TEMPORAL CHANGES IN THE SALT MARSH SYSTEM OF A NORTH SHORE LONG ISLAND POCKET BAY

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Salt marsh ecosystems serve many environmental functions including but not limited to: providing fishery and waterfowl habitat, providing a shoreline buffer against waves and storm surges, and mediating estuarine water quality. Because of their unique position between the land and sea, salt marshes have received much attention in the literature. Understanding the response of coastal environments to anthropogenic activities and changing sea level conditions is essential before developing coastal management and planning strategies and implementing protective measures (Stumpf and Haines 1998). Dredging is one human activity that has created much concern in Stony Brook Harbor, NY. The dates and extents of local dredging projects are well documented. How these projects have altered the depositional environment and impacted the local salt marsh ecosystem has been relatively unexplored. The results of radiometric analysis of five salt marsh peat cores indicate that salt marsh accretion has been variable over the past one hundred years. In the first half of the 20th century the marshes accreted slower than the rate of regional sea level rise as recorded at the tide gauge station at the Battery, NY. In the second half of the 20th century, concurrent with dredging projects and increased storm activity, the marshes have at times outpaced the rate of sea level rise. However, more recently on scales of 10 to 20 years, the marsh is again being outpaced. Peaks in accretion rates have been linked to years of dredging projects. These anthropogenic induced sedimentation events have been important in balancing accretion deficits and sustaining marsh growth and may become increasingly important in the near future given predictions of a rapid increase in post-glacial eustatic sea level rise. In this study, salt marsh loss has been documented and perimeter erosion observed. Mechanisms of erosion have been in part attributed to indirect affects of dredging including bathymetric changes resulting in channel shifting and tidal scour and the increase in boat wakes. If the goal of the State and local municipalities is to protect and preserve coastal wetlands, perimeter erosion controls will need to be considered.

Introduction

Stony Brook Harbor (Figure 1) lies in the towns of Smithtown and Brookhaven in Suffolk County on the north shore of Long Island, New York. This relatively shallow water body (mean depth 0.9 m at mean low water) is protected from Smithtown Bay and Long Island Sound by two baymouth bars: Long Beach (Town of Smithtown) and West Meadow Beach (Town of Brookhaven). The semi-diurnal tide fills and empties the embayment via a channel system, extending southwest from the entrance to the harbor in the northeast corner. Salt marshes have developed behind the two baymouth bars and at many locations along the shoreline of the harbor. Marsh islands have also formed. These marsh islands provide a barrier to tidal flow and form the channel system.

Sedimentation problems were first noted in Stony Brook Harbor over 100 years ago in 1882 when dredging was proposed for the first time (Robbins 1977). In the second half of the 20th century, recreational boating in the harbor has greatly increased, evident by the construction of two marinas and a deep water-mooring basin. This recreational use has necessitated the creation and maintenance of navigable channels, which, from time to time, have required dredging. A brief history of dredging is provided in Table 1. All depths given are referenced below local mean low water (MLW) (refer to Figure 1 for locations of dredging projects. Click on thumbnail for larger image).

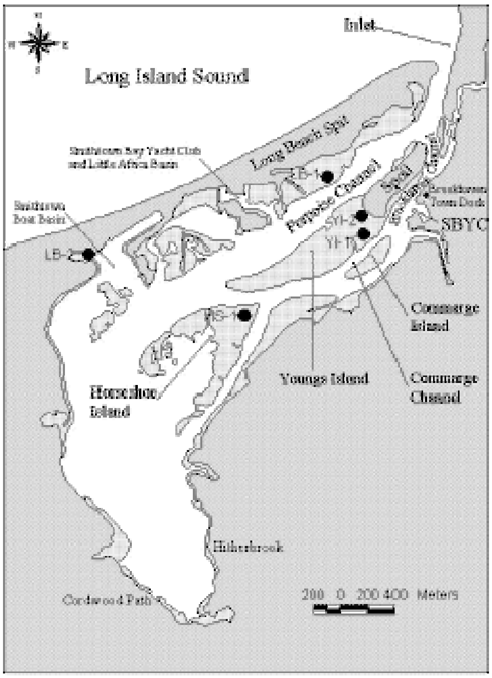

Figure 1. Place names in Stony Brook Harbor, NY. Black dots indicate locations of marsh peat cores extracted for dating

Dredging creates controversy due to its cost, and concerns over the health of the harbor resources including the salt marsh ecosystems. New York State Department of State (NYSDOS) has designated Stony Brook Harbor as a coastal fish and wildlife habitat of statewide significance, and describes the area as having one of the largest and most diverse coastal wetland ecosystems on the north shore of Long Island, and as being one of the most important waterfowl wintering areas in northern Suffolk County (NYSDOS 1987). In part because of this designation, a study was funded by NYSDOS to determine if dredging has any environmental impact on this relatively pristine harbor and more specifically the salt marsh system in Stony Brook Harbor. The impact of past dredging upon salt marshes was approached by investigating past and present marsh accretion rates. The reason for the historic approach is that the past sedimentation environment must be well understood before the interpretation of changes to the present sedimentation environment can be evaluated (Orson and Howes 1992).

Table 1. Brief Dredging History in Stony Brook Harbor

Year	Activity
1953	First dredging in northern Stony Brook Harbor, a 1.5 m deep channel created from the inlet to the Brookhaven Town Dock and the Little Africa Boat Basin and access channel were also created
1958	Porpoise Channel dredged to 1.8 m, Brookhaven Channel extended and dredged to 3.7 m, and new Smithtown Boat Basin and access channel created
1961	New Smithtown Bay Yacht Club Basin created expanding the existing Little Africa Boat Basin
1965	Major dredging activity including the deepening of Porpoise Channel to 3 m, the deepening of the Brookhaven Channel to 4 m, the creation of the Stony Brook Yacht Club Basin, along with the reconfiguration of channels near the inlet with the creation of spoil island expanding Youngs Island
1980	Maintenance dredging of the Brookhaven Channel to 1.8 m
1994	Maintenance dredging of both the Brookhaven Channel and Porpoise Channel to 1.8 m

1997	Maintenance dredging of Brookhaven Channel to 1.8 m

Substantial marsh losses are estimated from the comparison of the 1886 hydrographic survey of the harbor and 1976 New York State tidal wetlands maps. Marsh area, particularly of the island marshes, greatly decreased over this period from $1.9x10^{6}$ m^{2} to $1.3x10^{6}$ m^{2}. It is clear that many changes have taken place in the salt marshes of Stony Brook Harbor, but to what may they be attributed? When total marsh area is considered most of the decrease in wetland area is due to direct removal and burial of wetlands resulting from the dredging projects conducted between 1953 and 1965. In reviewing the dredging history of the harbor, 50% of this loss in wetland area ($3.0x10^{5}$ m^{2}) can be attributed to destruction and burial, leaving another $3.0x10^{5}$ m^{2} of wetland loss unaccounted for (Constantine 1985).

Marsh Accretion and Sea Level Rise

Is this loss due to an indirect effect of dredging or simply due to the inability of the marshes to keep pace with sea level rise? Figure 2 is a plot of mean sea level rise data collected at the tide gauge station at The Battery, in New York Harbor, the longest tide gauge record in the region. Rates of sea level rise and increase in marsh surface elevation were compared over several common time periods by comparing the slopes of regressions of subsets of the tide gauge data and marsh age-depth relationships resulting from ^{210}Pb dating (see Figure 1 for core locations). Table 2 contains a summary of six periods examined and the respective slopes of regressions. ANCOVA was performed to determine if significant differences between the rise in sea level and marsh accretion exist over the different time periods, with the null hypothesis that there is no difference in regression slopes or that marsh surface elevation is responding to the rise in sea level. In the first half of the century (1900-1950), with the exception of the HS-1 core, numerically all of the marshes are accreting slower than sea level rise, with the high marsh being significantly slower ($p<0.05$). In the second half of the century, during the era of dredging in Stony Brook Harbor, all marsh locations sampled (Figure 1) are numerically out pacing sea level rise with cores YI-1 and HS-1 accreting at significantly higher rates ($p<0.05$). When the period examined is shortened to the last thirty five years there is no difference between accretion and sea level rise, however the rate of sea level rise has increased. When the period is further reduced to the last ten to twenty years, sea level rise and marsh accretion appear uncoupled. Sea level has risen faster than marsh surface elevation at all sites sampled, although no statistical difference can be detected due to small sample size. As well, as the period analyzed is shortened the confidence in slopes decreases. Results of dating indicate variation in marsh accretion rates in the second half of the 20th century with, often large, positive deviations from core mean rates. This analysis indicates the importance of identifying the source(s) of these increases in growth rate, as they may aid in compensating for long and short-term accretion deficits.

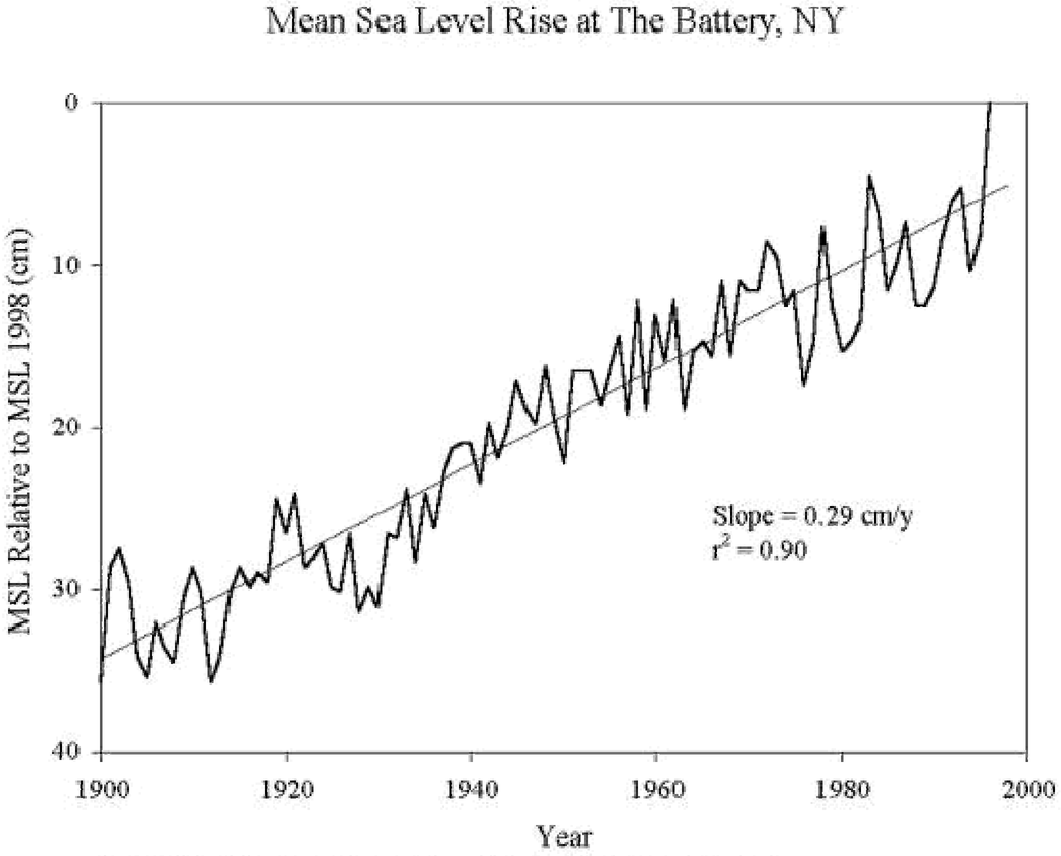

Figure 2. Mean Sea Level (MSL) recorded at The Battery, NY.

Table 2. Summary of ANCOVA of Sea Level Rise vs. Marsh Accretion

Period	Battery RSLR (cm yr^{-1})	YI-1 Marsh (cm yr^{-1})	YI-2 Marsh (cm yr^{-1})	HS-1 Marsh (cm yr^{-1})	LB-1 Marsh (cm yr^{-1})	LB-2 Marsh (cm yr^{-1})
1900-1950	0.287	0.203	0.202	0.309	0.164	0.145*
1950-2000	0.269	0.391*	0.327	0.410*	0.323	0.276
1965-2000	0.294	0.417	0.335	0.368	0.402	0.269
1980-2000	0.610	0.502	0.397	0.452	0.458	0.263
1990-2000	1.336	0.589	0.409	0.554	0.552	0.261

* denotes significant difference between marsh accretion and sea level rise, $p<0.05$

Dredging and Marsh Accretion

If the dredging activities themselves were increasing sediment load carried throughout the harbor one might expect to see peaks in accretion rates in the marshes in years dredging projects were undertaken. Alternatively, if it is not the dredging activity itself, the reworking and suspension of the resulting unconsolidated channel bottoms may have temporarily increased sediment load.

Figure 3 displays YI-1 accretion rates plotted against time. Rectangles indicate years in which dredging projects were undertaken in the harbor. Although the magnitude of increase may vary, it appears that in all but one of the years dredging occurred (1953), the marsh experienced an increase in accretion rate. The largest peak in accretion, approaching 0.8 cm yr^{-1}, coincides with the largest dredging project conducted in the harbor in 1965. Similar patterns were found in other cores dated (LB-1, YI-2).

The core extracted from the Horseshoe Island (HS-1) may be beyond the acute influence of the dredging projects conducted in the northern part of the harbor. The location of core HS-1 is more than 1.2 km from the end of the dredged Brookhaven Channel. The ^{210}Pb analysis indicates high accretion rates between the late 1930s and early 1960s, with the highest rate greater than 1.0 cm yr^{-1} in 1953. However, after approximately 1960, the accretion rate in this area is relatively constant (0.35 cm yr^{-1}) with only modest increases in the early 1980s and again in the late 1990s. The Horseshoe Island marsh is governed by different sedimentation processes than those in the northern part of the harbor. This is supported by lower modeled tidal velocities and bedload transport rates in this area, than in northern part of the harbor (Marcoe 1999, Georgas, pers. com. 2000). Marsh accretion in Stony Brook Harbor is spatially variable, a common finding in other salt marsh investigations on the East Coast of the United States, (Cundy and Croudace 1995, French *et al.* 1995, Leonard and Luther 1995, Christiansen *et al.* 2000).

Marsh Accretion and Storms

Thus far, the depicted peaks in accretion in each of the cores have been related in part to dredging activities, however there are other variables to be considered. Storms such as northeasters and hurricanes have been identified as important mechanisms in mobilizing sediments to marshes, particularly in those that do not receive riverine input, like Stony Brook Harbor (Stumpf 1983, Orson *et al.* 1987, Cahoon and Reed 1995, Cademartori 2000). Storm frequency, duration, strength and associated prevailing winds may exert considerable control over the spatial distribution of sediments throughout marshes (Gammil and Hosier 1992). Figures 4 displays the marsh accretion rates in YI-1 marsh core, where the rectangles represent years of major storms (hurricanes and northeasters) that may have impacted Stony Brook Harbor in the last century. On several occasions storms occurred in the same years as dredging projects, which may have acted in concert resulting in the peaked accretion. This obscures which event had the greater impact on the marsh.

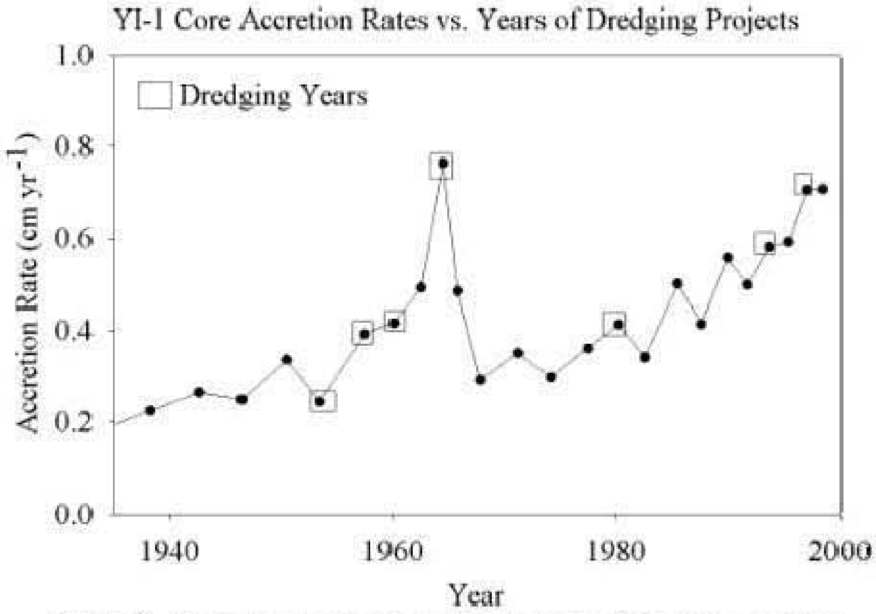

Figure 3. YI-1 marsh accretion rates vs. years of dredging projects.

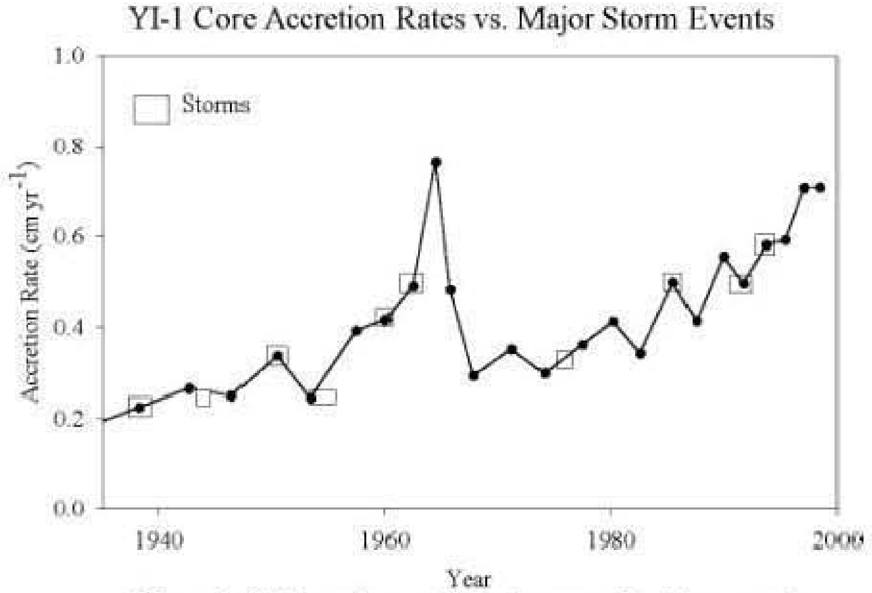

Figure 4. YI-1 marsh accretion rates vs. major storm events.

The 1938 Hurricane has been described as the worst natural disaster ever to befall Long Island (Dvoskin 1992). The eye of the storm passed directly over the area manifesting itself in a storm surge that was 1.4 m above normal in nearby Port Jefferson, NY (Army Corps of Engineers 1969). Sand lenses deposited by this storm have been identified in high marsh cores in Connecticut and Massachusetts (McCaffrey and Thomson 1980, Orson and Howes 1992, Orson *et al.* 1998). Although a distinct disturbance layer was not observed in core LB-2, the marsh experienced the highest accretion rate (0.43 cm yr^{-1}) around 1938. None of the low marsh cores analyzed recorded this storm in the form of increased accretion rates. This reiterates how differently high and low marshes may respond to even the same sedimentary process or event. As well, storms may produce increased wave energy and strong currents over the marsh that causes erosion of the marsh (Stumpf 1983).

The tide delivers material to the low marsh twice a day and the high marsh during spring tides. Therefore, it makes sense to look at events such as major storms to help explain variations in accretion departing from a constant rate. Major storms may not be represented in core chronologies for several reasons. Potential local marsh sedimentation events associated with storms are strongly dependent upon but not limited to: prevailing wind direction, generated wave heights, stage of tide, and marsh elevation. In meso-tidal systems, such as Stony Brook Harbor, storms persisting at low tide may barely flood the marshes and have no effect on accretion.

It is clear from the ^{210}Pb dating that the low marsh accretion rates have not been constant over the past 100 years. The variation must be due to temporal and spatial variability in sedimentation processes. Dredging and storms appear locally to have contributed to and help sustain vertical marsh growth in Stony Brook Harbor. Yet, the analysis of marsh area indicates substantial loss of salt marsh that is not due to mere removal or spoils deposition. Indirectly dredging may be in part responsible perimeter erosion through changes in bathymetry (both in the channels and areas remote from the projects) and changes in sedimentation patterns.

Causes of Salt Marsh Loss

Downs *et al.* (1994) highlighted three possible mechanisms of wetland erosion: interior ponding, channel formation and enlargement, and perimeter erosion. The most evident form of erosion observed in Stony Brook Harbor is that of perimeter erosion. An analysis of the area of Commarge Island indicates a substantial decrease in area over the past few decades alone (21% loss). Figure 5 is a photograph taken near Commarge Island in August, 2000. The photograph was taken looking north toward the inlet up Commarge Channel, and the steep faced marsh border on the left side of the photograph is the south side of Youngs Island. The appearance of this steep marsh border is a strong departure from the idealized model of marsh growth in which marsh vegetation gently transitions to barren tidal flats. The perimeter marshes in Stony Brook harbor have been surveyed by kayak and on foot. Erosion of the marsh border has taken place at many locations in the harbor, but none as severe as on the borders of the marshes on Commarge Channel.

Commarge Channel has changed substantially since 1967 when compared with a bathymetric survey performed in 1999. In 1967, most of the channel was at or just above MLW. Most of the area of Commarge Channel is now above MLW and the channel bed is composed of gravel. This may be an indirect effect of dredging, which has enhanced the deposition of larger grained material in the channel and marsh erosion in this area. Bathymetric changes have major implications on tidal currents. Modeled tidal currents in Commarge Channel are of the highest magnitude along any of the marsh borders throughout the harbor (Marcoe 1999, Georgas, pers. com. 2000).

Figure 5. Steep marsh border on southern side of Youngs Island.

Perimeter erosion has been attributed to wave action in other systems (Pye 1995). The natural wave regime has most likely been constant since the harbor was protected from large wind waves by Long Beach spit. However, waves generated by powerboats operating in previously non-existent channels have increased in the second half of this century. Waves do more damage to marshes when they are exposed (Wray *et al.* 1995) and the dredged channels allow boats to navigate at lower stages of tide. During higher stages of tide, water levels overtop the low marsh allowing wave energy to dissipate across the surface rather than against the marsh edge (Wray *et al.* 1995). Therefore, the impact of boat wakes may be a major concern and must be considered in any attempt to slow the rate of wetland perimeter loss.

It is proposed in this study that slumping along marsh borders aside from waves is due to strong tidal currents reworking marine deposits underlying harbor marshes. Salt marsh peats are riddled with a network of roots and rhizomes holding the matrix together, making them less susceptible to post-depositional disturbance than adjacent tidal flats (Cundy *et al*. 1997). However, the strong local tidal currents (~1 m/s) may rework the marine deposits, on which the marsh is growing. Redfield (1972) found that salt marsh islands are subject to erosion if channels shift and impinge on their borders. As well, island marshes are particularly vulnerable if adjacent channels are deeper than their total peat thickness. Underlying marine deposits are scoured away leaving overhanging peat.

Commarge Channel has been widened by erosion of the salt marsh banks on both sides of the channel by as much as 5 m. In Maryland, local marsh bank erosion has been measured at a rate of 1.2 m yr^{-1} (Wray *et al*. 1995), and in Delaware Bay, the rate of retreat has exceeded 5 m yr^{-1} (Phillips 1986). Considering that the island marshes in the northern part of the harbor are elongate, with several kilometers directly exposed to channels, this mechanism of wetlands loss may be significant. As well, bank erosion is occurring in the network of tidal channels within the marshes. Extensive barren areas were observed but not quantified within Youngs Island. Ponding and associated submergence stress on salt marsh vegetation may be a dominant mechanism of interior loss as in other systems and occurring at a similar rate as bank erosion (Downs *et al*. 1994).

Conclusions

Substantial salt marsh loss has been documented over the past 100 years. Fifty percent of the loss can be directly attributed to destruction and disposal of spoil associated with channel dredging projects. Lead-210 radiometric analysis of five marsh peat cores in Stony Brook Harbor indicates that marsh accretion rates have increased in the second half of the 20th century due to periodic inputs from dredging projects and increased storm activity. The salt marsh loss is not due to the inability of marshes to keep pace with rising sea level. However, on shorter time scales sea level appears to be greatly outpacing marsh vertical growth. The impact of anthropogenic induced sediment inputs associated with dredging may become increasingly important.

Dredging, although supplementing vertical growth, may be indirectly contributing to wetland loss through changes in harbor bathymetry and hydrodynamics. If State and local goals are to protect and preserve coastal wetlands, with documented lateral loss rates of meters per decade, erosion controls will need to be considered. Channel dredging in Stony Brook Harbor is proposed for the Fall of 2001. This may provide an excellent opportunity to further evaluate dredging impacts and erosion controls with real time monitoring.

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