The Relationship between Suspended Sediment Concentration and Sediment Deposition within a Macro-Tidal Salt Marsh Tidal Creek System

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Date: April 15, 2013

Letter of Approval

Hello Brenden,

Your Honours research Proposal looks good. The research plan is interesting and substantial, and the timeline prudently foresees most of the work to be finished by the end of the fall semester.

I would recommend that you carefully prepare – and review – your text, especially when you write your thesis.

The proposal is approved.

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May, 2012

The Influence of Suspended Sediment Concentration and Sediment Deposition within a Macro-Tidal Salt Marsh Tidal Creek System

By Brenden R. Blotnicky

Submitted (April 2013)

Abstract

Currently, in Nova Scotia, the primary source of energy comes mainly from carbon-based sources; there is an interest in developing cleaner, local renewable energy sources, such as tidal power in the Bay of Fundy. Our understanding of the impacts of tidal energy extraction on intertidal zones is severely limited. The purpose of this thesis is to examine the sediment dynamics (such as flocculation, role of vegetation, suspended sediment concentration, and deposited sediments) in a salt marsh tidal creek system in the Bay of Fundy. This data will be used in hydrodynamic models currently being developed, to assess the potential impacts of tidal energy extraction on intertidal sedimentation. The experiment took place during the Summer of 2012 through a series of concurrent projects. Suspended sediment concentrations were measured using a stage-bottle method at four locations along the Kingsport Marsh, Minas Basin at two elevations (relative to datum) at each site. Sediment concentration was determined using suction filtration. The deposited sediment was measured using three aluminum sediment traps at each of the four locations. All 39 tidal cycles of data were collected during high spring tides. The sites located closest to the creek received the highest amounts of deposited sediment. An increase in the availability of suspended sediment concentration resulted in higher opportunity for the sediment to be deposited on the marsh surface. The results of this study will enhance the knowledge of temporal and spatial influence that sediment dynamics have on the system and will assist in the baseline understanding of tidal power implementation in the Bay of Fundy.

Date: April 15, 2013

The Influence of Suspended Sediment Concentration and Sediment Deposition within a Macro-Tidal Salt Marsh Tidal Creek System

By Brenden R. Blotnicky

Soumettre (Avril, 2013)

Résume

En Nouvelle Ecosse, les premières sources d'énergie sont des produits de carbone. A cause de ça il y a beaucoup d'intérêt en le développement des sources régénère locale comme l'énergie a mer dans la Baie du Fundy. Il n'y a pas déjà assez d'information aux impacts que l'extraction fait sur les zones intertidale. L'objet pour cette thèse est pour faire l'examinassions des sédiments (comme floculation, végétation, concentration des sédiments en suspension, et des dépôts) au système marais salant en la Baie du Fundy. Ces résultes va être utilise par des scientistes en modelés hydrodynamique que sont développé pour s'évaluer des impacts par l'extraction d'énergie. Ces expérimentes se passer pendant l'été 2012 avec des autres projets. La concentration de sédiment en suspension est mesure avec la méthode de boite d'étape à 4 locations au Marais Kingsport, Minus Basin à 2 élévations par site. Concentration est détermine par la méthode de filtration. Les dépôts sont mesure par 3 piège aluminium au chaque locations. Tous les données sont accumule à marée haute printemps. Les sites plus proches à la mer reçu la plus grande quantité de concentration que donne l'opportunité pour le sédiment d'être dépôt sur la surface du marais. Ces résultats vont améliorer la connaissance des influences sédimentaires sur le système. Il va assister à la compréhension d'implémentation d'énergie marée à la Baie du Fundy.

Date : Avril 15, 2013

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Chapter 1

Introduction and Literature Review

1.0) Introduction

Currently, in Nova Scotia, coal is a primary source of energy, resulting in high carbon dioxide emissions into the atmosphere. This level of contamination has led to a shift in the mindsets towards alternative renewable sources of energy. The goal for Nova Scotia is to reach 25% of its energy in 2015, and 40% in 2020 (Farwell, 2009), coming from a renewable resource which includes solar, hydro, wind and tidal power. The Bay of Fundy hosts the highest tidal range in the world with a potential of 6.9 Gigawatt hours of power (MacMillan et al, 2007). As a result, tidal power development is seen as one of several likely candidates to fulfill the recommended renewable energy production goals.

The process of extracting tidal energy from a dynamic system, such as the Bay of Fundy, could have severe effects on the processes within that system (Friedrichs and Perry, 2001) in both the near and far field. Near field refers to areas within several kilometers of a turbine, whereas far field refers to areas in the upper reaches of the estuaries (e.g. mudflats and salt marshes). A change in energy entering the Basin may change the state of the system to an entirely new equilibrium condition. In order to have a better understanding of the full impact tidal energy extraction has on far field dynamics within the Bay, many components related to sedimentation must be considered. These include the natural variability within a system and the influence that meteorological events may have on the relationship between the suspended sediment concentration and the sediments deposited.

Marshes supply many important services such as regulating disturbance regulation, acting as a habitat, and providing a secure area for wildlife development (de Groot et al, 2002). Sea level is expected to rise by a range of 30-100cm by 2100 (Solomon et al, 2007), due to the effects of climate change. Rising sea levels will force more salt marshes inland, thus replacing the existing tidal freshwater marshes (Park et al, 1991). These freshwater marshes provide many services to the environment, such as plant growth, above ground biomass, and waste treatment (Craft et al, 2008). Increased sea levels will also result in higher tides within the Upper Bay.

Larger tidal ranges will transport higher amounts of sediment and increase the overall availability of sediment for deposition; increasing the inundation time over a marsh will permit more sediment in suspension to settle (Voulgaris, 2004). Sediment deposition is influenced by a complex, interacting range of variables including velocity, vegetation, elevation within the tidal frame, and sediment composition. In areas of the upper Bay, fine-grained sediment are predominant in the form of flocs (Milligan et al, 2001); therefore, an understanding of flocculation processes is critical. There are two major mechanisms by which the flocculation will occur in: i) electrostatic (Eisma, 1991), or ii) biological activity (van Leussen, 1997). However, in both cases suspended sediment concentration exerts a significant influence on ultimately how much sediment is deposited. Each tidal cycle is different; spring tides tend to have a higher variability than do neap tides in the sediment concentration (Voulgaris, 2004). Ultimately, sediment deposition is a function of both the availability of sediment in suspension and the opportunity for this to be deposited in tidal currents.

1.1) Description of a Saltmarsh

Many coastal lying areas are occupied by a saltmarsh system. Salt marshes provide an ecosystem essential for the survival and development of many species. The salt marsh is an intertidal zone that separates the land from the sea, acting as a buffer zone between the two ecosystems (Hsieh, 2004). During periods of high storm surge or during severe weather events, a salt marsh will protect the land from hazardous weather damage (Craft et al, 2009). As part of the buffer zone role, it will protect the land's integrity, as well as permit this land to be suitable for development and anthropogenic usage (Poirier, 2012). Salt marshes also create a habitat for many sea-based land animals and many bird species, allowing them close proximity to their prey and food sources (Webb et al, 2010).

A key role played by saltmarsh systems is the importance of its performance as a valuable sink for many chemicals (Mitsch & Gosselink, 2007). Carbon is one of the more predominant elements that is trapped within this type of ecosystem; this sequestration allows for the preservation of an atmosphere feasible for the majority of species on this planet (Newman and Belcher, 2011). Given the potential damage carbon can have on the environment, the sink and trap process provided by salt marshes is climate stabilizing.

Salt marshlands in coastal areas are subject to many different types of weather events with high variability. These types of environments are highly dynamic as a result of the high exposure to different weather systems. A salt marsh will always adjust towards a new equilibrium in respect to the changes it faces with tidal fluctuation and difference in energy ranges present (Morris et al, 2002).

Coastal wetlands are becoming more vulnerable, as they are under threat from many external components. Despite the adaptation processes, these systems are highly sensitive to alteration resulting in a fragile ecosystem (Zhen et al, 2011). Human stressors, such as dams and agricultural runoff, increase the erosion and degradation of wetlands (Kotze et al, 2012). Many coastal development processes may increase the vulnerability of a wetland by altering the behaviour of natural processes (tides or wind); this results in an alteration of sedimentation, which would require an adaption of the marsh function (van der Wal and Pye, 2004).

Coastal marshlands go through phases of being inundated (at high tide) to being exposed at low tide periods creating a cyclic pattern which occurs every tide. This condition of consistent inundation leads to the soil becoming either a) minerogenic, less than 35% organic matter, or b) organogenic, more than 35% organic matter (Mitsch & Gosselink, 2007). Salt marshes in the Bay of Fundy are typically identified as being minerogenic, and not organic soil based marshes. This low organic matter content is caused by the large influx of sediment relative to the low below ground organic matter production that many marshes experience. A minerogenic marsh will tend to have a higher elevation than the marsh rich in organic soil (Friedricks and Perry, 2001). The macrotidal state often leads to an increased chance of minerogenic marshes (Poirier, 2012).

Bay of Fundy salt marshes will often become either a net-deposited site or a net-erosional site, meaning they will gain or lose sediments respectively. This is part of the pattern that a marsh will take to adapt to the change in sea level, as well as to other conditions presented to it. These processes enable the marsh to adapt to new conditions as it strives toward equilibrium.

Sediment acquisition is highly important in the development of a salt marsh system. Sediment is imported by hydrodynamic methods, drawing sediment from other areas, likely an erosional site, to a new site. Sediment will be imported via various methods of tidal currents and patterns to the new location, where they will be deposited. Sites that contain a strong level of sediment retention, will develop a strong salt marsh area (Reed et al, 1999).

1.2) Tides and Hydrodynamics

1.2.1 Tides

The surface of the ocean will rise and fall periodically following a cycle. The ocean tides are influenced by the gravitational pull of two different forces, the moon and the sun. Approximately 30 percent of the gravitation comes from the sun and 60 percent from lunar forces (Barlow and Fisahn, 2012). The gravity from these forces will draw the water towards the source, creating an imbalance of the water throughout the ocean. As the planet rotates along its axis around the sun, and the moon rotates on its axis about the earth, the forces drawing in water will switch resulting in the creation of tides.

A tidal period can happen once daily (referred to as diurnal), but this rare occurrence usually occurs in coastal areas located near the equator. This phenomenon is caused by a change in solar and lunar declination and by a change in the plane of the elliptic (Desplanque and Mossman, 2004). In regions north and south of the equator, the shift of tides will occur twice daily (referred to as semi-diurnal tides). A full tidal cycle will be completed in approximately 12.42 hours from the time of the highest level of the ocean surface to the lowest (Boon, 1975).

Astronomical bodies have a huge role in the creation and impacts on tidal cycles. Typically, the forces coming from the moon and the sun work against each other as they are not aligned, thus decreasing the strength of the force on the ocean. When the moon and the sun are at a 90 degree angle in relation to the earth (forming an L shape), the forces create smaller tidal ranges called neap tides (Desplanque and Mossman, 2004). On occasions the moon will align with the sun and the earth. This process amalgamates the forces drawing the tides to work in unison; this creates a much stronger tide called the spring tide. During a spring tide, the highest rise of the ocean surface level is higher than a typical tide. Occurring every 27.55 days is another astronomical event known as a perigee tide (Desplanque and Mossman, 2004); this cycle results in higher tides as the distance between the moon and earth is the shortest. Opposite to this event, when the earth and moon are furthest from one another, is called the apogee tide resulting in a smaller tidal amplitude than the transitional period and perigee tides (Desplanque and Mossman, 2001). Finally, the saros cycle occurs every 18.6 years. This is where the moon will reach its highest declination, increasing the gravitational pull on the ocean, resulting in much higher tidal amplitude (Desplanque and Mossman, 2001; Poirier, 2011).

1.2.2 Hydrodynamics

The hydrodynamic parameters for coastal sedimentation are defined, in a study by Verney et al (2006). These include the overall seasonal fluvial discharge, tidal propagation, and the episodic energetic events occurring in the water at a current period. These events could be a swell in the tide, wind driven or vessel driven waves. The mean flow of a tide is dependent upon the vegetation density, spatial gradient of tidal waves and the landscape topography. Christiansen et al (1999) identifies that measuring the strength of a tides can be determined by quantifying the resolved horizontal velocity (one directional current), turbulent kinetic energy, and the settling velocity of the sediment. The turbulent kinetic energy determines the horizontal and vertical measurements in the water column without direction, including eddies formed in the water. Finally, the settling velocity is a measurement of the particular size of the grains will settle at a given time.

Inundation time, most often, will increase when the tidal ranges are higher as opposed to the lower tidal range. Higher tides generally will have an increased tidal velocity in the flow of the current over marsh bodies (Blanton et al, 2002). The role of flow velocity is to control the quantity and particle size of sediments that will be deposited from suspension. The highest acceleration of the tide velocity is at the onset of a flood (the bore) in a localized observation (French et Stoddart, 1991).

Biron et al (2004) identified, in a river study, that bed shear stress has been a fundamental component to the link between flow conditions and sediment transport. The shear stress in a macro-tidal estuary will vary from mouth to tidal creek (Dalrymple et al, 1992). Biron et al (2004) shows that there are different methods that can be used when measuring the shear stress on bed dynamics for different regions in an estuary. The forcing shear parameters, in estuaries, will impact the sediment dynamics of mudflats such as a change in turbidity (Verney et al, 2006). Shear stress on the bed will propagate the erosional processes and the re-suspension of sediments, which will impact the flocculation of particles in suspension.

Salt marsh surfaces act as a topographical threshold for tides containing two distinct regimes (below, over-marsh). A large over-marsh tide will create a dramatic asymmetry within the tidal current, causing a difference in the duration of flood and ebb currents (Blanton et al, 2002). Flood tides will often be shorter than the ebb tide in shallow water. The below-marsh tide will exhibit a steady flood/ebb with high velocity while the over-marsh tide will have a defined flood maxima and the ebb maxima are associated with the convergence toward the creek. This phenomenon is related to the marsh surface friction (French et Stoddart, 1991).

Physical geographic components influence the hydrodynamics of tidal currents. Verney et al (2006) observed that the hydrodynamic features downstream of the Seine River mouth, in France, presented similar conditions during the spring tide as during the neap tide. In the Santilla River there is a landward decrease in the width of the river, as in the Bay of Fundy, this will cause an exponential increase in the strength of M2 tidal currents (Blanton et al, 2002). Wind patterns have an influential impact on the hydrodynamics of an estuary during neap tide periods; this can cause erratic change in the discharge into the tidal basin (Boon III, 1975).

The salt marsh role in the hydrodynamics of tidal flow is imperative; they act as a morphological characteristic that, once inundated by water, will hold it and discharge it into drainage basins. The marsh will extract large amounts of tidal energy from the flood tides as water rushes in (Blanton et al, 2002), causing the strength to be diminished and the coastline will receive protection. The roughness of the surface (vegetation) is the main influence on impeding the flow velocity of ebb and flood tides on marsh surface while creating high flow unsteadiness (French and Stoddart, 1991). The vegetation will act as a preventative measure against the highly turbulent tidal flows. Christiansen et al (1999) observed that eddies, a main source in energy of flow, will be diminished by a factor of five from a specific location in the creek as it goes towards the marsh. *Spartina alterniflora*, the predominant low marsh species, will impact the patterns of drainage during the ebb and morphs the marsh by creating winding drainage pathways (Boon III, 1975).

1.3) Sediment Dynamics in a Salt Marsh

Sedimentation is a complex process occurring in salt marsh environments which is impacted by multiple factors. Relationships between biological and physical components exist, the physical processes will drive the movement of the sediments throughout the water channels (van Proosdij et al, 2000), and the biological organisms will modify it. The availability of sediment within the system and the opportunity of deposition will drive the sedimentation (Voulgaris and Meyers, 2003). The processes of sediment in suspension and the settling of sediments are closely related (Figure 1.1); this system is an iterative process of sediment movement. Mobile sediment will move freely (both vertically and horizontally) in the water column whereas stationary sediment will not move horizontally but may settle vertically. The settled mud becoming part of the seabed (Dyer, 1994).

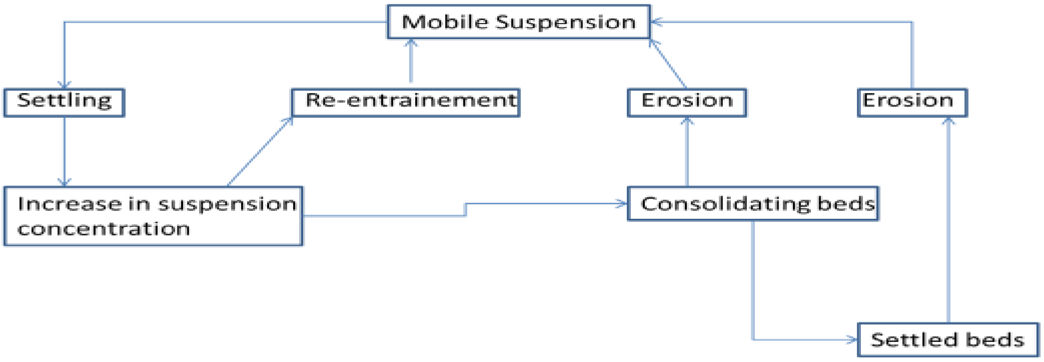


Figure 1.1 Sediment Transport Model (Dyer, 1994).

1.3.1 Suspended sediment concentration

Suspended sediment concentration refers to the amount of sediment within the water column, identified by a weight per volume, available to be deposited on the marsh (Davidson-Arnott et al, 2002). The idea of sediment in suspension refers to the sediment not being settled on the bed of the salt marsh however suspended within the water by some external influences.

Strong currents in the ocean will scour the banks and seafloor, causing erosion, which in turn breaks up and becomes sediment in suspension of the water body (Allen et al, 1976). Typically, the sediments from river systems will have a net seaward direction of movement (Collins, 1983) and be transferred to different coastal areas via tidal currents. The Bay of Fundy is a recipient of the erosional processes occurring elsewhere, as well as locally, and is supplied with large volumes of sediment (Amos and Tee, 1989). This supply of sediment will influence the marsh substrate and increase the sedimentation patterns (Davidson et al, 2002). Non-erosional occurrences influence how sediment arrives in the water body. These occurrences include river influx, ice melt (particularly on the marsh surface), and sediment dispersal (Amos and Tee, 1989).

The location within a water column impacts the overall concentration of suspended sediments. Spring tide conditions have a higher variability than neap tides (Voulgaris and Meyers, 2003). During the onset of inundation, sediment in suspension appears to be highest in the creeks (Davidson et al, 2002) this can be found in the inner-most part of a bay or tidal channel (Collins et al, 1983). Near bed regions in a water column will have a considerably high level of concentration in relation to the surface (van Proosdij et al, 2000; Collins, 1983). In ebb dominated creeks or channels the maximum concentration will occur at the highest of ebb flow (Voulgaris et al, 2003).

Decreases in suspended sediment will occur over the course of the flood tide (Davidson et al, 2002), suggesting a possible local re-suspension due to waves. Seaward bodies of water have a reduced amount of concentration (Amos and Tee, 1989). Voulgaris et al (2002) show that there is a decrease in the concentration of suspended sediments when the water is in a slack period. Slack periods will occur when the water column reaches its peak depth, occurring at the end of the tidal cycle (van Proosdij et al, 2000). The movement of water is the mechanism that keeps the sediment in suspension.

Voulgaris and Meyers (2003) noted that higher tidal ranges influence the increase of sediment availability to be input into the system. When wave action is induced upon the marsh, there will be increased levels of suspended sediment (Amos and Tee, 1989). Wave activity will also lead to re-suspension of sediments in later stages of the tidal cycle (van Proosdij et al, 2000), with spells of large wave swells having a positively correlated relationship with concentration (Collins, 1983). Localized surface waves result in varied responses of suspension and re-suspension of sediment, determined by Davidson et al (2002) in Allen Creek using the Optical Back Scatter (OBS) system.

Darke and Megonigal (2003) identify that there is a link between the sediment in suspension of flood tide waters and the rates of sediment deposition. There will be an approximate equilibrium found between the sediment in suspension and the total mass of sediment that become deposited (Amos and Tee, 1989). A major governing process of the sediment that becomes suspended is at discontinues pulsation of sediment influx to the estuary (Allen et al, 1976), bringing sediment into a system.

1.3.2 Flocculation and Sediment deposition

Salt marshes are very important zones in coastal areas for sediment exchange between suspension and deposition. They become the main facilitator of sediment transport (Davidson et al, 2002). This role is caused by marshlands sheltering it from high wave activity allowing for deposition of the fine sediments in suspension to occur. According to Allen et al (1976) this process is a continuous phenomenon.

Flocculation occurs when particles of sediment, floating in suspension, will sometimes become attracted to other particles close in proximity to them, creating a larger molecule of sediment in a water body. This attraction will occur due to the surface charge of the particles and the encompassing double layer (Dyer, 1989), the presence of organic material which will increase the potential of combing (Voulgaris and Meyers, 2003). This will lead to the aggregation of particles to form large floating clumps of sediment referred to as flocs. Identified in Figure 1.2 as the aggregated particles become larger they attract more particles creating a positively reinforced process of flocculation. Aggregation leads to rapid deposition in slack water periods (Dyer, 1994), which may result in movement upstream of sediments (Allen et al, 1976). Aggregation will transform single grains to flocs, while the process of disaggregation transforms flocs to single grains (Curran et al. 2004).

Flocculation of particles will increase with increasing amounts of sediment concentration being suspended in the system (Dyer, 1989), while a decrease in concentration will decrease the size of the flocs rendering them less likely to be deposited. Particle size is a variable component in estuarine systems however the flocculation process is heavily dependent on it for formation (Voulgaris et al, 2003). A macro-floc is more resistant to breaking down and will have a lesser likelihood of re-suspendion (Dyer, 1989). This will often occur in an estuarine system, where there is an increased amount of fresh water discharge (Voulgaris et Meyers, 2003). Higher hydrodynamic flow rates create more opportunity for particle collision and floc development.

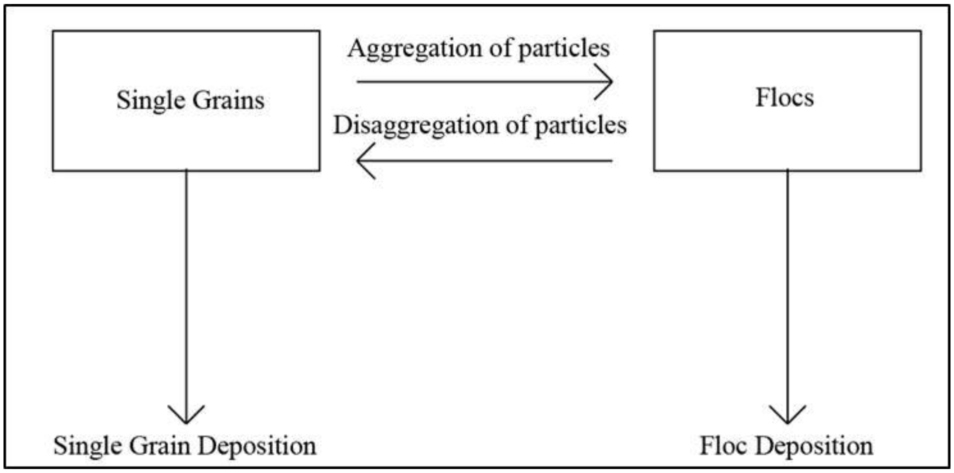


Figure 1.2: Single grains and flocs (Poirier, 2012)

The net accumulation of sediment causes the marshes to expand, both in a vertical and a horizontal direction (Davidson et al, 2002). The amount of sediment that is lost from suspension and that has accumulated on the marsh surface, after a full tidal cycle can be significant in areas of high concentration (van Proosdij et al, 2000). However, in other areas, this is a minor factor while the driver of marsh growth is below ground processes. The highest period of deposition will occur at the end of the ebb tide (van Proosdij, 2000).

Opportunity for sediment to deposit on marsh surfaces will occur when certain factors are taking place. These factors include wave activity, inundation time, water depth, and vegetation. All of these factors contribute to the amount of sediment that will be deposited. Darke and Megonigal (2003) found that rates of deposition on vegetated mudflats will be higher than mudflats with little to no vegetation. Marsh plants will encourage the deposition to occur (Davidson et al, 2002). In a study in the Bay of Fundy, performed by van Proosdij et al (2000), conditions of calm water at high tide showed that there was an influence on deposition when vegetation present. The vegetation will trap the sediment, forcing it to fall from suspension.

Inundation of the marsh surface will increase the opportunity of deposition; longer periods of surface inundation will result in more deposition (Voulgaris and Meyers, 2003). This relationship was found to be insignificant in the Cumberland Basin of the Bay of Fundy (van Proosdij et al, 2000). An increase in sea level, an overall elevation of the water column, would cause a decrease in the opportunity for sediment to fall out of suspension (Dyer, 1994; Davidson et al, 2002). The decrease of tidal range (Allen et al, 1976) combined with an elevated current velocity will result in elevated deposition. However, during slack low tides, marshes can act as a sink for fine sediments (Davidson et al, 2002). van Proosdij et al (2000) identifies a significant negative relationship with wave activity on sediment deposition. Wave-related transport of sediments, in the winter, is often caused by deposition of large ice blocks on a marsh (Davidson et al, 2002).

1.4) Purpose and Objectives:

Understanding the sediment dynamics (such as velocity, flocculation, role of vegetation, suspended sediment concentration, and deposited sediments) in the Bay of Fundy is very important to provide baseline knowledge of the current system for the development of tidal power and validation of hydrodynamic and sediment transport models. Performing a study at different elevations and zones within one particular marsh (creeks and upper marsh) will support an extensive understanding of the relationship between sediments in suspension and those deposited. It is currently not clear as to how the flocculation and grain size will relate to distance from the creek (Kranck, 1981).

This study will be used to determine the temporal and spatial influence of sediment concentration, and sediment characteristics under varying meteorological conditions, on sediment deposition.

1) Compare the variation of sediment deposition along a transect from the creek, the creek bank and marsh platform.

2) Evaluate the variation of suspended sediment concentration at different elevations within and between stations (20cm and 50cm above surface).

3) Determine the relationship of sediment composition both spatially and between tides.

4) Determine the variation in suspended sediment concentration and sediment characteristics within and between sites (e.g. elevation and distance from the thalweg).

5) Assess the impacts of meteorolgical conditions (e.g. wind speed, precipitation and temperature) on the suspended and deposited sediments.

6) Examine the relationship between suspended and deposited sediments.

It is predicted that the sediment in suspension will be in higher concentration near the creek bed and decrease with increasing elevation relative to datum. Locations containing a high concentration of sediment in suspension will have increased deposition of sediment. It is also predicted that the sites inundated for longer periods of time will result in higher amounts of sediment deposition. Thus, a positive relationship between the concentration of sediment in suspension and sediment deposition will be observed. Finally, vegetation will increase the opportunity for sediment to be deposited.

Chapter 2

Study Area

2.1 The Bay of Fundy

The Gulf of Maine, extending from the Atlantic Ocean, branches off to the Bay of Fundy (Desplanque and Mossman, 2001). The Bay is a narrow body of water (Figure 2.1) encompassed by the coastlines of New Brunswick and Nova Scotia. The bay can be divided into two separate regions, the upper (inner) bay and the outer bay. The upper bay environment is mostly coastal marsh lands, high sediment deposition. A lot of the coasts are highly diked for agricultural purposes in the 1600’s by the Acadians (Shaw et al, 2010). The upper bay is divided into two separate basins, the Chignecto Basin and the Minas Basin. Each of these contains different environments and variables imposed on it.

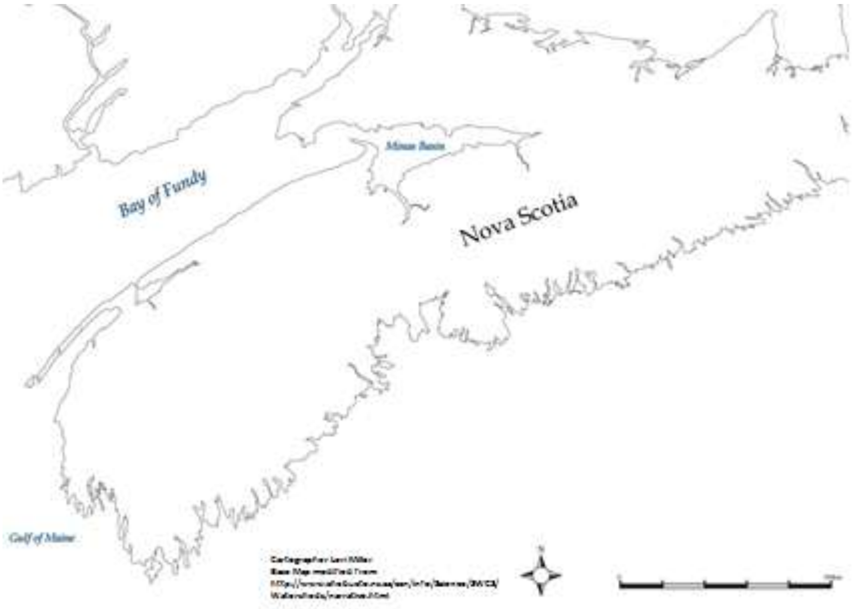


Figure 2.1: Map of the Bay of Fundy, identifying Kingsport research site location. Map digitized by Lori Miller (2012).

The Bay of Fundy was formed as a failed rift of the Appalachian mountain orogeny approximately 286-360 million years ago (Desplanque and Mossman, 2001). The rift occurred during the opening of what is now the Atlantic Ocean. During the years of the late Triassic period (200 million years ago) a process of sediment infilling began. This was followed by the basaltic lava eruptions, from the rift, and the ensuing deposition of sediment (Desplanque and Mossman, 2001). Found within some areas of the Bay are Cretaceous sediments overlaying the existing Carboniferous rocks. This suggests that there was a large deposition of sediments during the Cretaceous (Desplanque and Mossman, 2004). A series of geomorphological processes occurred including folding, uplifts and tilts. The majority of the Bay of Fundy coastline consists of mostly sandstone conglomerates resulting in the high likeliness of erosion to occur (Desplanque and Mossman, 2001), thus creating more sediment to be suspended and deposited in other areas of the Bay. The Bay hosts a high suspended sediment concentration with seasonal fluctuations being an influential variable (van Proosdij et al, 2000), this impacts the amount of sediment supplied to the upper bay salt marshes typically being exposed to the high concentration.

Historically, glaciation has played an integral role on the geomorphological features in this region. The Laurentide ice sheet covered the majority of Canada, including Eastern Canada, between 18000 and 20000 years ago. Due to the glacial movement, large moraines and drumlins were created and the sediment was deposited which has led to the formation of the current day maritime banks along the coastal areas (Desplanque and Mossman, 2001).

2.2 The Minas Basin

The Minas Basin, at the southeastern head of the Bay (bordered by Nova Scotia) is a sandy estuary characterized by sand flats and bars (Chumera et al, 2001) as well as being dominated by silt-laden waters (Hinch, 2004). This is a semi-enclosed passage of the Bay of Fundy, along with Chignecto Basin, extending from the Minas Channel to the Cobequid Bay at the innermost region. Approximately 200 million years ago, this region was a rift valley, which had failed, located near the current Equator (Hinch, 2004).

The tidal range in the Basin is the largest in the world, between high and low tide there is a 16 meter change in amplitude at the extreme regions of the Basin, with an average of 13 meters. Along with the change in amplitude of the tide results in an exchange in excess of 10 cubic kilometers of water rushing in and out of the Basin (Hinch, 2004). As a result of the large amount of water movement passing through, at the most narrow region of the Minas Channel gateway the current speeds will reach 4-5 meters per second (Hinch, 2004; Karsten et al, 2008). MacMillan et al (2007) suggest that there will be approximately 6.9 Gigawatts worth of energy to be extracted from the tidal power. This has drawn lot of interest for the implementation of tidal power development in the Minas Channel of the Minas Basin.

Tidal power in the Minas Basin has been implemented since the 1600's, extracting the energy from tidal mills producing very low levels of energy (Farwell, 2009). Tidal energy turbines have been considered as a method to extract the energy from the tides in the Minas Passage, creating a controlled exchange of water. Karsten et al (2008) suggest that this will have severe negative consequences of increasing the amplitude of tide for the States within the Gulf of Maine. This, along with ecological impacts, has led to the current technology of tidal power extraction. The method of in-stream turbines will reduce the likelihood of severe impacts on the Gulf of Maine as well as environmental effects are predicted to be substantially less than the tidal dam method.

Anthropogenic influences have occurred along the Minas Basin coastal region resulting in a change of the environment. The region was settled by Europeans in the 17th century, a lot of the area was converted into farmlands by way of diking of the land. Currently, coastal development (roads, buildings, along with dikes) is influencing many of the natural patterns and productivity the region may encounter (Bowron et al, 2011).

2.3 Kingsport Marsh:

The Kingsport marsh rests along the Habitant River at 45° 10' 0" North, 64° 22' 0" West (Maplandia, 2012) outside of Canning. The Habitant River is a terminal river feeding into the Cornwallis River. This site is located in the Annapolis Valley, in western Nova Scotia. Annapolis Valley spans approximately 126km (Crouse et al, 2011) reaching from the Minas Basin at the east end to the Annapolis Basin at the western end; it lies between the North Mountain and the South Mountain. The valley contains two main river systems, the Cornwallis River and the Annapolis River. The two rivers begin near Aylesford Nova Scotia. The Cornwallis River watershed holds 361km^2 of drainage area (Crouse et al, 2011), contributing to the river.

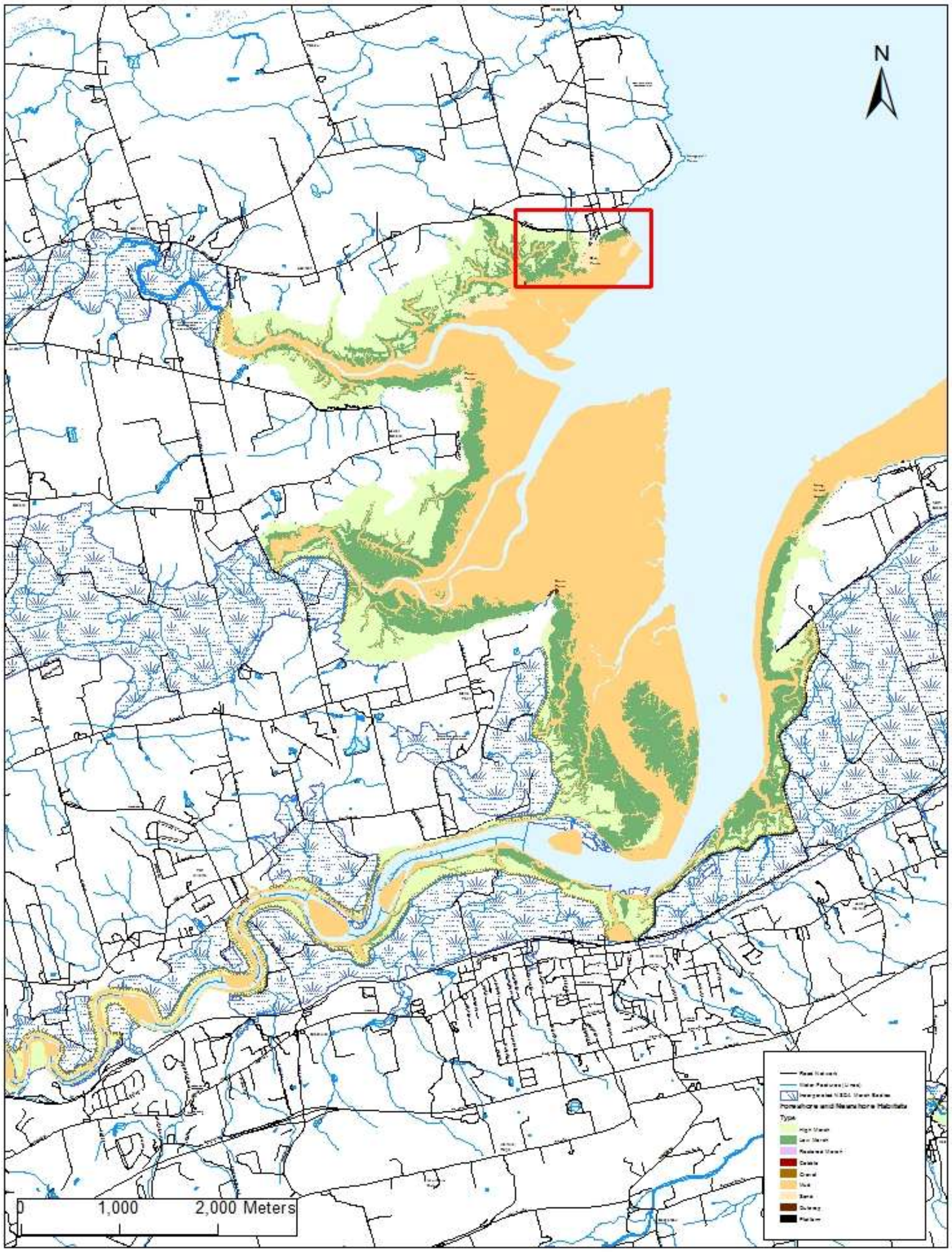


Figure 2.2: Map of the Cornwallis River estuary. Map developed by Barbara Parrott (2012).Identified by red box is the Kingsport Marsh study site.

An extensive marsh land spreads along both coastlines of the Habitant River. The focus site of the project occurs approximately one kilometer west of the township Kingsport. The site dimensions are approximately 250 meters to the south of the Highway 221. Fitting within a 100 meters squared region rests the entire study location. Kingsport Marsh, identified in Figure 2.2, is a high-marsh intertidal zone, reaching upwards of 50 feet from low to high tide. Three main creeks branch off from the opening to the Habitant River, the study site is the east most creek. This is a part of a terminal creek network feeding into the opening at the River, many feeder creeks contributing to the main creeks. At the end of the terminal feeder creek, of which the study location rests, there is currently a lot of slumping of the marsh. This may suggest that the tidal creek is being retreating from the seaward edge and growing in length (Cox et al, 2003).

Figure 2.3: Kingsport Marsh. Highlighted in red box is the specific area used during the study for gathering samples.

The sediment deposited on the marsh is silt-dominated, in this region of the Bay. A similar study was conducted at a site further in the Cornwallis River at Starr's Point in 2010. The mean grain size characteristics, at Starr's Point, ranged from 4.7 micrometers to 8.9 micrometers (Poirier, 2012). Typically, the mean grain size stayed within the classification of fine silt, with one event reaching the medium silt range.

This site is ideal for the research due to the lack of direct fresh water runoff, the macro-tidal conditions and the different staged marshes (from creek to high marsh with vegetation). It is easily accessible from a main road. It is also the site of the concurrent experiment being conducted by Emma Poirier (MSc Applied Science, SMU), Jessica Garwood (MSc Oceanography, Dalhousie University) and the Particle Dynamics Lab at the Bedford Institute of Oceanography.

2.4 Marsh Vegetation:

As part of this marsh, there are a distinct three definitive levels consisting of a creek, bank marsh and marsh surface. Each of these contained different habitats and vegetation species represented. The creek contained minimal to no vegetation at all. Along the bank of the marsh was dominated by *Spartina alterniflora* while on the marsh surface *Spartina patens* was the dominant species. The vegetation influences the hydrodynamics of a tidal marsh system and also acts as a trap for the sediment brought in from a tide (Davidson et al, 2002).

Spartina alterniflora (Figure 2.4), is found on the lower marsh areas of a salt marsh (Adam, 1990). As the low marsh receives a consistent partial flooding from the tidal flow, the requirement of high moisture quantity is fulfilled (Natural Resources Conservation Service, 2012). The plant requires the nutrients brought from the tide however will not survive if it is consistently flooded by water, it will diminish its possibility for attaining important nutrients from the sun. *S. alterniflora* grows in long course strands, sometimes greater than a few meters (Adam, 1990), and will stay erect during times of slack inundation. After colonizing and stabilizing the mudflat, *S. alterniflora* will continue to migrate towards un-colonized mud on a marshland. The formation of the plant causes it to sway, when submerged by water, which forces the sediments to fall from suspension (Davidson et al, 2002).

Figure 2.4: *Spartina Alterniflora* on Kingsport Marsh bank at bankfull tide during August 2012 deployment. Photo taken by Brenden Blotnicky (2012).

The other dominant marsh grass, *Spartina patens* (salt hay grass), tends to reside in the high marsh regions that reside closer to the land (Adam, 1990). Here, the grass will receive less frequent flooding events as well less vigorous tidal currents. The *S. patens* grass, Figure 2.5, tends to be a short and highly dense grass (Natural Resources Conservation Service, 2012).Typically, it will flop over and cover the marsh when not being inundated.

Figure 2.5: *Spartina patens* on Kingsport Marsh surface during the August 2012 deployment, mixed with the *Spartina alterniflora*. Photo taken by Brenden Blotnicky (2012).

Chapter 3

Methods and Research Design

3.1) Site Selection

The site selected was the Kingsport salt marsh, located to the northeast of the Town of Canning, Nova Scotia. This is located at the mouth of the terminal Habitant River, part of the Cornwallis River watershed in the Minus Basin of the Bay of Fundy. Kingsport marsh was selected on the basis of several criteria, it has a well-developed marsh (identified low and high marshes) that is receiving bank full and over marsh floods, far-field location from turbine test site and the easy accessibility for study purposes.

3.2) Site Design

At the selected site, approximately one kilometer from Main Street, there were four plots established. Each of these plots identified in Figure 3.1 were unique from one another and would represent different regions of a salt marsh environment. There were three plots (M1, M2 and M3) on the marsh surface and one plot in the creek (C4). The M1 site was on the top of the marsh, M2 was on the edge of the top surface and M3 was on the bank of the tidal creek (Figure 3.1). All of the marsh sites were vegetated. Finally, there was a non-vegetated plot within the creek, identified as C4.

Table 3.1: Plot identification

Name Identification	Location
M1	Marsh Surface
M2	Marsh Edge
M3	Marsh Bank
C4	Marsh Creek

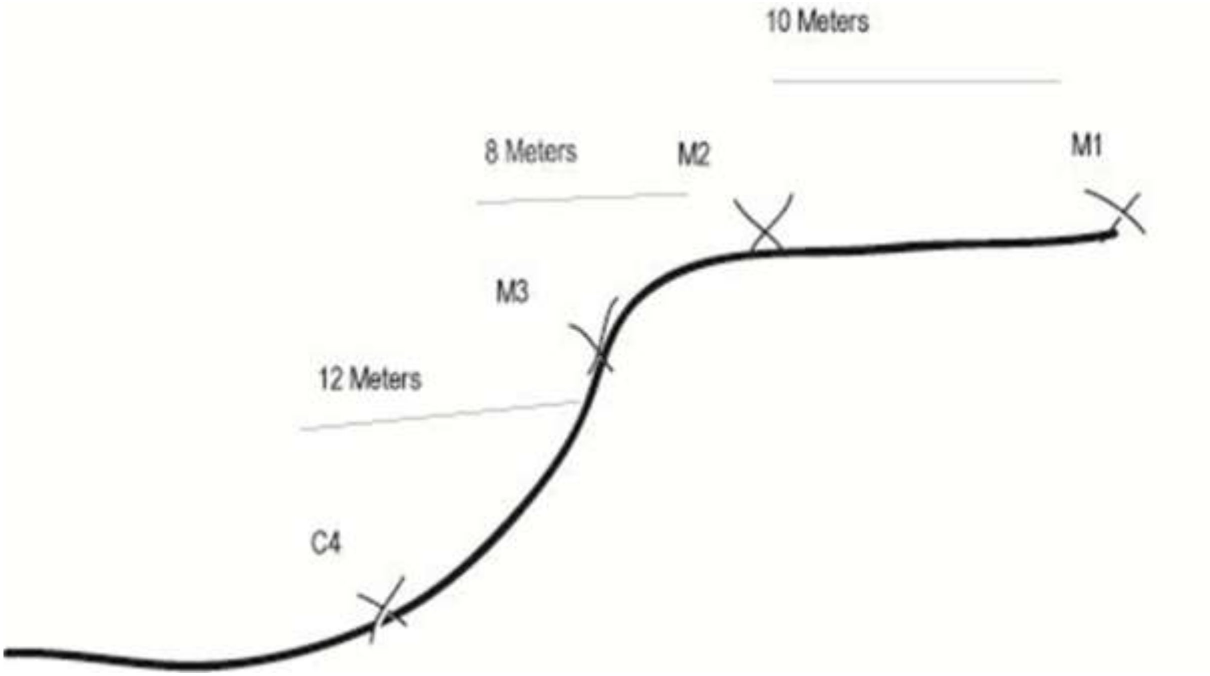


Figure 3.1: Site Diagram- An approximate cross-section of the location for the four plots used in the experiment.

The site hosted a tall wooden structure, shown in Figure 3.2, erected as a stand in between plots M1 and M2. The stand acted as a work station for marsh deployment activities and as a device to hold and preserve other components of the study, the ISCO Teledyne Automated Suspended Sediment Bottle Sampler. As the stand was a typical area of high foot traffic there were two self-constructed plank boardwalks built (approximately 8 feet long) in attempt to preserve the integrity of the marsh surface.

Figure 3.2: Site Layout- Distribution of plots.

3.3) Data Collection

3.3.1) Suspended Sediment Concentration

Rising stage bottles were used to gather the onset suspended sediment concentration (Silver, 2009). The apparatus shown in Figure 3.3 is a 2x4 post that was pounded into the marsh surface. At each of the selected plots two nails were used (30cm apart) as a resting device for the bottle. A 500mL bottle was placed on top of each of the nails, the bottle contained a nozzle with two copper pipes extruding from the rubber stopper. The lower pipe accepted the water into the bottle as the top pipe allowed the air to escape thus reducing the pressure in the bottle, drawing tidal water into the lower nozzle and preventing the stopper to pop off. The bottom pipe was faced towards the oncoming tide while the top pipe was faced away from the tide, as a measure of prevention of water entering both top and bottom. The sediment in suspension would enter the bottom pipe and rest in the bottom of the bottle. The bottle was held to the erected wood post with a hose-clamp fastened around both the bottle and post.

Figure 3.3: Stage Bottle Apparatus

After each of the tides the bottles were required to be changed, a fresh batch of labeled bottles were taken to each of the plots. The stopper was removed from the bottle and fastened on the new bottle; a top would be fastened on the sample and placed in a satchel. The new bottle with a stopper was fastened to the post. The sample bottle was placed in refrigeration as soon as possible, until processed, this would reduce the risk of losing the organic matter from the sample through decomposition.

Eight bottles of data were gathered during each tide, with each of the four plots having two bottles, at different heights above the marsh. There was a bottle placed at 20cm above the marsh surface and one placed 50cm above the marsh surface. This will help in understanding the variance between different elevations (relative to datum) at each of the four plots selected. The lower bottle was identified with an L and the higher bottle was identified with an H. Six deployments took place amounting to 38 tides worth of data collected. This resulted in a total of 304 bottles collected over the entire experiment.

3.3.2) Sediment Deposition

Sediment traps were deployed to acquire the sediment deposition data at the surface of the marsh shown by Figure 3.4. Two aluminum squared plates were held together by four metal legs, at each of the corners, along with butterfly nuts. The top plate has a circular hole in the top with an SOS pad in between. There was a pre-weighed, Whatman 5 90mm, fine paper resting on top of the pad exposed to by the hole in the aluminum plate. This formed the sediment trap where sediment would be deposited, over the course of one tidal cycle, from suspension onto the filter paper.

Figure 3.4: Sediment Traps- The method used for capturing deposited sediments.

The traps were carefully collected after the inundated water had receeded. After each of the tides, the traps had to be changed over. A clean set of traps, with a pre-weighed filter paper placed within it, were set level at the plot approximately 2 inches above the marsh surface. The sampled traps were opened for the filter to be removed and placed in a labeled petri dish. As soon as possible, in a dry area with minimal breeze, the dishes would be opened to dry for 24 hours.

At each of the four plots there were three sediment traps labeled A, B, C along with the code for the given site. This was designed to ensure the calculated value would be accurate and not relative to a specific placement of the trap with an average of the three. Each tide would retrieve twelve samples of deposition. Over the course of the experiment there were 37 tides of deposition data collected, this resulted in 444 samples total.

3.3.3) Acoustic Doppler Current Profiler

There was an Acoustic Doppler Current Profiler (ADCP) placed at the C4 site in the creek of the study site. The device was fastened to a bar with legs that reached into the muddy surface to be held in place. The water current velocity data, from each tide, was gathered during the entire tidal cycle using the ADCP current meter (similar to sonar). The current was transmitted into the water with the use of sound waves and the Doppler Principal; it would scatter back from the particle of sediment in suspension of the water column. The ADCP data collected is part of an ongoing study at the same site with Emma Poirier.

3.4) Lab Procedure

3.4.1) Suspended Sediment Concentration

The bottles, kept in refrigeration, would be poured into a 500mL beaker and the remaining (if any) in a 50mL beaker. Volume would be determined by the amount of water entered the bottle during the tidal cycle. The water, from the beaker, would then be poured into a suction filtration system (Figure 3.5). The base of the funnel held a pre-weighed Millipore membrane 8.0 um filters (containing nitrocellulose) filter paper. The suction filtration device uses a pump to drain the water from the funnel allowing for the sediment to remain on the filter paper. For some of the C4 plot deployments this process required a second round of filtration, on a new pre-weighed, as it was highly concentrated. The filter paper would be removed and placed in an open Petri dish to dry (for 24 hours) before being weighed with the sediment.

Figure 3.5 Suction filtration apparatus (Photo taken by Brenden Blotnicky, 2013).

3.4.2) Sediment Deposition

The Petri dishes were opened to allow for the filter paper to dry, in a dry windless area for approximately 24 hours. After being dried, the filter papers would be weighed as ‘post sediment weights’ in grams. This was compared to the suspended sediment on the filter papers. The amount of sediment was converted to g/m^2, as it was per filter space.

3.5) Data Analysis

3.5.1) Suspended Sediment Concentration

The data collected (weights and volumes) were entered into a spreadsheet on Excel Office. Concentration was determined by dividing the net sediment by the volume. At each of the four plots (both the high and low) all of the tides were averaged to determine the mean distribution at the site along with a standard error. The plots were then measured (as individual points) against the given water depth for each of the tides. All the calculations were completed using Excel computation.

3.5.2) Sediment Deposition

Using Excel, the net sediment was determined for each of the plots (and all three traps) for all the tides. For all the tides worth of data a blank filter paper (pre-weighed) was utilized to identify the humidity in the air, this was subtracted from the sediment laden filter paper. An average was determined, from the three traps, to ensure there was no bias based on tilt or depth of the traps legs. A standard deviation and standard error were derived and added to the plot. Each of the four plot means were measured against the ADCP derived water depth and the deposition data.

3.5.3) Statistical Analysis

Statistics were determined using the Mystat statistics software. To determine the significance of the relationships (change in water depth with change in sediment deposition and suspended sediment concentration, along with the suspended sediment concentration and sediment deposition) a Pearson Correlation Matrix was used. Statistical significance will be based on the Pearson Correlation (PC) value received. If the value is positive the relationship will be positively correlated and vice versa if negative. A strong relationship for this experiment will be considered as any PC value greater than 0.3.

An analysis of variance was completed using the ANOVA Repeated Measures method to determine significance of each plot relative to one another for both suspended sediment concentration and sediment deposition. Statistical significance will be determined at the 95% confidence (p-values lower than 0.05 being significant). There were no statistical methods used to determine the seasonal relationships or the weather relationships with the sediment data. For these variables, observation was used to identify a possible pattern.

Chapter 4

Results

In general, experiments were successful. Both variables (suspension and deposited) saw higher values of sediment at the creek level and decreased with distance from the creek. Water depth, inundation time, as well as vegetation all influenced variables on the amount of deposition and sediment in suspension.

Data for meteorological conditions were collected consistently from a week prior to the first deployment (shown in Figure 4.1). A period of time during the fall of 2012, including the September deployment, the wind vane (from the weather station) was out of operation. Thus, data for wind speed or direction could not be collected from the device. During the January 14 AM tide sediment traps were not laid to collect deposition data despite collecting data for suspended sediment concentration. In all, full data sets were received for 30 tides. Due to ADCP data not being recorded on the September 18 AM tide, an alternative solution was utilized for identifying the tide height. The data from the level logger (used in Masters Research for Emma Poirier) was used for identifying the approximate height of the tide maximum.

Date of Tide	Rising Stage Bottles	Sediment Traps	ADCP Data	Weather Station	Water Depth (m)	Notes
May 5 AM	✓	✓	✓	✓	7.907	
May 5 PM	✓	✓	✓	✓	7.639	
May 6 AM	✓	✓	✓	✓	8.273	
May 6 PM	✓	✓	✓	✓	7.831	
May 7 AM	✓	✓	✓	✓	8.432	
May 7 PM	✓	✓	✓	✓	7.913	
May 8 AM	✓	✓	✓	✓	8.434	
May 8 PM	✓	✓	✓	✓	7.75	
May 9 AM	✓	✓	✓	✓	8.139	
July 4 AM	✓	✓	✓	✓	8.08	
July 4 PM	✓	✓	✓	✓	7.544	
July 5 AM	✓	✓	✓	✓	8.066	
July 5 PM	✓	✓	✓	✓	7.5	
July 6 AM	✓	✓	✓	✓	7.837	
August 4 AM	✓	✓	✓	✓	7.822	
August 4 PM	✓	✓	✓	✓	7.404	
August 5 AM	✓	✓	✓	✓	7.533	
September 17 AM	✓	✓	✓	X	7.639	Wind vane down
September 17 PM	✓	✓	✓	X	7.807	"
September 18 AM	✓	✓	X	X	7.549	"
September 18 PM	✓	✓	✓	X	7.989	"
September 19 AM	✓	✓	✓	X	7.626	"
September 19 PM	✓	✓	✓	X	7.928	"
September 20 AM	✓	✓	✓	X	7.354	"
November 14 AM	✓	✓	✓	✓	7.605	
November 14 PM	✓	✓	✓	✓	8.29	
November 15 AM	✓	✓	✓	✓	7.771	
November 15 PM	✓	✓	✓	✓	8.298	
November 16 AM	✓	✓	✓	✓	7.789	
November 16 PM	✓	✓	✓	✓	8.22	
November 17 AM	✓	✓	✓	✓	7.552	
January 11 PM	✓	✓	✓	✓	8.275	
January 12 AM	X	X	X	✓	X	No deployment
January 12 PM	✓	✓	✓	✓	8.411	
January 13 AM	✓	✓	✓	✓	7.871	
January 13 PM	✓	✓	✓	✓	8.343	
January 14 AM	✓	X	✓	✓	7.922	No traps
January 14 PM	✓	✓	✓	✓	8.111	
January 15 AM	✓	✓	✓	✓	7.558	

Table 4.1 : Summary of collected data for 39 tidal cycles at Kingsport Marsh.

4.1 Sediment Dynamics

4.1.1 Inter-plot relationships

The inter-plot analysis of variance, for net deposition and suspended sediment concentration, found significant differences. The mean suspended sediment received a p-value of 0.00 while the mean net deposition received a p-value of 0.01, both of which are statistically significant at the 95 percent confidence interval. Figure 4.1 and 4.2 show that the plot location identified as C4 (meaning the creek) received both higher suspended sediment concentrations (Figure 4.2) and more sediment deposition (Figure 4.1) on average. The bottles placed at 10cm above the surface received more sediment concentration than those at the higher elevation relative to datum (50cm above the surface) identified for each plot in Figure 4.2. The mean deposition, identified in Figure 4.1, for M3 is higher than M2 and M1. On average the M2 site received less deposited sediments than all three other plots.

As seen in Figure 4.1, mean deposition is significantly different between the C4 plot and the other three plots (p-value=0.019 (M3), 0.00 (M2) and 0.001(M1)); similarly, the mean deposition is significantly different between the M3 plot and the remaining two plots, M2 and M1, (p=0.002 (both plots)). The M2 and M1 plots do not show a significant difference in mean deposition (p=0.208). The greatest significant difference of sediment deposition is shown between the plots C4 and M2, while the deposition is least significant between C4 and M3 (excluding plots that show no significant difference).

The mean suspended sediment concentrations at the C4H and C4L plots were statistically significant from all other plots (available in Figure 4.2). The p-value expressed to explain the significance between these two plots and all other plots was 0.00; this included the relationship between C4 plots. The only other very strong statistical significance was between shown between plots M3H and M2H (p=0.00). M3H was also significant from M1H (p=0.001) but not from M3L (p=0.565), M2L (p=0.5) and M1L (p=0.151). Plot M3L was significant from all plots, excluding M2L (p=0.123), achieving p-values of 0.001 (M2H and M1H) and 0.023 (M1L). The remaining plots were not statistically significant from one another. M2H was not significant from M2L (p=0.12), M1H (p=0.564) or M1L (p=0.155). Plot M2L did not show any significance between M1H (p=0.061) or M1L (p=0.266), while the M1 plots also shared no significance (p=0.138). With the exclusion of the C4 plot site, there was no statistical significance shown between the high and low plots at the same plot site (i.e M3H vs. M3L, M2H vs. M2L or M1H vs. M1L). All of the plots were significant from at least 1 other plot, not including either C4H or C4L. The first three plots to be inundated, lowest elevation relative to datum, have suspended sediment values that are significant from the highest number of plots.

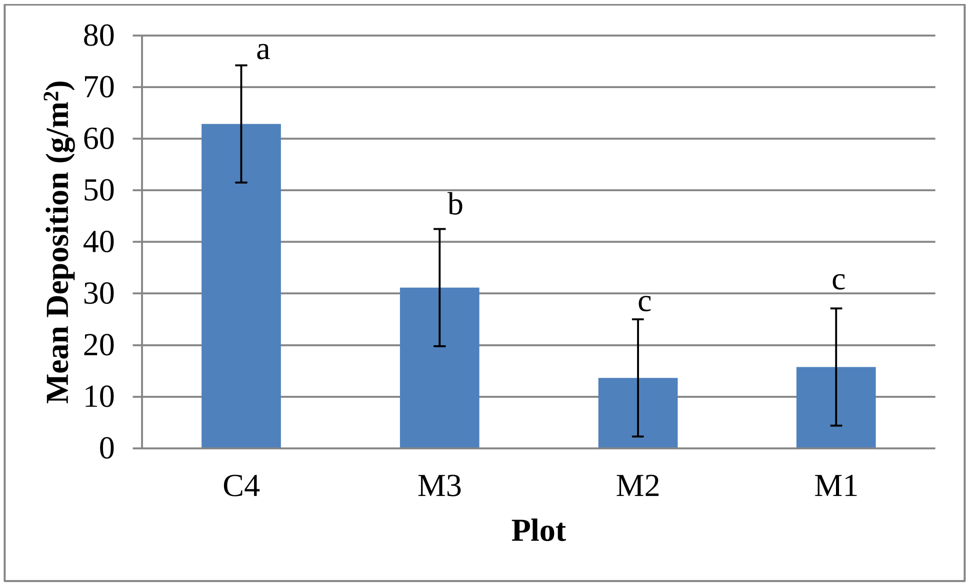


Figure 4.1: Mean deposition between all four plots. Significant differences are between plots that do not share a letter.

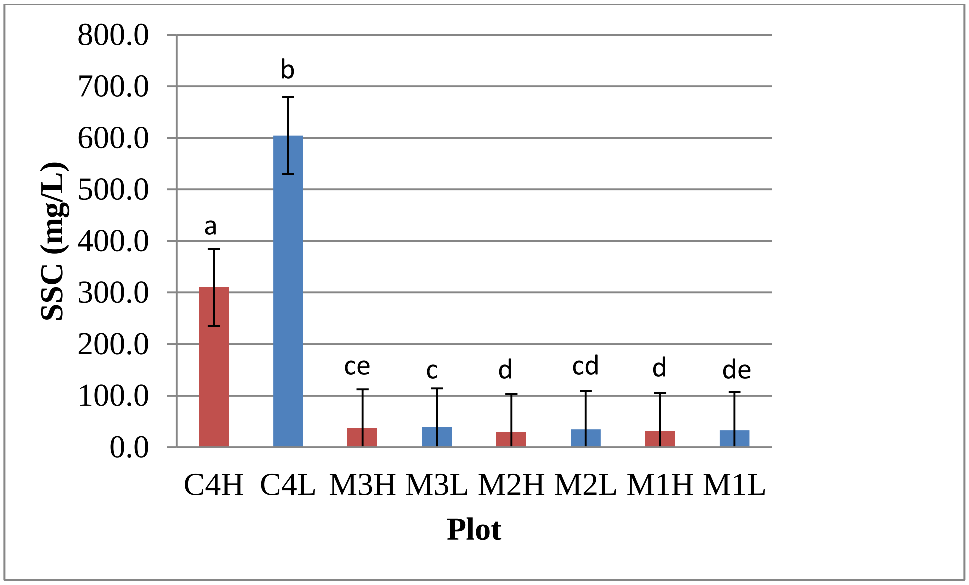


Figure 4.2: Mean suspended sediment concentration between stage bottle plots. Significant differences are between plots that do not share a letter.

4.1.2 Water Depth Influence

The water depth of each tide was compared to respective suspended sediment concentrations at each of the plots. The majority of the plots represented a positive trend of increasing suspended sediment concentration with increasing water depth; except for the C4H plot shown in Figure 4.6. Plot C4L shows a very weak negative correlation receiving a Pearson Correlation value of -0.086. Also, in Figure 4.5, M3L (PC=0.074) shows a weak correlation however it remains positive along with the remaining plots. The two plots with the strongest correlations were M3H (PC=0.403), shown in Figure 4.5, and M2H (PC=0.357), shown in Figure 4.4. The four remaining plots; C4L (Figure 4.6), M2L (Figure 4.4) and both of the M1 plots (Figure 4.3) have medium correlations, respectively PC=0.123, 0.204, 0.1 (M1H), and 0.209 (M1L).

There are a few anomalies in each of the graphs; they tend to show up multiple times at different plots. These events would be the points that don’t fit in with the rest of the regression; they typically have a much higher sediment concentration than other points at a similar water depth. The majority of the outliers are reoccurring, this meaning that the same water depth at 2 or more of the plots appears to have an exceptionally high concentration. When observing the data, many of the points occurred during the November deployment. Despite being an anomaly to the remaining data, many of these points are in fact supporting the positive correlation trends between each of the plots.

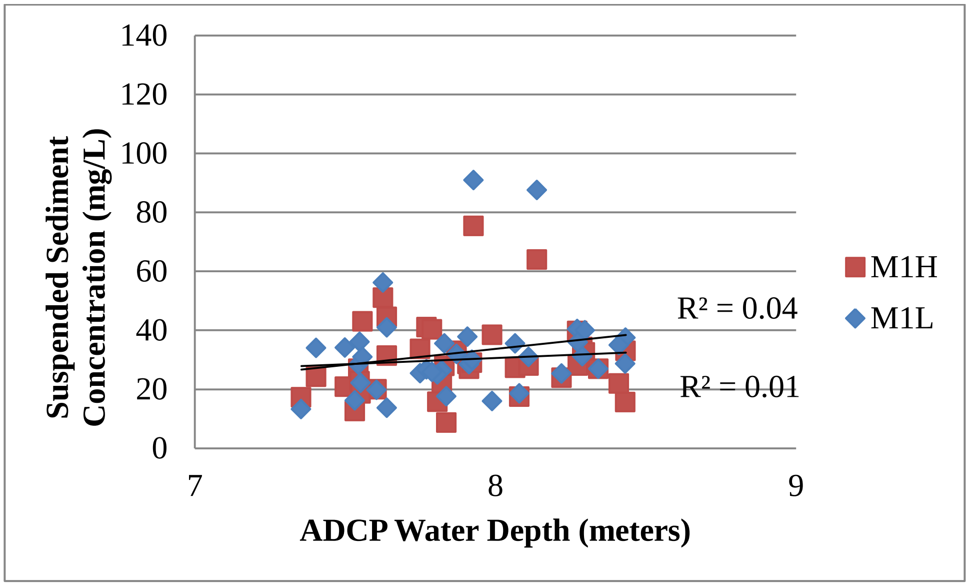


Figure 4.3 The influence of maximum water depth (meters), by tide, on the suspended sediment concentration value at the marsh surface (M1) plot for both high and low values.

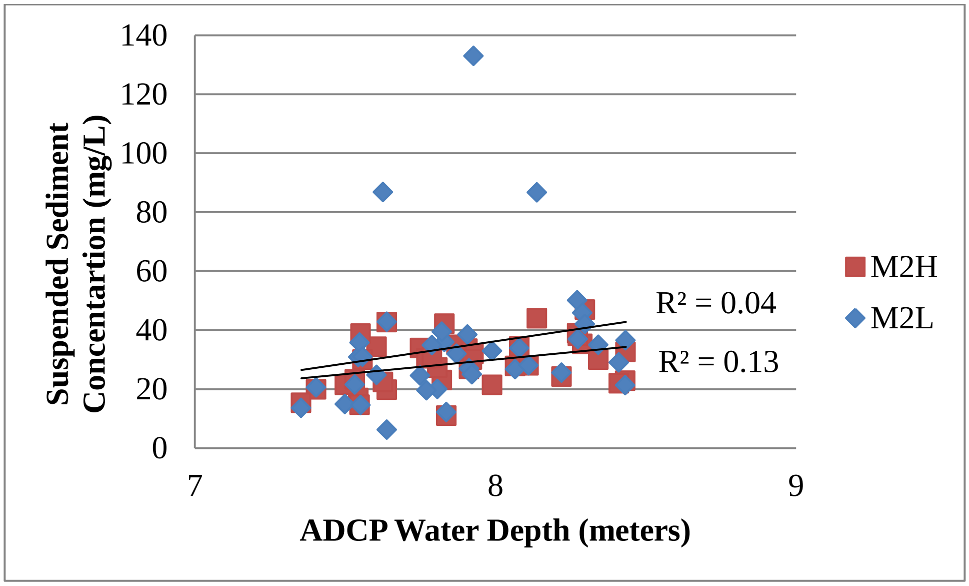


Figure 4.4 The influence of maximum water depth (meters), by tide, on the suspended sediment concentration value at the marsh edge (M2) plot for both high and low values.

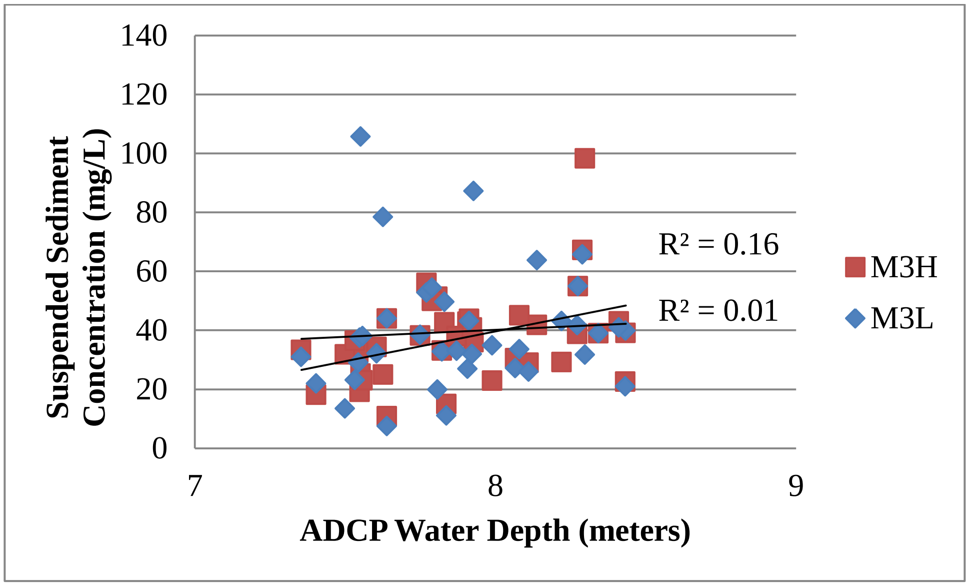


Figure 4.5 The influence of maximum water depth (meters), by tide, on the suspended sediment concentration value at the marsh bank (M3) plot for both high and low values.

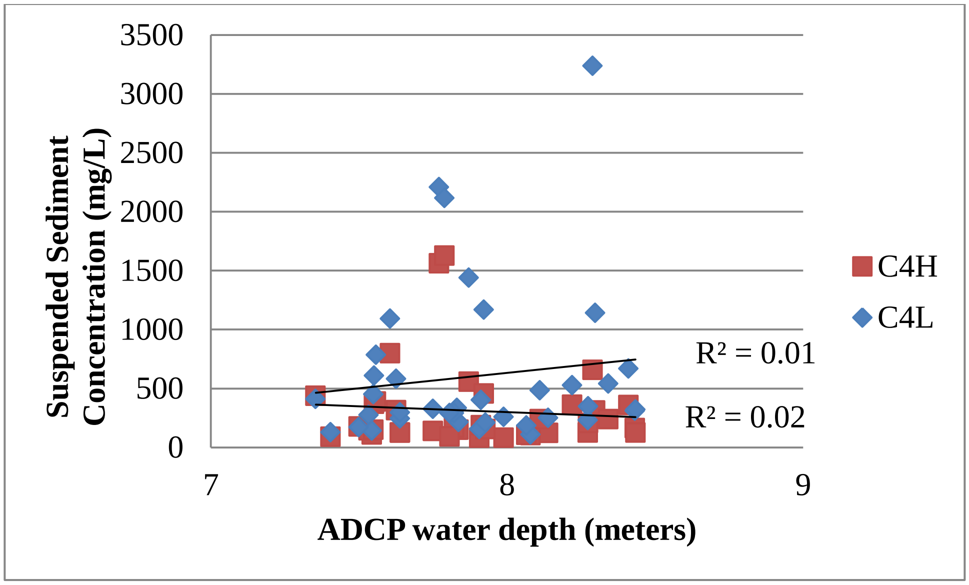


Figure 4.6 The influence of maximum water depth (meters), by tide, on the suspended sediment concentration value at the marsh bank (M3) plot for both high and low values.

The water depth of each tide was compared to the respective sediment deposition at each of the study plots. All three of the sediment deposition marsh plots were positively correlated with change in water depth. The only plot that received a negative correlation was the C4 plot, seen in Figure 4.10, the Pearson correlation value is equivalent to -0.005. Despite being a negative correlation it is a very weak correlation overall, minimal significance is given to the water depth variable for the C4 plot. The M1 plot, shown in Figure 4.7, had the strongest correlation receiving a PC value of 0.324. The plots M2 and M3 both showed medium strength relationships with correlation values of 0.287 (Figure 4.8) and 0.262 (Figure 4.9). The strength of the correlation, between sediment deposition and water depth, increases as it moves from a plot that was inundated longest (creek) to the plot that was inundated for the least period of time (marsh).

Unlike the data represented in the suspended sediment concentration graphs (Figure 4.3-4.6) there does not seem to be any anomalous points that have severe influence over the data. There are a few extreme values of deposition for any given water depth value, however, they are not in a position on the graph that would cause a major influence on the correlation (regard to Figure 4.9). Generally the trend of the data for the three marsh plots is increasing net deposition with increasing water depth. Shown on Figure 4.10 the points for C4 appear to be consistent, excluding a few high deposition values with low water depth. These values could have minor influence on the correlation to be represented as a negative relationship, however the correlation would still remain very weak.

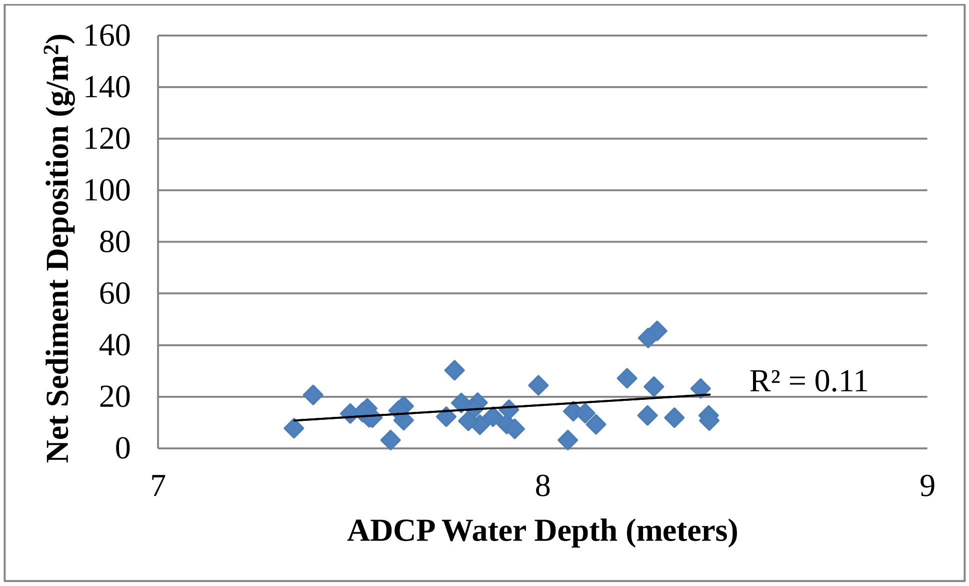


Figure 4.7 The influence of maximum water depth (meters), by tide, on the sediment deposition value at the marsh surface (M1) plot.

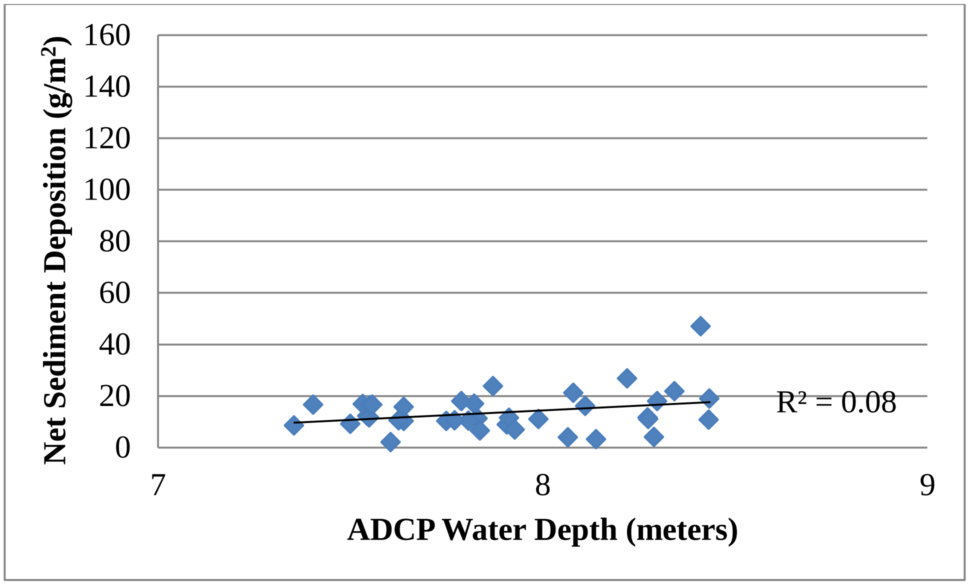


Figure 4.8 The influence of maximum water depth (meters), by tide, on the sediment deposition value at the marsh edge (M2) plot.

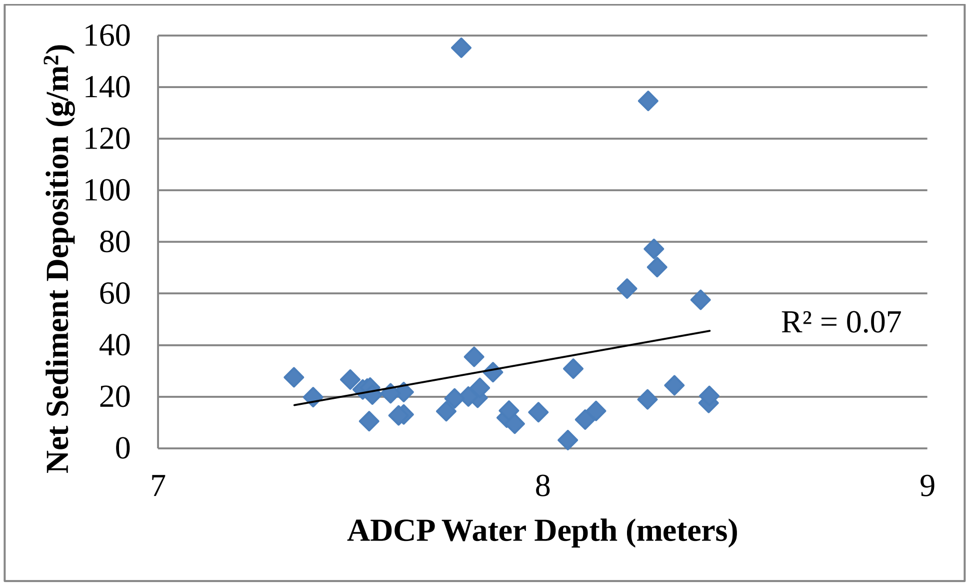


Figure 4.9 The influence of maximum water depth (meters), by tide, on the sediment deposition value at the marsh bank (M3) plot.

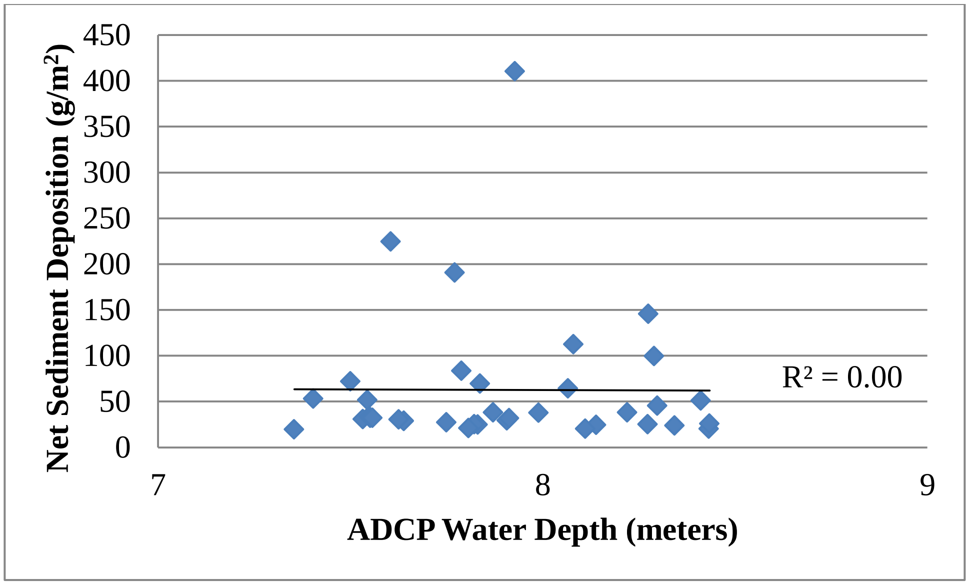


Figure 4.10 The influence of maximum water depth (meters), by tide, on the sediment deposition value at the marsh creek (C4) plot.

4.1.3 Sediment deposition opportunity

Ultimately sediment in suspension will be deposited on the marsh. This section will determine how the availability of sediment in suspension relates to the amount of sediment to be deposited on the marsh. The majority of the data, for each of the plots (Figure 4.11-4.14), have a large portion of the values clumped together near the low end of the net sediment deposition and the low end of the suspended sediment concentration. This clump of values is where the majority of the data is found, very little are outside of the clump.

Over half of the plots identify a positive correlation with increases in suspended sediment concentration result in increased levels of sediment deposition. The plots that saw negative correlations were M1L (seen in Figure 4.11) and both of the M2 plots identified on Figure 4.12, the Pearson correlation values were -0.055, -0.048 (M2H) and -0.167 (M2L) respectively. M1L and M2H are very weak negative correlations however M2L is a medium negative correlation between the two variables. Both of the C4 (shown in Figure 4.14) and M3 plots (Figure 4.13) have medium to strong correlations including the plot attaining the strongest correlation, M3H with a Pearson correlation of 0.482. The remaining plots had PC values of 0.302 (C4H), 0.208 (C4L), and 0.183 (M3L), all of which were medium strength correlations. The plot M1H had a very weak positive correlation (PC=0.018).

A few of the sites (see Figure 4.12 and Figure 4.14) saw the plot receive a much higher amount of concentration with a low amount of deposition, occurring at the plot closest to the marsh surface. These points on the graph would skew the data and may have an influence on how the correlation is represented. Particularly on plots M2 and C4 there were values of very high deposition with relatively low sediment concentration, again influencing a negative correlation.

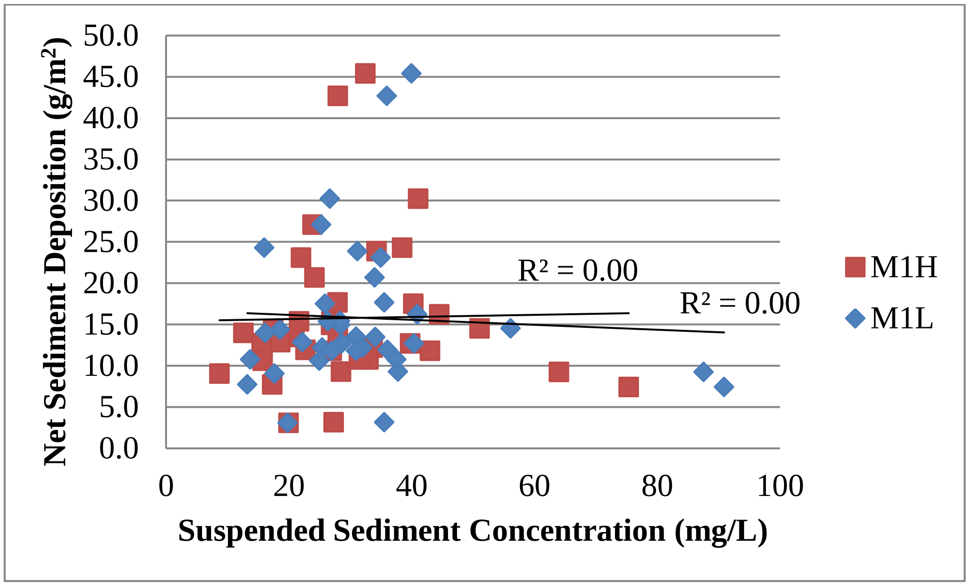


Figure 4.11 Marsh surface plot. Relationship between the suspended sediment concentration and the net deposited sediments at each of the marsh surface (M1) plots.

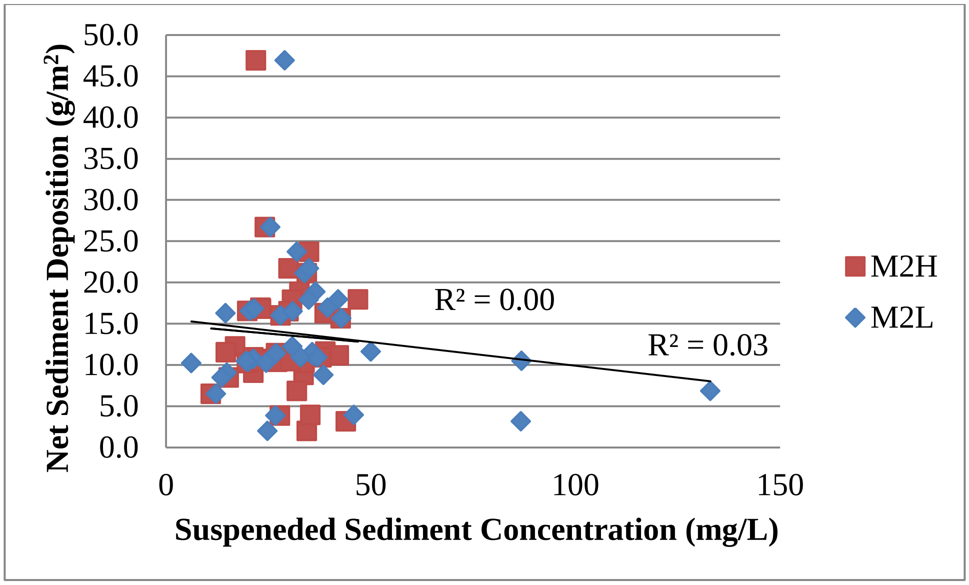


Figure 4.12: Marsh edge plot (M2). Relationship between the suspended sediment concentration and the net deposited sediments at each of the marsh edge (M2) plots.

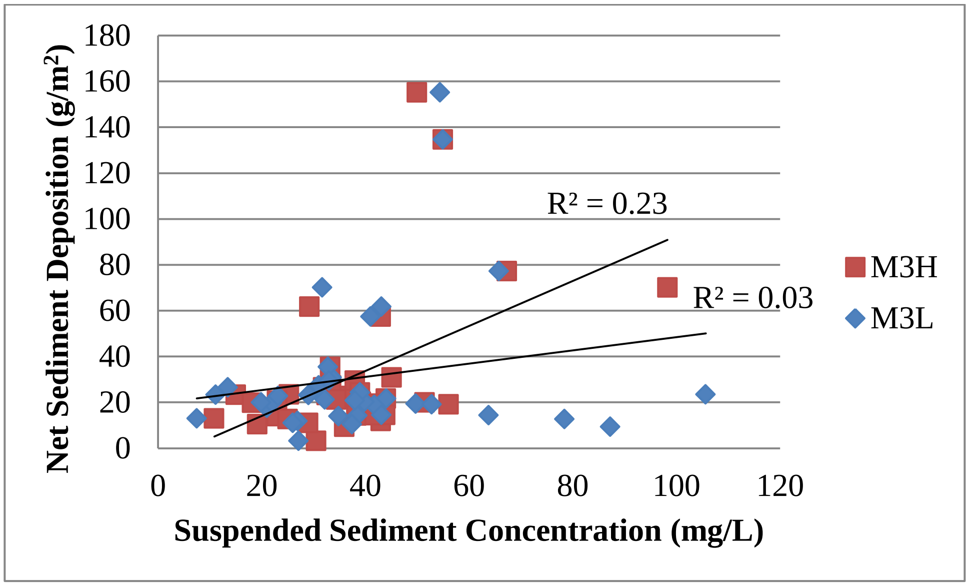


Figure 4.13: Marsh bank plot (M3). Relationship between the suspended sediment concentration and the net deposited sediments at each of the marsh bank (M3) plots.

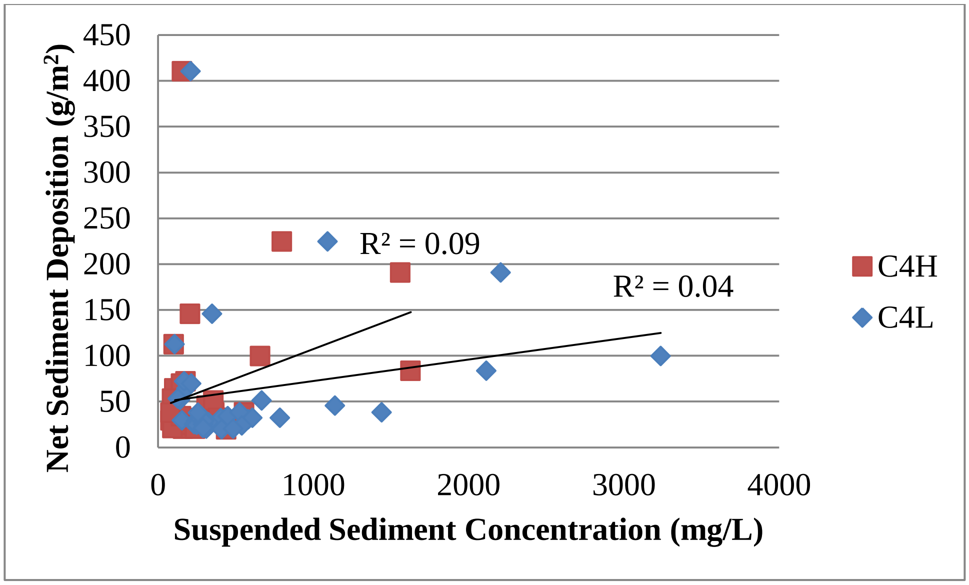
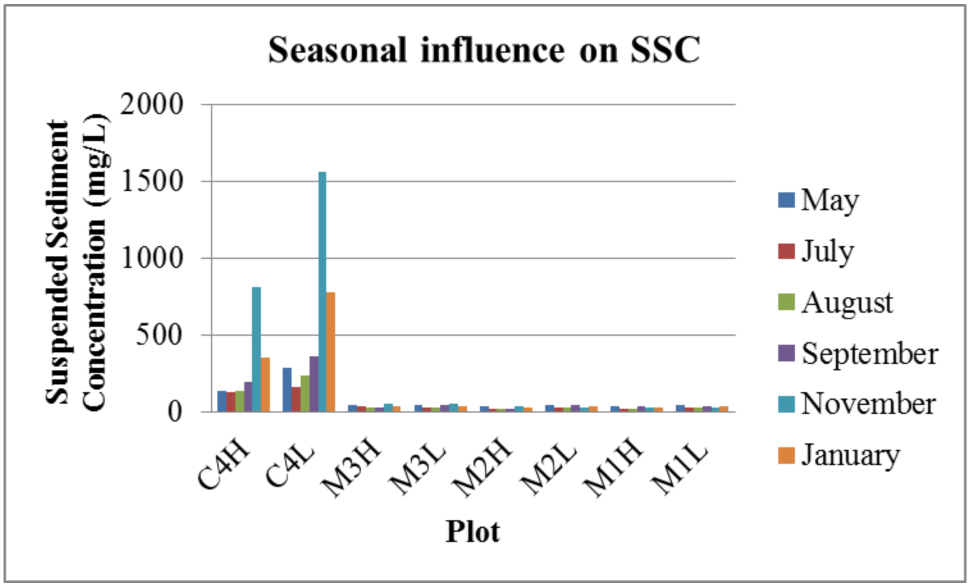


Figure 4.14 Marsh creek plot (C4). Relationship between the suspended sediment concentration and the net deposited sediments at each of the marsh creek (C4) plots.

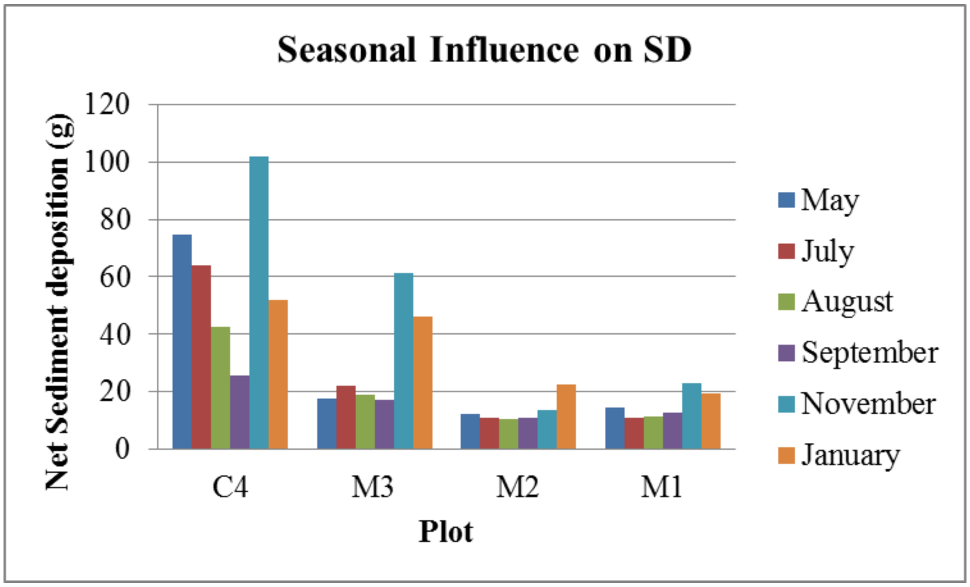
4.1.4 Seasonal Influence

The suspended sediment concentration average for the two C4 plots was much more during the two deployments occurring in the most frigid conditions (both November and January) than any of the other deployments (Figure 4.13). The November deployment has a much larger mean concentration, for both the C4 and M3 plots, than all other deployments. At the C4 plot there is double the amount of mean sediment concentration than the January deployment (the second largest mean concentration).The remaining two plots, there is very little variability in the mean concentration values between deployments. The January deployment for both plots is nearly double the next largest average suspended sediment concentration, the September deployment.

Typically the average sediment deposition for each of the plots was higher during the late fall and winter deployments, November and January shown in Figure 4.14. The deployment in November, excluding M2, saw the highest amounts of average deposition. The summer and fall deployments for all plots appeared to regularly receive the lowest amount of average sediment deposition. At the C4 and M3 plots, the sediment deposition (Figure 4.14) on average nearly tripled in November from the September deployments. It is also over double the amount as January and September, the closest deployment to the mean deposition in November is almost an average of 30 g/m^2 less. At the M3 plot, the November and January deployments have a much higher mean rate of deposition where they are approximately double any other deployment.



4.15: Seasonal influence on mean suspended sediment concentration at each of the plots for all of the deployments.



4.16: Seasonal influence on mean net sediment deposition over a single tidal cycle at each of the plots for all of the deployments.

4.2 Weather Condition Influence

A noticeable trend is observed in Figure 4.17 (c/d). The deposition values for the C4 plot are much higher during the period of the November deployment; also during the May 9 AM tide there was a substantial amount more than all other tides. The suspended sediment concentration receives a much larger amount of sediment during the November deployment at the C4 plot. Also, the C4 plot, receives a consistently larger amount of mean concentration (yet less than the November deployment) throughout the January deployment.

The deployments in May, and November all received precipitation events (Figure 4.17a). Despite having minimal precipitation during the September deployment, there was a long span of rain prior to the data collection period. Over a 20 hour period there was 55mm of precipitation. The deployments occurring in July and August did not receive precipitation, while the data were not collected for the January deployment. None of the tides during deployments received a severe precipitation event; all remained less than three millimeters of rain/snow. Other periods, between deployments, received high amounts (in excess of 8mm) of precipitation relative to the occurrences during the deployments. Despite not being as large of an event as others, the precipitation in September appears to have potentially influenced the high concentration results.

High wind events during the deployments occurred notably in the May, November and January deployments (Figure 4.17b). The January deployment received the highest average wind speed, reaching 4.1 m/s over the whole period of data collection. During the early stage of this deployment winds ranged between 7-13 m/s. The May and November deployments received an average wind speed of 1.98 and 2.43 m/s respectively, the average wind speed over the entire term of collection was 2.6 m/s. As shown on Figure 4.17b, the high winds for May mostly occurred at the end of the deployment and very little wind events in the early stage of the deployment.

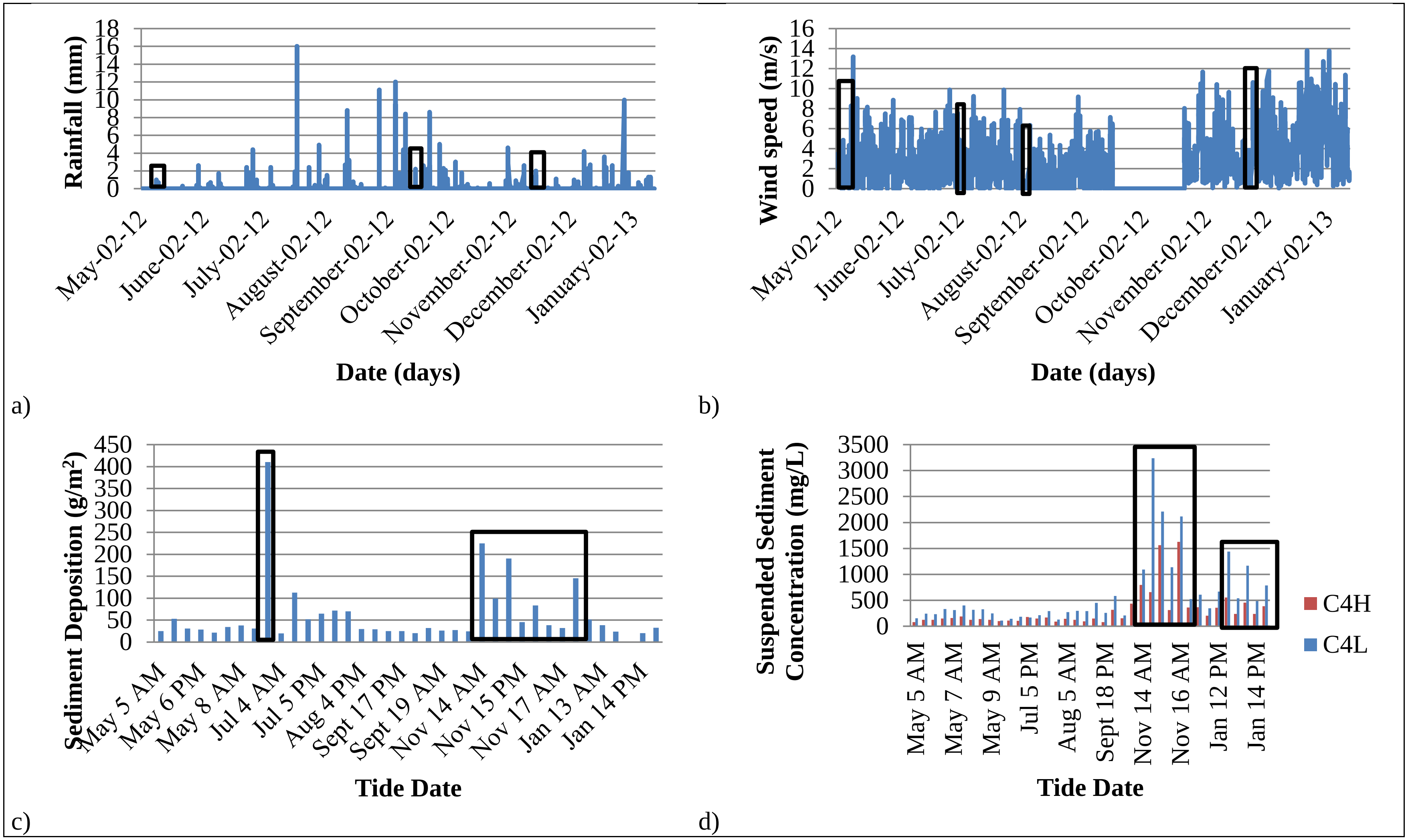


Figure 4.17 Weather pattern influence on C4 plot Concentration and Deposition (a-Rainfall, b-wind speed, c-deposition and d-SSC). Encompassed in boxes are the values of interest and when the study took place.

Figures 4.18 (c and d) show a noticeable trend in the sediment deposition data as well as the suspended sediment concentration data for the M3 plot. The entire November deployment, excluding the first tide, is well above any of the other values for deposition. The eight tide period of November 14 PM to November 18 AM saw the six highest deposition values at the M3 plot, the other two (November 15AM and 17 AM) were among the average values for the data collected. The highest value was received on the November 16 AM tide, this was approximately 5 times larger than the average of tides not occurring in November. All of the six aforementioned are a minimum of double the deposition from any other tide.

A less obvious trend occurs in Figure 4.18d, yet the suspended sediment concentration during the selected period is generally greater than the remaining tides concentration levels at both M3 plots. This period is larger than the sediment deposition, including some of the September and January tides, however it is mostly based on the November deployment. Both, the M3H and M3L plots have peaks that are nearly double the remaining tides. There is a tide in May that should be mentioned as a larger value as it exceeds the 60mg/L level.

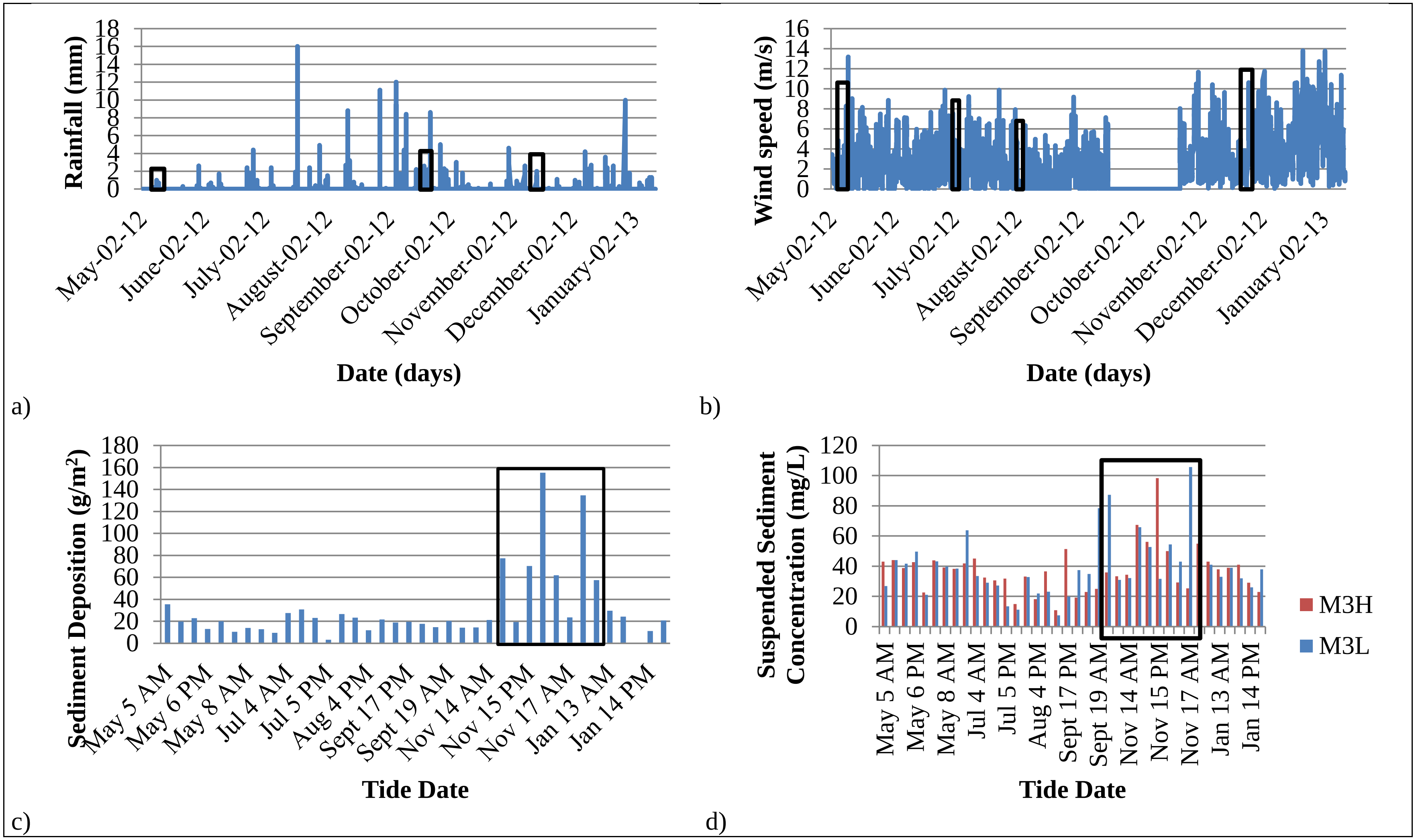


Figure 4.18 Weather pattern influence of M3 plot concentration and deposition (a-Rainfall, b-wind speed, c-deposition and d-SSC). Encompassed in boxes are the values of interest and when the study took place.

Chapter 5

Discussion and Conclusion

Sediment dynamics are a very complex and difficult study to understand, especially in a highly dynamic system such as the Bay of Fundy. It is very challenging and important to identify the behavior of sediments in tidal systems. Overall, this experiment will help in the overall comprehension of sediment dynamics involving the critical influences on the mechanics of the tidal systems. It is very difficult to comprehend the interactions between the sediments, vegetation, hydrodynamics and weather conditions (Allen et al, 1976; Christiansen et al, 1999; Murphy and Voulgaris, 2006; Voulgaris and Meyers, 2004). To accurately identify and create models of sediment dynamics many scientific studies of baseline data collection must be completed. In this chapter, research from other scientific studies will be drawn from to create a more broad understanding of the occurrences in this study. The data received from this study can assist future research being done in the field of comprehending various influences on the availability and opportunity of sediment dynamics within the Bay of Fundy.

5.1 Availability

Suspended sediment concentration is a defining variable with respect to sediment dynamics. The mere presence of any concentration suggests that there is sediment available within the water column. Given that it is present, it must have been brought from some place which provides the availability to study the sediment dynamics (Allen et al, 1976; Amos and Tee, 1989). Influential factors on the quantity of the concentration include the depth of water (and the inundation time), the proximity to the source of sediment, and the hydro-meteorological components (Blanton et al, 2002; Voulgaris and Meyers, 2003; and Verney et al, 2006).

In salt marsh environments it is common to see the inundation time increase as the water depth increases, while the inundation time will be less if the water depth is less. These two variables can be considered parallel (Torres et al, 2006), however not in all regions of a marshes. Topography also influences sediment deposition as each of the plots are continuously at a higher elevation from the creek (Torres and Styles, 2007). In the Kingsport study, for 7 of the 8 plots, there was an overall positive correlation between water depth and suspended sediment concentration. Thus, greater water depth time has resulted in higher concentration values also identified in Temmerman et al (2003). The excluded plot from this relationship is the C4L plot which is the initial plot to be inundated from the oncoming bore, corresponding with the findings in Torres and Styles (2007) that correlations between inundation and concentration are positive.

The mean suspended sediment concentration values, during the Kingsport study, comply with the study performed Poirier (2012) and French et al. (2000). The plots yielding the highest concentration were closest to the source while the plots furthest from the source, nearest the marsh edge, resulted in the lowest concentration values. The exception to this rule was the M2H plot which yielded the lowest mean concentration of all 8 plots. While observing the May 7 PM tidal cycle, from atop the wooden stand (Figure 3.2), it was unexpectedly noted that M1L is inundated prior to M2H and M1H is slightly after the inundation process commences for M2H, suggesting a very little change in elevation relative to datum between plots. Generally the mean concentrations of both

M2 and M1 plots are very similar and receiving no significant difference of suspended sediment.

The highest of all the mean concentrations was found at the C4L plot, yielding a value of 604.3 mg-l^{-1}, nearly twice the second largest C4H mean concentration (309.5 mg-l^{-1}). This plot resides in the creek at 20 cm above the surface resulting in it being the first plot to be inundated. It is also receiving the initial tidal bore which is highly sediment laden due to re-suspension of the mudflat. In a previous study, van Proosdij et al (2001), shows that there is a deviation in the concentration over the period of inundation on a mudflat. Peak periods of suspended sediment concentration during tidal cycle occur during the initial onset stage of the tide (Davidson et al, 2002; Poirier, 2012). The bottle sampling method, used in this study, only gathers the initial onset flood of water. When the bottle fills it will accept nor expulse any water or sediment from the contraption. The sediment concentration yielded in this data is only the onset concentration not the total concentration or average.

It was also found that at all 4 plots (C4, M3, M2, and M1) the suspended sediment concentration was higher at the 20 cm elevation than the 80 cm elevation, this may suggest that as the tide rises the sediment concentration is decreased. This finding is also presented in previous research (Collins, 1983; van Proosdij et al, 2000; Temmerman et al, 2003; Silver, 2009), and identifies that sediment will fall out of suspension throughout the rising of a tide (Davidson et al, 2002, Voulgaris and Meyers, 2003).

Table 5.1 A comparison of suspended sediment concentrations recorded in the vicinity of the Kingsport marsh.

Study	Comments	SSC (mg/L)
Amos and Mosher (1985)	Range	26-94
van Proosdij et al. (1999)	Mean	300
Davidson-Arnott et al. (2002)	Range	180-260
Dabourn et al. (2003)	Range	100-1700
van Proosdij (2006)	Range	118-346
Silver (2009)	Range (mean)	17-192 (68)
Blotnicky (2013)	Range C4 (mean)	81.2-3238.1 (456.9)
	Range M3 (mean)	7.5-105.7 (38.6)
	Range M2 (mean)	6.2-133 (31.8)
	Range M1 (mean)	8.7-90.9 (31.4)

Identified in Table 5.1, suspended sediment concentration can vary within many different marshes across the Bay of Fundy. The creek values from this study were much higher than the previous studies, excluding Dabourn et al (2003). The three marsh plots are comparable with many of the other studies notably Silver (2009) and Amos and Mosher (1985).

A factor influencing the suspended sediment concentration to be increased appears to be a meteorological attribute. Rainfall and increased wind speeds appear to have some impact on the concentration of sediment in the water column; this can be seen in the November deployment. Many of the high rain events and wind events during the study period were not captured during the selected deployments. There were notable increases in concentration after a strong meteorological event occurred in comparison to the rest of the deployment seen in May. The increase in storm like weather will cause higher waves and more availability for re-suspension to occur (Friedricks and Perry, 2001), thus increasing the concentration. Silver (2009) shows a lack of correlation between wind speed and suspended sediment concentration. While still showing slightly elevated concentration, both elevations for plots M1 and M2, did not appear to have as much of a pattern with the weather occurrences as plots M3 and C4.

It is found that periods of rainfall will influence the concentration to be higher than during periods of no rainfall. Murphy and Voulgaris (2006) show that during low tide periods a rainfall event may result in up to 50 percent increase in the sediment concentration in marsh environments. Influential rainfall, on the sediment concentration, was considered to occur during the 24 hour period prior to the sample measurement.

The seasonal variability appears to have a large influence on the data received in this study, showing that the fall deployment of November received well above any other deployment. This may suggest that prior to winter, the sediment load is highest. Murphy and Voulgaris (2006), show otherwise, the fall and spring periods are relatively similar with winter having the least sediment in suspension. The summer period (June, July, August) has a much higher mean concentration than the other three seasons. Perhaps, other regions in the Bay of Fundy receive higher rates of bioactivity (burrowing organisms, dying of vegetation) during the late fall resulting in more sediment being available to re-suspend. The vegetation is beginning to die off potentially resulting in less sediment being trapped on the marsh surface.

5.2 Opportunity

The sediment deposition is the key variable in these experiments, looking at what happens to it with respect to other variables helps identify how it is being impacted and will show the severity of introducing in-stream turbines into a tidal system. The main variable influencing deposition is found to be suspended sediment concentration.

Identified in Figures 4.11-4.14, increasing suspended sediment concentration results to a general increase in net sediment deposition (with exclusion to both elevations at the M2 plot). If sediment is available this will create the opportunity for it to be deposited. Greater inundation time results in a higher opportunity for sediment to be deposited on the marsh (Poirier, 2012; van Proosdij et al., 2006); water depth is considered to be a parallel variable with inundation time (Torres et al, 2006). All three of the marsh plots showed positive correlations with depth, the creek plot shows no correlation. Distance from the creek, along with topographical structure of the marsh also influences the hydrodynamics of the system which also influenced the rate of sediment deposition (Torres and Styles, 2007). Shown in Figure 5.1, both marshes have high rates of deposition at the creek plot and it decreases as it extends further into the marsh. Noted is the M2 plot receiving less mean net deposition than the M1 plot, which is only slightly elevated from the M2 plot thus disagreeing with the findings of Torres and Styles (2007) that higher elevations will receive less net deposition. This plot, however, was highly disturbed due to human footprints which may have resulted in a larger amount of availability due to re-suspension resulting in higher deposition at the plot.

Table 5.2 a: A comparison of the sediment deposition between three similar studies within a short vicinity of one another. In brackets is the standard deviation of the sample. Measured in $g \cdot m^{-2}$.

Study	**Creek**	**M3**	**M2**	**M1**
Silver, 2009 (Elderkin Marsh)	x	38.8 (36.6)	84.4 (49.2)	63.8 (36.0)
Poirier, 2012 (Starrs Point Marsh)	357.6 (85.5)	97 (25.2)	43.1 (17.0)	24.4 (9.6)
Blotnicky, 2013 (Kingsport Marsh)	62.9 (75.1)	31.1 (32.2)	13.6 (8.0)	15.8 (9.0)

Table 5.2 b: A comparison of mean net deposition results ($g\text{-}m^2$) from studies performed in the Bay of Fundy.

Study	**Marsh**	**Creek**
van Proosdij et al, 2006 (Allen Creek)	12.3-94.3 (range)	X
O'Laughlin and van Proosdij, 2012 (Starr's Point)	x	60-300 (range)

5.3 Future Considerations

The study of sediment dynamics and the impacts on tidal marshes will be ongoing as research for the tidal energy industry continues. It is very important to understand the influence the introduction of turbines into the Bay of Fundy will have on such a critical and vulnerable ecosystem such as the salt marshes. For these future studies there are a few recommendations which may help in creating a more conclusive result, however, financial and temporal restrictions are not acknowledged. Gathering more data, and more consistently, would be very important in developing a full understanding of the system. Performing similar experiments on different marshes within the same area would help identify if the results received were consistent with the whole ecosystem. This study was limited by time due to the nature of the program, however, gathering data on a more regular basis would allow for the trends to be more clearly identified. This study contained a large amount of samples, yet there were also a few months not included in the data set (June, October, December, and the February through April period). Murphy and Voulgaris (2006) perform a similar study occurring over multiple years; at least one full year will help identify a full seasonal trend relationship. Also, given that November doesn’t follow typical trends in past studies (Murphy and Voulgaris, 2006; Hutchinson et al, 1995); it may be a good idea to gather at least twice a month for a more concise representation.

During the tidal cycle, suspended sediment concentrations will deviate (van Proosdij, 2001). This suggests that there will be different concentrations at different times during the tidal cycle. The rising stage bottle method, for acquiring samples of suspended sediment, only receives the initial stage of suspended sediment for the given bottle being submerged. This means that during the whole cycle of the tide only the initial stage is being sampled; there will be no information on how the concentration changes at different stages of the tide. Using an ISCO sampling device (Poirier, 2012) information can be acquired for the entire cycle of tide; this method was performed during the Kingsport deployments but was not included in this report due to time restraints. Poirier (2012) also included velocities of the water profile, using an Acoustic Doppler Velocimiter and an Acoustic Velocity Current Profiler, which would have helped in understanding the relationship between current speed and sediment concentrations as well as sediment deposition.

It is expected that the sediment trap method, for acquiring deposition data, is not fully accurate. The trap will acquire the end result of sediment that is deposited on the filter paper. The opposite of the stage bottles method, where it is the initial influx of sediment collected, the final amount of sediment remaining on the trap is what will be counted. During the course of the tide there will be sediment being deposited on the trap and then being re-suspended in the water column until the trap is no longer inundated. To receive data for the stages of deposition the method will have to be innovated. Similar to van Proosdij et al (2001), continue to have three traps at each plot containing a sliding cover. After the initial flood stage trap one is covered, at high tide another is covered while the third remains uncovered during the course of the tidal cycle. The sediment will remain on the filter papers for the first two traps thus identifying the amount of deposition at three different stages of a tidal cycle.

5.4 Conclusions

The experiments completed for this project will be used in a large scale model of the hydrodynamics and sediment transport within a tidal marsh system as a part of identifying the far field impacts of introducing tidal energy extraction methods in the Bay of Fundy. Impacts on the far field environments must be examined through scientific studies to determine if the impacts lie within a natural variability range. It is important to gather data from many intertidal environments to gain a more comprehensive understanding of the relationships.

Depth, distance from the creek and suspended sediment concentrations were the three dominant variables impacting the sediment deposition at Kingsport marsh. The meteorological variable influenced a higher concentration of sediment suspended in the water column; as well seasonal influences impacted the suspended sediment concentrations. Kingsport marsh is a tidal salt marsh, in a dynamic system, with many physical and biological variables influencing the sedimentary processes that occur.

As the suspended sediment concentration and sediment deposition show positive correlations with increased water depth it can be said that introducing in stream turbines will influence the sediment dynamics in far field environments of the Bay of Fundy. If the amplitude of the tide were to be decreased, the marsh surface would be inundated less often and the sediment would not reach the marsh forcing it to remain in the creek. In turn, this would result in more availability for deposition at the creek and potentially lead to the creek being filled in with sediment. As the relationships are not incredibly strong, the overall impact of in stream turbines may be directly related to the quantity of energy extracted and not the mere presence of energy extraction devices.

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Appendix A

Statistics

Table A1: Statistical results of the Pearson Correlation test to determine whether or not the specific plots show statistical significance of suspended sediment concentration with change in water depth.

Plot	**Pearson Correlation**
C4H	-0.086
C4L	0.123
M3H	0.403
M3L	0.074
M2H	0.357
M2L	0.204
M1H	0.1
M1L	0.209

Table A2: Statistical results of the Pearson Correlation test to determine whether or not the specific plots show statistical significance of sediment deposition with change in water depth.

Plot	**Pearson Correlation**
C4	-0.005
M3	0.262
M2	0.287
M1	0.324

Table A3: Statistical significance of the mean suspended sediment concentrations between all plots using the ANOVA Repeated Measures test to the 95 % confidence level. The star resembles plots having significant difference from one another.

Plot	**C4H**	**C4L**	**M3H**	**M3L**	**M2H**	**M2L**	**M1H**	**M1L**
C4H	X							
C4L	0.00*	X						
M3H	0.00*	0.00*	X					
M3L	0.00*	0.00*	0.565	X				
M2H	0.00*	0.00*	0.00*	0.001*	X			
M2L	0.00*	0.00*	0.5	0.123	0.12	X		
M1H	0.00*	0.00*	0.023*	0.001*	0.564	0.061	X	
M1L	0.00*	0.00*	0.151	0.023*	0.155	0.266	0.138	X

Table A4: Statistical significance of the mean net sediment deposition between all plots using the ANOVA Repeated Measures test to the 95 % confidence level. The star resembles plots having significant difference from one another.

Plot	**C4**	**M3**	**M2**	**M1**
C4L	X			
M3	0.019*	X		
M2	0.00*	0.002*	X	
M1	0.001*	0.002*	0.208	X