Soils, Sediments, and Contamination

Richard A. Orson
Orson Environmental Consulting

William Price
Yale School of Forestry and Environmental Studies

Sasha Weinstein
Yale School of Forestry and Environmental Studies

ABSTRACT
Tidal flow has been restricted from the West River Marsh between Routes 1 and 34 in New Haven, Connecticut for the better part of this century. This has resulted in drier, less saline conditions within West River Memorial Park. Additional impacts to the system include placement of fill on the marsh surface and urban development along the borders and throughout the watershed. Changes in hydrology and the addition of fill have degraded the habitat and changed the system from a tidally flushed salt marsh to a poorly-drained, brackish wetland dominated by reedgrass (Phragmites australis). Our analysis of soils and sediments indicates that West River Memorial Park was a well-developed salt marsh system prior to tidal restriction. Sediments are not contaminated with high levels of metals, and the marsh system can be restored without negative impacts to water quality. Sediments that were placed as fill can be moved to create upland islands within the restored marsh system. This will allow for the re-establishment of salt marsh areas while creating a more diverse habitat and reducing costs of removing fill. Discussion in this chapter focuses on the soils, sediments, and water quality changes associated with the restoration of the West River Memorial Park tidal marsh.

Substrate characteristics are very important for the development of a wetland system. The structure and composition of the substrate will determine water holding capacity, nutrient cycling processes, and filtering capacity of the marsh system. The type of sediments and their salt concentrations influence soil chemistry and biogeochemical pathways. The rate at which these sediments accumulate also influences development of the plant community and, in combination with soil characteristics, controls the cycling and sequestering of pollutants within these systems (Orson et al. 1992a).

Substrates in tidal salt marshes are typically silts and clays mixed within an organic peat matrix. Accumulated plant remains form the most important component of salt marsh substrates. The roots, rhizomes, and culms of marsh grasses are well preserved due to wet, oxygen-depleted conditions and salts. Because this material is slow to decompose, it accumulates over time and forms the basis for vertical marsh development (McCaffrey and Thomson 1980, Orson and Howes 1992). Although most peat forms from accumulation of the in-situ organic fraction (plant remains), a portion of the substrate
is dependent on external sediment sources. When tidal marshes are located along the open coast, much of the mineral sediment comes from the reworking of near shore areas (erosion and resuspension). However, when the marsh is located along a river, such as the West River system, mineral sediments also come from local upland sources as well as mineral sediments of the watershed that are carried downstream (both suspended and bedload).

Since marshes occupy the lowest elevations of the landscape, and their substrates accumulate from both local and regional sources, the substrates record the depositional history of a watershed, its land use patterns (i.e., periods of erosion), and its pollution history. These marshes act as sinks in the landscape (Nixon 1980, Simpson et al. 1983); they retain sediments, thereby keeping river channels from filling with muds, and they sequester and retain pollutants from the open water column, thus reducing negative impacts to downstream aquatic environments.

POLLUTION CONTROL

The mechanisms by which tidal marshes retain and sequester pollutants are only beginning to be understood (Orson et al. 1992a). Some pollutants accumulate in vegetation and are transferred to the substrate as plant material is buried and decomposes (Giblin et al. 1980, Simpson et al. 1983, Orson et al. 1992a). Uptake of pollutants by vegetation can be seasonal. During the growing season, plants can actively limit the uptake of heavy metals. But, when plants are dormant during fall and winter months, their culms and roots absorb higher concentrations of pollutants directly from the water column and transfer it to the substrate (Simpson et al. 1983, Orson et al. 1992a).

Other pollutants that are carried on highly reactive clay and silt particles can accumulate in sediments. Pollutants carried on clays and silts settle too slowly to be removed from moving water. However, when these suspended particles flow over a vegetated surface water movement slows down. Grasses act as baffles in the water column, and particles have time to settle out of the water on to the marsh surface.

Suspended particles may also accumulate in the marsh system as a result of flocculation. Flocculation occurs as freshwater bearing suspended matter mixes with saltwater. Positive salt cations reduce the natural negative charge of the particles, allowing them to combine into aggregates. The aggregates grow in size, and eventually settle out of the water column.

Coastal tidal marshes are nutrient limited systems (Valiela and Teal 1974, Mendelssohn 1979, Simpson et al. 1983). Because of this, they can remove large concentrations of nitrogen and phosphorus when tides are restricted from flowing over salt marshes, the marsh substrates not only lose the ability to remove pollutants, but can release pollutants into the aquatic ecosystem.
from the water column (DeLaune and Patrick 1980, Aziz and Nedwell 1986, Wiegert and Penas-Lado 1995) by processes in their sediments and substrates (Thompson et al. 1995). Thus, tidal marshes are important for maintaining the health of the estuary by limiting impacts of enriched upland runoff and problems associated with nutrient enrichment of adjacent water bodies.

Tidal marsh substrates are also important sites for many biogeochemical pathways. For example, sulfuric acid, a principal constituent of acid rain, can be cycled to a less acidic form (hydrogen sulfide, pyrite) in salt marsh substrates, thus mitigating the influences of acid precipitation on coastal waters (Dent 1986).

Tidal marsh sediments and substrates also provide habitat for many species of coastal invertebrates including economically important crabs and shellfish. Mussels require a muddy substrate within specific elevations on a vegetated marsh surface (Olmstead and Fell 1974). The distribution of many crab species is also dependent on sediment grain size. Other benthic organisms (i.e., tube worms) are sensitive to grain size as well as rates of sedimentation within stream channels. Because many fish and birds feed on benthic organisms, sediments and substrates are important for maintaining trophic food webs.

TIDAL RESTRICTION

When tides are restricted from flowing over salt marshes, as in the case of West River Memorial Park, a number of changes occur. Some of the pollution remediation processes described above are reversed. As saltwater is excluded, freshwater inputs from rain and upstream drainage reduce substrate salt concentrations. Tidal restriction also lowers water tables and increases the exposure of substrates to air. Subsequent dewatering of sediments and increases in the decomposition of organic matter preserved in the peat often result in compaction of the substrate and a corresponding loss of elevation of the marsh surface (Roman et al. 1984).

The increase in freshwater and oxygen penetrating further into the substrate can alter biogeochemical pathways as well. For instance, reduced sulfur compounds (i.e., pyrite, hydrogen sulfide) that were stable in the salt marsh may oxidize and produce sulfuric acid that is released back into the water column (Dent et al. 1976). Releasing acids can also remobilize heavy metals that have been bound to clay and organic particles. Oxidized sediments can also degrade organic matter and contribute to changes in metal complexes that can then be released into the water column (Allen et al. 1990). As a result, oxidation of marsh soils and the remobilization of heavy metals and other pollutants due to tidal restriction can negatively impact water quality.
SALT MARSH RESTORATION AND WATER QUALITY

Experience has shown that when tides are returned to a formerly restricted marsh system there is a decline in water quality within the first few months due to flushing of stored contaminants out of the peat. In time, however, constant tidal flushing usually reverses the impacts of restricted flow and restores the former water quality of the system.

Marsh systems that have been drained or restricted often show a marked increase in anoxic or hypoxic conditions, which may negatively impact fish and benthic organisms. After tidal flushing has been restored, the effects of oxygen depletion can be reversed, and the habitat can return to more stable oxygen conditions.

A well inundated tidal salt marsh is very effective as a sediment sink within the landscape. In systems where saltwater has been restricted, the loss of flocculation and an increase in peat decomposition will increase the amount of suspended load available to the river system. When tides are reintroduced to a marsh there may be an immediate flush of clays and silts out of the system. But this flush is temporary. As tidal flushing continues, flocculation will increase, decomposition will decrease, and the salt marsh benthic community can become reestablished. These changes will decrease the amount of suspended load available to the river and aid in reducing sediment deposition downstream. Within a few growing seasons after the reintroduction of tides, the negative effects of tidal restriction can be reversed and improvements to water quality achieved.

METHODS

Preliminary sampling of soils and sediments was necessary to identify the type and depth of fill deposited on the marsh surface, characterize the marsh community prior to tidal restriction, and identify potential problems associated with soil chemistry that might result from salt marsh restoration within West River Memorial Park. Heavy metal contamination of existing substrates was of concern, because of the watershed’s industrial history and because the source of fill was uncertain.

To characterize the marsh substrates and determine the depth of the former marsh surface, sediment cores were taken using a Russian peat sampler (a manual side chambered coring device). Continuous cores were removed in sections from two locations on the north peninsula. The first core was considered a preliminary sample, and only the second, more detailed core (Fig. 1) is discussed here. The core extended down to a depth of 2.5 m and represented the zone that will be most affected by the reintroduction of tides. Each core

Figure 1. Soil sample and core locations in West River Memorial Park, New Haven, Connecticut.
section was analyzed for color, texture, and plant remains. Dominant
substrate color changes were noted immediately upon removal of
the sediments by comparisons to a Munsell Color chart (Orson et
al. 1992b). To characterize changes in dominant plant communities
through time, we determined the relative abundances of plant taxa
at various depths using roots and rhizomes preserved within the
peat (Niering et al. 1977, Orson et al. 1987, Orson and Howes
1992). Changes in grain size, plasticity, stickiness, and mineral content
and texture were determined using field identification techniques de-
scribed by U.S. Soil Survey Staff (1975).

Metals analysis and preliminary characterization of fill material
were conducted by hand-digging eight pits. Pit locations (Fig. 1)
were chosen to represent observed variations in elevation and
vegetation. According to field observations, elevation differences
corresponded well with vegetative cover and provided a good
estimator for locating pits that would represent a variety of condi-
tions (Table 1). (Elevations relative to National Geodetic Vertical
Datum were based on maps compiled by Kenny and Barten 1993.)

We dug pits with a shovel until the water table was reached
(usually within the first 36 cm), then continued with a bucket auger.
Soil horizons were designated based on observed shifts in color,
texture, or amount of preserved organic matter. Samples were taken
from most horizons for laboratory analysis of metal concentrations,
organic fraction, color, and texture. Samples were sealed in Ziploc
bags and transported back to a laboratory for storage and analysis.

To determine the presence of pollutants, samples were ashed and
analyzed for heavy metals including cadmium (Cd), copper (Cu),
lead (Pb), and zinc (Zn). Approximately 0.5 g of sample was air
dried, sieved, and then oven dried at 100°C for two days. Samples
were then re-weighed and ashed overnight at 500°C. Organic con-
tent was estimated from weight loss on ignition (LOI) and was
calculated as

\[
\text{% LOI} = \frac{(\text{oven dry weight} - 500^\circ\text{C weight})}{(\text{oven dry weight} - \text{crucible weight})} \times 100
\]

<table>
<thead>
<tr>
<th>Elevation (NGVD)</th>
<th>Solidago spp.</th>
<th>Rubus spp.</th>
<th>Phragmites spp.</th>
<th>B. populi folia</th>
<th>Q. palustris</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5-3.5</td>
<td>Site 1 &amp; 5</td>
<td>Site 6 &amp; 7</td>
<td>Site 2 &amp; Core</td>
<td>Site 3</td>
<td>Site 4</td>
</tr>
<tr>
<td>3.5-4.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.5+</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
These criteria are from the Connecticut State Remediation Standards. Regular, direct contact with these levels of contamination in residential areas would pose a risk to human health. Although the restoration area is not residential, these state criteria are presented to represent minimum acceptable levels of contamination. A mass-analysis extraction method is used to estimate the state criteria exposure levels. We also used mass-analysis, but our reaction strengths were much more aggressive than those used by either the state or US EPA. Therefore, our method would result in higher estimates of contamination. Nevertheless, our results remain well below the state criteria.

Table 2: Sediment characteristics and metal concentrations of soil samples taken from the potential salt marsh restoration area in West River Memorial Park, New Haven, Connecticut.

<table>
<thead>
<tr>
<th>Site</th>
<th>Depth (cm)</th>
<th>Texture</th>
<th>%LOI</th>
<th>Cd mg/kg</th>
<th>Cu mg/kg</th>
<th>Pb mg/kg</th>
<th>Zn mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>0-8</td>
<td>SLTCLY</td>
<td>16.8%</td>
<td>0.4</td>
<td>12.0</td>
<td>87.1</td>
<td>37.7</td>
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<tr>
<td></td>
<td>8-17</td>
<td>SLTCLY</td>
<td>8.5%</td>
<td>0.6</td>
<td>4.4</td>
<td>14.1</td>
<td>35.1</td>
</tr>
<tr>
<td></td>
<td>17-30</td>
<td>SLTCLY</td>
<td>10.5%</td>
<td>0.4</td>
<td>4.6</td>
<td>10.9</td>
<td>52.0</td>
</tr>
<tr>
<td></td>
<td>&gt;30</td>
<td>SLTCLY</td>
<td>5.7%</td>
<td>0.2</td>
<td>5.1</td>
<td>6.7</td>
<td>19.0</td>
</tr>
<tr>
<td>Site 2</td>
<td>0-8</td>
<td>SLTCLY</td>
<td>41.7%</td>
<td>0.6</td>
<td>27.6</td>
<td>174.5</td>
<td>35.8</td>
</tr>
<tr>
<td></td>
<td>8-24</td>
<td>SNDY</td>
<td>1.5%</td>
<td>0.3</td>
<td>2.1</td>
<td>26.4</td>
<td>29.7</td>
</tr>
<tr>
<td></td>
<td>&gt;24</td>
<td>SLTCLY</td>
<td>6.6%</td>
<td>0.2</td>
<td>4.8</td>
<td>6.7</td>
<td>24.0</td>
</tr>
<tr>
<td>Site 3</td>
<td>13.5-26</td>
<td>SLTCLY</td>
<td>6.9%</td>
<td>0.4</td>
<td>6.4</td>
<td>31.5</td>
<td>27.8</td>
</tr>
<tr>
<td></td>
<td>26-36.3</td>
<td>SNDY</td>
<td>2.5%</td>
<td>0.1</td>
<td>3.0</td>
<td>7.2</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td>36.3-46.5</td>
<td>SLTCLY</td>
<td>5.1%</td>
<td>0.3</td>
<td>5.9</td>
<td>17.5</td>
<td>27.2</td>
</tr>
<tr>
<td>Site 4</td>
<td>8-43.5</td>
<td>SNDY</td>
<td>1.9%</td>
<td>0.3</td>
<td>3.4</td>
<td>15.2</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>43.5-56</td>
<td>SNDY</td>
<td>2.7%</td>
<td>0.1</td>
<td>5.8</td>
<td>16.5</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>56-70.8</td>
<td>SLTCLY</td>
<td>6.3%</td>
<td>0.3</td>
<td>15.7</td>
<td>64.3</td>
<td>24.4</td>
</tr>
<tr>
<td></td>
<td>&gt;70.8</td>
<td>SNDY</td>
<td>0.7%</td>
<td>0.1</td>
<td>3.4</td>
<td>1.7</td>
<td>9.5</td>
</tr>
<tr>
<td>Site 5</td>
<td>5-9</td>
<td>SLTCLY</td>
<td>9.9%</td>
<td>0.4</td>
<td>3.3</td>
<td>20.2</td>
<td>21.5</td>
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<tr>
<td></td>
<td>10-15</td>
<td>SLTCLY</td>
<td>11.7%</td>
<td>0.4</td>
<td>4.8</td>
<td>23.6</td>
<td>19.2</td>
</tr>
<tr>
<td></td>
<td>15-18</td>
<td>SLTCLY</td>
<td>7.0%</td>
<td>0.3</td>
<td>2.5</td>
<td>19.3</td>
<td>17.1</td>
</tr>
<tr>
<td></td>
<td>18-23</td>
<td>SLTCLY</td>
<td>9.4%</td>
<td>0.3</td>
<td>2.5</td>
<td>13.8</td>
<td>20.6</td>
</tr>
<tr>
<td></td>
<td>54</td>
<td>SLTCLY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>108</td>
<td>SLTCLY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site 6</td>
<td>0-6</td>
<td>SLTCLY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6-14</td>
<td>SLTCLY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>62</td>
<td>SLTCLY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site 7</td>
<td>30.5</td>
<td>SLTCLY</td>
<td>11.09%</td>
<td>0.4</td>
<td>9.2</td>
<td>24.6</td>
<td>27.7</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>SLTYSND</td>
<td>4.96%</td>
<td>0.2</td>
<td>18.5</td>
<td>45.5</td>
<td>27.3</td>
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<tr>
<td></td>
<td>105</td>
<td>SNDY</td>
<td>1.49%</td>
<td>0.1</td>
<td>5.9</td>
<td>9.6</td>
<td>12.7</td>
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<td>Connecticut Residential Criteria</td>
<td>N/A</td>
<td>N/A</td>
<td>34.0</td>
<td>2500.0</td>
<td>500.0</td>
<td>2000.0</td>
<td></td>
</tr>
</tbody>
</table>

1 SLTCLY = silty clay, SNDY = sandy, and SLTYSND = silty sand.
2 These criteria are from the Connecticut State Remediation Standards. Regular, direct contact with these levels of contamination in residential areas would pose a risk to human health. Although the restoration area is not residential, these state criteria are presented to represent minimum acceptable levels of contamination. A mass-analysis extraction method is used to estimate the state criteria exposure levels. We also used mass-analysis, but our reaction strengths were much more aggressive than those used by either the state or US EPA. Therefore, our method would result in higher estimates of contamination. Nevertheless, our results remain well below the state criteria.
Ashed samples were digested with 50 ml 6N HNO₃, and analyzed for Cu, Cd, Zn, and Pb using inductively coupled plasma emission spectroscopy (Perkin Elmer).

To estimate the area within West River Memorial Park that can be restored through the reintroduction of tides, topographic surveys from 1924 (City of New Haven Parks Department) and a preliminary survey from 1993 (Kenny and Barten 1993) were compared for differences in elevation. The area to be restored was estimated based on a preliminary approximation of areas of fill and subsidence.

RESULTS AND DISCUSSION

The soil core indicated that salt marsh existed at the site for many centuries prior to construction of tide gates within the last 100 years. Evidence of a salt marsh system extended from a depth of approximately 2.5 m to 0.9 m (not adjusted to NGVD). More recent material taken between 1.3 m and 0.9 m indicated the decline of salt marsh and establishment of a mixed community. Between 0.9 m and 0.5 m there was evidence that the organic material was highly decomposed, and suggested a shift toward drier conditions. Sand dominated the sediments above 0.5 m, showing the depth of fill at that location. *Phragmites* rhizomes were identified within the upper 0.5 m of vertical development, indicating recent establishment of a *Phragmites* community. Due to compaction as a result of surface drying and placement of fill, it is not possible to assign precise dates to these horizons without further research.

Our preliminary analysis of metals did not indicate high concentrations of Cd, Cu, Pb, or Zn at any site or depth (Table 2). Contamination is typically assessed using U.S. Environmental Protection Agency (US EPA) methods and criteria (US EPA 1979). Our metal extraction method was more aggressive than the US EPA method, and this complicates direct comparison with regulated contaminant levels. However, comparison of our results with other New England sites tested using our method indicated that metal concentrations in the sediments from West River Memorial Park were low (Gaboury Benoit, Yale F&ES, personal communication). In most instances, our samples had lower concentrations of heavy metals than many upland forested areas within the region (Thomas Siccama, Yale F&ES, personal communication). Furthermore, metal concentrations in our samples were well below Connecticut’s standards for residential areas (Table 2).

A complex mosaic of sediment types and layering is typical in areas affected by severe, spatially heterogeneous disturbances. Thus, we sampled to characterize a variety of observed sediment types and presumed sediment sources. This is reflected in the variation
of metal concentrations within and among pits. Sediment metal concentrations show expected correspondence with texture class and organic matter content (estimated using LOI). Where textures were finer (silty-clays), and organic matter higher (e.g., 42% for a sample from Pit 2), metal concentrations were highest. The opposite was true for the coarser sediment fractions (sands) with lower organic matter (<10%). We would expect these patterns to occur throughout the area we did not sample. Calculating metal levels more precisely would require more detailed mapping of soil types throughout the park.

A preliminary approximation of the area which can be restored using area below 2.5 ft National Geodetic Vertical Datum (NGVD) is shown in Table 3. Only the areas between the dredged channel and the West River were considered, because the athletic fields and other developed perimeter areas will not be restored to salt marsh. The estimates presented here are based on surveys conducted by Kenny and Barten (1993) and represent a preliminary estimate of the potential area to be restored. Before restoration plans can proceed further, a more detailed topographic survey of the site should be conducted.

**HISTORIC CONDITIONS**

Based on core analysis, West River Memorial Park includes an area that began developing as an open mud flat thousands of years ago. Salt marsh vegetation became established during the time represented within the 2.5 m depth of our core. Material taken from the core between 2.3 m and 1.3 m indicated that a mature salt marsh community, complete with low and high marsh, had developed. Material above 1.3 m indicated subsequent changes to the system. Salt marsh grasses were replaced by other species, which suggests some hydrologic manipulation at the time. These observations are consistent with those from other sites that have been subjected to hydrological manipulations and agriculture, both on the sites and throughout the watersheds.
The shifts in vegetation and the highly decomposed nature of the organics between 0.9 and 0.5 m may correspond to the period when tide gates were installed at the mouth of the marsh system. Drying would have increased decomposition and led to compaction of the marsh surface. When sandy fill was added to the marsh surface (indicated within the uppermost 0.5 m) substrates were further compacted. This probably led to additional lowering of the marsh surface, somewhat offsetting increases in elevation due to the placement of fill on the marsh. Conditions which favored the colonization of reedgrass during the last fifty years include lowering of the marsh surface (flooding kept other upland species from invading the site), the addition of sand (better drainage), and the reductions in salts in the sediments (from continual freshwater flushing).

Surface topographic surveys will be important in estimating how much area can be restored in West River Memorial Park by increasing tidal flushing alone. Surveys conducted by New Haven’s Department of Parks, Recreation and Trees in 1924 showed that the elevation of these “meadows” was 2.0 to 2.5 ft NGVD. Recent surveys by Kenny and Barten (1993) showed that a reference salt marsh located downstream near Spring Street has an elevation between 2.5 and 3.0 ft NGVD. Therefore the target elevations for restoration at West River Memorial Park should be about 2.5 ft NGVD. Restoration may require lowering the surface of areas identified by Kenny and Barten (1993) to be above 3.0 ft NGVD. Areas situated between 2.0 and 2.5 ft. NGVD may be left intact depending on the water elevations achieved after tides have been reintroduced. Areas significantly lower than 2.0 ft NGVD may be too low for restoration and will revert to open water unless additional fill is used to raise the surface to at least 2.0 ft NGVD. Using these estimates of elevation, complete tidal flushing would restore 45% of the present marsh area located on the center island. If, on the other hand, the fill is removed and the surface regraded, the area of marsh restoration can be doubled.

The Connecticut Department of Environmental Protection’s Wetland Restoration Unit could move sediments and regrade the marsh surface using their amphibious equipment. Although the methods and the technology to move the fill are available, there are economic considerations that must be included in the final analysis. Removal and dewatering of marsh sediments can be very expensive. An alternative to removal of sediments from the site is moving the fill into piles to create upland islands on the marsh surface (Rozsa and Orson 1993). Creating islands would reduce costs of fill disposal and increase habitat diversity.
HEAVY METAL POLLUTION AND WATER QUALITY

Results of the metals analysis show that concentrations of heavy metals are low and will not be of concern when tidal flushing is restored to the system. Although there may be a slight decrease in water quality as flushing begins (i.e., oxygen content, Portnoy 1991; nutrient mobilization, Seitzinger et al. 1991), this should be limited and will probably only last for the first few months. Restoration of the West River Memorial Park should result in better water quality within the first few years of the project.

RESTORATION PROBLEMS AND GOALS

Reestablishing surface elevations will be contingent upon the final goals of the restoration effort. We suggest that the system be restored to an elevation capable of supporting low marsh habitat (ca. 2.25 to 2.75 ft. NGVD). This will help increase the pollution filtering capacity of the site, because low marshes are inundated on all high tides, not just spring tides. A low marsh design will also protect against invasive plant species. Some of the plant species currently growing at the site are tolerant of saline conditions, but only salt marsh grasses are tolerant of both salts and extensive flooding. By considering tide height and surface elevations in the restoration plan, the amount of active management (e.g., planting *Spartina* spp. or removal of invasives) can be greatly reduced.

The best substrate for the growth of the plants will be the former salt marsh peats. However, in areas where the peats have subsided and are below the flooding tolerance of salt marsh plants, fill can be used to raise the surface elevations. This fill can be taken from existing areas where the elevations are too high.

The reintroduction of tidal flushing will eventually return the substrate in the West River Marsh to a highly reduced, saline condition. The rate of recovery and the time required to return the function of the system will depend upon the ability to control surface elevations in relation to flooding and to replace the biological processes of the system. Past experience with restoration projects in Connecticut suggests that, depending on factors such as funding and the amount of active management, restoration can begin almost immediately, although it will require five to fifteen years to be complete (Rozsa 1995). As the system is restored, its function will also return. Eventually the system will act as a sink for sediments and pollutants within the watershed and provide habitat for coastal biota. Based on other restoration projects, the system should stabilize within two decades and remain a healthy ecosystem if its hydrology is not further altered.
CONCLUSIONS

The West River Memorial Park was a salt marsh system for many centuries before it was degraded. Salt marsh restoration will return the habitat to its former function in the landscape and improve the water quality of the West River ecosystem. Since levels of metal contaminants found within the sediments were low, it will be possible to use existing sediments and fill to create upland habitats (islands) while restoring large portions of marsh habitat. The system is restorable, and plans should proceed to reverse years of neglect and damage to a very important urban, salt marsh habitat.

REFERENCES


RICHARD A. ORSON
A paleoecologist with over 15 years experience in tidal marsh restoration and environmental management, Dr. Orson has degrees in biology and botany and received his Ph.D. in Ecology at Rutgers University in 1989. A former Assistant Professor of Geography and Environmental Sciences, he has had his own environmental consulting firm since 1995. His research interests include impacts of sea level rise on coastal marsh development, modelling heavy metal accumulations in wetland systems, and applications of paleoecology to managing coastal habitats. Dr. Orson was a member of the original team that helped establish the State of Connecticut's coastal marsh restoration program.

Richard A. Orson, Orson Environmental Consulting, P.O. Box 921, Branford, CT 06405, Tel: (203) 483-9234, Fax: (203) 481-1189, raorson@aol.com

WILLIAM PRICE
William Price received a B.S. in Biology at the University of Notre Dame. He has worked for NASA, studying soils hydrology in boreal ecosystems, and the U.S. Forest Service’s Pacific Northwest Research Station, studying forest productivity. He is currently pursuing an M.F.S. degree at the Yale School of Forestry and Environmental Studies (F&ES), focusing on the socio-economic linkages between water resource use and aquatic ecosystems.

William Price, Yale School of Forestry and Environmental Studies, 205 Prospect St., New Haven, CT 06511, william.price@yale.edu

SASHA WEINSTEIN
Sasha Weinstein received her B.S. in Environmental Science from Brown University. Before resuming her formal education, she worked in several urban parks and preserves where she designed and taught environmental education programs, led restoration activities, and conducted wetlands research. Sasha is currently a Master's student at Yale F&ES studying urban open space planning and management.

Sasha Weinstein, Yale School of Forestry and Environmental Studies, 205 Prospect St., New Haven, CT 06511, sasha.weinstein@yale.edu