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Hydrology and Ecological Analysis of Upper Green Harbor River Relative to Potential Restoration of Tidal Exchange

by

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MCZM Massachusetts Wetland Restoration Program

February 23, 2007

Overview

A preliminary hydrological and ecological study of the tidally restricted region of the Green Harbor River ecosystem was undertaken for the Massachusetts Wetland Restoration Program (WRP) by Coastal Systems Program, School for Marine Science and Technology (SMAST) at the University of Massachusetts, Dartmouth from July to October 2006. This work was undertaken in collaboration with Applied Coastal Research and Engineering (ACRE) and The Louis Berger Group Inc., the prime contractor on this project, as part of a larger effort to provide technical analysis to support decisions as to the potential ecological responses to varying degrees of increased tidal exchange through the tide gates currently restricting flow between upper and lower Green Harbor River, a major estuary discharging to Cape Cod Bay. The overall study included field data collection and modeling to support analysis of potential changes within the tidal river and to the historical emergent tidal marsh areas, which now exist mainly as low lying forest, fields and fresh and brackish water wetlands.

The hydrology and ecology portion of the overall project is described in this technical report and is based upon the following tasks:

1. Estimate freshwater flow and nutrient discharge from the freshwater portion of the Green Harbor River to the headwaters of Green Harbor River Estuary.
2. Evaluate present levels of nutrient related constituents and transport within the main channel of the estuary and its 2 tributaries: Bass Creek and Wharf Creek.
3. Evaluate sediment/porewater constituents in restricted and unrestricted wetland habitats within the Green Harbor River System.

In addition to the present report, data sets were collected by SMAST scientists to support the hydrodynamic modeling by ACRE and other aspects of the Louis Berger team's technical assessment. These include:

- estuarine bathimetry
- continuous records of estuarine conductivity at 5 sites
- creek bank qualitative survey for potential overflow sites under elevated tide stage

Freshwater Nutrient Flows to Green Harbor River

Daily freshwater nitrogen loads from the watershed of Green Harbor River to the estuary were evaluated to obtain an integrated estimate of N loading from all sources in the watershed up-gradient of the site of the stream gauge (Figure 1). This value represents the actual nitrogen reaching the estuary (i.e. after natural attenuation), rather than the nitrogen input to the watershed. Estimates of nitrogen loading were obtained using bi-weekly measured freshwater flows combined with continuous water level data obtained by a pressure transducer and data logger in place from July – October, 2006 (Station GH Stream, Figure 1). Stream flows were determined bi-weekly from direct measurements of stream cross sectional area and velocity. Stream discharge was represented by the summation of individual discharge calculations for each stream subsection for which a cross sectional area and velocity were obtained. The formula used to obtain stream flow (discharge) is:

$$Q = \Sigma (A*V)$$

where:

Q = Stream discharge (m^3/sec)
A = Stream subsection cross sectional area (m^2)
V = Stream subsection velocity (m/sec)

The stream discharge calculated for each subsection is summed to obtain the total discharge for the stream at the site (Figure 1). The bi-weekly stream discharge measurements were used to develop a stage-discharge relationship (rating curve) that was, in turn, used to obtain estimates of discharge volumes from the detailed record of stage measurements (made every 10 min.) recorded from the pressure transducer to the attached data logger. Stage data were averaged to obtain hourly stage estimates. The rating curve was applied to these data to estimate hourly discharge. The hourly data were combined to yield a 24 hr flow estimate. The resulting daily flows were merged with nutrient data collected at the stream site (Figure 2) to determine N loading rates to the lower river (Table 1).

Figure 1. Station Locations for freshwater flow measurements, for water quality sampling and for sediment porewater sampling in Green Harbor River, July – October, 2006.

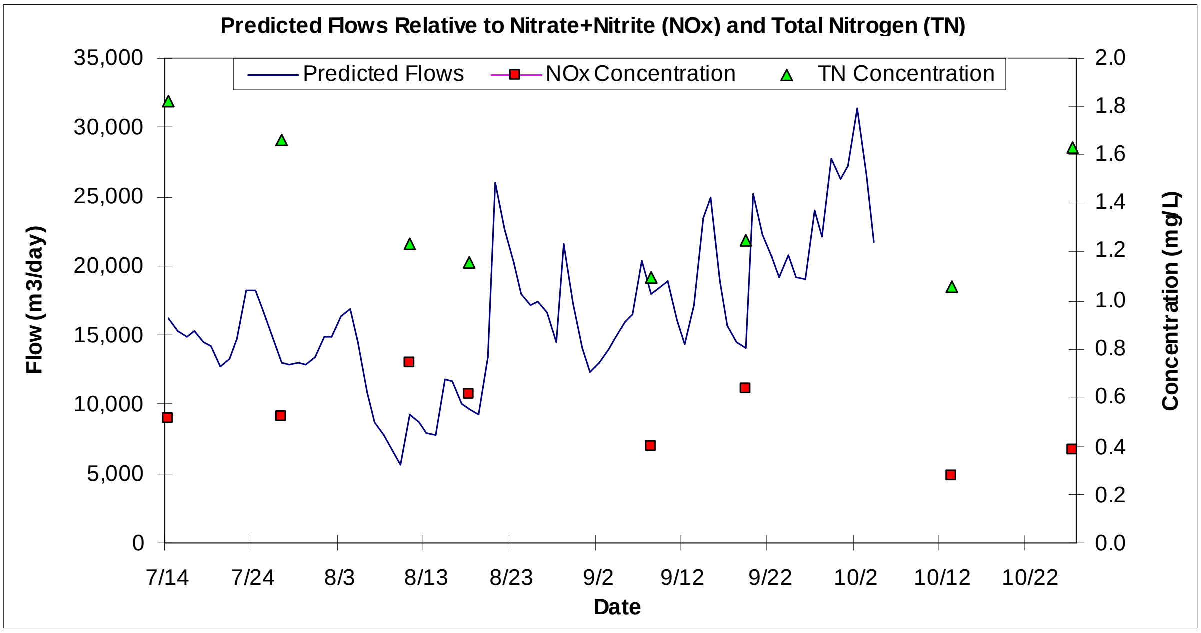

Figure 2. Predicted flows relative to Nitrate/Nitrite (NOx) and Total Nitrogen (TN) concentrations, Green Harbor River July to October, 2006.

Parameter	Daily Flux			Concentration			
	Mean	SD	Units	Mean	SD	N	Units
Freshwater Flow	16,391	5,287	m^3	NA	NA	NA	NA
Salt	3,016	597	Kg	0.2	0.0	7	ppt
PO4	0.60	0.18	Kg	0.042	0.017	7	mg/L
NH4	1.24	0.89	Kg	0.108	0.084	7	mg/L
NO3	7.04	0.79	Kg	0.571	0.120	7	mg/L
DIN	8.24	1.41	Kg	0.679	0.123	7	mg/L
PON	1.57	0.50	Kg	0.109	0.041	7	mg/L
Bioactive N	9.81	1.84	Kg	0.792	0.134	6	mg/L
Organic N	9.13	3.23	Kg	0.692	0.265	6	mg/L
Total N	17.37	4.43	Kg	1.371	0.299	6	mg/L
Total Pigments	50.66	12.32	g	3.53	2.08	7	ug/L

Table 1. Mean daily (± SD) fluxes of freshwater, salt and nutrients and mean salt and nutrient concentrations from samples collected from the freshwater site (Station GH Stream) in Green Harbor River.

It appears that the freshwater inflow from the Green Harbor River represents virtually all of the freshwater runoff and groundwater recharge from the upper watershed (3.29 sq miles, watershed #2) and its associated watershed within the lower watershed (0.49 sq miles, watershed #1) delineated by the U.S. Army Corps (1983). The total daily average stream flow, based on water balance (annual rainfall of 27.5" yr^{-1}: obtained from DEP/SMAST Massachusetts Estuaries Project data base), from these watershed areas is estimated at 16,310 m^3 d^{-1} compared to the measured average flow over the study period of 16,391 m^3 d^{-1}. This agreement in predicted versus measured flows supports the contention that the stream is the predominant transport pathway for freshwater and associated nutrients, from its associated watershed into the estuary. It should be noted that estimates of freshwater leaving the estuary through the tide gates on the ebbing tide of 14,600 m^3 d^{-1} (described below) also agrees well with these estimates. This latter estimate is based upon the modeled tidal flows and the measured salinity within the lower estuary and boundary waters.

The measured daily rates of total nitrogen input to the Green Harbor River Estuary, 17.4 kg N d^{-1} (Table 1) or 6,355 kg N yr^{-1}, are similar to N loads to estuaries quantified by the DEP/SMAST Massachusetts Estuaries Project (www.oceanscience.net/estuaries). Many of the suburban and rural watersheds of similar sizes in s.e. Massachusetts have been found to range from 5,299-8290 kg N yr^{-1}. While a quantitative watershed nutrient loading analysis was not part of the present effort, it appears that the water quality within the Green Harbor River does not result from an inordinately high nitrogen input from the upper watershed. Instead, it appears that the impaired nutrient related water quality within the estuarine reach results from the integration of its restricted tidal flushing and its present nitrogen input, primarily from the River's freshwater reach.

The stream nitrogen loading to the estuarine reach of the Green Harbor River Estuary is typical of groundwater fed streams in permeable aquifers in southeastern MA. The overall flow is relatively constant over the study period and there was relatively small variation in the levels of inorganic and organic nitrogen species. In addition, 47% of the stream nitrogen load is in inorganic forms (nitrate and ammonium), predominantly nitrate, generally indicative of a groundwater transport pathway prior to entering the surface water flow (Table 1). However, there was also significant organic nitrogen, of which 17% was in particulate form.

Water and Nutrient Exchanges, Restricted Green Harbor River Basin

Nutrient related water quality parameters were assayed bi-weekly at 10 sampling sites throughout the estuarine reach of the restricted portion of the Green Harbor River from July – October 2006 (Figure 1). Samples were collected at mid-depth and analyzed for salinity, Orthophosphate (PO4), Nitrogen series and Chlorophyll pigments. Mean concentrations and standard deviations were calculated for all nutrient data and are shown in Table 2.

The water quality (nitrogen, chlorophyll a pigments) clearly indicate estuarine waters that are eutrophic, nitrogen-enriched to the point where associated water column and subtidal habitats are likely impaired. The total nitrogen levels are very high by comparison to most estuarine waters, (~2 mg TN L^{-1}), throughout most of the estuary. Generally, total nitrogen levels above 0.7 mg TN L^{-1} are associated with impaired estuarine benthic habitats. Similarly, chlorophyll a pigments above 10 ug L^{-1} are indicative of nitrogen enrichment and average levels of 30 ug L^{-1}

or higher are indicative of severe nutrient-related stress. Within the upper Green Harbor River Estuary, total pigments averaged >50 ug L-1, consistent with the total nitrogen data and strongly suggestive that the subtidal benthic habitat is impaired.

The water column data can be coupled with the hydrodynamic modeling results to indicate the amount of the various constituents that are exported from the restricted estuarine reach to the down-gradient basin. It is also possible to determine the amount of freshwater discharged through the tide gates during each tidal cycle using the modeled water flows through the gates at flood and ebb tide combined with the measured salinities in the lower portion of the restricted estuary (Stations GH 4&6, Figure 1) and in the unrestricted area down-gradient of the tide gates (Station GH 5). This calculation assumes that over long periods of time, the system is maintaining salt balance (i.e. not storing or losing salt). Based upon an average flood volume of 67,324 m^3 per tide and estuarine and boundary salinities of 24.4 ppt and 27.1 ppt, respectively, a freshwater outflow of 7,450 m^3 per tide can be calculated. This estimate agrees well with the stream inflow measurements described above (16,310 – 16,391 m^3 per day).

Estimates of constituent mass transport through the tide gate is straight forward and indicates that there is a net export of nitrogen from the restricted estuarine reach to the lower basin of 10.93 kg per tide (21.42 kg TN d^{-1}). This estimate suggests that there is little additional net nitrogen input directly to the upper estuary other than from the Green Harbor River freshwater discharge. Note that net nitrogen input, is input in excess of any nitrogen removal that occurs during transport through the estuary, primarily through denitrification. Determination of the actual nitrogen input to the estuary through groundwater inflow and attenuation during transport was beyond the scope of the present effort. However, it does appear that nitrogen export through the tide gates may be a significant input to the estuary down-gradient of the tide gates.

Comparing the relative shifts in the abundance of nitrogen species from the freshwater stream discharge point through the estuary to the tide gates and in the down-gradient tidal export clearly indicates that the restricted estuarine reach is converting inorganic nitrogen into organic forms, most likely through phytoplankton production. Nitrate is the largest fraction of the nitrogen pool in the stream waters, with inorganic nitrogen representing 47% of the TN pool. In contrast, in the lower estuary (GH4&6), inorganic nitrogen represents only a small fraction of the TN pool, 8%. This pattern of conversion of inorganic to organic nitrogen forms during passage through an estuary is characteristic of temperate systems. If the nitrogen inputs are sufficiently high, this conversion, through phytoplankton production, leads to observed negative effects on estuarine habitats (eutrophication), and is the cause for the present conditions in the upper Green Harbor River Estuary.

Increasing tidal exchange within the restricted region of the estuary would almost certainly improve the nutrient-related water quality due to the decreased residence time of waters within the basin. In addition, as long as the present nitrogen removal processes that occur during transport in Green Harbor River remain unchanged, the total nitrogen loading to the down-gradient estuary will also remain unchanged. However, it is not possible to fully determine the effects of increased tidal exchange in this system on nitrogen export from the present study.

Table 2. Mean concentrations (± SD) of salt and nutrients taken over a 6 week period from September – October 2006 in Green Harbor River

Location	Station	N	Salinity (ppt)		PO4 mg/L		NH4 (mg/L)		NOX (mg/L)		DIN (mg/L)		Bioactive N (mg/L)		Organic N (mg/L)		Total N (mg/L)		Total Pigments (ug/L)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Green Harbor River	GH Stream	9	0.2	0.0	0.046	0.017	0.090	0.074	0.511	0.154	0.605	0.179	0.730	0.181	0.759	0.276	1.364	0.296	3.65	0.82
Green Harbor River	GH1A	4	3.3	1.6	0.036	0.017	0.038	0.042	0.188	0.123	0.226	0.148	0.733	0.428	1.195	0.705	1.421	0.571	32.79	49.11
Green Harbor River	GH1	1	13.6	NA	0.017	0.000	0.008	NA	0.004	NA	0.012	NA	1.880	NA	2.666	NA	2.677	NA	**116.79**	NA
Bass Creek	GH2A	3	12.6	8.0	0.010	0.007	0.105	0.071	0.020	0.014	0.090	0.089	1.203	0.212	1.863	0.059	1.952	0.096	57.18	33.89
Bass Creek	GH2	1	11.1	NA	0.008	0.000	0.010	NA	0.006	NA	0.016	NA	1.117	NA	1.829	NA	1.845	NA	70.97	NA
Green Harbor River	GH7	4	19.7	2.8	0.012	0.006	0.007	0.006	0.011	0.011	0.016	0.016	1.528	0.937	1.987	1.007	2.003	1.014	86.30	55.12
Wharf Creek	GH3	4	19.5	7.2	0.010	0.004	0.036	0.012	0.094	0.122	0.121	0.128	1.671	0.388	2.166	0.303	2.287	0.429	76.46	14.64
Green Harbor River	GH6	4	24.9	3.0	0.006	0.002	0.026	0.018	0.027	0.040	0.052	0.053	0.277	0.091	0.631	0.123	0.683	0.128	13.94	9.43
Green Harbor River	GH4	4	23.9	3.1	0.009	0.003	0.026	0.017	0.028	0.031	0.054	0.046	0.225	0.085	0.563	0.082	0.616	0.124	7.70	6.92
Marina	GH5	4	27.1	1.4	0.014	0.004	0.039	0.013	0.022	0.014	0.061	0.025	0.216	0.054	0.498	0.066	0.559	0.082	7.19	2.25

DIN = Dissolved Inorganic Nitrogen, the sum of NH4 and NOx concentrations
Bioactive N = DIN + PON (Particulate Organic N)
Organic N = Dissolved + PON
Total N = Organic N + DIN
Total Pigments = Chlorophyll a + Pheophytin

Sediments
The chemistry of the wetland sediments in Green Harbor River are the proximate determinant of the species mix and productivity of the plant communities. The ultimate determinant is the depth and extent of tidal flooding and the salinity of flood waters. Sediment properties within the restricted and unrestricted marsh areas of Green Harbor River were assayed in order to predict potential plant community changes pre- to post-hydrodynamic alteration and to quantify post-alteration changes. Because there is no typical salt marsh habitat within the restricted portion of the Green Harbor River system, the majority of wetland areas exist within the small intertidal zone along the shoreline of the river. *Phragmites* dominates in the lower portion of the river while freshwater species such as *Typha* mix with the *Phragmites* in the upper reaches of the river and its tributaries, Wharf and Bass Creeks.

Primary sediment assays included porewater salinity, sulfate and sulfide (a plant growth inhibitor), and bulk sediment properties. Porewater samples were collected from marsh sediments September 21, 2006 at 2 sites along the shoreline in the restricted portion of Green Harbor River and from 1 control site in the unrestricted salt marsh below the dike (Figure 1). At each of the 2 restricted sites, plots were established in the sediments along the shore. In the salt marsh below the dike, plots were established in low, high and *Phragmites zones* (Figure 1). In each plot, duplicate porewater samples were collected from 3 depth intervals: 0-5 cm, 5-10 cm and 10-15 cm. Samples were analyzed for salinity, sulfate and sulfide. Sediment cores (0-5 cm) were taken from all sites where porewater was sampled and analyzed for % water, bulk density, % Carbon and % Nitrogen.

Salinities. Sediment porewater salinities were lowest (< 10 ppt.) at Site 1 in the upper reaches of the river, higher (12-17 ppt.) at Site 2 near the mouth of Wharf Creek, and highest (30-31 ppt.) in the salt marsh downstream of the restriction at the dike (Figures 1 and 3).
At Site 1, the mean salinity decreased from 7.1 ppt. at 0-5 cm to 5.8 ppt. at 5-10 cm to 4.9 ppt. at 10-15 cm (Figure 3).
Site 2 salinities showed the same depth gradient, decreasing from 16.4 to 15.8 to 12.6 ppt. at the same depth intervals (Figure 3).
At the unrestricted site, salinities in low and high marsh sediments showed no depth gradient and were in the 30-31 ppt. range at all depths (Figure 3). Salinities in the *Phragmites* zone were lower than in the low or high marsh zones, increasing slightly with depth from 20.6 ppt. at 0-5 cm to 21.8 and 21.7 ppt. at 5-10 and 10-15 cm, respectively. The lower salinities found in the restricted sites are due to flows and impoundment of groundwater from the watershed. Site 1 is furthest upstream and closest to the headwaters of the river. Site 2 is slightly more saline due to its closer proximity to the dike and to salt water intrusion through the dike from the unrestricted portion of Green Harbor River. Salinities in the unrestricted low and high marsh zones are more typical of New England coastal wetlands subjected to regular unimpeded tidal flooding. In the *Phragmites* zone of the unrestricted salt marsh the relatively lower salinities compared to the low and high marsh zones show the importance of groundwater and road runoff to this site along the upland border of the marsh.

The restoration of tidal exchange will not just increase the frequency and extent of flooding, but should increase the salinity of flood waters in Green Harbor River and its associated wetland areas. This increase in salinity is due to the larger volume of saline tidal waters entering the now restricted portion of the river, thereby diminishing the amount of salinity dilution that can occur from the "fixed" rate of freshwater inflow. Therefore, increasing tidal exchange through the dike provides multiple mechanisms for the shift from fresh and brackish plant communities to the *Spartinas* typical of salt marsh habitat.

Sulfate

Sediment porewater sulfate profiles followed a similar pattern to salinities (Figure 4). Mean concentrations were lowest at Site 1, ranging from 6.2 mM at 0-5 cm to 5.0 mM at 5-10 cm and 4.6 mM at 10-15 cm.

At Site 2 near the mouth of Wharf Creek, mean concentrations decreased slightly from 15.8 mM at 0-5 cm to 14.8 mM at 5-10 cm to 5.4 mM at 10-15 cm (Figure 4).

At the unrestricted site, sulfate in the low marsh slightly decreased with depth from 23.1 mM at 0-5 cm to 22.8 mM at 5-10 cm to 19.5 mM at 10-15 cm. In the high marsh sediments, mean concentrations increased slightly from 19.9 mM at 0-5 cm to 21.8 mM at 5-10 cm and then decreased slightly to 21.4 mM at 10-15 cm.

At the *Phragmites* site, mean concentrations were lower than in the low or high marsh zones, increasing slightly from 14.4 mM at 0-5 cm to 14.9 mM at 5-10 and 10-15 cm (Figure 4).

Porewater sulfate concentrations at each of the sites mirror their corresponding salinities. Since sulfate is supplied to wetland sediments by flooding tidal waters, higher salinities indicate larger stores of sulfate in sediment porewaters. As with salinities, lowest sulfate concentrations are located at Site 1, furthest upstream from the dike and the highest levels are in the tidally unrestricted porewaters of the low and high marsh zones. The *Phragmites* zone has lower concentrations of sulfate due to groundwater intrusion and road runoff along the upland border.

As stated above, restored tidal flooding will increase the salinity of the river which includes higher sulfate concentrations. These flooding waters will, in turn, act as a larger source of sulfate to sediment porewaters.

Sulfides

Mean porewater sulfide concentrations at Site 1 were 23.3 uM at 0-5 cm decreasing to 8.1 uM at 5-10 cm and increasing slightly to 10.3 uM at 10-15 cm (Figure 5).

At Site 2, concentrations were below detection at 0-5 cm but increased to 32.7 uM at 5-10 cm and 342.0 uM at 10-15 cm (Figure 5).

At the unrestricted site, sulfides in the low and high marsh plots were significantly higher than at the 2 restricted sites. Mean low marsh concentrations increased with depth from 17.2 uM at 0-5 cm to 118.1 uM at 5-10 cm to 385.0 uM at 10-15 cm. In the high marsh sediments, mean concentrations increased 165.8 uM at 0-5 cm to 462.2 uM at 5-10 cm to 636.1 uM at 10-15 cm.

At the *Phragmites* site, mean concentrations were lower than in the low or high marsh zones, increasing slightly from 7.4 uM at 0-5 cm to 51.2 uM at 5-10, decreasing to 27.4 uM at 10-15 cm (Figure 5).

Since wetland sulfides are a product of biological sulfate reduction in anoxic sediments, porewater sulfide concentrations were generally directly proportional to sulfate levels at the 3 study sites in Green Harbor River. Site 1 had both the lowest sulfate and sulfide concentrations while porewaters in the salt marsh below the dike had levels much higher than either site in the restricted portion of the river and typical of porewater sulfides in coastal New England salt marshes. In addition, sulfide concentrations were higher in the deeper, anoxic sediments than in the more surficial, relatively oxidized layers at Site 2 and in the tidally unrestricted marsh. Site 1 had no consistent depth gradient but was severely depleted of sulfides relative to the other 2 sites.

As porewater sulfate concentrations increase with the restoration of tidal flooding to the river, sulfate reduction in the anoxic sediments will increase and with it, sulfide levels. Higher sulfide concentrations in the porewaters will create a more inhospitable environment for *Phragmites* and other brackish/freshwater plant communities. These physiologically stressful conditions will promote the re-invasion of the wetlands by *Spartina* grasses which have internal mechanisms for survival in such conditions.

Bulk Sediment Properties

The top 5 cm of sediment at each of the porewater sites were analyzed for % water, bulk density, % carbon and nitrogen. Sediments at Site 1 contained the highest % water (84.5) and % carbon (23.3) and nitrogen (1.51), and the lowest bulk density (0.16 g/cm^3) (Table 3). Site 2 sediments had a bulk density of 0.38 g/cm^3, 67.1% water and were 7.53% carbon and 0.51% nitrogen (Table 3). In the salt marsh below the dike sediment properties were similar in the low and high marsh zones. Bulk density was 0.27 and 0.33 g/cm^3, respectively, % water was 72.1 and 75.3, % carbon was 11.40 and 11.64, and % nitrogen was 0.83 and 0.91, respectively. Sediments in the *Phragmites* zone were 62.4% water with a bulk density of 0.57 g/cm^3, and were 9.28 %carbon and 0.71% nitrogen (Table 3).

Sediments at Site 1 had a lower density but higher carbon and water content than sediments at Site 2 or in the unrestricted marsh below the dike (Table 3). Site 1 is likely an area of deposition of organic-rich fine particles from upland soils while Site 2 and the *Spartina* marsh outside the tide gates contain sediments with more inorganic materials deposited by offshore waters on flooding tides.

Freshwater within the emergent "marsh"

The general observations of surface water and sediment salinities within the emergent areas of the restricted region of the Green Harbor River Estuary are consistent with the hydrodynamic data and modeling, which indicate that flooding by estuarine waters is uncommon, except in the lower areas directly adjacent to the tidal creeks in the lower basin. The surface of much of the upper emergent "wetland" is dominated by freshwater plants, typically species that are sensitive to salt water. It appears for preliminary analysis that these areas have developed a freshwater lens in response to the artificially low Mean Sea Level (MSL) in the tidal creek versus in the adjacent bay. The lower MSL and lack of tidal flooding with saline waters is the mechanism through which this freshwater lens could develop in response to direct precipitation and some localized surface water inflows (Figure 3, Table 2). The extent to which this lens may be associated with the larger upland groundwater flow system is not known at this time, but most likely this association would be limited to the southwestern portion. Based upon this conceptual model, re-establishment of tidal flooding would most likely have its largest initial impact on sediment salinities in the northern and eastern low lying regions.

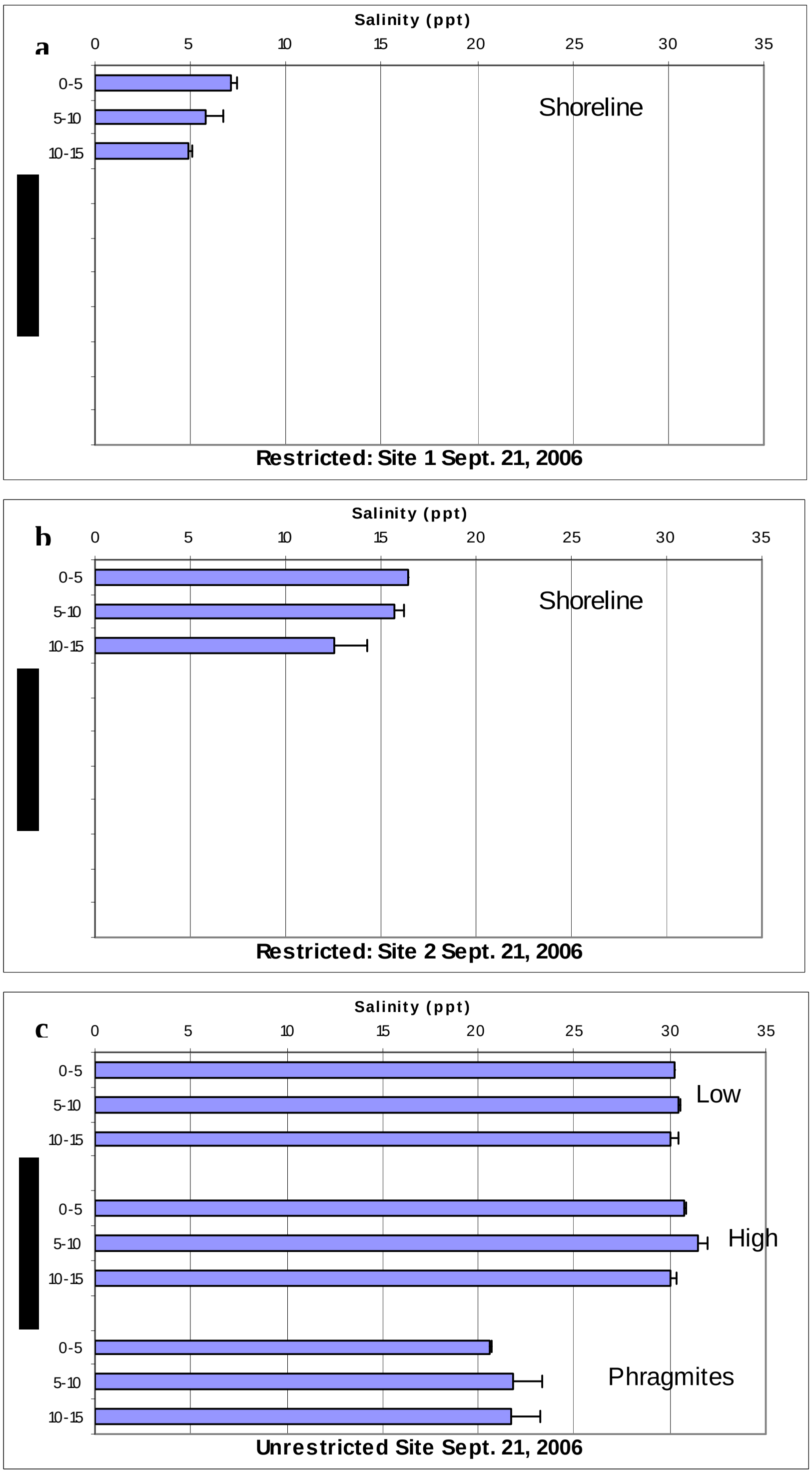

Figure 3. Salinity profiles in tidally restricted and unrestricted wetland sediments in the Green Harbor River system, September 21, 2006

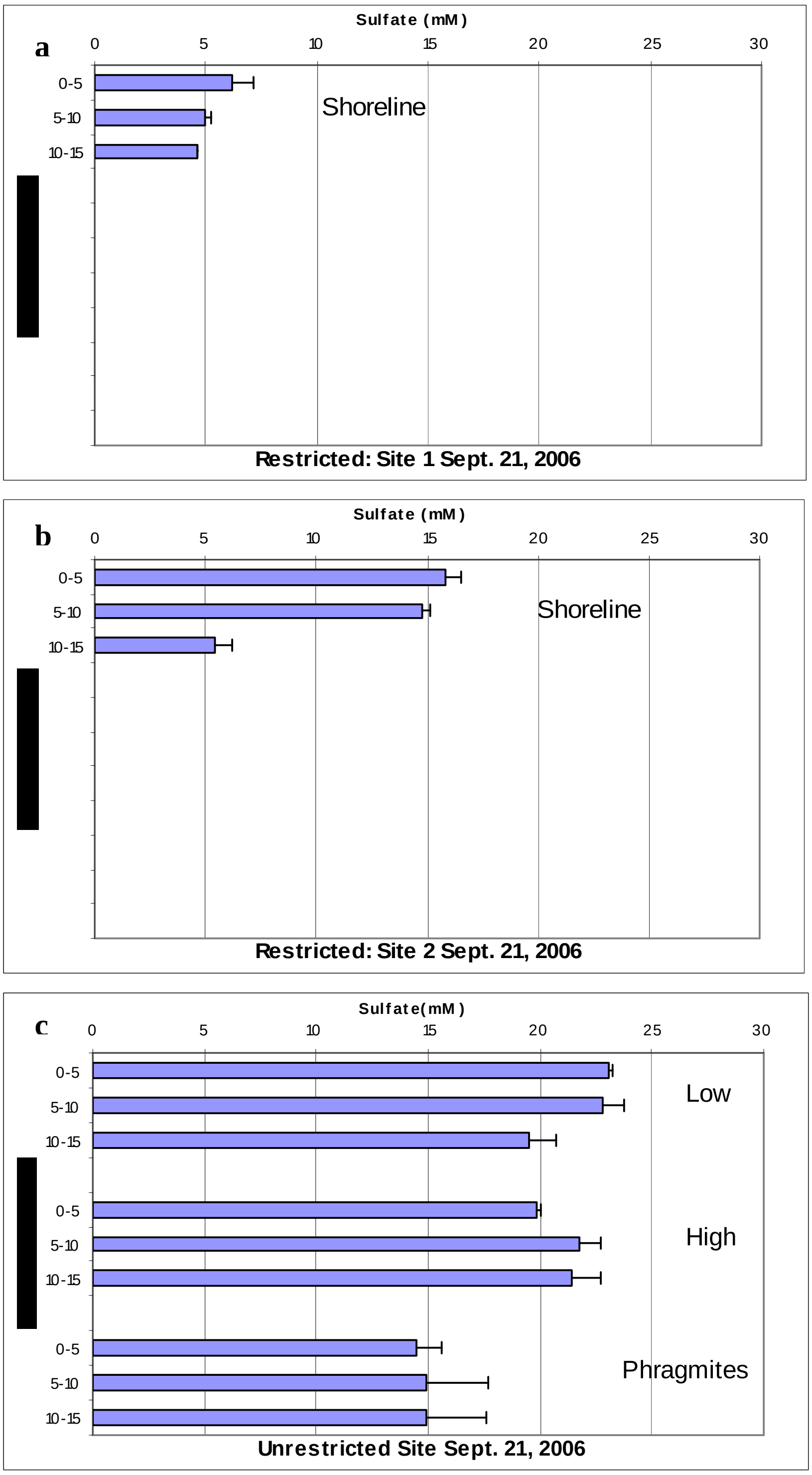

Figure 4. Sulfate profiles in tidally restricted and unrestricted wetland sediments in the Green Harbor River system, September 21, 2006

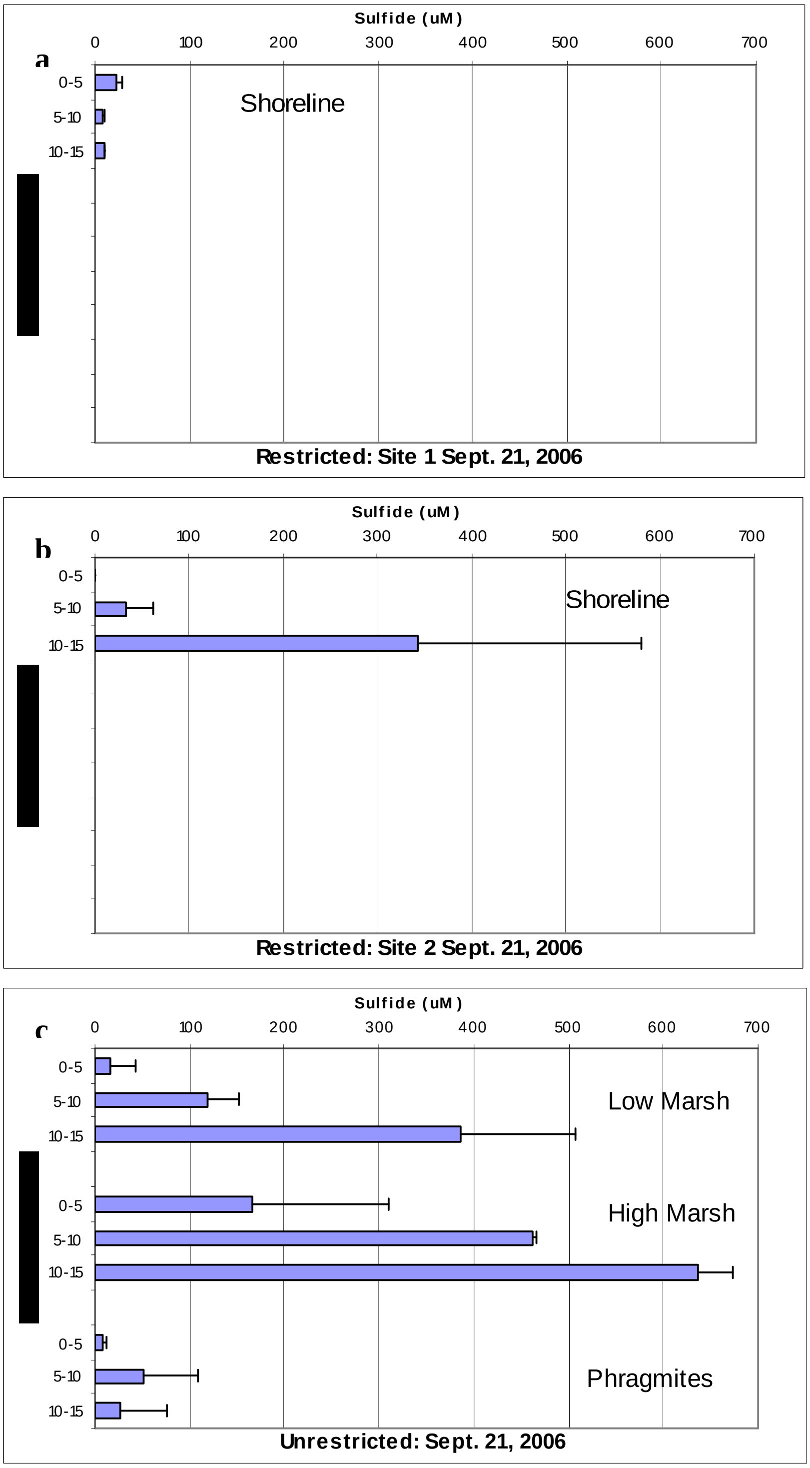

Figure 5. Sulfide profiles in tidally restricted and unrestricted wetland sediments in the Green Harbor River system, September 21, 2006.

Table 3. Sediment properties in the top 5 cm. in tidally restricted and unrestricted wetland sediments in the Green Harbor River system, September 21, 2006.

Station ID	**% Water**	**Dry Bulk Density g/cm^3**	**%C**	**%N**	**C/N**
Restricted Site 1	84.5%	0.16	23.33	1.51	17.97
Restricted Site 2	67.1%	0.38	7.53	0.51	17.19
Unrestricted Low Marsh	72.1%	0.27	11.40	0.83	16.09
Unrestricted High Marsh	75.3%	0.33	11.64	0.91	14.87
Unrestricted *Phragmites*	62.4%	0.57	9.28	0.71	15.16