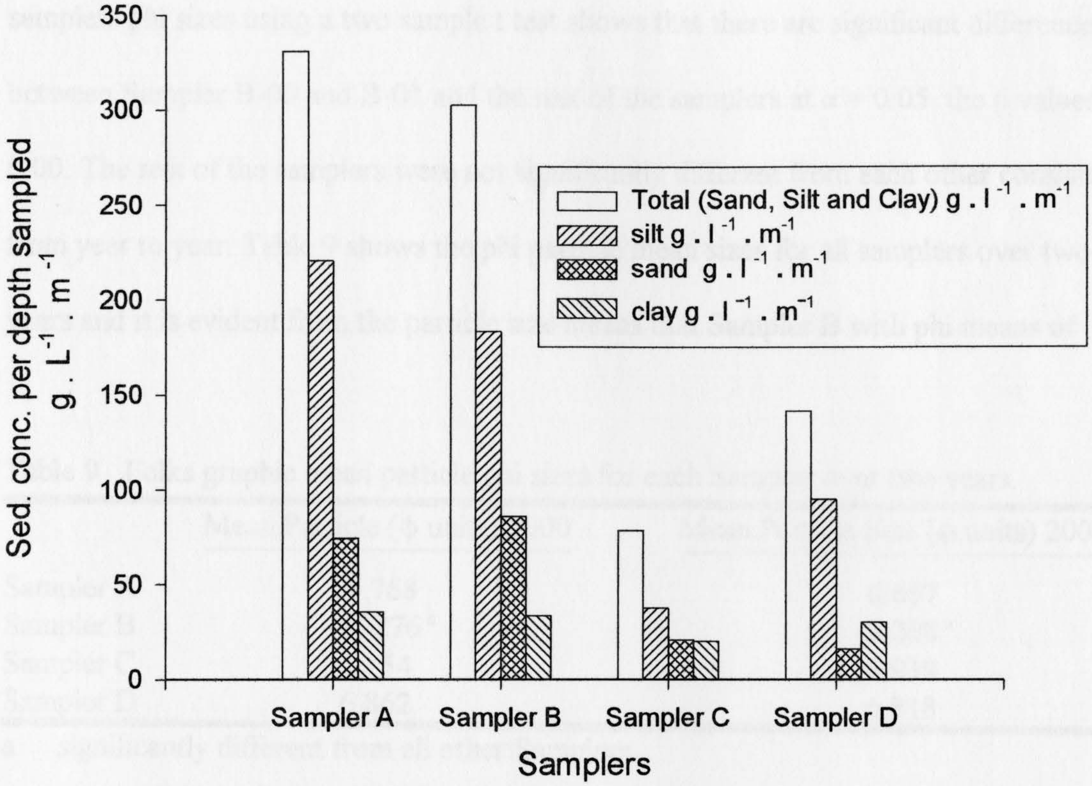

Fig. 17 Total sediment at each sampler for CD 186, 2000 and the components of the sediment based on size analysis of composite samples.

liquidization of the soil can occur at lower pressures. Due to the aforementioned, deposits of higher silt to sand ratios would not be more structurally stable (once buried) than at the wetted surface unless they were buried deeply.

Composite samples of sediment are multi-modal and usually the modal descriptive statistic is used since it is not influenced as much by the tails and outliers of a frequency but to adequately describe the distribution. This study used the 16 th, 50 th and 84 th quartile in calculating the Folks graphic mean for analysis (Royce, 1970). Comparing samplers phi sizes using a two sample t test shows that there are significant differences between Sampler B-00 and B-01 and the rest of the samplers at $\alpha = 0.05$ the p values = 0.00. The rest of the samplers were not significantly different from each other consistently from year to year. Table 9 shows the phi particle mean sizes for all samplers over two years and it is evident from the particle size means that Sampler B with phi means of

Table 9 Folks graphic mean particle phi sizes for each Sampler over two years.

	Mean Particle (ϕ units) 2000	Mean Particle Size (ϕ units) 2001
Sampler A	6.768	6.667
Sampler B	6. 276 [a]	6.308 [a]
Sampler C	7.154	6.939
Sampler D	6.862	6.818

a significantly different from all other Samplers.

6.276 ϕ and 6.308 ϕ for 2000 and 2001 indicates a coarser particle distribution while Sampler C mean phi values of 7.154 and 6.939 respectively indicates a finer particle distribution.

Another descriptive statistic commonly used in characterizing particle size distributions is skewness, which relates the departure of the mean from the median and can indicate the dominance of coarse or fine sediments in the sample (Royce, 1970). Using Folk's inclusive graphic expression, the log of the skew value can be negative or positive. A negative value indicates a coarse skewed distribution which corresponds to a dominance of fine particles with a tail of coarse particles since the fines have been removed from the tail area by alternating tidal currents. Sampler B from Table 10 is negatively skewed for the days shown and for both years this trend predominated (78 % of the samples) at this sampler. Positive skew values indicate a fine skewed distribution where coarse particles dominate due to the tractive competence (Royce, 1970) and the tail has unlimited finer particle sizes that can be entrained. All the other samplers at some point in time varied

Table 10 Skewness and sorting for selected days in 2000 and 2001 covering all samplers.

Skewness (ϕ units) 2000					Sorting (ϕ units) 2001				
Calender	Samplers				Calender	Samplers			
Day	A	B	C	D	Day	A	B	C	D
186	0.004	-0.079	0.233	0.190	201	-1.684	-1.782	-1.530	-1.334
188	0.000	-0.409	-0.017	-0.269	203	-1.737	-1.727	-1.576	-1.392
214	-0.135	-0.410	0.426	0.020	230	-2.088	-2.135	-1.699	-1.764
242	-1.130	-0.211	0.795	0.184	230	-1.687	-1.778	-1.527	-1.299
245	-0.049	-0.132	0.865	-0.056	261	-1.930	-1.780	-1.623	-1.792

from a negative value to a positive value as shown in Table 10 for the year 2000 which is a measure of the dynamic sediment transport environment. The value of zero would indicate perfect skewness which occurred on CD 188 in Table 10.

The sorting coefficient reflects the dispersion of the particles, and the phi values of the sorting coefficients can be compared directly (Royce, 1970). Folks inclusive graphic standard deviation was used to determine the sorting of the landward sampler locations and data in Table 10 reveal that the landward sampler locations are about equal in coefficients and are 1.1 X on average better sorted than the seaward sampler locations.

Table 10 has two CD that are the same which is a reflection that sampling was done for each tide and there are two tidal events usually each day. The maximum differences for sorting was Sampler B-01 which was 2.12 X more sorted than Sampler A-01 and Sampler C-00 was 2.02 X more sorted than Sampler A-00. Comparing the sorting to the median in a dot plot (Fig.18) showed there was a strong positive correlation at Sampler C-00 with the lowest value of 0.650 suggesting a more dominant fluvial environment than a tidal one due to its elevation.

There is also a strong positive trend present in the dotplots (Figure 18) when the skewness to the median are compared. Since the median is not as sensitive to extreme values there is a strong positive correlation between the medians of each sampler and their skewness for both years. The lowest correlation coefficient was 0.72 for Station D-01.

The competence of the flood tide currents were displayed when the particle sizes of the sediment concentrations were examined. Researchers (Dalrymple et al., 1978) in their examination of Cobequid Bay found that coarse to medium sand was the dominate particle size, while here, depending upon where in the estuary, different particle sizes dominated different locations. It was discovered that at Sampler B very fine sand was the dominant particle and at Sampler D it was silt and all particle sizes within the water column were of the finer material.The competence of the tide was such that the majority of the sediment sample concentrations were well sorted and skewed in the negative direction indicating a predominance of fines. When the degree of sorting was compared

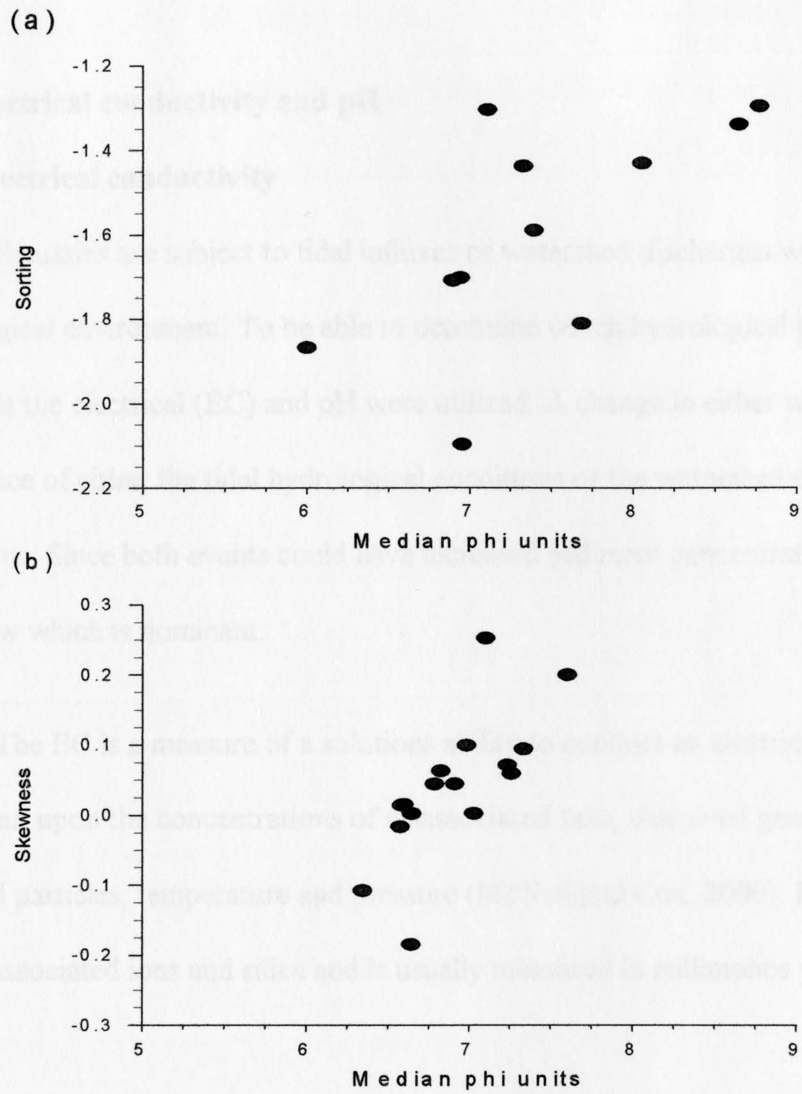

Fig 18 (a) Sampler C-00 dotplot of median phi units versus sorting showing a positive trend.

(b) Sampler D-01 dotplot of median phi units versus skewness showing a positive trend.

to the median size obtained at the different locations it was discovered that Sampler C is more fluvial in nature, possibly a reflection of its higher elevation when compared to the other sampler locations.

3.4 Electrical conductivity and pH

3.4.1 Electrical conductivity

Estuaries are subject to tidal influxes or watershed discharges which can affect the hydrological environment. To be able to determine which hydrological parameter is dominant the electrical (EC) and pH were utilized. A change in either would reflect the dominance of either the tidal hydrological conditions or the watershed discharge conditions. Since both events could have increased sediment concentration the EC and pH will show which is dominant.

The EC is a measure of a solutions ability to conduct an electric current and is dependent upon the concentrations of disassociated salts, dissolved gases, suspended colloidal particles, temperature and pressure (McNeil and Cox, 2000). It is not affected by non disassociated ions and silica and is usually measured in millimohos per cm (mmhos cm^{-1}).

There is no direct conversion of EC into mg L^{-1} of salt due to the variable ion exchange rates of different materials at different temperatures. Usually large sets of data at a known temperature are used to establish a ratio of salt to EC for that particular set of data (McNeil and Cox, 2000). Muggridge and Rutherford (2000) state that in a soil solution the salt concentration in mg L^{-1} is approximately equal to 640 x EC converted to decisemiens per metre (dSm^{-1}) and the conversion rate from mhos cm^{-1} to dSm^{-1} is EC in mhos cm^{-1} x1 (Soil Science Society of America, 1990). Using the value of 35 g L^{-1} (Mwanuzi and De Smedt, 1999) of salt in sea water, the daily averaged salt measurements shown in Table 11 are less than the value of seawater at each Sampler for 2000 and 2001. What is evident is that the peak values all occur within 30 d of each other annually, evidence that the estuary has reached a maximum tidal intrusion rate verses freshwater runoff.

Table 11 Maximum salt values for all samplers during 2000 and 2001.

	2000		2001	
Sampler	Calender Day	Maximum Salt (gm L^{-1})	Calender Day	Maximum Salt (gm L^{-1})
A	243	20.2	234	22.0
B	245	15.6	235	19.2
C	242	12.3	262	16.0
D	234	9.0	234	12.2

During 2000 sample analyses for electrical conductivity (EC) was conducted within 60 d of sample collection and in 2001 within 24 hrs. Salinity provides an indicator of the hydrology within an estuary by directly providing a measure of salt water and fresh water influences within an estuary (Wenner and Geist 2001) and Fig 18 shows Sampler B-01 salt averages per sampling period to sampling period until a peak value during CD 229 to 238 is reached and then declines as rain events increase later in the year. All of the samplers exhibited this trend but at the landward ends of the estuary there was more variability similar to the change in line slope for the 1.8 m depth between sampling periods

CD 171 to 178 and 200 to 209 in Fig 19.

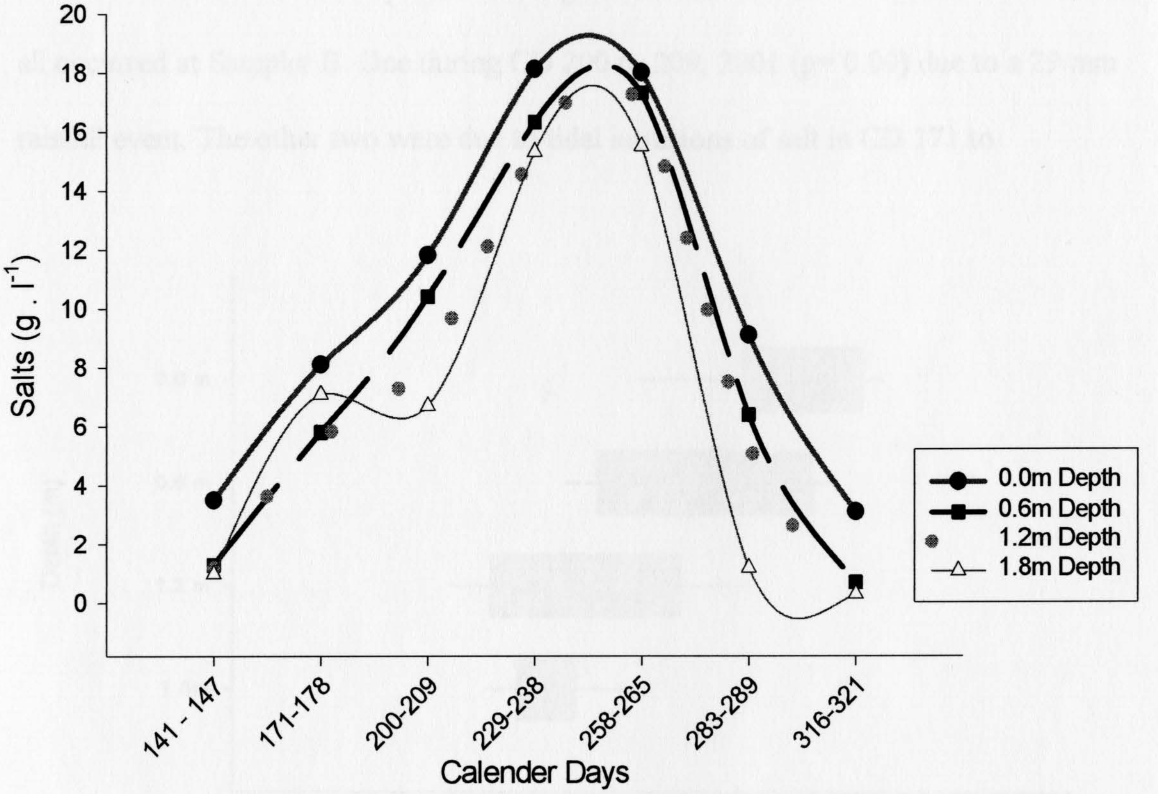

Fig. 19 Sampler B salt concentrations at four sampling depths during 2001.

Luketina (1998) states that a well mixed estuary mainly has salt fluxes in a longitudinal direction and negligible ones in a vertical direction. The Salmon River Estuary was sampled a total of 12 tidal periods over 2 y at four sampler locations for a total of 48 individual sample sets. There were three sample sets with sample numbers either too small for statistical analysis or no samples were collected, due to sampler malfunction or the tidal high was lower than expected and the sample closest to the surface was above the tidal high, leaving 45 individual sample sets. At $\alpha = 0.05$ a one way ANOVA revealed that 3 sample sets had significant differences in a vertical direction and all occurred at Sampler B. One during CD 200 to 209, 2001 ($p = 0.00$) due to a 29 mm rainfall event. The other two were due to tidal intrusions of salt in CD 171 to

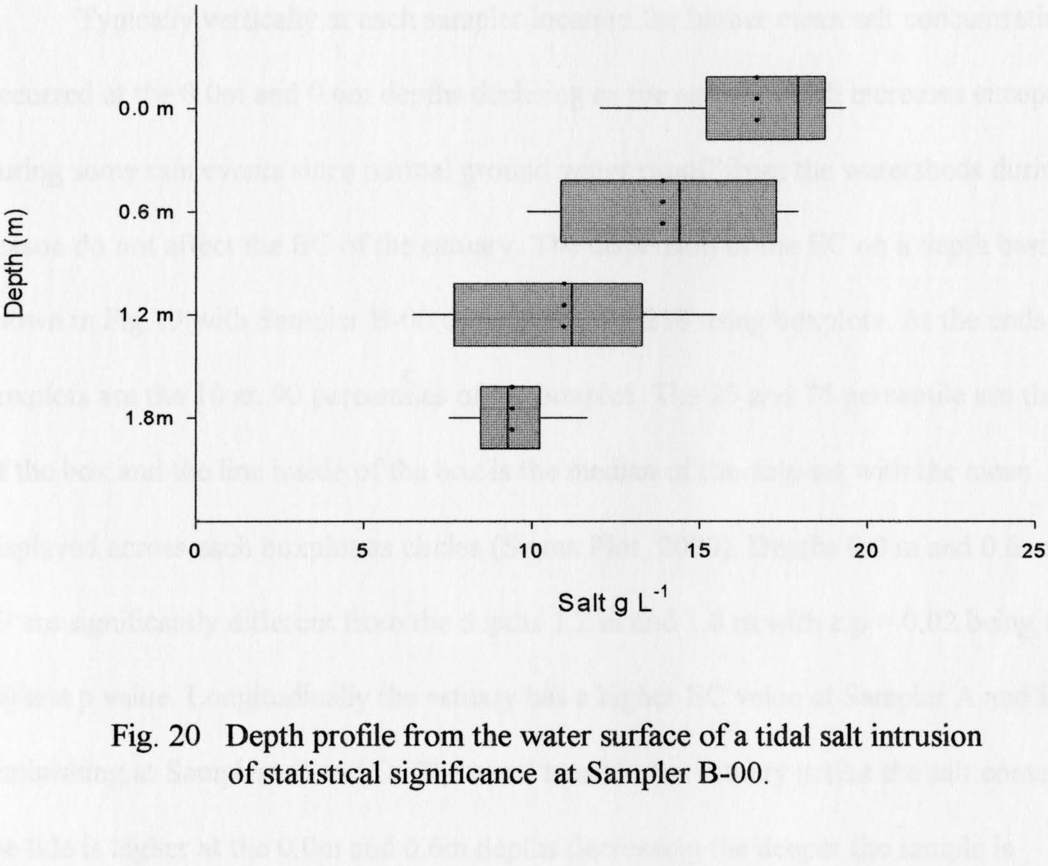

Fig. 20 Depth profile from the water surface of a tidal salt intrusion of statistical significance at Sampler B-00.

178, 2000 ($p = 0.00$) and the other CD 316 to 321, 2001 ($p = 0.00$). Figure 20 shows data from Sampler B-00 during CD 171 to 178 and the result of a the tidal influx is indicated by the salt concentrations diminishing from the surface downward. A two sample t test at $\alpha = 0.05$ between the salt concentrations at each depth show that the 0.0 m is significantly different from all other depths with p values of $p = 0.03$, $p = 0.00$ and $p = 0.00$ respectively going downward from the surface. The 0.6 m depth is significantly different from the 1.8 m depth with p values of $p = 0.00$ but is not significantly different from the 1.2 m depth and the salt concentration at the 1.2 and 1.8 m depths are not significantly different from each other.

Typically vertically at each sampler location the higher mean salt concentrations occurred at the 0.0m and 0.6m depths declining as the sample depth increases except during some rain events since normal ground water runoff from the watersheds during the season do not affect the EC of the estuary. The dispersion of the EC on a depth basis is shown in Fig.19 with Sampler B-00 during CD 209-218 using boxplots. At the ends of the boxplots are the 10 an 90 percentiles of the boxplot. The 25 and 75 percentile are the ends of the box and the line inside of the box is the median of the data set with the mean displayed across each boxplot as circles (Sigma Plot, 2000). Depths 0.0 m and 0.6 m Fig. 19 are significantly different from the depths 1.2 m and 1.8 m with a $p = 0.02$ being the highest p value. Longitudinally the estuary has a higher EC value at Sampler A and B diminishing at Samplers C and D. The usual trend in the estuary is that the salt content of the tide is higher at the 0.0m and 0.6m depths decreasing the deeper the sample is collected. The salt concentration drops as the depth increases due to the incoming tide over rides the fresh water in the estuary. There also occurs an overlap of individual salt concentration at different depths which is a result of the hysteresis of the estuary's hydrological environment.

Sampler A-01 during sampling period CD 170 to 178 is graphed on a daily basis in Fig 21 and includes a rain event. The ends of the box plots represent the 25 and 75 percentile regions of the distribution, the 50 percentile is the bar and the mean is represented by the row of two dots thru the box plots. Typically the salt concentrations

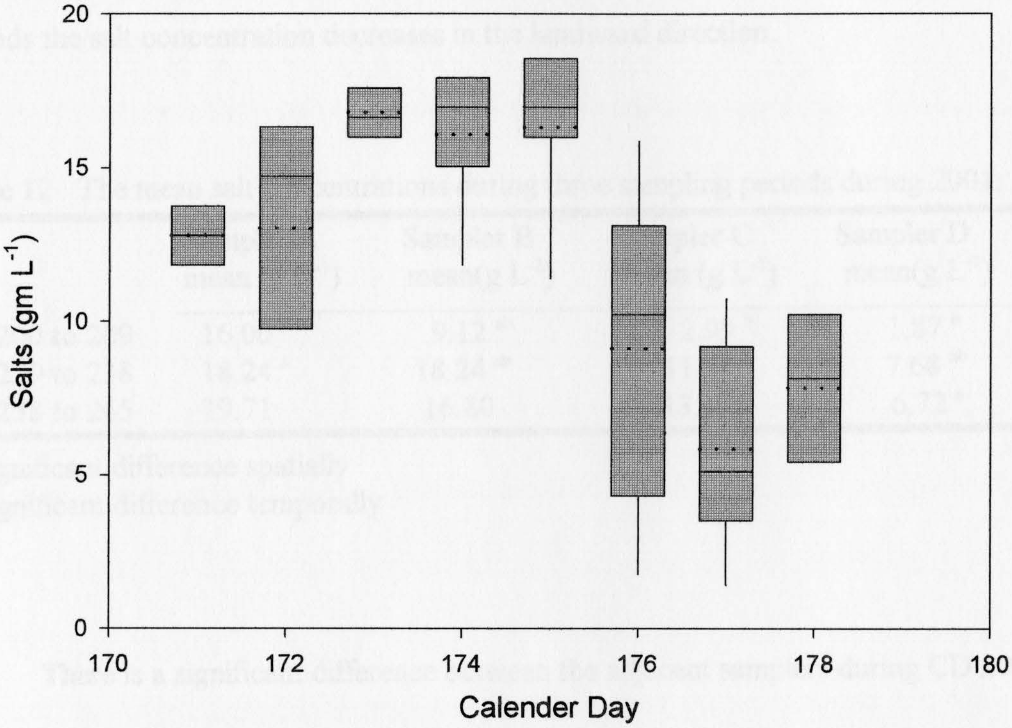

Fig. 21 Sampler A-01 during CD 170 to 178 graphed on a daily basis with a significant rain event.

averaged on a daily basis increase until the tidal high peak for the sampling period is reached and then maintains the increased salt content until a rain event occurs, in this sampling period a 52 mm rain during CD 176 to 177. A significant drop in salt concentration was recorded at all of the samplers after this size of rain event.

Taking the mean of the EC at each sampler location during each sampling period there were discovered to be differences spatially along the estuary. Using a two sample t test at $\alpha = 0.05$ between any adjacent samplers it was found that there was always a significant difference in EC during any sampling period somewhere along the estuary. Table 12 presents data for three sampling periods during 2001. For all three sampling periods the salt concentration decreases in the landward direction.

Table 12 The mean salt concentrations during three sampling periods during 2001.

	Sampler A mean ($g\ L^{-1}$)	Sampler B mean($g\ L^{-1}$)	Sampler C mean ($g\ L^{-1}$)	Sampler D mean($g\ L^{-1}$)
CD 200 to 209	16.00 [a]	9.12 [ab]	2.99 [b]	1.87 [b]
CD 229 to 238	18.24 [a]	18.24 [ab]	11.52 [b]	7.68 [ab]
CD 258 to 265	19.71	16.80	13.12	6.72 [a]

a significant difference spatially
b significant difference temporally

There is a significant difference between the adjacent samplers during CD 200 to 209 with p values of 0.01 between Samplers A and B, but Samplers B, C and D were not significantly different from each other ($p = 0.07$). During the next sampling period CD 229 to 238 Samplers A and B salt content are now equal in concentration and Samplers C and D are still not significantly different from each other. This shows the tidal push into the estuary extends equally to Sampler B as shown in Table 6 and has increased the salt contents in the landward and higher elevation samplers. During the next sampling period CD 258 to 265 the estuary is not significantly different between Samplers A and B and

Samplers B and C showing the extent of the tidal intrusion into the estuary.

Temporally the estuary has significant differences between the sampling periods at each sampler. In Table 11 comparing the increased salt content of each sampler from one period to another reveals that the mean salt concentrations are significantly different for Samplers B, C and D from CD 200 to 209 when compared to CD 229 to 238 with all p values equal to 0.00. Comparing CD 229 to 238 with CD 258 to 265 sampling periods show that there is no significant difference between samplers and reflects the dominance of the tidal intrusions into the estuary and the lack of runoff during this period.

Correlations between the tide and sampler salt content varied over the study. The sampling period with the strongest tidal to salt content was CD 229 to 238 in Table 12. During each tidal intrusion there are a maximum 14 samples that could be collected from all of the sampler locations and depths. During this sampling period there are seven sampler locations and depths that are strongly correlated to the tidal intrusions and the correlations ranged from 0.63 to 0.89.

At the 0.0 m and 0.6 m depths the salt concentration tended to be the highest at most sampler locations showing that the incoming tide rode over the watershed discharge. Samplers A and B had higher salt concentrations than Samplers C and D which was expected and spatially the salt concentrations followed the tidal elevation cycle. When the tide rose the salt concentrations rose and falling only when a rain event ≥29 mm occurred.

There was only one sampler where the salt concentration changed vertically significantly between depths and that was at Sampler B.

3.4.2 pH

The samples for pH were only analysed for 2001 since the 2000 samples were not all tested within 24 hrs of collection and the values obtained for the year 2000 are considered suspect. Sea water has a pH of 8.0 (Molina et al., 2002) yet a healthy estuary can a pH between 6.0 and 8.5 (Wenner and Geist, 2001) and this is exactly the range of the pH values for the Salmon River Estuary, which were found to be between 6.0 and 8.4.

Initially each Sampler was compared within each sampling period vertically on a depth basis by ANOVA at $\alpha = 0.05$ which revealed that no Samplers were significantly different within each sampling period. Figure 22 shows the pH values averaged at each depth sampled for Sampler B-01 over the year showing the temporal changes occurring in the estuary. The estuary has an initial high pH due to the greater watershed runoff in the Spring and as the tidal influence increases the pH diminishes and does not recover before freeze up, indicating tidal dominance.

In order to compare sampling period to sampling period at each sampler, the pH values were averaged for each sampling period and Fig. 23 shows what occurred during CD 141 to 147. Annually the pH means range from 7.7 to 7.9 with the lower mean value at Sampler A and the higher mean value at Samplers C and D. There is no significant

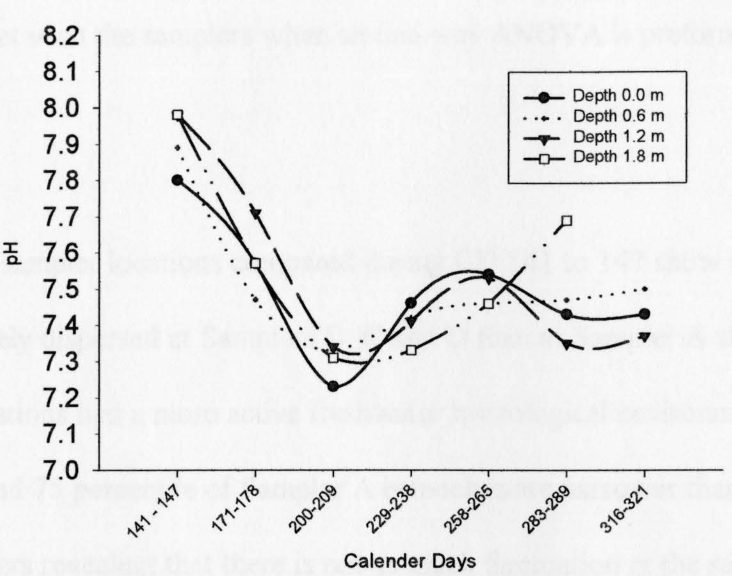

Fig. 22 Temporal changes occurring at Sampler B-01 on a depth basis.

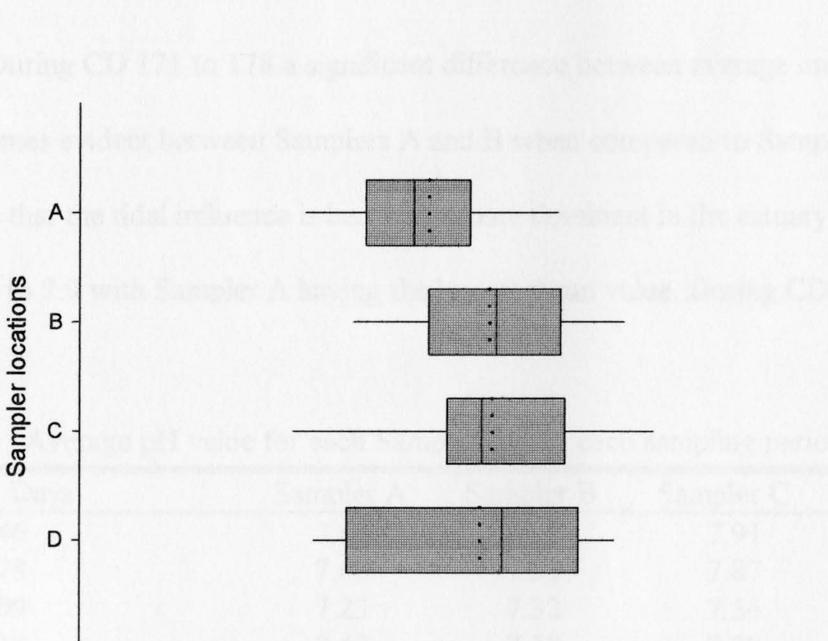

Fig. 23 Each sampler averaged over CD 141 to 147 showing initial pH values in 2001.

difference between the samplers when an one way ANOVA is preformed at $\alpha = 0.05$, (p = 0.18).

The sampler locations compared during CD 141 to 147 show that the estuary pH is more widely dispersed at Samplers B, C and D than at Sampler A showing that these sampler locations had a more active freshwater hydrological environment. The 25 percentile and 75 percentile of Sampler A is much more narrower than the ones for the other samplers revealing that there is not as much fluctuation at the sampler and note there was found to be no significant difference annually between the means of the samplers for pH at the different sampler locations.

During CD 171 to 178 a significant difference between average mean pH's (Table 13) becomes evident between Samplers A and B when compared to Samplers C and D evidence that the tidal influence is becoming more dominant in the estuary. The pH ranges from 7.4 to 7.9 with Sampler A having the lowest mean value. During CD 200 to

Table 13 Average pH value for each Sampler during each sampling period.

Calender Days	Sampler A	Sampler B	Sampler C	Sampler D
141 to 146	7.69	7.90	7.91	7.87
171 to 178	7.40	7.55	7.87	7.88
200 to 209	7.23	7.32	7.56	7.64
229 to 238	7.42	7.38	7.38	7.60
258 to 265	7.58	7.50	7.50	7.95
283 to 289	7.35	7.37	7.44	7.66
316 to 321	7.38	7.43	6.97	7.33

209 the estuary pH range drops to 7.2 to 7.6 a drop from CD 141 to 147. There remains a significant difference between the Samplers A and B compared to Samplers C and D with p = 0.00 at α = 0.05, using a two sample t test. The estuary pH pulses upward during CD 229 to 238 ranging from 7.4 to 7.6 and the reason for the pH increase is not evident. An ANOVA at α = 0.05 produces a p value of 0.00 for the whole estuary and Samplers A and B using a two sample t test at α = 0.05 still remain significantly different from samplers C and D.

Figure 24 shows CD 259 to 265 where Samplers A, B and C using an ANOVA test at α = 0.05 gives p = 0.00 showing they are significantly different from Sampler D.

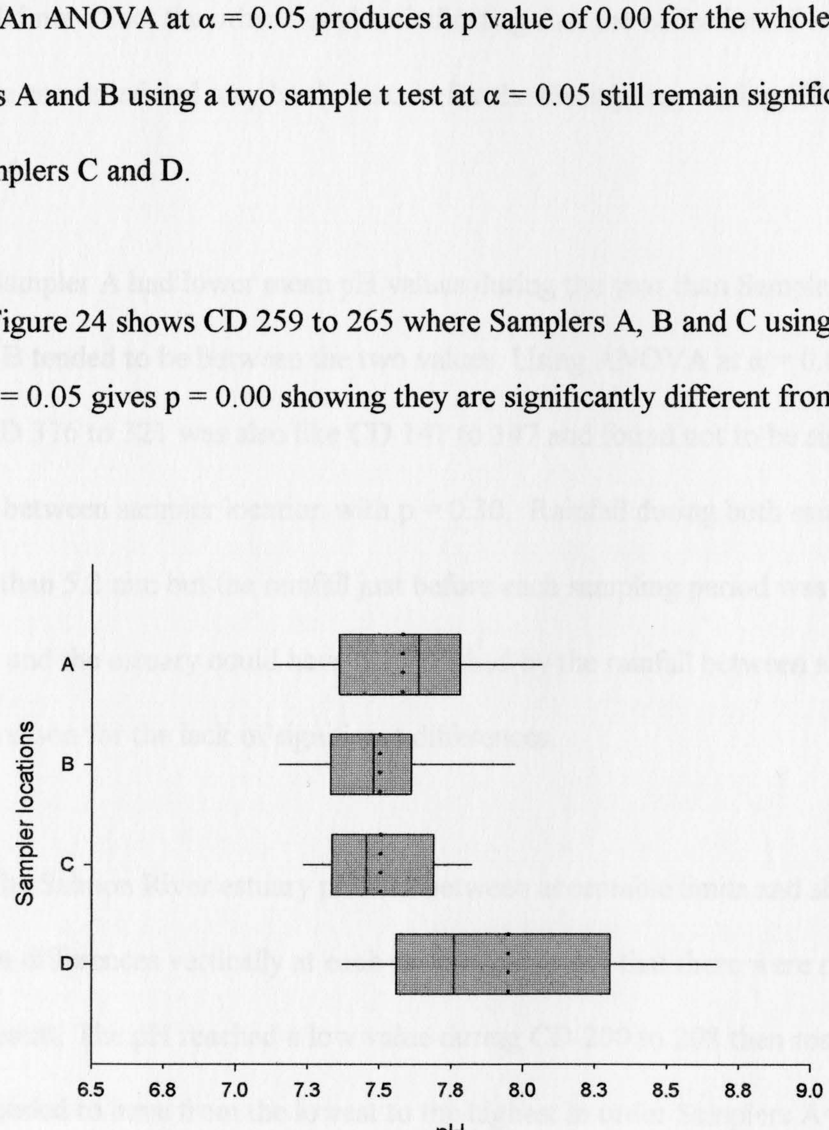

Figure 24 Showing the effects of a rain event on the estuary pH during sampling period CD 258 to 265.

The pH means ranged from 7.5 for three samplers to 7.9 at Sampler D. The increased pH is due to a 29 mm rain event which only affected Sampler D evidenced by the larger boxplot. The other sampler locations had a much narrower boxplot showing at this time of the year the rain event did not affect the lower elevated Samplers A or B. This rainfall did not affect the other samplers indicating that the collection of rain data was not as precise as needed and may be the reason for the discrepancy during CD 229 to 238 at Sampler A.

Sampler A had lower mean pH values during the year than Sampler C or D and Sampler B tended to be between the two values. Using ANOVA at $\alpha = 0.05$ sampling period CD 316 to 321 was also like CD 141 to 147 and found not to be significantly different between sampler location with $p = 0.30$. Rainfall during both sampling periods was less than 5.2 mm but the rainfall just before each sampling period was greater than 96.4 mm and the estuary could have been flushed by the rainfall between sampling periods thus the reason for the lack of significant differences.

The Salmon River estuary pH was between acceptable limits and showed no significant differences vertically at each sampler, showing that there were no different layers present. The pH reached a low value during CD 200 to 208 then rose slightly. The estuary tended to have from the lowest to the highest in order Samplers A<C<B<D. Showing that the majority of runoff came from Sampler D for this year since Sampler C and D flow into Sampler B.

3.5 Tides and tidal bores

3.5.1 Tides

The sediment transport mechanics of the estuary are the watershed discharge and the tidal influxes. During the season the tidal transport dominates but to what extent this changes the hydrological conditions is not known therefore measurements of the tides were conducted.

Tidal flood and ebb cycles were measured at the Veterans Memorial Highway (Site 1) by a Campbell Scientific SR50 Sonic Ranger (Fig 6). The sonic ranger emits a sound wave and based on the time lag for the signal to return the distance is determined from a set reference. Each reading is calibrated for temperature in order to overcome atmospheric noise and is accurate plus or minus 0.4 % of the distance measured. The sonic ranger was mounted under the Veterans Memorial Highway bridge crossing the Salmon River Estuary with the measurements collected on 60 s intervals and averaged every 15 min before being stored in a Campbell Scientific CR 10 data logger (Campbell Scientific). The sonic ranger operated from CD 98 , 2000 until after ice formation in the river CD 322, 2000 and was disconnected until the spring of 2001. Unfortunately the sonic ranger malfunctioned and was not measuring again until 100 days of the tidal collection season were past in 2001. Once the equipment was reinstalled the data logger was set to store the tidal elevations on a 1 min time interval in order to measure the tidal bore occurring in the estuary. Annual high tide water elevations ranged from 5.72 m to 9.46 m in 2000 and 6.24 m to 9.32 m in 2001 while the predicted tidal ranges were 6.6 to 8.7 for 2000 and 6.7 to 8.6 for 2001. All measured tidal highs and sounding measurements are based on geodetic elevations and therefore can be compared to each other.

The four 7.22 m tides in Fig 25 were recorded during 2000 and each took 60 min to progress from no tidal water to a high tide. The tidal curves show the quickly rising flood tide versus the slower falling ebb tide, since tidal outflow is considerably longer in time duration than the inflow and the vertical rate of increase on the flood tide increases faster than the rate of decrease on the ebb tide side. Uncles et al., (2002) comparing different estuaries by tidal currents found that estuaries with flood tide dominance could accumulate fine sediment within their upper reaches and that the ratio of maximum flood current to maximum ebb current was greater than unity for flood tide dominated estuaries. Using the rate of tidal vertical rise in Fig 25 as a component of the tidal velocity in the y direction, the maximum flood rate of rise over the maximum ebb rate of drop gave a ratio of 1.71 for CD 294 , 2000 and a ratio of 2.71 for CD 178, 2000 all greater than unity which held true for all other tidal profiles in 2000 and for the 1 min intervals in 2001. When comparing the ratio of flood tide rate of vertical rise to ebb tide rate of vertical drop for CD 199 and 294, 2000 it shows the flood tidal influence diminishing due to the increasing height of the estuary bottom.

An interesting comparison occurred between Sampler A-00 CD 188 and Sampler B-00 CD 300 which were both above a fluid mud value of 20 g L^{-1} shows that fluid mud concentrations can dominate different parts of the estuary at different times of the season.

The evidence of the fluid mud layer at Sampler B which is in the middle of the estuary according to Cooper (2002) is another indication of the estuary being dominated by the flood tide.

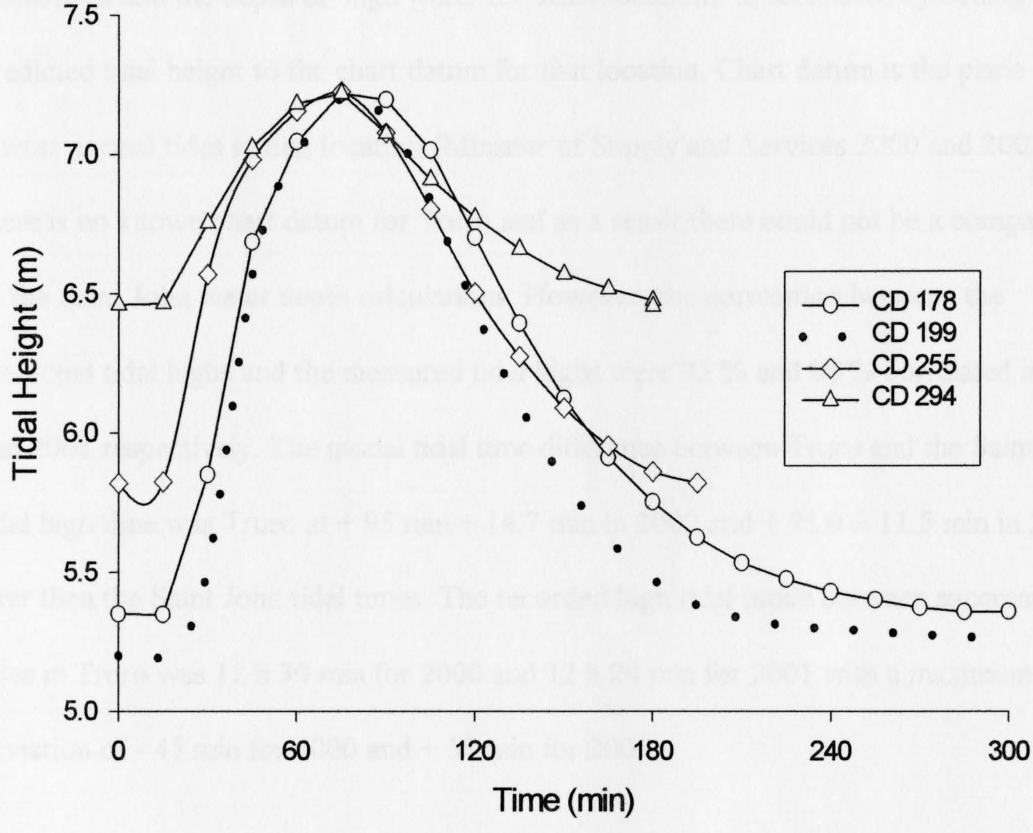

Fig. 25 Four tidal curves of 7.22 m height recorded at Site 1 for 2000.

Comparing flood tide durations for 2000 it is shown that CD 199 was 240 min while by CD 294 the flood tidal duration was 105 min less than half of the earlier flood tide. As the year progresses the individual tidal curves become flatter in appearance indicating less tidal energy present, likely as a result of the estuary bottom increasing 1.24 m in elevation between CD 199 and 294 and the slope of the estuary itself becomes less pronounced.

The closest primary reference port in the Canadian Tide Tables is Saint John, New Brunswick and the depth of high water for other locations is calculated by adding the predicted tidal height to the chart datum for that location. Chart datum is the plane of lowest normal tides at that location (Minister of Supply and Services 2000 and 2001) and there is no known chart datum for Truro and as a result there could not be a comparison to the Saint John water depth calculations. However, the correlation between the predicted tidal highs and the measured tidal highs were 95 % and 98 % correlated in 2000 and 2001 respectively. The modal tidal time difference between Truro and the Saint John tidal high time was Truro at + 95 min ± 14.7 min in 2000 and + 91.0 ± 11.5 min in 2001 later than the Saint John tidal times. The recorded high tidal mode between successive tides in Truro was 12 h 30 min for 2000 and 12 h 24 min for 2001 with a maximum deviation of - 45 min for 2000 and + 58 min for 2001.

At high slack tide, the slope of the water surface is assumed to be near zero over the study area and at the limits of the study area there are three bridges where regular cross sections of the estuary channels were taken at different times of the year. Using the geodetic elevation of the estuary bottom and deducting it from the geodetic tidal height the total depth of water can be determined. Table 14 shows the recorded tidal height at the

Site 1 by the sonic ranger and the calculated tidal water at each Site cross section. A negative value represents no tidal intrusion at that time and there are numerous days in both years where Site 2 has no tidal presence such as CD 210, 265, 272 and 346 in 2001. For both years of the study the water depths are variable in magnitude due to the difficulty of the tides to penetrate the landward locations of the estuary as the year progresses and the fact that the estuary bottom is being rapidly infilled.

Table 14 Tidal water depths at the Sites 1, 2 and 3 for 2001.

Calender Day	Tide(m) Recorded	Bridges (m) Site 1	Site 2	Site 3
200	8.56	5.55	1.31	3.25
210	7.25	7.94	- 0.18	1.11
228	8.20	8.47	0.82	2.12
258	8.06	6.66	0.33	1.23
265	8.13	5.60	- 0.18	1.42
272	6.80	2.09	- 0.46	0.27
287	8.05	3.84	0.76	1.56
294	7.76	3.64	0.47	2.73
315	7.67	2.51	0.43	2.03
322	8.16	3.99	0.28	2.49
336	8.40	3.09	1.25	2.98
346	7.17	3.02	- 0.04	1.65

Bedload movement is evident when CD 210, 2001 is compared with CD 265, 2001 and the different depths of water at each cross section are examined. CD 210 has a tidal height of 7.25 m and due to gullies within the estuary bottom is able to put 7.94 m of water at Site 1. Later in the summer at CD 265 a 8.13 m tide occurs but is only able to place 5.60 m of water at Site 1 and comparing the two days shows that the tidal high difference is + 0.88 m higher but the depth of water difference is - 2.34 m less on CD 265. This infilling of the estuary with sediment deposits is important since the deep zone of a channel is the area where the maximum tidal and runoff erosive currents would occur. At Site 2, comparing the same two days, reveal that neither tide reach the site. This is directly due to the increase in the sediment deposits elevation on the bottom of the estuary. Failure of the tides to reach Site 2 means that these tides are depositing their sediment loads during slack water further downstream. The fact that the 8.13 m tide on CD 265 did not reach Site 2 indicates that the sediment deposit gain is equal to the tidal height gain of 0.88 m while at Site 3 the water depth is actually deeper on CD 265 when compared to CD 210 . The differences between the water depths at the three sites shows the changes occurring within each section of the estuary depending upon the hydrological conditions that occurred between the measurement periods.

Site 3 being lower in elevation than Site 2 is more tidal than Site 2 and the depth of water between them is variable. Usually the water depth is a 2 fold increase deeper at Site 3 over Site 2 but on CD 322 it is 8.9 fold deeper and there was no recorded rainfall 24 h previous. The normal 2 fold difference in water depth between the two sites allows for a greater deposition of sediment in the estuary channel at Site 3.

Minute analysis of the tidal profile revealed a physical characteristic of the estuary. The Bay of Fundy becomes shallow and funnels in the landward direction causing a tidal bore to appear in the Salmon River Estuary. This funneling effect causes the leading edge of the tide when it reaches its landward limit to reflect back onto itself and is known as resonance. Figure 25 shows some tidal curves for different tidal bores which were recorded on CD 223, 278 and 308 (2001) at Site 1. It shows various CD in incrementing heights in 2001 and the resonance of the tide as a secondary bump on the tidal profile. The tidal resonance was found to start at tides above 8.70 m And progressively became more pronounced. In 2001 the highest recorded tide was CD 232 with a 9.31 m tidal elevation (Fig 26) and there were 144 more tides below that height that had evidence of a resonance.

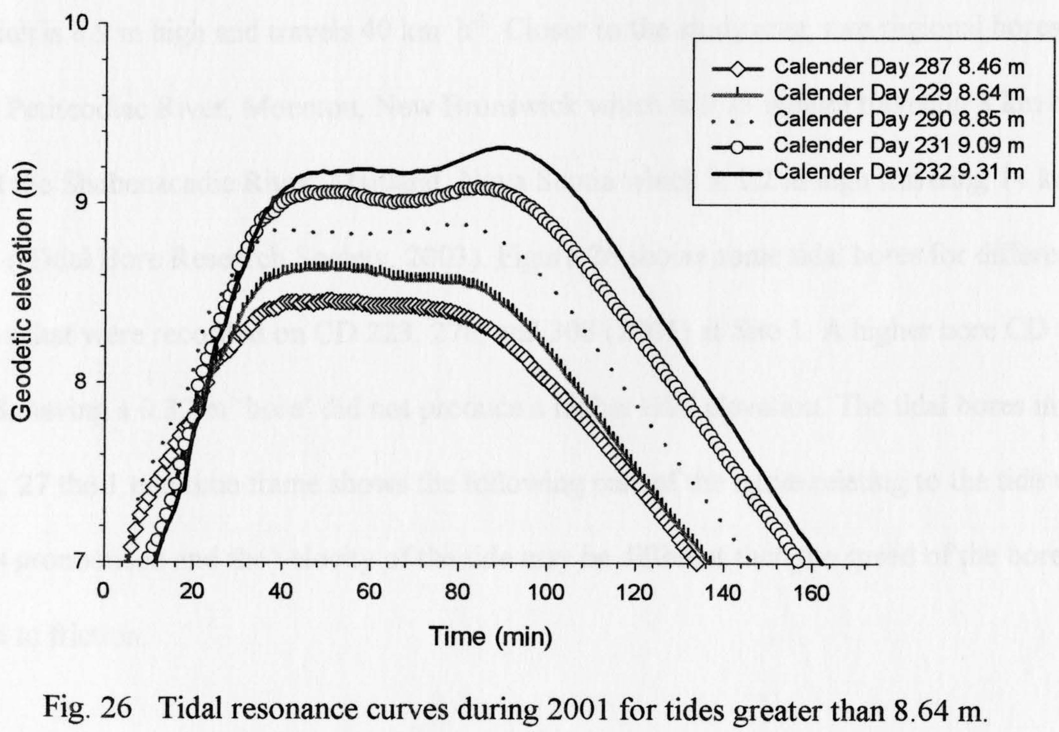

Fig. 26 Tidal resonance curves during 2001 for tides greater than 8.64 m.

The tidal measurements of the Salmon River Estuary were found to be highly correlated to the predicted highs and were higher than the predicted tidal highs by 0.76 m and 0.72 m in 2000 and 2001 respectively. Examination of the tidal curves show that the flood tide was the dominant sediment transport mechanism during the study years.

3.5.2 Tidal bores

The amount of sediment within a water course depends upon the size of the sediment and the ability of water flowing around that particular particle to suspend or cause the sediment to roll along as saltation. Tidal bores occur when the incoming flood tide overcomes the bottom friction of the estuary and reaches a flat area where it can flood landward. The highest bore in the world is Qiantang Jiang in Zhejiang Province, China, which is 8.9 m high and travels 40 km h^{-1}. Closer to the study area, two regional bores are the Petitcodiac River, Moncton, New Brunswick which is 0.75 m high traveling 8 km h^{-1} and the Shubenacadie River, Maitland, Nova Scotia which is 1.2 m high traveling 14 km h^{-1} (Tidal Bore Research Society, 2003). Figure 26 shows some tidal bores for different days that were recorded on CD 223, 278, and 308 (2001) at Site 1. A higher bore CD 308, having a 0.32 m 'bore' did not produce a higher tidal elevation. The tidal bores in Fig. 27 the 1 min time frame shows the following part of the curve relating to the tide was less pronounced and the velocity of the tide may be different than the speed of the bore due to friction.

Engineering fluid mechanics consider tidal bores to be a form of a hydraulic jump which can occur in dam spillways or drops in channel elevation. Wherever they occur the flow of water speeds up and then meets deeper water, causing a back breaking wave to form and dissipating the water energy from the faster current. The velocity and speed of a hydraulic jump can be estimated and since tidal bores are traveling upstream in a channel their speed can also be estimated at one point along that channel. One primary assumption

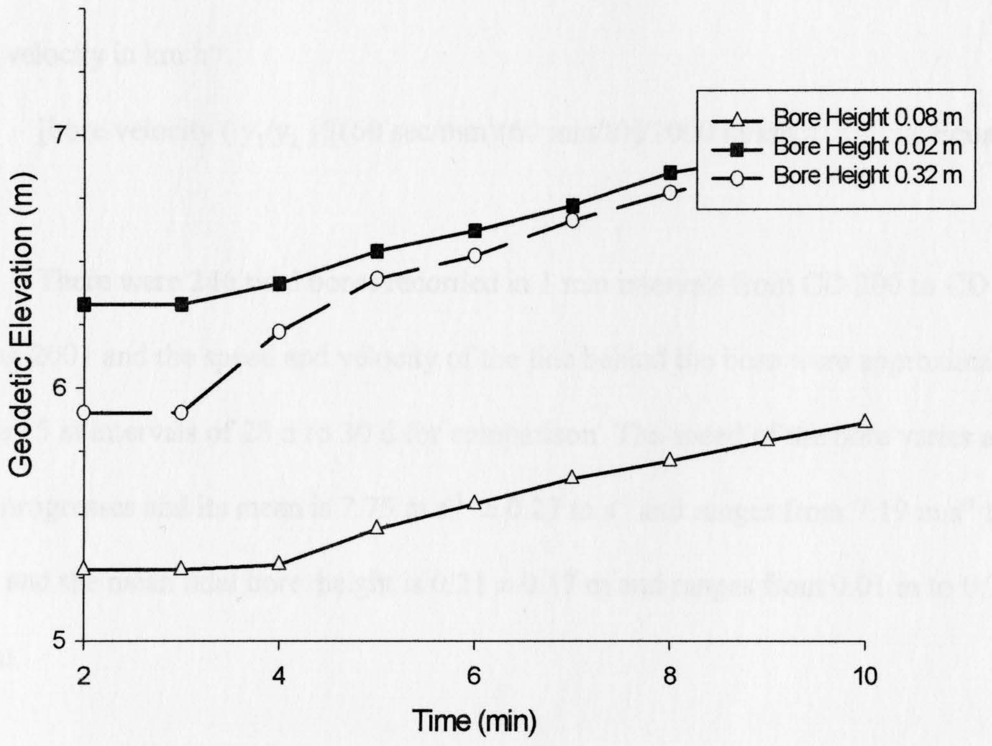

Fig. 27 Tidal curves of different tidal bores which were CD 223 bore 0.02 m, CD 278 bore 0.08 m and CD 308 bore 0.32 m.

to be made is that the channel width is constant and therefore the calculations are only approximate, but it does show that the bore and tide has the energy to be able to resuspend and move sediment in a landward direction. It should be noted that the velocity and speed of the tide is applicable only to Site 1 since elevation changes in the estuary bottom and estuary curvature will change the velocity of the bore and tide behind it. The bore speed is calculated by relating the relative water depth before (y_1) and after the bore (y_2) to each other and gravity (g) (Williams and Elder, 1989).

Approximate bore velocity in ms^{-1} :

$$[(g\, y_2/2\, y_1)\,(y_2 + y_1)]^{1/2} \qquad \text{(Equation 1)}$$

and the approximate speed of the tide behind the bore relative to the land is calculated by tidal velocity in km h^{-1}:

$$[\text{bore velocity }(y_1/y_2)][(60\text{ sec/min})(60\text{ min/h})]/1000\text{ m/km}. \qquad \text{(Equation 2)}$$

There were 246 tidal bores recorded in 1 min intervals from CD 200 to CD 346 during 2001 and the speed and velocity of the tide behind the bore were approximated in Table 15 at intervals of 28 d to 30 d for comparison. The speed of the bore varies as the year progresses and its mean is 7.75 m s^{-1} ± 0.27 m s^{-1} and ranges from 7.19 m s^{-1} to 8.47 m s^{-1} and the mean tidal bore height is 0.21 ± 0.17 m and ranges from 0.01 m to 0.72 m in height.

Table 15 Tidal bore and tidal speed approximations for 2001.

Calender Day	Tidal Bore Height	Tidal Bore (m s^{-1})	Tide (km h^{-1})
200	0.61	7.67	3.00
228	0.15	7.40	0.70
258	0.11	7.49	0.50
287	0.01	7.95	0.05
315	0.24	8.03	1.10
342	0.15	7.81	0.66

The mean tidal velocity is 0.99 km h^{-1} ± 0.23 km h^{-1} and ranges from 0.03 to 3.18 km h^{-1} during the year. From Table 15 the tidal bore speed varies as does the tidal velocity of the tide which decreases in magnitude as much as 10 fold comparing CD 258 and CD 287 and a 22 fold increase in tidal velocity between CD 287 and CD 315.

Even though there was evidence of the tidal bore being able to stir up the bottom sediments correlations between the tidal bore height or velocity to sediment concentration per meter of depth is not evident for any sampling period or between the depth of sample.

3.6 Rain Events

Another mechanisum that could transport sediment in the estuary besides the tidal fluxes was the runoff from rainfall events in the watersheds. The measurement of the rainfall could help explain some of the variability in the sediment deposits due to runoff events.

The rainfall for the estuary was collected at three rain gauge sites within a 6 km radius of the Park Street Bridge. The sites were at the Stella Jones Wood Treatment Plant for all of 2000, from late 2000 to 2001 at the Agro-Tech Development Park and at the Environment Canada weather station in Bible Hill for all of the years with missing data in year 2001. No one year contained a complete rain record and the gaps were filled with rain data from the other rain gauge sites.

Environment Canada, on their web site: www.climate.weatheroffice.ec.gc, have calculated the normals for weather at the Bible Hill station for the interval 1971 to 2000. Each year of rain fall was compared to the normals of that month and plotted in Figure 28. The monthly rainfall for 2000 and 2001 start the year near normal values but then digress

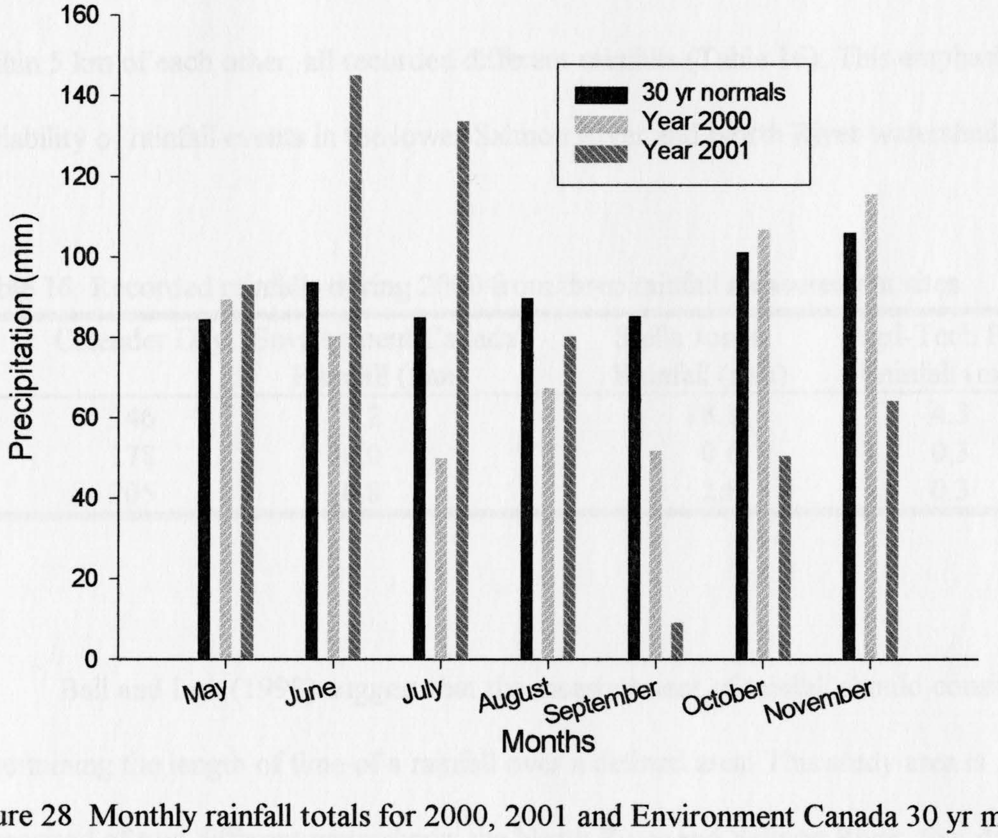

Figure 28 Monthly rainfall totals for 2000, 2001 and Environment Canada 30 yr monthly normals.

from the norm. In 2000 the rainfall falls below the Environment Canada normals and remains there until almost the end of the summer before ending the year slightly above the normals. Rainfall for 2001 is completely different than the normals in that there was excessive rainfall early in the year and then a drought after mid season and not recovering at all in the fall. An ANOVA analysis at $\alpha = 0.05$ of the rain data showed no significant differences ($p = 0.66$) between the monthly rainfall data and the monthly normals calculated by Environment Canada for 1999, 2000 and 2001.

Singh (1997) found that rainfall can vary significantly over an area greater than 1 km. This was found to be the case for the study area, the three rainfall measurements sites, within 5 km of each other, all recorded different rainfalls (Table 16). This emphasizes the variability of rainfall events in the lower Salmon River and North River watersheds.

Table 16 Recorded rainfalls during 2000 from three rainfall measurement sites.

Calender Day	Environment Canada Rainfall (mm)	Stella Jones Rainfall (mm)	Agri-Tech Park Rainfall (mm)
146	7.2	18.1	4.3
178	0.0	0.6	0.3
205	0.8	2.8	0.3

Ball and Luk (1998) suggest that the measurement of rainfall should consists of determining the length of time of a rainfall over a defined area. This study area is comprised of two different watersheds, the North River and Salmon River, that drained through Site 1. Using the estuary bottom elevations, which were measured by the sonic ranger, and graphing them along with the recorded rainfalls for 2000 (Figure 29) one can see that some rain events are reflected in the bottom elevations. Rainfall for 2000 was used for analysis since hourly totals were available and there were more frequent events

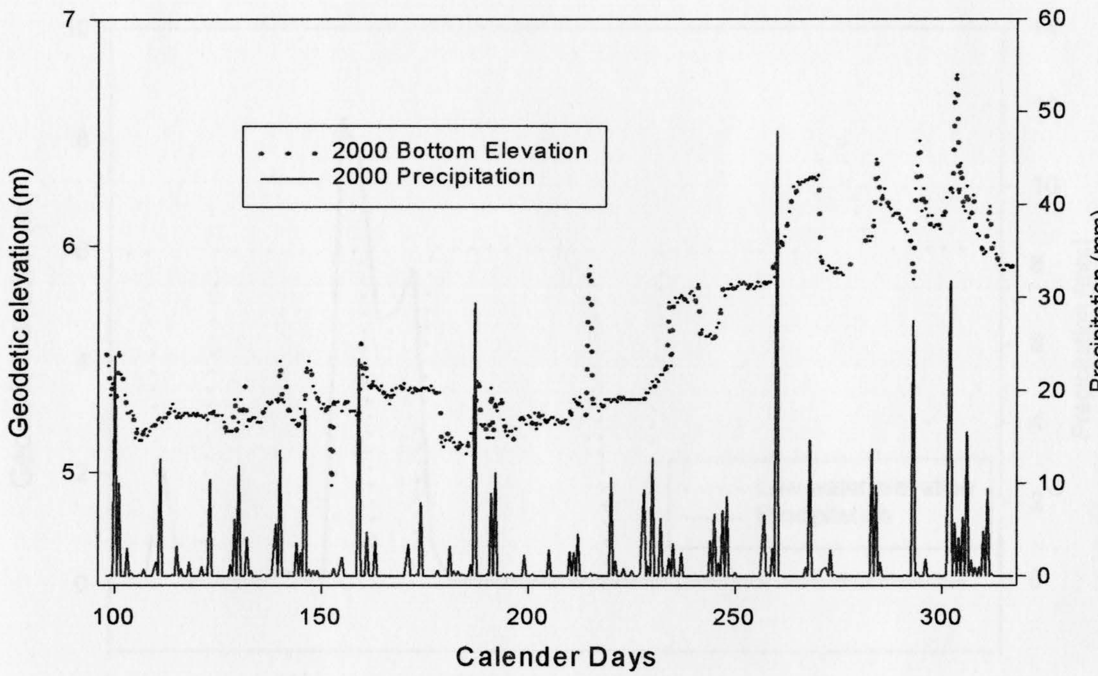

Fig. 29 Estuary bottom elevations and recorded rainfall for 2000 showing relationship

then in 2001. The sonic ranger was not always positioned over the outflowing water channel and therefore not all rain events were captured by the sonic ranger, only those that caused a noticeable increase in low tide water surface elevations. The rainfall was compared to the estuary mud elevations in order to determine if there was any correlation between the estuary mud elevations and the rainfall events. Analysis revealed that there was no correlation between these two variables for 2000 or for 2001. There were several rainfall events that seemed to affect the estuary water level elevations and the indications from Fig. 30 suggest that these are rainfall events greater than 14 mm.

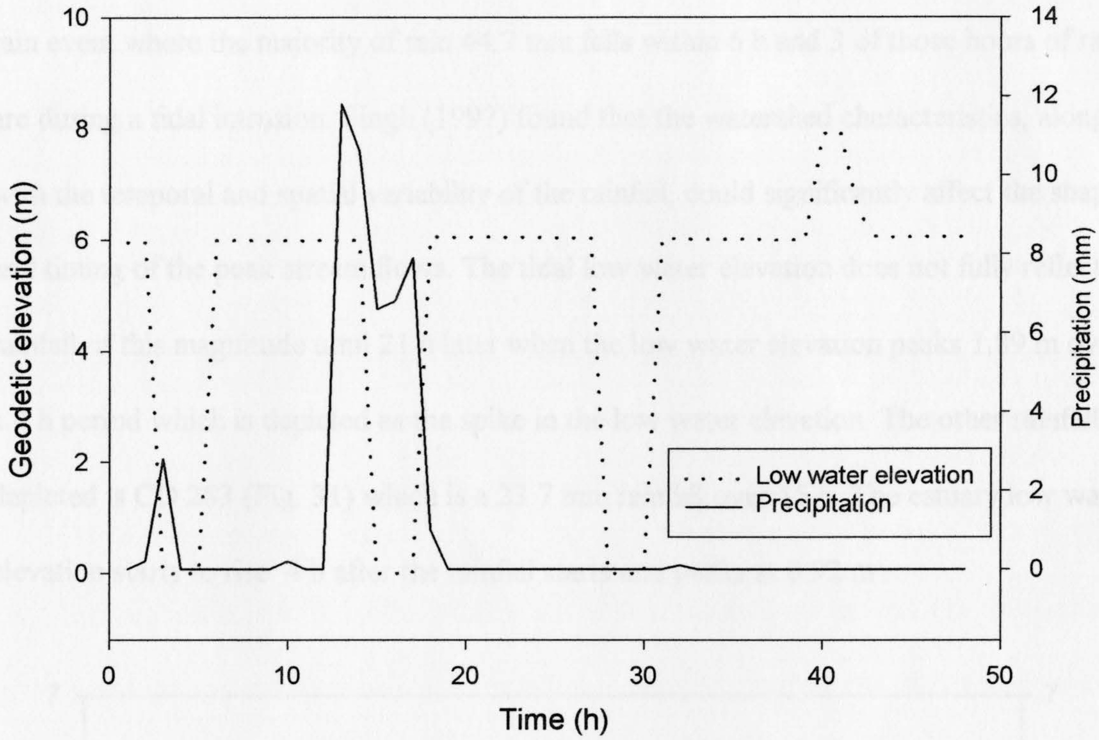

Figure 30 Calender Day 260, 2000 showing the effects of rainfall runoff on the estuary low water elevation.

There are numerous rainfall events which could be examined, but a limiting factor is the rainfall duration. A 14 mm rainfall over 24 hours is shown in Fig. 30, but when examined further there is not be any discernable trend evident since part of the discharge curve was masked by tidal intrusions. Therefore two rainfalls > 23 mm and lasting over 24 hours will be examined.

In Fig. 31 the rainfall on Calender Day 260 has two tidal intrusions which were equated to zero since they were deducted from the estuary tidal high. There is a 47.9 mm rain event where the majority of rain 44.7 mm falls within 6 h and 3 of those hours of rain are during a tidal intrusion. Singh (1997) found that the watershed characteristics, along with the temporal and spatial variability of the rainfall, could significantly affect the shape and timing of the peak stream flows. The tidal low water elevation does not fully reflect a rainfall of this magnitude until 21 h later when the low water elevation peaks 1.89 m over a 4 h period which is depicted as the spike in the low water elevation. The other rainfall depicted is CD 283 (Fig. 31) which is a 23.7 mm rainfall over 15 h. The estuary low water elevation starts to rise 4 h after the rainfall starts and peaks at 0.92 m

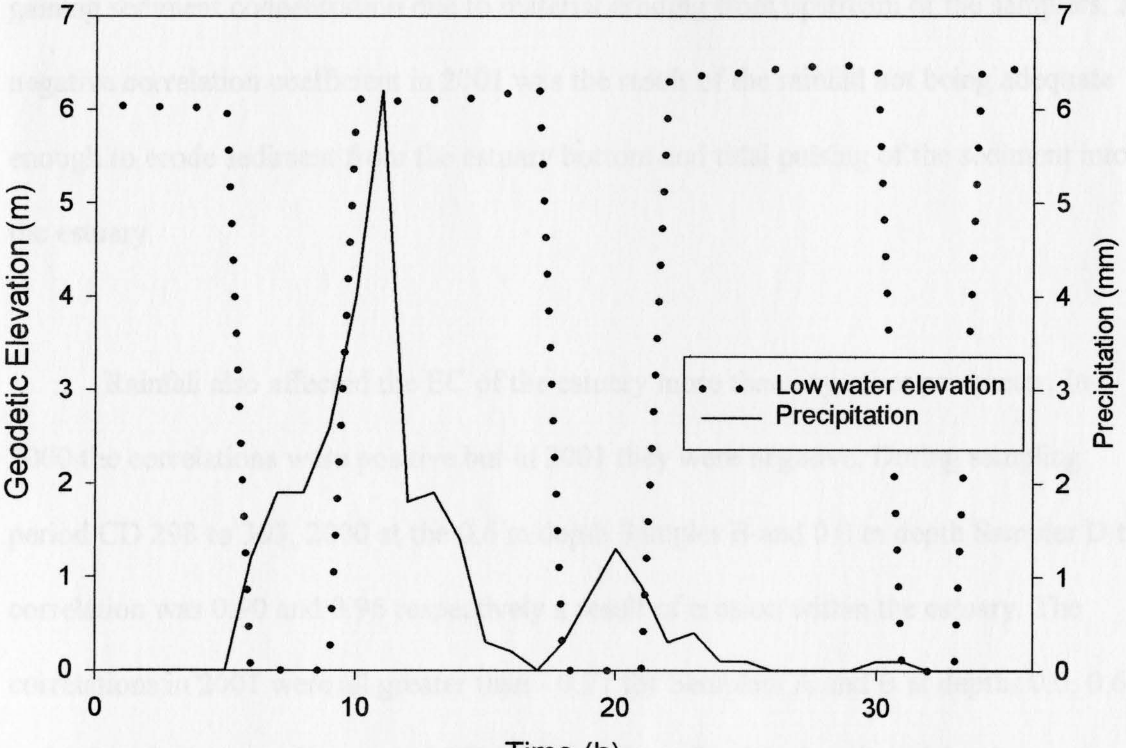

Fig. 31 Calender Day 283, 2000 showing the effect of a 23.7 mm rainfall over 15 hours gradually changing the low water elevation.

higher 6 h from the end of rainfall.

Correlations between the rainfall and sediment concentration were variable depending upon the time of year and the sampler. During 2000 there was a positive correlation (0.70) during sampling period CD 210 to 218 for the 0.6 m depth at Sampler B and sampling period CD 298 to 303 for the 0.0 m depth at Samplers C and D and the correlation was 0.99 for both samplers. During 2001 there was a negative correlation (-0.78) at the 0.6 m depth Sampler D, CD 171 to 178 and at the 0.6 m depth, Sampler B (-0.88) for CD 823 to 289. Positive correlations mean that the estuary at that sampler was gaining sediment concentration due to material eroding from upstream of the samplers. A negative correlation coefficient in 2001 was the result of the rainfall not being adequate enough to erode sediment from the estuary bottom and tidal pulsing of the sediment into the estuary.

Rainfall also affected the EC of the estuary more than any other parameter. In 2000 the correlations were positive but in 2001 they were negative. During sampling period CD 298 to 303, 2000 at the 0.6 m depth Sampler B and 0.0 m depth Sampler D the correlation was 0.90 and 0.96 respectively a result of erosion within the estuary. The correlations in 2001 were all greater than - 0.71 for Samplers A and B at depths 0.0, 0.6 and 1.2 m during sampling period CD 200 to 209 a reflection that the tidal pulse was occurring at that time.

The seasonal trend in the rainfall is to be lower than normal during the summer and higher in the later part of the year. Yanni et al., (2000) stated that in South-western Nova Scotia the precipitation rates rise in the autumn and are generally highest in December due to less precipitation occurring and more evapotranspiration.

The annual rainfall was not similar to the 30 y monthly totals and showed that the events diminished as the season progressed. Even though the sonic ranger was not over the watershed discharge at all times it did capture the changes in the estuary bottom elevation. Rainfall events $\geq$ 14 mm were discovered to have an effect on the bottom elevation and that rainfall duration affected the discharge curve of the estuary.

CHAPTER 4 - Summary and Conclusions

The suspended sediment concentration of the Salmon River Estuary was highly variable on a daily basis. Successive tides were found to have sediment concentrations as much as 134 X greater or as little as 98 X less than the previously sampled tide. The sediment concentration tended to be more variable the further inland the sample was collected, a reflection of the more dynamic hydrological environment at these locations. The fact that the concentrations were so variable lead to using average sediment concentrations for each sampling depth in a given sampling period. Annually the sediment concentrations within the estuary ranged from 0.00 g L^{-1} to a high concentration of 706.6 and 946.3 g L^{-1} in 2000 and 2001 respectively.

Sediment concentration values were found to exceeded 20 g L^{-1} for more than 80 % of the samples collected annually, the value used by some investigators to describe 'fluid mud'. The sediment concentration increased with depth and longitudinally the sediment concentration was lower at the landward sampler locations. Seasonally the sediment concentrations increased at all locations indicating a hydrological occurrence called tidal pulsing. The amount of sediment remaining in the tidal water column was high and quite variable depending upon the hydrological events occurring in the estuary. Calculations of the suspended sediment load over the study area for several tidal heights were calculated, and the loading ranged from 75,376 m^3 to 152, 859 m^3. This represents a significant amount of sediment which remained in the water column. These amounts translate into 14 m^3 to 32 m^3 per m of estuary studied which remained in the water column and was able to flow with the tide.

Sediment deposits from the tidal intrusions were significant enough to affect the estuary discharge channels. The deposition was variable but was the dominant trend during the summer and the maximum discharge filled by the deposited sediment was on average 47.5 % of the available discharge channels capacity. Calculation of the maximum deposited sediment volumes in the estuary at one time is 515,247 m^3. This material remained until winter freeze up and erosion events on average were able to remove only 16.2 % of the material deposited annually leaving the remaining 30 % of the deposited material in the estuary discharge channels. These remaining deposits are speculated to play some role in the frequent ice jams and resultant floods in the Salmon River Estuary.

Rates of erosion were variable temporally and spatially within the estuary with the seaward end of the estuary having the highest rate at 1.6 cm d^{-1} and the most landward locations having rates of 1.1 and 0.8 cm d^{-1}. The rates of deposition were much higher at the seaward end and could reach 8.6 cm d^{-1} while rates of deposition were 4.0 cm d^{-1} at the most landward locations. As a result of this sedimentation the estuary gradient became shallower as the year progressed, eventually reaching 0.11 m km^{-1} of estuary which is equivalent to 0.01 cm m^{-1}. This shallowing of the estuary gradient affects the discharge efficiency of the estuary channels by decreasing the runoff water velocity. The steeper the gradient the greater the water velocity and a shallow gradient will decrease the water velocity from the runoff coming from the watersheds.

Water currents are able to move sediment based on their competence and particle analysis was able to determine the competence of the flood tidal currents. Measured from the Veterans Memorial Highway 102 bridge longitudinally, the estuary was found to be dominated by fine sand at the 2500 m mark whereas silt dominated at the 4542 and 4819 m of the estuary. Clay sized particles were evenly distributed over the whole estuary, likely a reflection of their longer settling time. The distribution of the sand and silt showed that the water currents were strong enough to move fine sand to the 2500 m area but unable to move these larger particles beyond that point. Silt, being a smaller particle, was moved to the extremes of the study area in the landward direction considered to be a sign of tidal pulsing.

Sorting is an indication of the tidal competency to move a particle in one general direction. Poor sorting is indicative of a variable current regime in the area, resulting in a heterogenous mix of particle sizes. The degree of sorting was found to be higher as one moved in the landward direction and sorting was found to decreased in the seaward direction which suggests the current regime in the landward direction was not as variable.

Electrical conductivity measurements were used to determine how far the tidal influxes influenced the estuary. The EC was converted to a salt concentration and analysis revealed that the salt concentration increased gradually at all depths sampled and at all 4 sampler locations until a peak concentration was reached. This concentration 22.0 gm L^{-1}

which was below the value for salt water (35.0 gm L^{-1}). The seasonally lower rainfall during the summer allowed the tidal intrusions to become the dominant hydrological force over the whole estuary. Salt concentrations on a daily basis followed the tidal sequence during each sampling period and dropped slightly as the tidal highs dropped. The further from the water surface and landward the sample was collected the salt concentration was found to decline in value.

The pH was generally higher in the spring of the year due to runoff and rainfall and decreased as the sediment concentration increased into the estuary. The pH never fully recovered from the Spring values and tended to be lower in the Fall on average by 0.57 pH units, a significant drop.

Tidal elevations were generally higher that those predicted at the closest primary reference port Saint John, N.B. reflecting the physiology of the Bay. The tidal times for high tide were usually 95 ± 14.7 minutes and 91 ± 11.5 later than the predicted St. John times. Tidal profiles revealed conclusively that the estuary is flood tide dominated and is capable of pushing large amounts of sediment landward. The competence of the tide to move particles show that the stronger currents tend to dissipate after the 2500 m distance since the fine sand component of the sediment water column is greatest there and lower further landward. Above this point there still is enough current to push silt sized particle to the 4542m and 4819 m distances.

Tidal resonance occurs when the incoming tide reaches the landward direction and reciprocates back upon itself. There was a tidal resonance detected when tidal measurements were collected at 1 min intervals but the resonance occurs but only at tidal influxes greater than 8.7 m.

Tidal bores are not correlated with the sediment concentration or the resultant tidal peak height and the approximate bore speeds and following tidal speeds are quite variable. Tidal bore speeds ranged from 7.19 m s^{-1} to 8.46 m s^{-1} with a mean value of 7.75 ± 0.27 m s^{-1} and the estimated tide following the bore ranged from 3.18 km hr^{-1} to 0.03 km hr^{-1} and the mean was 0.99 ± 0.23 km hr^{-1}. The actual bore heights were found to average 0.21 ± 0.17 m and ranged from 0.01 m to 1.03 m.

The influence of rainfall was seasonal but it could affect the estuary over the short term by erosion and by either increasing the EC and decreasing the pH or visa versa depending upon the amount of rainfall. Rain events for the two years of the study were below the calculated 30 year normals for the area. There was difficulty in recording rainfall related stream discharge events due to the fact that events over 13 hours in duration would have their discharge curves inundated by one or more tidal influxes. Rainfalls of 14 mm or greater tended to influence the estuary low water elevations without necessarily eroding the bottom.

The Salmon River Estuary is a flood tide dominate estuary with stratified suspended sediment concentrations at values exceeding 20 g L^{-1}. Due to the seasonal nature of the rain the estuary is a salt dominated estuary with tidal resonance. Sediment deposits are such that during the season and by freeze up they do restrict the discharge area of the estuary channels. These restrictions in the discharge channels influence the runoff regime within the estuary by shallowing of the runoff gradient due to infilling and if the deposits of sediment remain until freeze up they may play a part in the reoccurring winter ice jams and resultant floods prevalent within this section of estuary.

Further study is needed to determine if over time the combination of land subsidence and tidal rise will make the estuary a more tidally dominate since the tides will be able to reach further landward. and if the estuary channel infilling has an effect on the formation of the ice jams within the estuary.

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