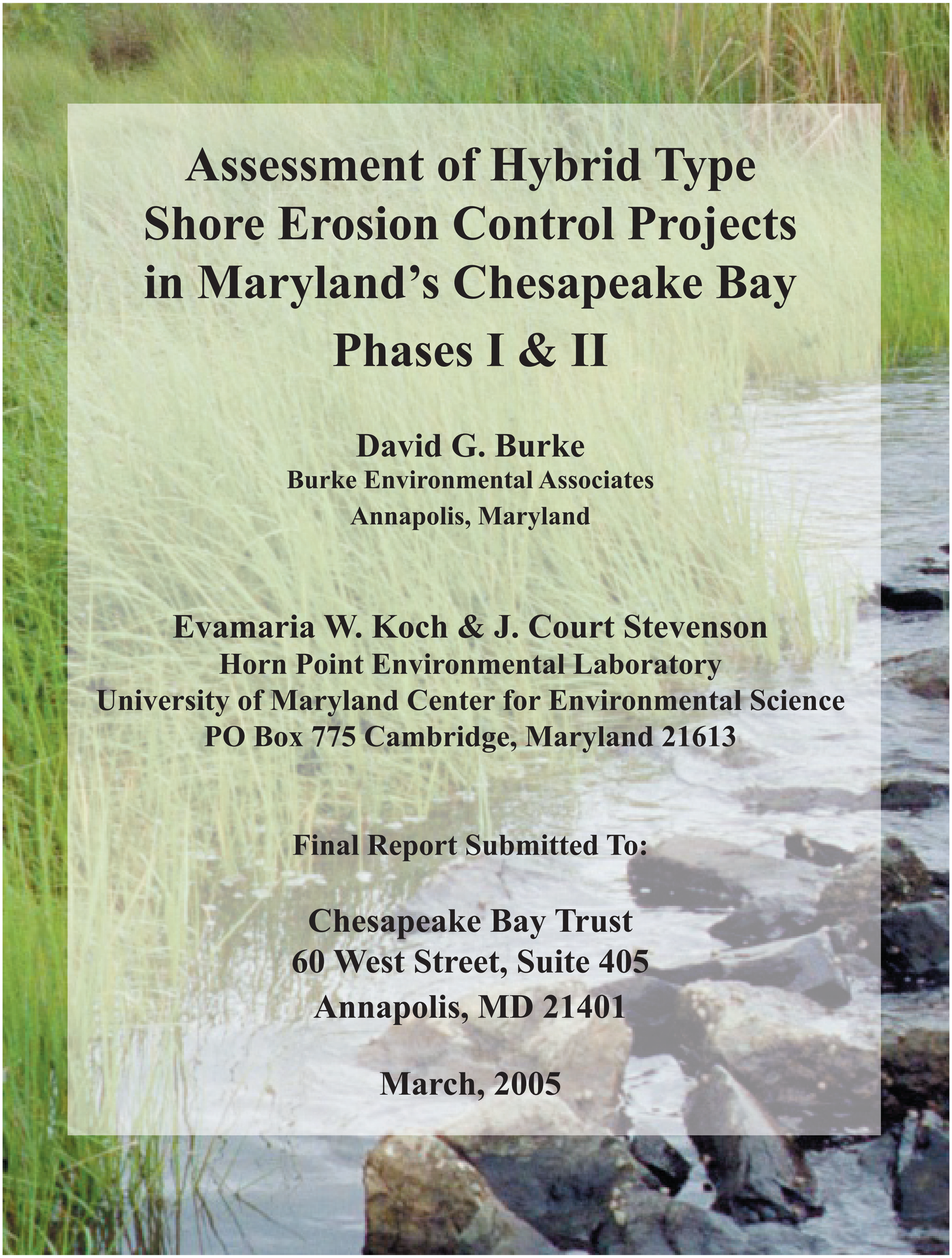

Assessment of Hybrid Type Shore Erosion Control Projects in Maryland's Chesapeake Bay

Phases I & II

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Executive Summary

Shoreline erosion around the edges of Chesapeake Bay has long been viewed as a problem by landowners prompting them to try many means to control it. Often the solutions involved hardening the shoreline with rock revetments, groins and a variety of other structures varying from wooden bulkheads to piles of tires staked along the edge of the Bay. However, these structural solutions had considerable drawbacks. Not only were many of them unsightly, but also they often eliminated sensitive marsh and beach habitats at the edge of the Bay which are key in maintaining a variety of traditional Bay species such as Terrapin turtles. Over the last several decades the concept of non-structural shoreline protection emerged whereby scarps or bluffs of eroding shorelines were re-graded and planted with marsh vegetation. Although non-structural approaches often stabilized low wave energy shorelines, establishment of marshes alone is often insufficient to resist wave action in areas with considerable wave energy. Over the last decade there have been a variety of hybrid type "Living Shoreline" projects where a combination of structural and non-structural approaches were employed to arrest shore erosion, while attempting to maintain them as productive habitats. These have become increasingly popular in the upper Chesapeake in recent years and have drawn considerable amount of public as well as private funding. However, despite the increasing reliance on hybrid approaches and a variety of designs which have now been put in place, little or no comparative assessment of these projects has yet been carried out. The purpose of this project is a comprehensive study of success and difficulties of a range of recent hybrid projects, so that recommendations could be formulated and provided to the public.

During the spring and summer of 2004, a survey team from the University of Maryland, Burke Environmental Associates, and J.A. Rice Inc. assessed 8 separate hybrid type shore erosion control projects. The projects consisted of 4 Maryland Department of Natural Resources sites (Phase I sites) and 4 Chesapeake Bay Trust sites (Phase II sites). The projects were originally funded and managed by Maryland Department of Natural Resources (DNR), Shore Erosion Control (SEC) program, and Chesapeake Bay Trust (CBT). All projects involved the creation and restoration of marsh fringe habitat using sand fill material and marsh plantings contained by a breakwater, stone groins perpendicular to the shoreline, or rock sills – generally set parallel to the shoreline a short distance offshore. Two sites created fringe marsh habitat through the use of stone containment groins (Wye NRMA; Eliott R.) while 6 sites (Aspen Institute 1996 and 1998; Epping Forest; Jefferson Patterson Park & Museum; London Town and South River Farm Park) predominantly used sills to create fringe marsh habitat. One of the 6 sites, Jefferson Patterson Park, also used an attached, planted breakwater system to establish a sand beach and fringe marsh component. The study team worked with representatives from Maryland Department of Natural Resources, Coastal Zone Management Division and SEC to select the Phase I locations. The principal objective of the study was to document physical and biological changes that occurred at each site and along the immediate shoreline environment between the initial installation and the assessment. The assessment is one component of a Chesapeake Bay Living Shorelines Stewardship Initiative that has been launched to better understand how these techniques

have performed and to formulate improved technical guidance for future non-structural and hybrid type erosion control projects (a.k.a. “living shorelines”). The study was concurrently funded by the DNR Coastal Zone Management Division through a grant from the National Oceanic and Atmospheric Administration, and the Chesapeake Bay Trust

Data collected *in situ* and analyses performed in the lab during the study incorporated a variety of elements including: a land survey of the bank, marsh, and physical structures in cross-section, showing location and elevations; transects through the marsh community and near shore environment detailing plant species characteristics, wildlife usage and other biological conditions of the marsh habitat and submerged aquatic vegetation (SAV); wave period and height; marsh and near shore sediment characteristics; near shore depth profiles; water column nutrient concentration; and epiphytic loading.

The 8 living shoreline sites examined by the research team had variable erosion and marsh stability responses that, to a great extent, reflected the basic purpose of the project and the degree of structural protection associated with the fringe marsh. Two projects were designed more for habitat benefits than erosion control. These “habitat first” projects experienced the greatest shoreline or bank erosion; and marsh stress or direct loss of shoreline. These sites used different, very low profile sill configurations to protect the fringe marsh areas during non-storm conditions. The 2 stone groin projects experienced a moderate degree of marsh stress or loss. The remaining 4 sites used sills and a breakwater system to achieve erosion control first and habitat creation as a secondary benefit. As a class of projects, the “erosion control first” group had the least erosion and habitat loss.

A few key factors contributed to the relative success of the “erosion control first” sites. These sites generally deployed more massive, higher elevation sill structures and a breakwater system to attenuate wave energy and achieve a more stable environment where little or no bank or shoreline erosion occurs and the marsh communities are mostly healthy. In contrast, at the “habitat first” and groin sites, a number of variables including: bank erosion; higher average fetch; substrate conditions; boat wakes; steepness of marsh gradients; marsh shading; movement of groin structures; and littoral drift patterns intervened to present additional stress to the marsh community, causing greater loss of overall vegetated area and shifts in plant species. Healthy SAV populations adjacent to coastal structures have the potential to further contribute to wave attenuation. These aquatic plants were found adjacent to a variety of structures (sills, groins, breakwaters) suggesting that their presence may not be detrimental to SAV. Instead, water quality and depth seemed to be the parameters that determined the presence or absence of SAV adjacent to the coastal structures studied.

Part I: Summary of Project Assessment Locations and Types

Background

Shoreline erosion around the edges of Chesapeake Bay was noted as a problem as early as the 1600s when marked boundary trees along the shoreline separating property owners fell into the Bay, prompting many disputes that had to be resolved by local land commissions. Later in the 1700s one of the signers of the Declaration of Independence, Charles Carroll, wrote a letter to his father complaining that erosion was a greater threat to their plantation at Poplar Island than the British! Perhaps not surprisingly the first serious efforts to stabilize the shoreline were around the early ports and landings in the eighteenth century. These were usually bulkheads and similar structural approaches, modeled after European efforts to curtail erosion along the Thames and other estuaries. These were often costly and only used sporadically by wealthy landowners and towns to protect their landings in the vicinity of quays and piers in the colonial period. However, the expansion of steamboat lines in the 19th Century brought about many more projects throughout the Chesapeake. Preferred methods involved placement of wood, brick or stone (where locally available) at the waters edge, which hardened the shoreline.

In the 20th Century, with the increasing availability of high quality cheap cement and concrete, many more miles of shoreline were armored. Barges also brought large rocks and boulders to many tidewater shorelines from quarries at the fall lines of major tributaries and were used to armor the shore. Early in the 1900s structural approaches also included construction of groins running perpendicular to the shoreline which could also trap particulates from long shore currents. Of course, less affluent shoreline owners often resorted to a variety of makeshift structures including desperation moves such as piles of tires staked along the edge of the Bay to help reduce wave action. Despite their varying ability to arrest erosion, these structural solutions have considerable ecological and other drawbacks. Not only were many of them unsightly, but also they often eliminated the convoluted and complex habitats at the edge of the Bay. These low lying marshy areas are often viewed as being important for key species in the shallows including the Terrapin turtles – one of Maryland's emblematic species.

In the last quarter of the 20th Century, the concept of non-structural shoreline protection emerged in Chesapeake Bay primarily through the initial efforts of Dr. Edgar Garbisch who founded Environmental Concern.   Instead of relying on physical structures he advocated the re-grading of scarps or bluffs of eroding shorelines to produce gentle slopes which were then planted with native marsh species such as "Common Cordgrass", *Spartina alterniflora*.   Although non-structural approaches often stabilized shorelines with low wave energy, it is now clear that marsh establishment is often insufficient to resist wave action, particularly in areas with considerable wave energy. Over the last decade there have been a variety of hybrid type projects constructed where a combination of structural and non-structural approaches were employed to arrest shore erosion, while attempting to maintain them as productive habitats. These have become popular in many tributaries of the upper Chesapeake in recent years and have drawn considerable amount of public as well as private funding. However, because of the increasing reliance on hybrid approaches, and despite the plethora of projects that have now been put in place, there is little or no consensus on the relative merits of various designs. Our goal here is to do a qualitative and quantitative assessment of these to ascertain the effectiveness of various approaches. This should allow better recommendations to public and private shoreline owners who are interested in not only slowing erosion rates on their property, but also in protecting the prospects for a variety of living resources which depend on the Bay's shoreline.

Chesapeake Bay Trust and Maryland Department of Natural Resources awarded grants to the University of Maryland Center for Environmental Science, Horn Point Laboratory to conduct an assessment of 8 separate Chesapeake Bay shore erosion control projects that were completed during the time period of 1990 to 1998. Additional staff support for the project was provided through a Keith Campbell Foundation grant. The authors of this report include: David G. Burke, Burke Environmental Associates LLC; Dr. Evamaria Koch, University of Maryland Center for Environmental Science, Horn Point Laboratory; Dr. J. Court Stevenson, University of Maryland Center for Environmental Science, Horn Point Laboratory. Mr. Robert A. Kundrick, registered land surveyor with J.A. Rice, Inc., served as the project manager for the survey team. The assessment documents the physical and biological responses of certain types of shore erosion control projects that provide benefits beyond shoreline stabilization. These project types have been variously referred to as: 1) "non-structural" shore erosion control projects (using only marsh planting or beach replenishment & organic materials such as Coir fiber logs); 2) "hybrid" shore erosion control projects (using marsh plantings with stone containment groins, planted sills, continuous or segmented sills, breakwaters, and beach replenishment with breakwaters); and 3) "living shorelines" a recent term that includes both of the previous project types. The authors of this report define a "living shoreline treatment" as: **A shoreline management practice that provides erosion control benefits; protects, restores or enhances natural shoreline habitat; and maintains coastal processes through the strategic placement of plants, stone, sand fill and other structural and organic materials (e.g. bio-logs, oyster reefs, etc).** It is hoped that the information determined through this investigation will play a role in affirming or modifying construction and design guidance for future "living shoreline" treatments. This assessment work is being conducted in association with the multi-entity collaborative effort called the Living Shorelines Stewardship Initiative.

Under Phase 1 of this study, funded by Maryland Department of Natural Resources (DNR), 4 sites were examined. Each of the projects on these sites were originally funded (in part) and managed through the Shore Erosion Control (SEC) program of the Maryland Department of Natural Resources. The SEC program was established by law in 1968 to address shoreline and stream bank erosion problems along the main stem of Chesapeake Bay and tidal tributaries. SEC project management services typically involve a substantial amount of oversight and include several phases: initial technical assistance; application review; project agreements; design; construction; project payments; and loan repayments. The SEC program played an important role in providing guidance to the investigators in selecting appropriate sites to assess and by furnishing "as-built" drawings, project records, field notes and photos that were essential to performing the field analyses.

Under Phase II of this project, funded by the Chesapeake Bay Trust (CBT), 4 additional sites were assessed. Three of the Phase II sites were funded in part or entirely by CBT.

Project Selection

During the spring of 2004, project researchers and DNR representatives met to discuss selection criteria for the Phase I sites. DNR has funded over 400 non-structural shore erosion control projects that could be used as candidate assessment sites. To simplify logistical considerations and contain costs, it was decided to focus on projects that were located on the Eastern Shore in the Wye River area within close proximity to the University of Maryland, Horn Pt. Lab. The group established other criteria that included the following conditions to be met for a Phase I site to be selected:

1. Availability of design drawings (with “as-built” documentation);
2. An installation period dating back 5 years or more;
3. A variety of contractors;
4. A mix of public and private site locations to ensure greater likelihood of access;
5. A mix of characteristics in the physical setting of the sites including variations in bank type, bank height and wave climate;
6. A mix of project designs and types including various combinations of sills, and stone containment groins.

Phase II sites were selected on the basis of being funded by CBT and having a mix of: 1) shore erosion protection, with secondary habitat benefits; or 2) habitat creation with secondary erosion control benefits. Most of the Phase II sites did not have “as-built” survey documentation and therefore, did not provide a detailed basis for assessing performance based upon a known set of prior conditions. Nonetheless, the assessment included biological and physical indicators of performance that helped formulate an overall perspective of living shoreline treatments.

Table 1 provides an overview of the project locations including relevant statistics associated with each assessment location and type. To facilitate future assessments of these sites, specific transect lines and their corresponding “stations” are cited in the table. These “stations” make reference to survey locations that were either found on the original drawings and specifications (when these were available) or that were developed during this assessment by J.A. Rice, Inc. Transects containing elevation data, and other physical and biological information were collected at these stations. Appendix 2 contains elevation and some plant community information provided by J.A. Rice Inc. Also, where available, assessment sites are identified by a contract number which serves as a file locator for all information associated with the project.

Table 1. Project Locations – Phase I

Property Owner / Location	DNR Contract #	Waterway	Feet	Completed	Description
"Aspen '96" Aspen Institute Wye Woods Conference Facility Wye Woods Way – at Quarter Creek, Wye Island Queenstown, MD	NS-96-03	Wye River	660	11/25/1996	Marsh Fringe w/Segmented Sill (north) Transect Stations: 0+50; 1+50; 3+90; 6+40; Note: transects continue through sill structure & beyond
"Aspen '98" Aspen Institute – same as above	NS-SEC-98-01	Wye River	840	8/27/98	Marsh Fringe w/Continuous Sill – 265' (north) Transect Stations: 0+00; 1+00; 2+00 Segmented Sill (south) Transect Stations: 1+00; 2+00; 4+00; 5+00 Note: transects continue through sill & beyond
"Eliott Robertson" Peter & Frances Wolf 208 Brickhouse Dr., Queenstown, MD 21658	95-05 (Eliott Robertson)	Wye River	273	12/15/95	Marsh Fringe w/Stone Containment Groins (full & small size surface groins) Marsh Transect Stations: 0+00; 1+50; 2+73 (adjacent to groin) Groin Stations: 2 +73 (#5), #4, #3, #2, #1
"Wye NRMA" Wye Island VI Wye Island Natural Resources Mgt. Area, off Granary Creek Dr., Queenstown, MD	NS-89-04	Wye River	1142	9/27/90	Marsh Fringe w/Stone Groins (full size, partially embedded) Marsh Transect Stations: 42+70; 39+70; 35+70; 32+20; Groin Stations: 42+90 (groin-17); 39+65 (groin-13); 36+20 (groin-9); 35+20 (groin-8); 32+20 (groin-3)

Table 1. Project Locations – Phase II

Property Owner / Location	Contract/Grant #	Waterway	Feet	Completed	Description
"Epping Forest" Drevar Park; Epping Forest Subdivision; Drevar Circle & Severn Rd.; Annapolis, MD	CBT grant # 6236	Severn River at mouth of Saltworks Creek	a) 72'x23' (avg.) planted sill b) 95' sill with tombolo	Late fall, 2003	a) Attached, low profile, planted sill with irregular, crescent shape – transect #1 (station 0+39); b) stone sill – transect #2 (station 1+32)
"JPPM" Jefferson Patterson Park and Museum; JPPM Museum Services Center 10515 Mackall Rd St Leonard, MD 2068	Calvert SCD contract S.C.E. 03.05 Not funded by CBT	Patuxent River at mouth of St. Leonard Creek	a) 100'x 37' planter breakwater b) 178' sill c) 110' sill (approx.) d) 82' sill	a)1998 b)1999 c)1986 d)1986	a) Attached planter breakwater – transect #1(station 48+60) b) "Typical" sill with 1 "spur" opening– transect #2 (station 28+11) c) Low profile, continuous sill (over-topped by daily tides) – transect #3 (station 2+18 north) d) "Typical", continuous sill – transect #4 (station 0+50 north)
"London Town" London Town Public House	Anne Arundel Co. DPW contract # 2507-G; partially funded by CBT; no #	South River near mouth of Almshouse Creek	600'sill	1995	Continuous stone sill – transect #1 (station 2+00); transect #2 (station 3+00); transect #3 (station 4+00); transect #4 (station 5+00)
"South River FP" South River Farm Park	Funded by CBT; no #	South River at Mayo Pt.	1,657' sill	1995	Low profile, segmented stone sill – station 14+90; station 11+47 (transect #1); station 7+04 (transect #2); station 3+82; station 1+32

Part II: Procedures and Protocols

Transect lines for biological, geological and physical data collection were selected for each project based upon an evaluation of “as-built” engineering plans, “as-built” field survey notes, site conditions and the type and number of structures deployed at each location. For Phase II sites, where as-built drawings were generally unavailable, particular attention was paid to sampling areas that reflected typical site conditions and/or specific living shoreline treatments of special interest. Transect lines generally extend at a perpendicular angle from a selected landward point at or above the shoreline bank running across the shore and nearshore zones into shallow water beyond the location of any fill, planted area or shore protection structure. Transect lines generally followed the location of a survey station number taken from engineering drawings of the project site. Since the biological team conducted their survey before the land survey team, there are some differences in the number and location of the transect lines. Generally, the biological survey transect line is in close proximity to or is exactly the same as the land survey transect line. There are additional land survey lines to determine the top of perpendicularly extending stone containment structures. These lines also correspond to a selected location found on site engineering plans and “as-built” field survey notes compiled by J.A. Rice, Inc. or Resource Conservation and Development agency. A photographic record of the transect locations was also compiled.

Land survey and elevation data was collected with the following instruments: 1) NIKON A10 Total Station - 5 Second Accuracy; 2) SOKKIA Set 330R3 Total Station - 3 Second Accuracy. Cross-section plots and maps were prepared and saved in AutoCAD 2000 format. Control points for each project site were, to the extent possible, taken from points noted on engineering plans. Some points were not recoverable. The project at Wye Island NRMA had used wooden hubs, along their traverse line, which were not recovered. One control point was found between the two projects at Aspen Institute (Aspen 1996 and 1998). One control point was found at the Eliott Robertson site, now owned by Wolf. New control points were set at each site by J.A. Rice Inc.

The overall cover and health of the vegetation was assessed using transects which began at the toe of the scarp (point marked with a survey flag) and run out perpendicular to the bank over the marsh and sill (if present) to open water. The divisions of the vegetation zones were noted as well as bare spots and open water along the transect. The average height of canopy of each zone was noted and the cover was estimated in a ¼ square meter quadrat marked off in a 10 cm x 10 cm grid. The depth of water in the sub-tidal portion of the transect was determined by using a meter stick. This enabled the team to calculate the off-shore slope (as well as note the presence or absence of submersed plants). In addition to plants present along the transect, signs of animal usage were also noted (including fish, invertebrates etc). In addition, soil survey data was used to estimate bank erodibility at each location (Table 2).

Table 2. Site Soil Characteristics

Site	Soil Type on the bank and texture (% slope upland) & general embankment stability-erodibility
Aspen 1996*	Mattapex silt /fine sandy Loam (10-15%) highly erodible
Aspen 1998*	“ “ / “ “ “ (“ - “) “ “
Eliott R.*	Othello & Elkton Soils (5-10%) moderately erodible
Wye NRMA*	Matapeake Silt Loam (2-5%) moderately erodible
Epping Forest+	Collington, Wist & Westphalia (25-40%) highly erodible
JPPM+	Coastal Beaches (1-5%) not highly erodible
London Town+	Annapolis-Urbanland complex (5-15%) highly erodible
South River FP+	Donlonton Fine Sandy Loam (2-5%) potentially highly erodible
South River FP+	Colemantown Fine Sandy Loam ((0-2%) potentially highly erodible
South River FP+	Annapolis Loamy Sand (2-5%) potentially highly erodible
South River FP+	Annapolis Loamy Sand (5-10%) highly erodible

* Matthews & Reybold 1966. (Table 12, p.68).
+ National Soil Information System database, June 20, 2003. Anne Arundel County Maryland. URL: http://efotg.nrcs.usda.gov.

Sediment samples were collected along each transect line in the marsh area as well as in the sub-tidal area offshore of the structures. Where appropriate, a third sample was collected in the inundated area just shoreward of the breakwaters. Each sample was collected using a sediment core 5 cm in diameter. The top 10 cm were placed in a plastic bag and, in the lab, analyzed for sediment organic content (combustion at 450^{o}C for 4 hours) and grain size (sieving) according to Erftemeijer and Koch (2001).

Wave gauges (MacroWave, Coastal Leasing) were deployed offshore of the study site at a depth of approximately 70 cm. These recorded at a 5Hz frequency and a total of 4096 points were collected every 15 minutes and Fast-Fourier transformed (PCSpec, Coastal Leasing) in order to obtain significant wave height and wave period. The wave climate was recorded for a period of one week at each site.

Epiphytic cover is often measured as an indicator of water quality. At each site, ten artificial leaves (1 x 20 cm transparent plastic (Mylar) strips, n=10) were deployed at approximately 70 cm depth to estimate epiphytic loading (organic and inorganic; Brandt and Koch 2003). These were retrieved after 7 days in situ. Water column nutrient samples were collected at the same time and returned to the lab for analysis of total nitrogen and phosphorus as well as for various nitrogen (NH_4^+, NO_2 + NO_3, NO_3) and phosphorus species (PO_4). Water temperature was quantified every 15 minutes using an automated temperature logger (Stowaway, Onset Computers) positioned immediately adjacent to the epiphyte strips.

Part III: Site-By-Site Evaluation and Summary of Collected Data and Observations

Section A: Evaluation of Physical Parameters

A.1. Site Characteristics

Shoreline protection is usually required in areas undergoing wave-induced erosion where land loss is not acceptable. Therefore, wave parameters are of the essence when understanding the effectiveness of living shorelines. DNR sites tended to have shorter fetches (0.08 to 1.17 miles) than CBT sites (0.52 to 8.5 miles) (Table 3, Hardaway et al., 1992). All sites (except London Town) were exposed to the NW or S which are the directions from which the strongest winds originate in the Chesapeake Bay area suggesting that shoreline protection was necessary to attenuate storm waves. At London Town, wind-waves can still contribute to shoreline erosion but it appears that boat-induced waves may be the major component of shoreline erosion at this site.

Table 3. Fetch, Bank and Project Types

Site	Average/Longest Fetch (miles)	Direction	Bank Type & Angle low = <10' high = >10'	DNR SEC Project Type
Aspen 1996	0.49 / 1.17	NNW	high 40-45 degrees	hybrid
Aspen 1998	0.52 / 1.14	NNW	high same	hybrid
Eliott Robertson	0.07 / 0.08	SE	high 15 degrees	hybrid
Wye NRMA	0.16 / 0.46	SSE	low, except south end high -16' 40-45 degrees	hybrid
Epping Forest	0.82/2.42	SE	low 15-20 degrees (for parallel sill) low 5 degrees (for irregular sill)	hybrid
JPPM	2.14/4.2	S	low 15-20 degrees (for sills c & d) high 30-40 degrees (for sill b) low <5 degrees (for breakwater)	hybrid
London Town	0.52/0.96	NE	high 25-30 degrees (except 1st 200 feet)	hybrid
South River FP	2.55/8.5	SE	mostly high 40-50 degrees	hybrid

When boating activity is absent, fetch is a good indicator of the wave energy expected at a site. For example, the lowest wave energy was found at Eliott Robertson's site which also had the smallest fetch (Figure 1A). Waves at Aspen 1998, a site with a larger fetch, were comparable to those at Eliott Robertson. These were relatively small (< 0.1 m) perhaps due to the gentle offshore slope at the site or the relatively calm winds during the 7 day period over which the waves were recorded. CBT sites had slightly higher significant wave heights than DNR sites and the highest waves were observed at JPPM which also had a relatively high fetch. The highest waves for all sites (up to 0.5 m) were observed at Wye NRMA. While sampling, we observed boat-generated waves. One boat generated 37 waves which locally increased water turbidity. Therefore, the significantly higher waves at Wye NRMA could have been a result of boating activity. Extensive boat traffic in the London Town area also has the potential to affect the wave climate. Therefore, boat traffic should be considered when evaluating possible Living Shorelines and other coastal structures.

Sediment characteristics can be a better indicator of wave exposure than wave heights as waves tend to be measured over a relatively short period of time (days) while sediments represent a long-term (weeks to years) equilibrium with local hydrodynamic conditions. For example, sub-tidal sediments at Eliott Robertson were quite fine (mainly silt + clay, Figure 2a), an indication of quiescent conditions and a small fetch. All other sub-tidal (i.e. offshore) sites were dominated by fine sand (Figure 2), a sediment type indicative of stronger hydrodynamic conditions than in areas where silt and clay are deposited. Although guidance governing the construction of coastal structures call for fill material to be medium to coarse sand with a median grain size of 0.6 mm, the marsh area of the studied sites was dominated by finer fractions (fine sand) except for Aspen 1998, London Town and JPPM where medium sand dominated (Figures 2A & B). Fine sand may be adequate for low wave energy sites but will not offer a stable substrate on high energy shorelines or during storm events. The offshore areas tended to reflect the general sediment composition of the marsh area but often had a higher fraction of fine particles than the marshes. This difference is likely due to the sediment deposited in the intertidal area for shoreline stabilization.

Sediment availability and transport also need to be considered when evaluating a Living Shoreline site. The main source of sediment at Eliott Robertson's (Figure 3) seems to be the erosional banks (not yet covered with rip rap or sea-walls). These are usually fine particles which are deposited in the creek and are easily resuspended by even the slightest activity such as wind and/or boating. The slope of this shoreline is quite steep (Figure 4) suggesting possible shore (sub-tidal) erosion (or dredging for boat access). As the wave energy at this site is relatively small, perhaps the source of energy for shoreline erosion in this creek is boating activity. The transition between the sand deposited in the marsh area during the construction of the groin and the soft, highly organic sediments of the sub-tidal zone is quite abrupt. It is possible that, when sand particles from the marsh/construction zone are resuspended and deposited in the soft subtidal substrate, the sand will sink into the suspended mud substrate and not replenish the beach at a later time. Therefore, a net export of sand is expected at the Eliott Robertson site.

In contrast, at Wye NRMA, sand seems to be transported by storm events or during high tides forming a sand spit at the northern end of the study site (Figure 5). This sand spit has been deposited in relatively deep waters forming a very steep shoreline (Figure 4 Wye NRMA 39+70). It appears that if the groins had extended farther offshore they

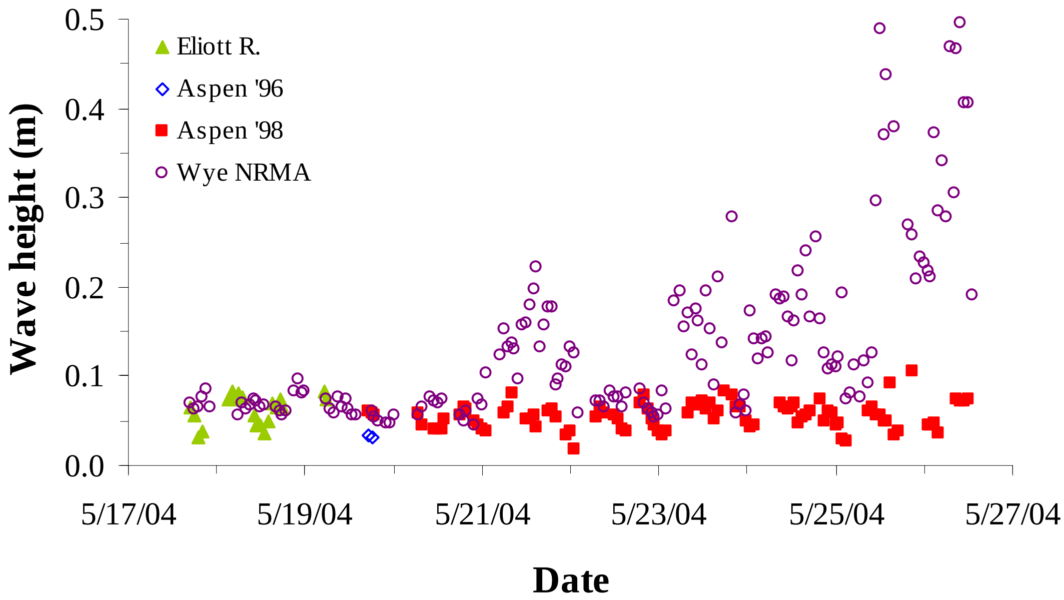

Figure 1A. Significant Wave Height at the DNR Study Sites.

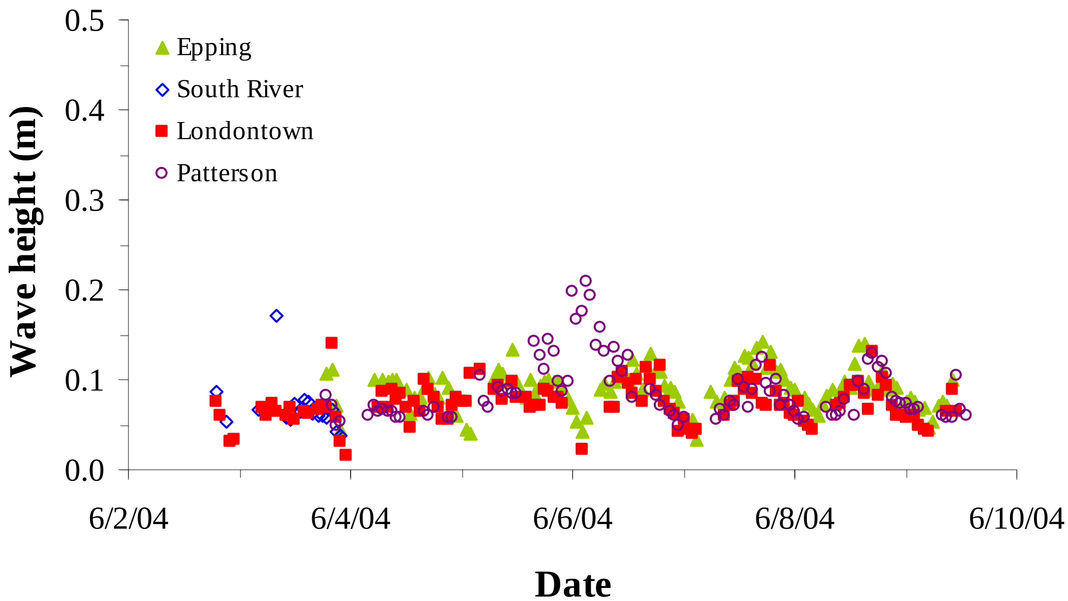

Figure 1B. Significant Wave Height at the CBT Study Sites. The oscillations in wave height observed between 6/5 and 6/10 are a result of tidal fluctuations (more vertical wave attenuation during high tide than at low tide).

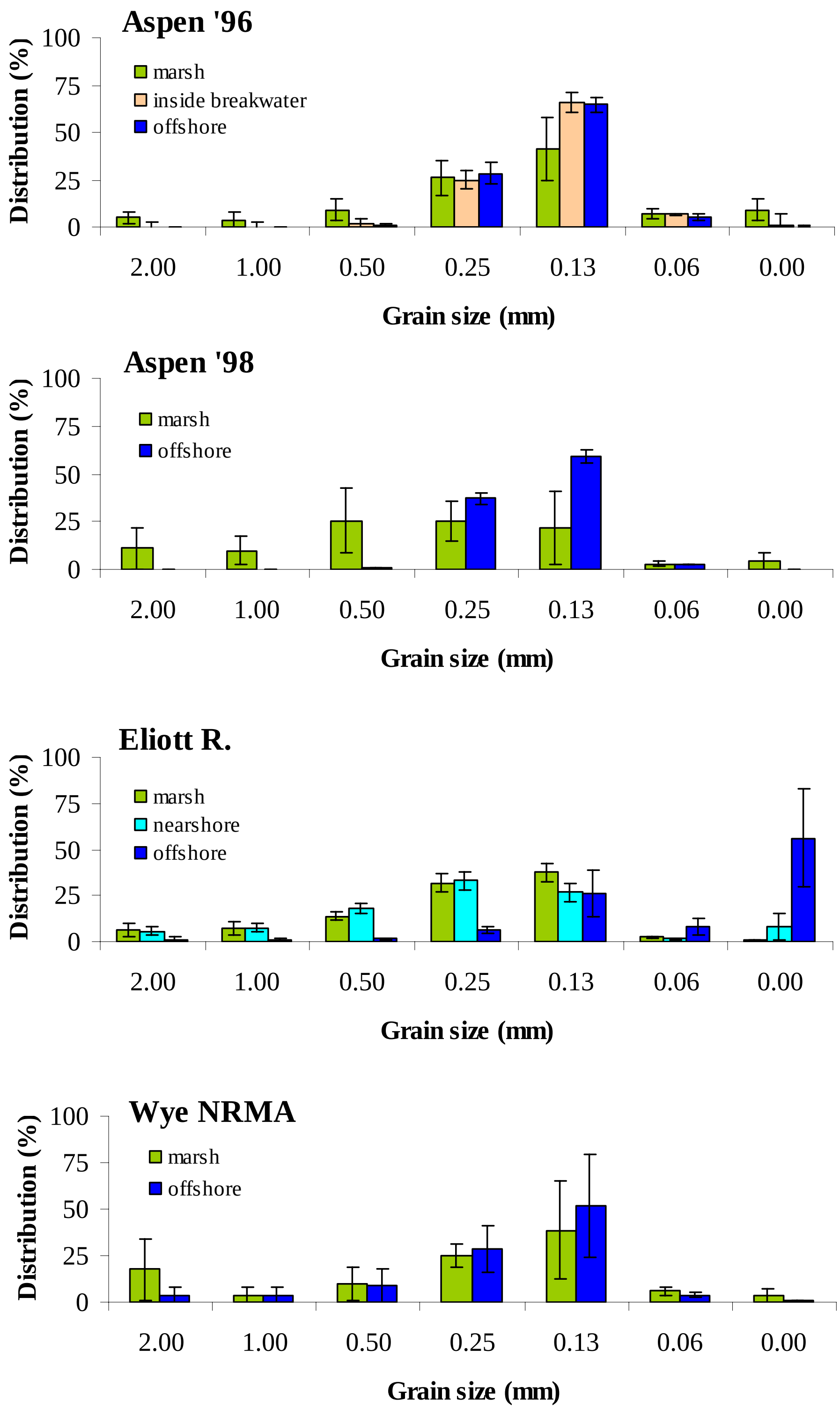

Figure 2A. Sediment Grain Size Distribution for DNR sites. Offshore samples were collected at a depth of approximately 0.7 m. Grain size classed are as follows: gravel (2.00 mm), very coarse sand (1.00 mm), coarse sand (0.5 mm), medium sand (0.25 mm), fine sand (0.13 mm), very fine sand (0.063 mm) and silt + clay (0.00 mm).

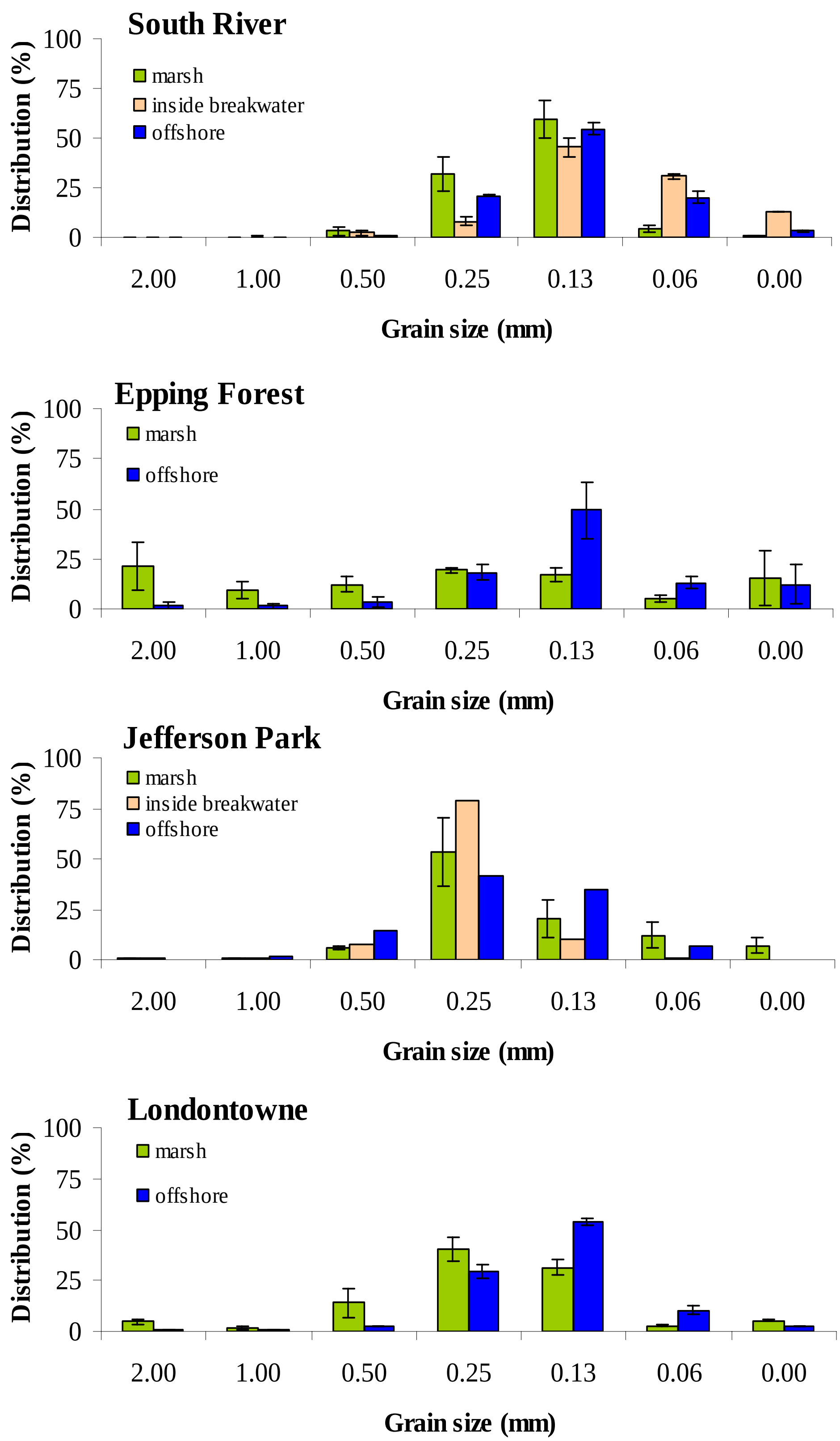

Figure 2B. Sediment Grain Size Distribution for CBT sites. Offshore samples were collected at a depth of approximately 0.7 m. Grain size classed are as follows: gravel (2.00 mm), very coarse sand (1.00 mm), coarse sand (0.5 mm), medium sand (0.25 mm), fine sand (0.13 mm), very fine sand (0.063 mm) and silt + clay (0.00 mm).

could have trapped more of these sediments minimizing the formation of this sand spit. Other areas adjacent to the study site are less steep and extensive shallows can extend quite far offshore (Figure 4 Wye NRMA 32+20). Such shallows attenuate waves as they propagate onshore thereby protecting the shoreline even in the absence of breakwaters or groins.

At the Aspen sites a net northeast – southwest longshore sediment transport seems to occur as seen in figure 6. The northern end of the study site has a relatively steep slope (Figure 4) which becomes less steep as one moves south. Along the 1998 phase of the project, the slope becomes steeper once again.

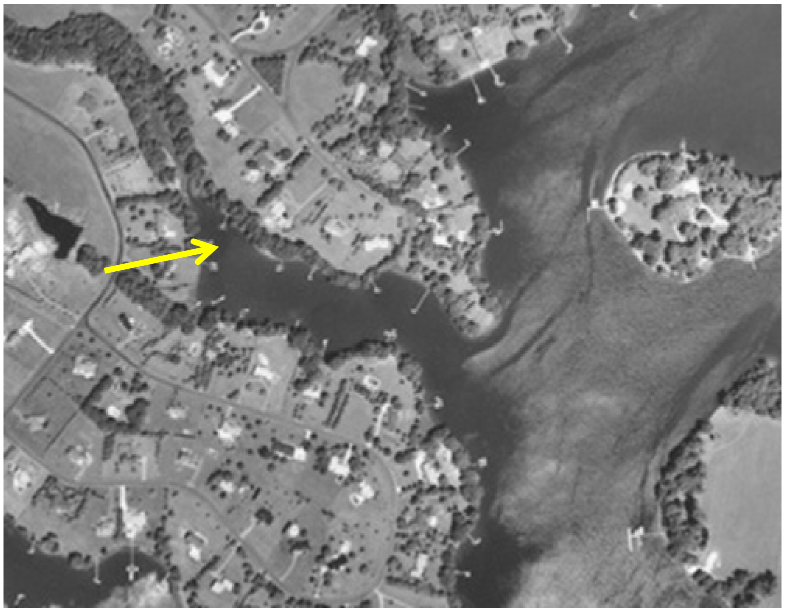

Figure 3. Aerial view of Eliott R. Site. The groins at Eliott R.'s were located in a relatively quiescent creek with very soft sediments. Long shore transport appears to be minimal leading to no or little trapping of sediment by the structures. Instead, the sand deposited in the marsh zone may be lost once resuspended (see text).

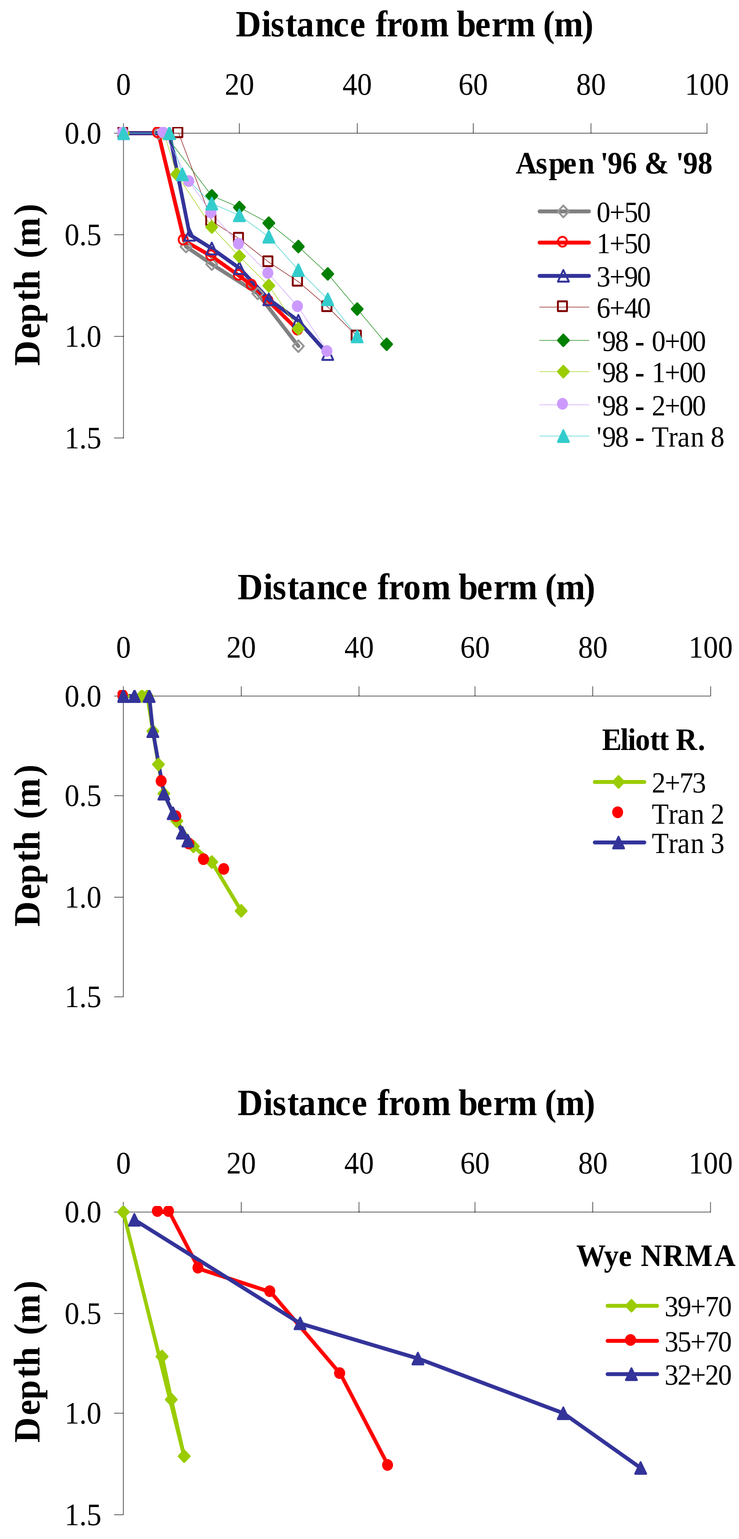

Figure 4. Present shore profiles at DNR sites. Measurements of water depth at each transect within each site. Each line represents a transect perpendicular to shore.

Figure 5. Aerial View of Wye NRMA site. The groins at Wye NRMA do not seem to extend far enough into the water to trap the sediment being transported by longshore currents. As a result, a sand spit is forming at the eastern end of the project (arrow). Perhaps only fetch and wave climate were considered when designing this structure but boat-generated waves appear to also be quite significant at this site.

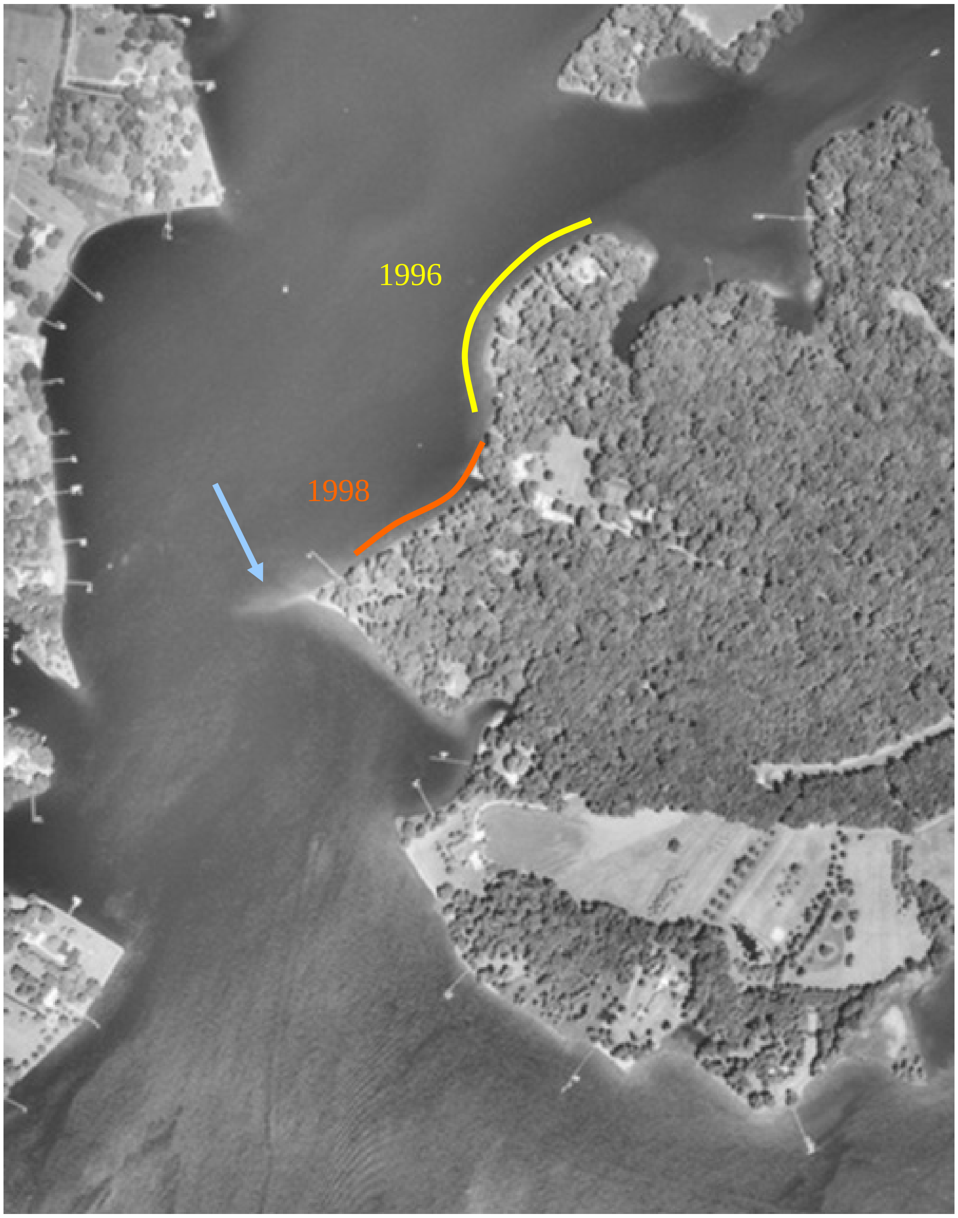

Figure 6. Aerial view of Aspen '96 and Aspen '98 Sites. Note the sand tongue extending into the river (arrow); apparently a result of northeast – southwest longshore transport.

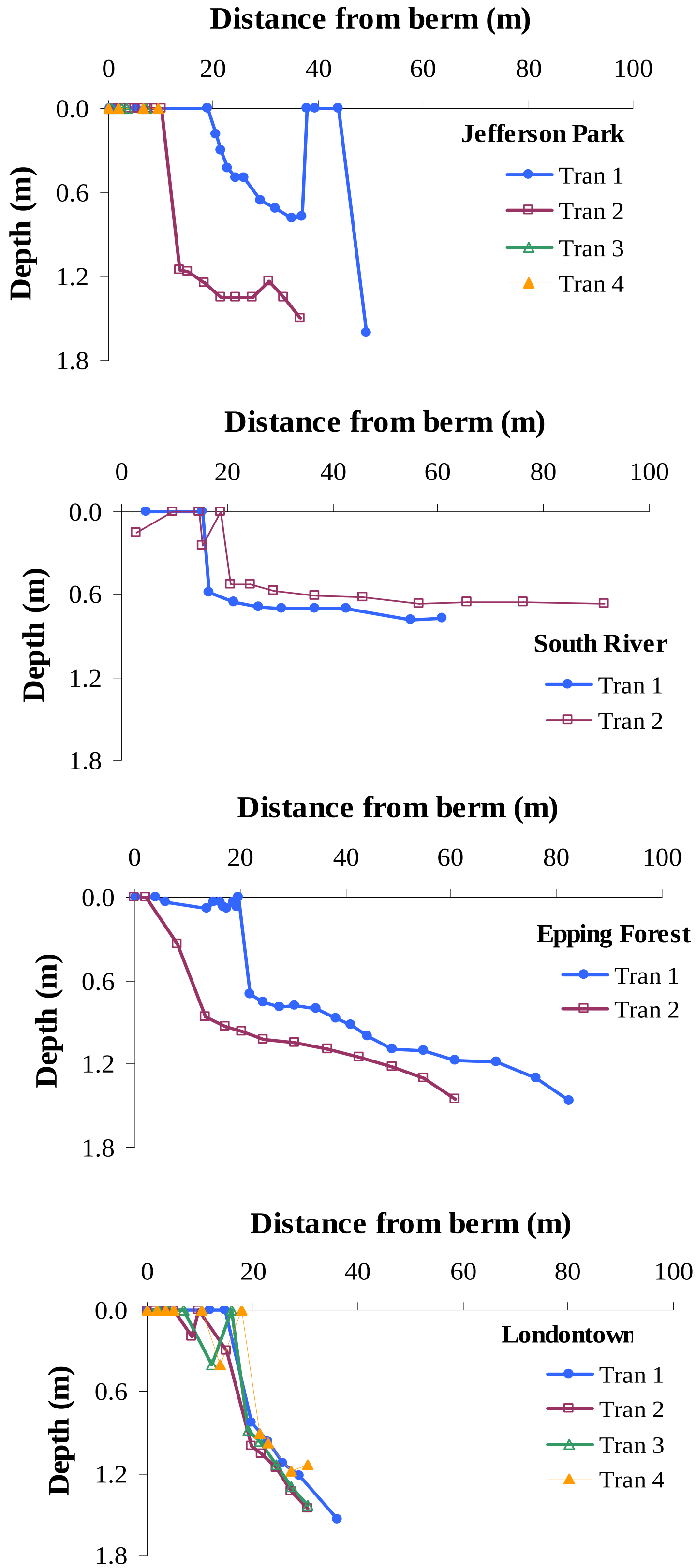

Figure 7. Present shore profiles at CBT sites. Measurements of water depth at each transect within each site. Each line represents a transect perpendicular to shore.

The vegetated sill at Epping Forest is located adjacent to the mouth of a creek that deposits sediments in the form of a fan in the offshore area (Figure 8). As a result, the slope of the shoreline is gentle (Figure 7) and supports some submersed aquatic vegetation (SAV); *Ruppia maritima* and *Potamogeton perfoliatus*. The source of the sediment is not only the creek but also adjacent embankments that are/were eroding. The adjacent areas appear quite sediment-starved (lack of sedimentary features).

The general pattern of sediment transport adjacent to JPPM seems to be southward. This is particularly visible at the southern tip of the park where a series of 3 vegetated attached breakwaters protect the shoreline (Figure 9). The area between these breakwaters traps floating algae and, as a result, does not appear to support the growth of SAV (personal observation). Additionally, the area offshore of these breakwaters is too deep (> 7 ft) to sustain the growth of SAV (Figure 7). Sills further north along JPPM are smaller in magnitude and support a narrow strip of marsh shoreward of the structure. Although SAV may appear to be present offshore of one of these areas (yellow arrow in Figure 9), ground truthing revealed this also to be drift algae (mostly *Ulva lactuca*) and not SAV. Therefore, the area offshore of JPPM does not seem to support the growth of SAV, possibly due to the steep slope and/or relatively high wave exposure. Steep slopes are also observed on land in the form of banks. Some of these appear to be a good source of sediment as seen by sediment plumes originating from specific points in Figure 9.

Although the area immediately adjacent to the sill at London Town is relatively deep (4 to 5 ft; Figure 7), it supports an extensive SAV bed occupying the entire water column at time of sampling. This vegetation provides important ecosystem services such as habitat and food for aquatic animals in the area as well as wave attenuation. As a result, the vegetation not only contributes to shoreline protection but also allows for a healthy aquatic system immediately adjacent to the structure. The submersed area shoreward of the sill is not as healthy as the temperature in this shallow basin with restricted exchange with the open water rises to levels that appear to be detrimental to aquatic animals. As a result, this area is mostly devoid of animals although it supports healthy marshes. The system adjacent to the breakwater at London Town seems to be somewhat sediment starved (no clear sand spits or sediment plumes) except for the area southeast of the study site.

The area adjacent to the South River Farm Park site is characterized by a broad sand shoal (Figure 11) with a gentle slope (Figure 7) which is colonized by *Ruppia maritima*. This SAV bed, although sparse, was quite extensive and flowering at the time of sampling. The source of sediment that formed this shoal may be the eroding bank at the study site and/or the beaches south and northwest of there. Independent of the source, sediment dynamics in this area is extensive as can be seen by the patterns in Figure 7.

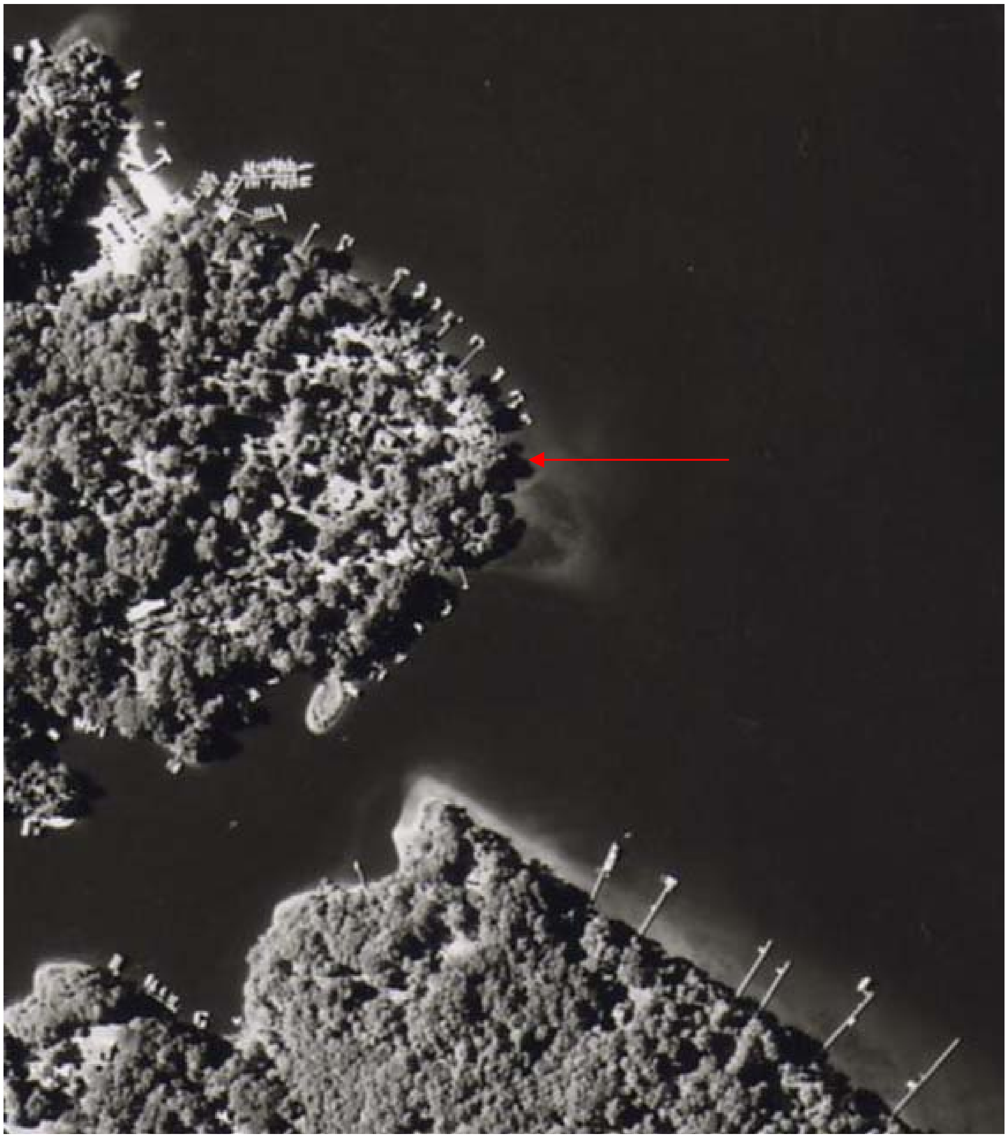

Figure 8. Aerial view of the Epping Forest Site. Note the sediment fan just south of the vegetated breakwater (red arrow).

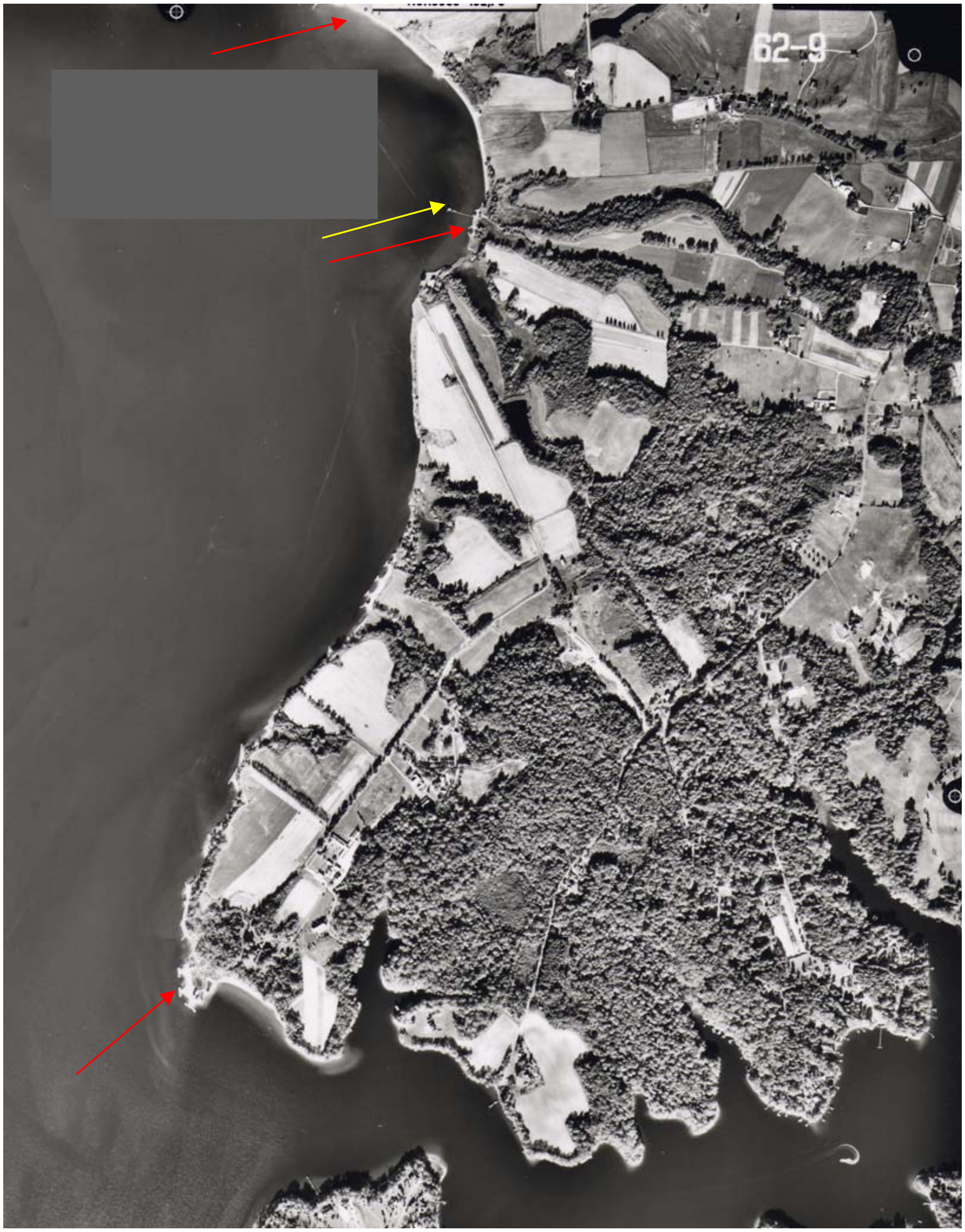

Figure 9. Aerial view of the Jefferson Patterson Park Site. Red arrows indicate sites where data were collected and yellow arrow indicated location where the wave gauge was deployed.

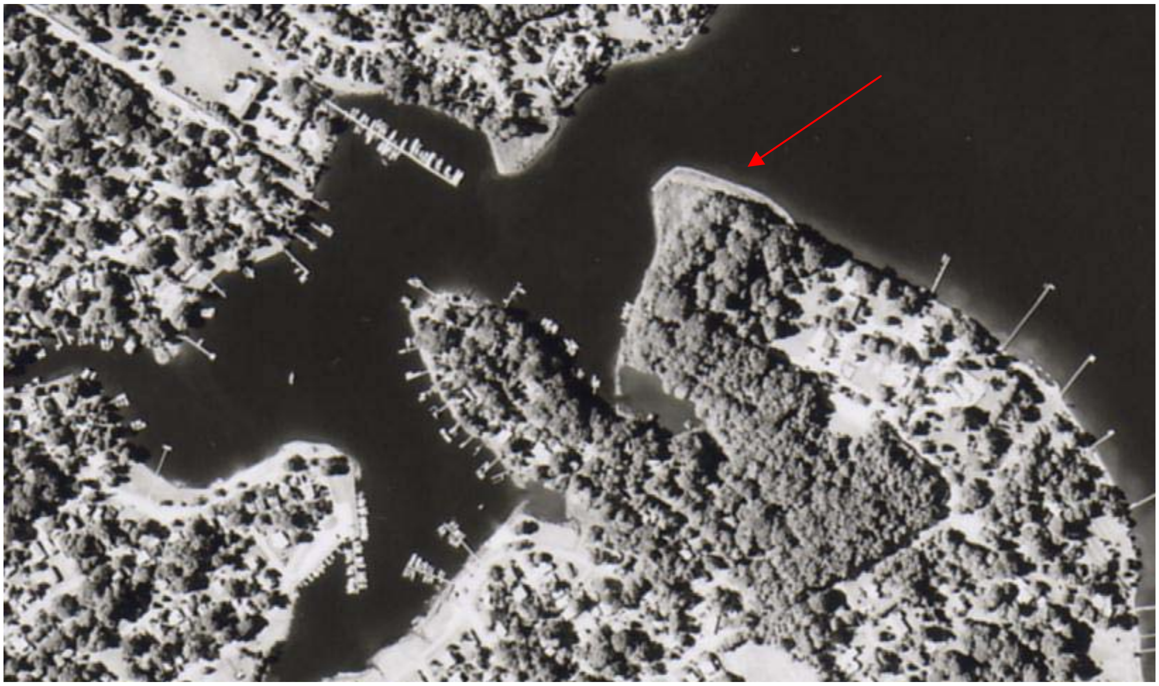

Figure 10. Aerial view of the London Town Site. Note the lack of sediment patterns adjacent to the structure but their presence SE of the breakwater.

Figure 11. Aerial view of the South River Farm Park Site. The structure at this site is obscured by the shadow of the trees. Note the broad shoal adjacent to the shore and the patches of submersed aquatic vegetation.

A.2. Original Design

This section provides two tables (Table 4A and 4B) containing highlights of the basic design components for each project. Numerous detailed drawings are on file with DNR SEC; Anne Arundel County Dept. of Public Works, and the Calvert County Soil Conservation District. These drawings could not be readily reproduced because of the size, quantity of materials and quality of the “second generation” paper copies provided to the contractor. All ratios used in the table are expressed as “rise to run”. Some photos of “as-built” conditions were available from the DNR SEC file and are in the Appendix.

Table 4A. Site Project Designs Phase I (from pre-construction specs.)

Site & Linear Ft.	**Planting Plan**		Slope	Containment Structure
	Spartina patens dimensions	*Spartina alterniflora* dimensions		
Wye NRMA Section (VI) 1,070’	8.5’ width planted on 18” centers	13’ width planted on 18” centers	not specified in plan	17 stone groins: 22’ long; 2’ wide at top; variable bottom width; side slopes of 1:1.5; elevation at top of groin (water)= +1.0’ MLW and +3.3’ MLW at bank;
Aspen 1996 660’	variable width planted on 18” centers above +1.7’ MLW	variable width planted on 18” centers between +0.5’ and +1.7’ MLW	variable: from 1:8 to 1:10 on new fill & some 1:6 on existing *S. patens*	segmented sill: in 200’ sections with 5’ gaps for aquatic life; 1’ wide at top; side slopes of 1:1.5; variable bottom width of 6’-8’; top of sill at +2.0’ MLW
Aspen 1998 855’	same as above; also on north section marsh is shorter than south sections	same as above; also on north section marsh is shorter than south sections	all slopes 1:8	segmented sill: in 200’ sections with 5’ gaps for aquatic life; 1 continuous sill segment of 265’; 1’ wide at top; side slope on shore side 1:1.5; side slope on water side 1:2; variable bottom width of 6’-8’; ; top of sill at +2.0’ MLW
Eliott R. 273’	avg. 11’ width on 18” centers from MHW to bankface	avg. 4’ width on 18” centers from +1.0 MLW to MHW	variable: slope of planted marsh surface appears to be approx. 1:6	3 stone surface groins: 30’ long; 1’ wide at top; 7’ wide at bottom; 3’ tall at bank; 1’ tall at water; located at each end and middle; side slopes 1:1; 2 stone surface groins: 30’ long; .5’ wide at top; 2.5’ at bottom; 1’ tall at both ends; side slopes 1:1; located in middle on either side of full size groin

Table 4B. Site Project Designs Phase II (from preconstruction specs. & survey information)

Site & Linear Ft.	Planting Plan *Spartina patens*	Planting Plan *Spartina alterniflora*	Slope	Containment Structure
Epping Forest (detailed plans and "as-built" unavailable) 167' (2 site areas)	planted in clusters within tombolo area of irregular sill (not planted in standard sill)	planted in intertidal zone of irregular shaped sill and behind standard sill	unknown	a) crescent shaped perimeter sill: 4'to8' wide (at base)with variable elevation of +.31' to +.70'MLW b)standard sill: ±8' wide sill (at base) with avg. elevation of +.41' MLW (measurements derived from survey drawings, not design specs. – may be inaccurate)
JPPM (detailed plans and "as-built" only available for planter breakwater and station 28+11) 470' (4 site areas)	used in planter breakwater and at each transect site from Spring High Water to +6' or where shown on plan and cross-section (generally to toe of bank)	not used at breakwater site, planted at sill sites on 1.5' centers between Mean Tide Level (+0.6') and Spring High Water (+1.5')	unknown	a)planter breakwater: 100'x23'at top, 75'base; 1:1.5 side slopes; 600-1600 lb. armor stone; attached "tombolo", +2.5 MLW elevation b) "typical sills": 4' top; 20' base; 400-1200 lb. armor stone +2'MLW elevation c) low profile sill: design specs. unavailable
London Town 600'	used along entire length of project, 10' landward from MHW	planted along entire length of project from approx. MLW to MHW (variable, unknown width)	1:10	continuous sill: 2' top; ±24' base; 1:1.5 side slopes; 300-1000 lb. armor stone; +2.5 MLW elevation
South River FP (detailed plans and "as-built" not available) 1657'	used along entire length of project from MHW landward (variable, unknown widths)	planted along entire length of project, landward from approx. MLW to MHW (variable, unknown width)	unknown	segmented sill: 19 sills; ±75' long; ±15' openings;

A.3. As-Built and Current Elevation Transects

The land surveyor team compiled cross sections of the transect lines at 34 separate locations. Each transect is correlated to an engineering station located on detailed drawings. A horizontal scale of 20 and a vertical scale of 5 was chosen to better detect changes in marsh surface elevations and movement of structures. The cross sections and accompanying photos are included in Appendices 2 & 3. It should be noted that elevation points at the bases and top (center) of stone structures were the chosen field protocol. For Phase I sites, RC&D field notes of "as-built" marsh width and groin elevation details were used as a comparison. RC&D surveys include additional measurements of the "width" of sills. J.A. Rice Inc. surveys include a more extensive cross section of the topography, typically extending to the top or the bank and beyond most sill structures (channel-ward). In a few instances the Rice surveys show a higher elevation of the top center of the sill structures at the Aspen Institute sites. This, in all likelihood, is due to placement of the rod on a particular rock that represented a higher elevation than the average. A .5' to 1' deviation is possible based on this error factor alone, however, attempts were made to place the rod on a location representing the "eyeball" "average" across the top of the structure. For Phase II sites, "as-built" conditions were largely undocumented. Therefore, the discussion of Phase II sites, regarding physical and biological integrity (section a.5 of this report), is addressed in a different manner, using data derived from a combination of survey team observations and land survey data.

A.4. Phase I Sites: Physical Integrity of Original Design Including Resulting Changes in Structural and Biological Components

A series of tables (Table 5) addressing "marsh break" and groin elevation changes and other information have been prepared based upon the analysis of land surveyor data derived from "as-built " and "current" day time frames. A precise alignment of "as-built" and "current" cross sections was not possible due to the lack of control points found in general and because control points were not established at the base of each station. However, it appears that the survey data, in combination with other collateral data generated during the study, is accurate enough to provide a reasonably good composite picture of the changes which have occurred from the time of construction to the present. In general, "as-built" field survey measurements and notes were taken by Resource Conservation and Development group (a contractor of DNR) to describe the distances between "marsh breaks" and fill containment structures. The land survey data reflects two general categories of vegetation data expressed on tables as marsh "Break 1" and "Break 2". Break 2 includes linear measurements of *Spartina alterniflora* and Break 1 includes linear measurements of *Spartina patens* and sometimes other miscellaneous species. Only limited notes could be recorded via the survey instrument, thus Break 1 data includes only a representation of the distribution of *S. patens* and a mix of other terrestrial and wetland species. The total linear length of Break 1 plus Break 2 can and does, in several instances, exceed the original linear extent of planted fill material indicated on the field notes compiled by RC&D. This situation occurs as a result of two factors: 1)"base of bank" conditions changing from upland and wave caused erosion; and

2) recording of *S. patens* or other species establishing themselves at a higher elevation on the slope of the bank. More detailed notes of wetland vegetation characteristics were documented by the biological survey team and are noted in the section entitled "Marsh Community Health and Nutrient Buffering Capacity".

Table 5. Phase I Sites: Marsh "Break" Changes (in feet).

Wye NRMA

Station #	Survey	Break 1 Other	Break 1 *S. patens*	Break 2 *S. alterniflora*	Total	Change	Comment
42+70	as-built		11	7	18	-8	change factors: for *S. alterniflora* – possible excessive wrack may have caused barren area in combination with minor slope change (as-built 1:7.7 to current 1:6.4), sediment starvation from nearby spit; shading likely cause of reduced *S. patens*.
	current	5	5	0 (barren)	10		
39+70	as-built		13	8	21		change factors: minor erosion, slope (as-built 1:7.7 to current 1:6.9), shading (*S. patens*) Additional vegetation observed, not noted here
	current	6	0	6	12		
35+70	as-built		17	7	24	-1	change factors: some erosion evident, slope (as-built 1:7.4 to current 1:5.3)
	current	5	11	7	23		
32+20	as-built		16	5	21	-6	change factors: erosion caused "gaps" in former *S. alterniflora* marsh edge, clumps of marsh detaching, shading causing die-back of *S. patens*, slope (as-built 1:6.4 to current 1:5.1) more erosion likely; profile shows excessive drop in marsh elevation - avg. 1.5' lower – may be survey control error
	current		6	9	15		

Aspen – 96

Station #	Survey	Break 1 Other	S. patens	Break 2 *S. alterniflora*	Total	Change	Comment
0+50	as-built		9	10	19	6	change factors: *S. alterniflora* expanded into former *S. patens*; *S.patens* moving up bank; no erosion; slope (as-built 1:7 to current 1:8 – along all but back portion of slope)
	current		9	16	25		
1+50	as-built		9	10	19	3	change factors: *S. alterniflora* expands into former *S. patens; S. patens* somewhat more confined by steep bank; slope flattens from 1:7 to 1:10
	current		6	16	22		
3+90	as-built		9	13	22	8	change factors: *S. alterniflora* remains fairly constant as does slope (as-built 1:7.6, current 1:7.3)
	current		16	14	30		
6+40	as-built		16	13	29	8	change factors: bank sloughing looks plausible from profile and recent conditions; current slope of *S.alterniflora* area very gentle(1:16 – in *S. alterniflora* area) from possible upland sediment contributions; similar upslope migration of *S. patens*
	current		16	21	37		

Aspen – 98

Station #	Survey	Break 1 Other	*S. patens*	Break 2 *S. alterniflora*	Total	Change	Comment
north 0+0	as-built		6	11	17	9	change factors: stations 0+0; 1+0; and 2+0 are contained within the longest, unsegmented sill area of Aspen 98 and 96; note how “as-built” and “current” profiles closely align and *S. alterniflora* marsh lengths are very close to as-built; station 1+0 appears to have bank sloughing possibly impacting *S.patens*
	current		16	10	26		
north 1+0	as-built		16	14	30	-4	
	current		13	13	26		
north 2+0	as-built		9	16	25	2	
	current		11	16	27		
south 1+00	as-built		17	10	27	1	change factors: all stations on south sections of Aspen 98 show slightly higher marsh surface elevations
	current		16	12	28		
south 2+00	as-built		15	17	32	-2	elevation above “as-built”; deposition of bank soils possible - may also be survey control error via benchmark on pier
	current		15	15	30		
south 4+00	as-built		14	11	25	3	Sta. 2+00 – muskrat burrow disrupts marsh development; wave deposited sediment accumulation behind sill results in barren *S. alterniflora* area – recovery likely; small sills placed behind sill openings appear to be moderately helpful for marsh stability verses no small sills in Aspen 96; much elevated marsh surface of Sta. 5+00 is coincident with largest water “gap” (6’) behind sill.
	current		15	13	28		
south 5+00	as-built		15	14	29	-5	
	current		17	7	24		

Eliott Robertson

Station #	Survey	Break 1 Other	S. patens	Break 2 *S.alterniflora*	Total	Change	Comment
0+0	as-built		9	7	16	-6	change factors: loss of sand fill material may be associated with 2.4' drop of end of groin #1 (at water); as-built gradient too steep – 1:5.8; current slope 1:5:3; soft nearshore bottom captures eroded material; possible shading caused loss of *S. patens*
	current	4		6	10		
1+50	as-built		12	8	20	-2	change factors: marsh surface lower; slope (as-built 1:6.3 to current 1:5.7);
	current		11	7	18		
2+73	as-built		7	7	14	2	change factors: marsh profile very stable; current slope 1:6.1
	current		7	9	16		

An assessment of changes in groin elevations was also performed (Table 6). To facilitate the assessment, categories of change were developed to better describe the potential degree of affect resulting from the change. The change categories are: <.5' = No meaningful change (this degree of change is within the margin of error expected from rod placement and/or survey error); .5' to 1' = Some change (this degree of change is likely beyond a potential margin of error, but, by itself is not likely to cause noticeable biological or physical changes); >1' = Potential meaningful change (this degree of change has the potential to cause changes in the biological and/or physical characteristics of the site and may be linked to other conditions, characteristics or events). When some change or a potential meaningful change occurred, other collateral data was examined in an attempt to better understand how the overall project was affected.

Table 6. Phase I Sites: Groin Elevations.

Eliott Robertson Groin Elevations (in feet)

Groin: #	Location	Survey Date: 10/94	6/04	Elevation Differential	Change Category
5	top/bank	3.8	3.5	-.3	no meaningful change
	top/water	0	-.9	-.9	some change
4	top/bank	3.8	3.6	-.2	no meaningful change
	top/water	.7	.1	-.6	some change
3	top/bank	3.9	3.8	-.1	no meaningful change
	top/water	.4	-1	-1.4	potential meaningful change
2	top/bank	4.1	3.8	-.3	no meaningful change
	top/water	.6	.2	-.4	no meaningful change
1	top/bank	3.5	3.3	-.2	no meaningful change
	top/water	.7	-1.7	-2.4	potential meaningful change

Wye Island NRMA Groin Elevations (in feet)

Groin: #	Location	Survey Date: 8/90	6/04	Elevation Differential	Change Category
3	top/bank	3.5	2.9	-.6	some change
	top/water	1.4	1.1	-.3	no meaningful change
8	top/bank	3.5	3.5	0	no change
	top/water	1.6	1.1	-.4	no meaningful change
9	top/bank	3.2	2.9	-.3	no meaningful change
	top/water	1.6	1	-.6	some change
13	top/bank	3.5	3.2	-.3	no meaningful change
	top/water	1.6	.9	-.7	some change
17	top/bank	3.3	3.2	-.1	no meaningful change
	top/water	1.2	0	-1.2	potential meaningful change

The change criteria were also applied to the sill structures for the Aspen Institute sites (Table 7). Each cross section provides a reasonably accurate comparison of changes, particularly of the top center of the sill profile. An examination of the cross sections at each sill location suggests the structures remained stable. This is not surprising as they are situated on top of medium grain sands and are quite substantial with typical dimensions consisting of: 1’ across the top (+2.0’ MLW); 6’-8’ across the bottom; a 1:2 slope on the channel-ward side; a 1:1 ½ slope on the landward side; Class I Rip Rap (5# to 150#). Small sills were located just behind each 5’ opening between the sills on Aspen ’98; while Aspen ’96 did not have such openings. Somewhat larger open water pools existed behind the sills on Aspen ’96, which appears to provide greater access and habitat value, and somewhat less erosion control.

Table 7. Phase I Sites: Sill Elevations.

Aspen '96 & '98 Sill Elevations (in feet)

Aspen '96 Sill Station:	Survey Date: 10/96	6/04	Elevation Differential	Change Category
0+50	2.0	2.3	+.3	no meaningful change
1+50	2.3	2.1	-.2	no meaningful change
3+90	2.3	2.2	-.1	no meaningful change
6+40	2.1	2.5	+.4	no meaningful change
Aspen '98 Sill Station:				
north 0+0	2.3	2.4	+.1	no meaningful change
north 1+0	2.0	2.1	+.1	no meaningful change
north 2+0	2.0	1.8	+.2	no meaningful change
south 1+00	2.1	2.2	+.1	no meaningful change
south 2+00	2.1	2.2	+.1	no meaningful change
south 4+00	2.0	1.9	-.1	no meaningful change
south 5+00	2.0	2.5	+.5	some change

A.5. Phase II Sites: Physical Integrity of Original Design Including Resulting Changes in Structural and Biological Components

The narrative below briefly reviews, on a site by site basis, structural/physical factors and observations affecting the performance of living shoreline treatments assessed during Phase II. Table 8A, along with other data presented in this report was used as a basis for the narrative discussion.

Epping Forest

The irregular vegetated sill structure used to create a natural-appearing fringe marsh is unlike all other living shoreline treatments assessed in this report. This type of living shoreline treatment is sometimes referred to as "small marshy islands". The primary purpose of the project is marsh habitat creation, with a secondary shore erosion control benefit. This site had the third longest average fetch of all eight sites (0.82 miles) and the lowest average sill elevation (+0.41'MLW). The project is young in age and has not had sufficient time to permit an evaluation of potential long-term results. A combination of

Table 8A. Phase II Sites: Sill Elevation (in feet)**, Marsh Slope and Erosion Data**

Site	Sill/Breakwater Elevation (in ft. + MLW)	Marsh Slope	Erosion: Bank Marsh	Comment
Epping Forest	Irregular sill (section 1): .70 (front); .58 (rear) Standard sill: (Section 2): .42	1:20: inside sill 1:51: tombolo 1:6.4: tombolo	none slight moderate none	root zone of *S. alterniflora* stressed; low plant density erosion of bank evident in 2 areas behind & to right of sill
JPPM	Planter breakwater: 2.72 (sta.48+60) "Typical" sill (sta.28+11): 1.97 Low profile sill (sta. 2+03): 1.41 "Typical" sill (sta. 0+50): 1.97	N/A 1:5.9 1:10 1:21	N/A minor none none none none none none	planter breakwater: 20' segment of sand fill & *S. patens* impacted – damaged from tropical storm Isabel – natural recovery is likely
London Town	Sill: (sta. 2+00): 2.25 (sta. 3+00): 2.57 (sta. 4+00): 2.56 (sta. 5+00): 2.73	 1:20 1:26 1:10 1:7.7	 none see text none none none none none none	area of open water increases behind sill moving from sta. 2+00 to 5+00
South River FP	Segmented sill: (sta.1+32): 1.19 (sta.3+82): n/a (sta.7+04): .84 (sta.11+47): 1.03 (sta.14+90): 1.21	 1:14 1:14 1:16 1:10 1:12	 slight moderate moderate moderate severe severe severe severe slight slight	a combination of shore & bank erosion; deep burial of marsh plants & predation from geese are causing problems – see text

factors poses multiple challenges for marsh establishment within the crescent-shaped area. These factors include: long fetch; high boating activity; minimal wave attenuation, a low profile sill elevation and the compact configuration of the sill structure itself. The rear sill, located a few feet behind the leading sill (on the left side of the crescent), is located such that additional scour is generated when waves overtop the leading sill and then immediately encounter this secondary wave barrier. The attached tombolo behind the structure appears to be performing well although marsh establishment is also limited. The minimum slope standard of 1:10 is exceeded, providing an excellent potential gradient for *S. alterniflora*. The standard sill is building a tombolo that may ultimately attach to the sill structure, as it appears there is sufficient sediment supply for this to occur. The elevation immediately behind the sill structure (-2.60 MLW) is presently too deep for permanent marsh colonization. Although *Spartina alterniflora* was observed growing in up to 0.6 ft. of water during the growing season (at Wye NRMA) this species does not tolerate year-around anoxic substrates. Thus, *S. alterniflora* may occupy a broader tidal range during the summer growing season, retreat in the dormant season and once again advance into oxygen deficient substrates in the summer months. During a one year period of observation, this situation was observed on a portion of the London Town site, where no *S. alterniflora* was present behind the sill for a distance of several feet, however, by August, it had advanced several feet closer to the sill.

Although SAV is present offshore of this structure its relative low density is unlikely to attenuate waves to a significant level. It should be noted that the project designer, Keith Underwood, related to us that SAV reappeared in the area since the construction of the vegetated sill. However, the Severn River has been slowly re-vegetating since the mid-1980s when no populations could be found in the mainstem of the river (J.C. Stevenson pers. observations). It is likely that the improving water quality is due to a number of factors, including reductions in point source nutrients, better sediment control at construction sites and the virtual abandonment of agriculture in the watershed; as well as reduction in turbidity in the shallows because of various shoreline projects along the Severn River shoreline.

In summary, it is very likely that a number of habitat elements at Epping Forest will persist over time. However, substrates located within some portions of the crescent, may require further design adjustments to achieve a less dynamic state, which will further facilitate marsh establishment and habitat benefits. For example, raising the offshore sill and adding some sand to the system may suffice to create an intertidal habitat fully suitable for marsh plants (i.e. decrease the inundation time of the sediment).

Jefferson Patterson Park and Museum (JPPM)

All sites at JPPM were primarily designed for shore erosion control (to protect archeological resources) with secondary habitat benefits. This goal was achieved. The attached, planted breakwater structure was used for headland control in a high wave energy area. This structure is part of a system of 3 attached breakwaters that have been designed to allow the shoreline between the structures to retreat inland at a predicted rate and reach a natural equilibrium. The structure has performed well in the face of extreme storm events, including Hurricane Isabel, and colonization of both *S.patens* and *S. alterniflora* has been successful. Both the “typical” sills (as labeled in the design drawings) with elevations of approximately +2.0’ MLW have provided sufficient protection for healthy marsh systems and little or no bank erosion. In contrast, SAV was absent from the area probably due to the relatively high depths (> 1.5 m) adjacent to the structures. Station 28+11 is sloped at an angle somewhat less than the design standard, however, it does not appear to be a problem. All other marsh surface slopes meet or exceed the DNR design standard. The low profile sill allows for daily overtopping of the tides and permits a more normal hydrologic and water exchange regime than the fringe marsh systems found within the higher elevation “typical” sills. It should be noted that the lower elevation sill functions so as to avoid shore erosion because it is “buffered” by higher elevation sills on either side and occupies an area of slight shoreline indentation that acts like a small embayment. This low profile sill would likely not provide sufficient protection if it were to continue at the lower elevation for a long interval. Further, the landward elevation of the fill area is at a sufficient height to allow for a good connection with the toe of the bank and appropriate wave attenuation in storm events.

London Town

Of all the sill projects studied in this report, the London Town site provides the largest sill structure in elevation and total size relative to total average fetch. The open water habitat behind the sill increases moving from east to west (toward stations 4+00 and 5+00). Similarly, the marsh surface slopes increases in steepness. Additionally, an obvious rise in elevation at station 5+00 exists (colonized by *Phragmites*), potentially indicating that more sand fill material behind the sill has been transported further landward. A review of the inspection record in 1995 showed that a 10’-15’ strip of fill material was unvegetated. Also, the tide was 1 to 1.5 feet above average MHW at that time. Although it is uncertain where this unvegetated strip was located, it seems plausible that the problem was near stations 4+00 and 5+00. With no plant base to help stabilize the fill material, this might be one factor that helps to explain the larger expanse of open water in this area. Other possibilities exist as well – including more anoxic substrate conditions. Overall, it seems that the structure was more than adequate for the wave climate of this site. Although it also appeared that tropical storm Isabel had rearranged the backshore sediments, no active bank or marsh erosion was evident. Outside of temperature issues behind this continuous sill (discussed in other sections of this report), both habitat and shore erosion control benefits have been achieved at the London Town site. SAV was also abundant offshore of this structure to a degree that wave attenuation by this vegetation was likely (although not measured). This dense SAV bed provides valuable habitat for estuarine species.

South River Farm Park

This site has the largest average and longest fetch of all sites. It has also experienced the most severe bank erosion and loss of marsh. For 9 years prior to hurricane Isabel, the South River FP sill and marsh fringe creation project had been well-established with a robust marsh community and a stable, largely vegetated bank structure. The project greatly reduced erosion and sediment sources which, according to some South River conservationists, then facilitated the return of nearby SAV and oyster communities. However, as a result of hurricane Isabel, it is estimated that approximately 5-6 feet, on average, of the bank was eroded. Based on photographic evidence, the marsh surface elevation may have been temporarily raised, in many areas, by 1.5’-2’. An evaluation of historic shoreline locations dating back to 1847 also shows a long-term pattern of erosion at South River FP. Since the park site at this location is heavily forested with no manmade structures, the erosion did not result in any costly damage. The marsh loss is due to a combination of: deep burial of marsh plants from the recently eroded bank sediments; continual erosion and movement of sand material along the unstablized shoreline; and by intense predation of migrating geese. While it appears that much of the eroded bank material was initially captured by the robust marsh community which existed previous to Isabel, it is likely that some of this material is now moving into deeper waters, as far less marsh structure exists to mitigate this occurrence. A transect of deep core sediment samples has been taken to better characterize the situation. The existing low profile sill averages +1’ MLW, the second lowest elevation of all sills examined under this study. The sill was installed at a minimal cost, of under $30 per linear foot, utilizing volunteer labor. Unfortunately, the shoreline is now in a dynamic, unstabilized state (especially during extreme storms), which will require, at a minimum, replanting of marsh grass to restore the area to pre-Isabel conditions. South River FP was visited and discussed as a part of the South River Living Shorelines Framework project being undertaken by Chesapeake Bay Foundation and several partner organizations. During this visit, the evaluation team discussed raising the elevation of the sill structure by up to 2 feet, particularly in front of the high bank areas. The ecosystem function of wave attenuation simulated by the sill could be enhanced by a denser SAV population at this site. The existing *Ruppia maritima* bed is healthy but at densities unlikely to contribute significantly to wave attenuation. Therefore, improvement of water quality could contribute to wave attenuation (although not during extreme events when tidal levels increase more than 0.5 m).

A.6. Phase I Sites: Design Features in Relation to Bank Type and Project Selection Criteria.

The banks of each site vary in their heights and steepness, but are generally composed of unconsolidated to moderately consolidated sands with some silts and clays in stratified layers. Severe erosion of the banks was not observed to be a problem, except for some rather large, consolidated blocks of soil that had dislocated from the bank face and were deposited on the back slope of the marsh at Aspen ’96. Other periodic sloughing of the bank face was evident at both Aspen ’96 and ’98 – likely due to a combination of weathering of the unvegetated, steeply sloped portions of the bank and some occasional wave attacks from 25 year storm events – the design storm of these structures.

Compacted sandy soils with forest cover have natural angles of repose from 35 to 50 degrees and can be expected to be stable if other active causes of slope failure (e.g. shore erosion, groundwater movement, deforestation etc.) are absent. At Wye NRMA, a protective forested buffer and some grass cover next to the corn field contributed to stable bank conditions. However, it did not appear that any pruning or trimming of tree limbs had taken place in recent years. This has likely caused the disappearance of *S. patens* in various locations along the site, as noted in this report.

Maryland DNR Shore Erosion Control program (Table 8B) has created some general guidelines for selecting non-structural, hybrid and structural projects based on a variety of factors. With the exception of the South River Farm Park site, all sites are reasonably aligned with these criteria. Although the number of sites assessed through this study process are insufficient to make definitive adjustments to the general DNR criteria, it would appear that marsh fringe creation using stone groins and “low profile” sills may require further refinement. For example, the fetch range of groins with fringe marsh is identified as 1 to 1.5 miles. In each of the two groin projects assessed in this report both were well under this criteria, yet each had experienced some degree of marsh erosion from wind or boat generated waves.

Table 8B. Erosion Control Project Selection Criteria*

Shoreline Environment				
Low Wave Energy		***Medium Wave Energy***		***High Wave Energy***
Criteria:	creek, cove	minor river	major tributary	main stem Bay
water depth (ft)	-1.0	-1.0 to -2.0	-2.0 to -4.0	-4.0 to -15.0
fetch (miles)	0.5	1.0 to 1.5	2.0 or more	2.0 or more
erosion (ft/yr)	2 or less	2 to 4	4 to 8	8 to 20
Erosion Control Treatment				
Non-structural Projects		***Hybrid Projects***		***Structural Projects***
beach replenishment		marsh fringe w/groins		bulkheads
fringe marsh creation		marsh fringe w/sills		revetments
marshy islands		marsh fringe w/breakwaters		stone reinforcing
coir logs edging, groins		beach replenishment w/breakwaters		groins & jetties

*Criteria Source: DNR Shore Erosion Control Program

It is interesting to note that at the Eliott R. site, water depths for all three transects at 20 meters from the bank base are 1 meter deep, which corresponds with water depths listed under “main stem Bay”. This also occurs in combination with the soft offshore sediments and along with the groin data showing 2 of 5 groins at water’s end with “potential meaningful change”. Also, noted in Table 8B is the fact that the Eliott site, in spite of having an average fetch several times lower than all other projects, experienced comparable wave height conditions to the Aspen sites – possibly due to boat wakes. Boat wakes, again, in the case of Wye NRMA appear to have added substantial stress to the immediate shoreline environment.

Section B: Biological and Water Quality Effectiveness Assessment

B.1. Marsh Community Health and Nutrient Buffering Capacity

Wye Natural Resources Management Area (RMA)

This site differs from others on the Eastern Shore that we evaluated. This project was at the edge of a large agricultural field which is now owned by the State of Maryland and under the jurisdiction of the Department of Natural Resources. Once slated for extensive development, this area is still being farmed in much the same way it has been for the last

50 years or more. During the first site visit on the morning of May 17, 2004, maize had been planted several weeks previously and had just emerged in the surrounding fields which no doubt had been fertilized at seeding. Obviously an important nutrient source in the Wye watershed, there was a grass and weed buffer zone at the edge of the field before the forest which had grown up along the bank which marked the old erosion scarp of the project. The height of the bank varied from approximately one meter at the eastern end of the project to nearly two meters at the western end.

We began making observations on the eastern end of the project which appeared to be an accreting sand bar at Sta. 42+70 (Figure 12). Behind the bar there was an assortment of macro-algae including *Ulva lactuca* and *Enteromorpha intestinalis* plus wrack of "Horned Pondweed" *Zannichellia palustris*. The transect was laid out in such a way that it only touched a small section of *S. patens* (40 cm long) 14-15 ft and *Spartina alterniflora* (45 cm tall) from there to 17-18 ft before it went across the subtidal zone to the sand spit which was dominated by marsh Elder *Iva frutescens*. At the next transect (39+70) there was much more marsh present beginning with a zone of "Seaside Goldenrod", *Soldigo sempervirens* on the bank side covering 1-2 m. After a bare area from 2-3 m *I. frutescens* dominated from 3-4.5 m which graded into a *Spartina alterniflora* community from 4.5-7 m. The *S. alterniflora* canopy was 1 m tall and very dense (100% cover). Offshore there was only a sparse bed of *Z. palustris* estimated at < 10% cover.

At the third transect (35+70) there was a bare area 1 m out from the berm and a wrack line that was 2-3 m wide. The first vegetation on this transect was *S. patens* which was found from 3-4 m from the bank and was 45 cm tall and covered an estimated 88% of the area in the ¼ m square quadrat. The *S. alterniflora* zone began at 5.8 and went to 7.9 m (tide line) and was 90% tall with 100% cover. Transect #4 (32+20) had a tree adjacent to the bank in what would have been in the *S. patens* zone, but now was covered with a morning glory vine. The *S. alterniflora* zone (100% cover) was 1.2 m in ht and began 2 m from the bank and stretched to 4.3 m, where the tide line began. The roots from the tree extended into the *S. alterniflora* zone suggesting the shoreline had moved considerably inland since this project was initiated.

Although there was considerable marsh erosion west of the initial transect and sand spit, the animal use along this shoreline appeared high with the following species noted: snakes, mussels, barnacles, horseshoe crabs, and various mammal tracks in the sand, as well as numerous small fish at the marsh edge. One obvious factor at the site was various tree species overhung the marsh, shading it in the afternoon; it is uncertain whether removing them might improve the marsh at this site. We have found that 5 m of fringe marsh in mesocosms can remove up to 80% of the nitrate in groundwater passing through the root zone, so the existing system is capable of significantly buffering the Wye River from the large agricultural fields now maintained by the Department of Natural Resources (DNR) on the island. The overall robustness of the marsh suggests that there is enough light for plant survival and the nutrients emanating from the fields above are having a positive effect on plant growth. The more pressing issue at this site appears to be the erosion at the seaward margin which was not arrested by the groin construction.

There was one clump of marsh plants which was eroded into the sub-tidal area. A sill might be a better option at this location to help protect the marsh from wave action which appeared to be exacerbated by boat traffic in traveling in the channel of the Wye River (Figure 13).

Figure 12. Accreting sand spit at Wye at Transect #1 (42+70)

Figure 13. Boat navigating the Wye River near the shoreline project

Eliott Robertson (now Wolf) Property

This site was the only site we studied on the Eastern Shore which was located on a suburban property on the east side of Bennett Point in Queen Anne's county. The property was visited on May 17, 2004 and was well-landscaped with a pool in the backyard with a considerable lawn leading to a wooded buffer area and then a bank before reaching the narrow marsh along the cove. The owner had a small "T" shaped pier with a 21 ft Chapparal boat on the lift. Most of the marsh (figure 14) could be observed from the pier, and it was obvious even at a cursory glance that the site diagram of the proposed work on file at the DNR was inaccurate, since the plan showed no bend in the project. The string fence on the east side of the project that was installed at transplanting was largely intact where the pier was connected to the shoreline and indicted that little planted marsh had been lost here.

The first transect set up (Station 2+73 on plan) had "Marsh Mallow" *Hibiscus moscheutos* and "Poison Ivy" *Rhus radicans* mixed together 0-1 m from the toe of the bank. "Marsh Elder", *I. frutescens* dominated 1-3 m from the bank before giving way to *S. alterniflora* marsh which was noted from 1.5 - 4 m (tide line). The *Spartina* was 1.2 m tall and had about 50 % coverage along this portion of the transect, indicating a rather thin community (which was shaded by overhanging limbs). Transect #2 was laid out just east of the #3 groin. Here the lower 0 – 1.5 m area adjacent to the toe of the bank had "Japanese Honeysuckle", *Lonicera japonica*, mixed with a tall grass *Festuca arundinacea* . At 1-3 m from the toe, *Iva frutescens* dominated with *Spartina alterniflora* present from 3- 5 m (tide line), with approximately 80% cover. The last transect at the westernmost edge of the project had upland vegetation in the upper most 0-2 m with *I. frutescens* from 2-3.5 m. Spartina alterniflora was only a meter wide and stretched from 3.5-4 m from the toe with only 60% coverage with a canopy ht of 1.4 meters.

The thin vegetation and overall height suggests there is considerable stress on the fringe marsh, particularly in the western part of this project. Both shoreline erosion and shading by overhanging branches appear to reduce the robustness of the marsh at this end of the site. Also the relatively steep angle of the marsh surface (indicated by upland vegetation) on the landward side of Transect #3 indicates that the initial grade of this project was not even close to what has been a rule of thumb for installing comparable shoreline projects (1 ft rise for every 10 ft perpendicular width of marsh). Another troubling observation at this site was that there were many less signs of animal usage. In fact the only item noted was water snakes which were observed in the marsh and in the shallows. This strongly contrasted with the site on Wye Island detailed above and may be due in part to the prevalence of suburban homes in the landscape adjacent to the marsh. However, the lack of *S. patens*, suggest that the marsh system is much less diverse than the previous and simply may not support a large diversity of consumers either. In addition, the marsh here is steeper and less wide (especially on the western end of the project) suggesting that there is much less nutrient buffering capacity. This project may have benefited from installation of a low sill to keep more of the material in place (instead of groins) and more coarse sand to maintain a shallower angle of repose for the substrate. The relatively modest marsh buffering capacity may be not as problematic as it would be if the land were still in agricultural fields, but argues for parsimonious use of lawn and garden fertilizers at this location and installation of advanced denitrification systems installed in septic tanks.

Figure 14. Shoreline along Eliott Robertson project.

Aspen -- 96

The Aspen Institute operates an overnight facility for retreats and has control of a mile or more of shoreline on what was previously Arthur A. Houghton Jr.'s estate in Queen Anne County. Houghton's family had controlling interest of the Corning Glass Works. The Aspen Institute has erected cabins just outside the 100 ft buffer area along the river. The magnificent sunset view to the west is kept clear by mowing the grass below the scattered trees in the buffer, preventing natural succession to occur. The fact that several of the trees close to the bank were obviously blown down in recent storms (tropical storm Isabel), suggest that this would be an excellent study site to look at what a recently installed sill (1996) would do under relatively unshaded shoreline conditions. The site was first surveyed on May 19, 2004 beginning at the northeastern end at the entrance of Quarter Creek, behind the greenhouse and maintenance facility for the property. The erosion scarp was estimated at 2 m at this end of the project and rises to almost 3 meters at the southeastern end.

Transect #1 (Station 0+50) had an extensive mat of wrack in 0-2 m from the toe of the bank and *S. patens* at 2-3 ft. The *S. patens* canopy was 75 cm tall and 100% vegetated. The *S. alterniflora* zone was 3 m wide going from 3 – 6 m from the toe, and was 75 cm tall with only 50% cover (Figure 10). At 6-9 m there was a shallow open water area before encountering the sill at 10.7 m. There were large numbers of killifish in the pool during the study team visit and they were also observed beyond the breakwater by E. W. Koch when she installed the wave gauge at this location. There were also extensive populations of barnacles on rocks of the sill with *Enteromorpha*, *Ulva lactuca* (i.e. "Sea Lettuce"), and red algal species present in the pool and beyond the sill. One immediately important feature in this project which contrasts strongly with the previous two, is a totally new habitat, a quiescent pool was created shoreward of the sill (Figure 15) with a sandy gravelly bottom, adding considerably to the habitat diversity along this shoreline.

Transect # 2 (Station 1+50) was located 100 ft from the eastern end of the project and had very similar zones as the previous. There was a dense amount of wrack 0-2.5 m from the toe of the bank and a meter wide *S. patens* zone from 2.5-3.5 m which was only 30 cm high with 50% cover. The *Spartina alterniflora* zone had apparently grown out further towards the sill, stretching from 3.5-7.2 m and the canopy here was 75 cm with 80% cover. The pool was less than a meter wide at this point, stretching from 7.2-8.0 m when the first rock emerges from the water at the base of the bank (the crest is at 7.2 m). The assemblage of algae and killifish was observed throughout the site and will not be reiterated for each transect hereafter, but this was the first observation of the SAV *Zannichellia palustris* sprigs at the site at 100 m in 88 cm water.

Continuing southwest, Transect #3 (Station 3+90) (45 ft from a sill opening) had a slightly wider zone of wrack 0-3 m from the toe of the bank with *S. patens* 3-4.5. The canopy height of the *S. patens* was 35 cm and the cover a mere 30%. The *S. alterniflora* zone measured 4.5-8.4 m from the toe with a canopy ht of 60 cm with 50 % vegetated. Water snakes were noted in the pool at this location. The last transect (Station 6+40) on the southwest portion of the project had no significant wrack with the *Spartina patens* beginning at the toe of the bank and extending 4.7 m seaward. The *S. alterniflora* went right out to the rock (4.7-9.5 m) with no pool present. Additional signs of animal utilization present at this location besides barnacles and *Ulva* were horseshoe crab shells in the marsh and a raccoon tail. This suggests that there was considerable deposition on the south side of this project, which undoubtedly has contributed to the relatively healthy *Spartina* marshes along the shoreline.

The curious feature about these marshes is the lower canopy height compared to the previous locations on Wye NRMA and the Eliott R. property discussed above. The lower canopies could be due in part to higher light levels when culms are less elongated. The slightly lower cover could be associated with the relatively lower nutrient inputs than the previous two sites, since the grass above the bank did not appear to be fertilized. Therefore, this site may have relatively lower incoming nutrients than the previous two that were evaluated. Also, an important feature not often articulated about this type of living shoreline project is that it may be more nutrient retentive. Indeed the semi-isolation of the marsh and pool from the rest of the river may provide a more efficient buffering system than simply installation of groins to slow shore erosion. However, the authors are somewhat cautious in comparing this site with the previous two, because of their age and other important differences. This project is only eight years old and it may change over time, with the *Spartina* marshes growing taller, for example.

Figure 15. Transect 0+50 at the northeast end of Aspen 96 project.

Aspen – 98

Two years after the installation of marsh on the northwest side of Wye Woods there was another large shoreline project begun in 1998 (Figure 16) to afford more protection to the southeast. Unlike the Aspen 96 shoreline, this area is largely intact forest, before encountering a private residence with a pier on a point.

The first transect (Station 0+00, north) was just to the north of the boat basin and had a wrack line from 0-1 m from the toe of the bank with *Phragmites australis* mixed with *S. patens* at 1-4.5 m. The *Phragmites* canopy reached 2 m in height and had achieved 100 % cover, whereas the *Spartina patens* canopy was 60 cm tall with only 30 % cover. This was the only location we found a significant population of *Phragmites* and it is not clear why it has not been invaded at other sites. *Spartina alterniflora* occurred 4.5-7 m along the transect and it was 1 m tall with 90% cover with sprigs of *P. australis* present. The *S. alterniflora* zone continued almost to the rock sill (Figure 11; top of rock was 8.3 m). Similar to Aspen 96, at this site we noted barnacles on the rocks, as well as the presence of *Ulva* and *Entermorpha*, but no SAV out front of the sill, which may not be too surprising since the Secchi depth was only 60 cm.

The remaining transects on this project were laid out southwest of the boat basin. The next one was at Station 1+00 and the wrack zone extended 0-3 m from the toe of the bank with 70 cm tall *Spartina patens* present from 3-4 m (from the toe). *Spartina alterniflora* was relatively robust with green shoots at 1 m, but there were also brown flowering culms that were up to 1.6m. The *S. alterniflora* extended to the sill on this transect with no pool of water behind it (Figure 11). The top of the sill was at 8.2 m and beyond that there were a few shoots of *Zannichellia palustris* observed in approximately 1 m deep water. Also noted along this transect were horseshoe crabs and barnacles.

The third transect (Station 2+00) had wrack from 0-1.7 m from the toe of the bank and *Spartina .patens* at 1.7-3.3 m and it was 90 cm high, but with only 20% cover. The *Spartina. alterniflora* zone extended 3.3-7.3 m from the toe and was 1 m tall with old culms to 1.8 m and cover was 60%. One of the unique features along this transect was the presence of large burrows which may have been excavated by muskrats and in addition there appeared to be new sandy material deposited at 7.3-9.0 filling in the area between the *Spartina alterniflora* zone and the rock of the sill (top was at 10.4 m from toes of bank). It appeared that this new material must have been an overwash deposit during a recent storm, most likely Hurricane Isabel which hit the area the previous September. Beyond the sill there were only two shoots of *Zannichellia* noted along the transect which extended 108 m from the toe of the bank.

The last transect was at the very end of the project and had 0-3 m of wrack with 70 cm high *S. patens* at 3-4 m (at 40 % cover). *Spartina alterniflora* extended from 4-8 m to the edge of the rock of the sill (top was at 8.9 m). The *Spartina alterniflora* was 1.1 m high with old culms reaching 1.7 m with 70 % cover. Extensive populations of barnacles were noted on the rocks of the sill and up in the wrack were several horseshoe crab shells. However, there was no submersed aquatic vegetation observed in the shallows beyond the sill.

Figure 16. Aspen '98 shoreline southwest of boat basin looking towards a private pier.

The extensive fringe marsh which is now in place at Aspen 98 would be expected to have high denitrifcation potential. However, since most of the area adjacent is in forest, the actual amount of nitrogen nutrient buffering would not be large. Thus, the placement of this fringe marsh is less than ideal in terms of reducing the impacts of non-point sources. Perhaps the most pressing problem in terms of nutrients in this area is the fact that the unusually high precipitation in the 12 months previous to the survey of these sites resulted in much higher runoff than average (33 cm compared to 15 cm per yr) causing elevated nutrients in the Wye River (Ken Staver, pers. com, data from watershed studies at the nearby Wye Research & Education Center). The ideal arrangement would be to have these fringe marshes installed and protected with sills along agricultural fields or areas of shoreline where the groundwater from septic systems breaks out into the estuary.

EPPING FOREST

This site on the Severn River was only planted the previous fall when we surveyed it (in early June of 2004). As discussed above, this small project was somewhat unique (among the eight that we studied) because it consisted of plantings on several island breakwaters which were part of an alluvial fan of a small creek which drains the Epping Forest subdivision. In view of the fact that this project had just been completed, it is not surprisingly that the marsh at this location was very poorly established when we laid out the transects. Transect #1 was located at the eastern end (downstream) of the project and ran from the upland bank outward across the small created island which was only sparsely vegetated (see figure 17 below). The *Spartina alterniflora was* 80 cm high, *Spartina patens* was 35 cm high and *Schoenoplectus* 45 cm.

What was of greater concern than the actual stature and low density of the plants, however, was our observation that several of the *Spartina alterniflora* plants that had been established just behind the bayward rocks on the tombolo had exposed roots. These bare roots were the result of sediment erosion which on the top of the structure which is exposed to wave activity at high tide. It appeared that the low profile of double rock berms may actually create more wave action. In order to compensate for this Keith Underwood, the designer had also installed a layer of gravel on top of the tombolo. The gravel does inhibit resuspension under low to moderate wave energy. However, this substrate is not what this species usually is associated with in more natural settings and it remains to be seen how well the *Spartina alterniflora* will survive here at this location in future years.

Transect #2 was laid out upstream of transect #1 and the *Spartina alterniflora* here was also of very short stature (40-50 cm high). Since plants on both transects were all considerably less in stature than any site we had seen previously, it suggested nutrient limitation (often associated with gravel substrates) might also be a problem at this site, as well as wave action. *Spartina alterniflora* marshes which were established in 2003 on Poplar Island had more than double the height of the Epping Forest Plants -- even in pure sand substrates. Both Poplar Island (Jenifer Harlan, Maryland Environmental Service, pers.com 2004) and Epping Forest marshes had been amply fertilized at planting (K.

Underwood, pers. com, 2004). However, fertilization at Epping Forest was done at planting in the fall when little plant growth was possible because of lowering temperatures. Spring growth may have been inhibited at the Epping Forest Site by leaching of fertilizers during winter months of 2003-2004. The sandy and gravel substrate utilized in this project provide ample exchange with surface waters during high tide, promoting fast release of the osmocoate fertilizer.

Although it was obviously too early to determine the ultimate success or failure of vegetation at Epping Forest, early indicators concerning marsh establishment were not propitious. Moreover, the very sparse vegetation cover and close proximity to housing, coupled with the obvious public use of this small park adjacent to this project, all suggests that the marsh habitat was not significant in terms of animal habitat. In fact, no animals were noted in the marsh zone, but there was a dead raccoon floating rotting in the shallows nearby; providing an ample aroma that permeated the eastern end of the site. Nevertheless, there were numerous killifish and/or mummichogs obvious during our assessment in the protected quiescent areas behind the breakwaters and there is undoubtedly valuable subtidal habitat which has been created at the Epping Forest Project. The fish also no doubt also benefited from the extensive beds of *Ruppia maritima* and *Zannichellia palustris* (with apparently some *Vallisneria americana*) offshore of the breakwaters.

Figure 17. Keith Underwood (center) at the Epping Forest project with David Burke.

Figure 18. Eroded substrate of *Spartina* at Epping Forest.

Unfortunately, other benefits often associated with marshes such as nutrient buffering (via uptake) and denitrification are minimal in this project. The small stature of the plants and the low density at present would provide little sequestration here in plant tissue. Furthermore, the gravel (figure 17, above) at the East end and sand at the west end (figure 17, above) that were brought in for this project were undoubtedly low in organics and this limits the denitrification potential at Epping Forest. It is unclear without more detailed study of the watershed whether significant nutrient loadings are running out of this subdivision into the Severn River. The steep slopes throughout the subdivision obviously produce large volumes of runoff after storms which resulted in an alluvial fan in the Severn River (see figure 8 above) and if nutrients are high emanating from lawns and/or septic systems, there may be problems. If indeed nutrient loadings are a significant factor, the mouth of the creek running at the edge of this project (the mouth of which is visible in figure 17) might have been altered to create a tidal pond and allow more water detention. However, this incorporation goes well beyond the principles now utilized in living shoreline projects and might best be viewed as the next generation of designs.

South River Farm Park

As discussed above in regard to the structural analysis, the shoreline at South River Farm Park has eroded considerably since the late 1840s, when the first triangulated surveys were completed for this portion of Chesapeake Bay. The high rate of erosion here is undoubtedly due to the wave activity associated with the very long fetch in the Northeast direction (which was especially vulnerable during Hurricane Isabel). Some members of the site team had visited this shoreline in 2003, just before Isabel hit the Bay in September. At that time the *Spartina alterniflora* was well established behind the breakwaters and even up to 2 meters in height in many locations. The stature and obvious health of the *Spartina alterniflora* was even greater than we had observed at the

Eastern Shore sites in 2004. In addition, the *Spartina alterniflora* appeared to be aggressively colonizing the upper elevations beyond the normal high tide zone of the beach deposits that had been laid down during earlier storm events. There appeared to be surprisingly little *Spartina patens* and *Distichlis spicata* in the beach profile. This site had been bulkheaded at one time as we discussed above and quite possibly *Spartina patens* and *Distichlis spicata* had been obliterated and they never re-established themselves in their natural position after the sill project had been initiated. Whatever the reason for its advance to higher elevation than normally encountered, the *Spartina alterniflora* stems appeared to be particularly robust and they were often spaced along lines reflecting the arrangement of underground rhizomes.

Our initial 2003 impression was that this project at South River Farm appeared to be very successful in slowing erosion of the banks by retaining sand on the beach which would otherwise have been carried offsite (if the low sill which John Flood and a group of volunteers had constructed about seven years before was not in place). In addition, biological utilization of the shoreline appeared to be high because the low sill in this project was designed to have numerous breaks, allowing for ample exchange of water and aquatic organisms. Also when we visited in 2003 there was a very healthy bed of *Ruppia maritima* observed just outside of the sill in flower. Apparently, this bed had been first noticed just after the project was completed and the reduction in shore erosion was correlated well with the reappearance of SAV. However our evaluation in June of 2004 of the vegetation along the South River Farm Park showed how dramatically it had been altered by Hurricane Isabel. The most obvious factor was that many trees that were previously on the crest of the bank had fallen across the beach (figure 19, below) which had been previously densely colonized by *Spartina alterniflora* marsh. The trees and snags made traversing this shoreline very difficult.

Most of the mid to upper portion of what had been a robust population of *Spartina alterniflora* was now literally buried under one or more feet of sand as a result of Isabel. Only the lower portions of the *Spartina alterniflora* zone survived in small patches. A core taken on the lower beach near the mid-low tide zone showed that even there accretion was in the range of 5-6 cm (figure 20, below). In many areas along the South River Farm Park shore, not only was the beach absolutely devoid of vegetation from the normal low tide line to the toe of the bank, but also the bank itself was, in several areas, completely free of vegetation when we assessed the site in June of 2004. A variety of grass and woody shrub species had been observed on the bank at South River Farm Park before Isabel in 2003. This fresh escarpment was of concern in terms of future erosion.

Although some transport will undoubtedly occur, it is not certain how much of the material on the upper beach would be exported from the site. It should be pointed out that the rare and endangered “Puritan Tiger Beetle”, *Cicindela puritana,* depends on these types of eroding banks and cliffs for habitat during its larval stages, before it emerges in June to mate along the adjacent beach-front. It could be argued that this type of Park (with no structure near the shoreline), is the ideal setting for a “Puritan Tiger Beetle” refuge, since it is relatively secluded and not open to public access. Furthermore the even more rare (in Maryland) “Northeastern Beach Tiger Beetle”, *Cicindela dorsalis dorsalis,* spends its entire two year life cycle on the beach, and the fallen trees may yet be more protection for this species. These habitat concerns need to be weighed along with risks that the eroded sand from the banks during Isabel may be moved offsite and needs to be better stabilized.

Figure 19. David Burke observing the fallen trees at South R. Farm Park- June, 2004.

Accordingly John Flood took the opportunity to plant some *Spartina alterniflora* in one location on the beach which was bare at the time of our visit as a test of survival (figure 21, below). While we took data at the site he planted about 80 seedlings of *Spartina alterniflora* in 8-10 inch diameter shallow holes he excavated with a bucket corer.   What was surprising was his technique of placing the seedlings in the holes he made without any attempt to replace soil adjacent to the roots, thereby closing the holes. In his experience, he had concluded that this planting approach preserved the delicate root hairs of the *Spartina alterniflora* better and the next tide would essentially provide the energy needed for sediment closing the holes. This planting was carried out close to the first transect we laid out at the site. The transect was begun at the toe of the bank where a six foot 2” by 6’ piece of driftwood was inserted in a 1-2 ft deep hole to mark our location in a more permanent fashion than is possible with a simple wire survey flag. There was little vegetation on the upper portion of the transect until a small (one meter diameter) patch of *Spartina alterniflora* was encountered near the mid tide line. We rated it as 50% cover and the tallest culms were only 75 cm tall, again much more modest than what we had seen on the Eastern Shore. The second transect we laid out had no marsh vegetation at all. Despite the obvious stress on the intertidal community there were numerous signs of wildlife including deer and raccoons. We also observed small fish, mussels, barnacles, copepods and polychetes associated with the shallows and the low breakwater structure and there were also "Green Flies" and "Dragon Flies" present when we were there, reflecting perhaps the lack of spraying that most likely was carried out at Epping Forest with houses in close proximity and a small park bench for viewing the Severn River. Also, when we were at the site, *Ruppia maritima* was in flower, demonstrating that there was still considerable habitat associated with the shoreline and shallows outboard of the sill structure at South River Farm Park.

Figure20. Sediment core at South R. Farm Park, June 2004 showing 5-6 cm over the old black organic marsh layer.

Figure 21. John Flood planting *Spartina,* South R. Farm Park, June 2004.

London Town

A little over two miles (3.5 km) upstream from South River Farm Park is historic London Town which was founded in 1683 and was the location of the courthouse for Anne Arundel County from 1684 until 1695, when Annapolis became the capital of Maryland and replaced it as the focal point of the area. Afterward London Town remained important however, as the site of the ferry landing on the south bank of South River where a large brick public house was constructed by Richard Brown in the 18th Century. The stabilization of the shoreline here is regarded as extremely important to protect the Brown House and other important archeological finds in the area. Since this absolute stabilization of the shoreline was deemed a necessity (in contrast to South River Farm) this shoreline project was much more robustly constructed with a high sill of very large rocks with fill imported to construct a marsh between the sill and the 3-30 ft high banks.

We laid out four transects for monitoring the vegetation during our site assessment on June 2, 2004. The first transect began in a non-tidal wetland seep dominated by “Jewell Weed”, *Impatiens capensis*, near a Cypress tree just off the trail leading from the historic London Town garden. Nine feet out from the beginning of transect (towards the water) was a population of “Narrow leaved Cattail”, *Typha angustifolia*, which quite possibly was planted as part of the shoreline project. The *Typha* was found from 9 ft to 36 ft along the transect and had a coverage of 60 %. On the bayside of the Typha zone there was a 3 ft wide line of wrack (figure 22) covering some of the *Spartina alterniflora* zone which eventually got denser until it reached 100% cover in the direction of the sill. The *Spartina alterniflora* zone was approximately 9 ft wide extending from 39 ft to 48 ft from the initial starting point on the transect and continued to the rock on the sill.

Figure 22. David Burke behind *Typha* zone,transect #1, London Town .

The next transect (# 2) was laid out to the West Northwest (upriver) of the first and began with upland herbaceous vegetation for the first 5 ft behind a berm (5-12 ft) with a thick wrack line from 12-17 ft before the *Spartina alterniflora* zone which extended from 17 ft to 28 ft from the base of the Bank. Coverage of the *Spartina alterniflora* was rather sparse at 40%, the tallest plants were one meter in height. Between the *Spartina alterniflora* zone and the breakwater there was a 20 cm deep pool from 28-32 ft along the tape (from the base of the bank. This pool widened and deepened as we went westward. At transect #3 we found upland vegetation 0-7 ft from the bank, a ditch from 7-13 ft and then a sandy berm from 13-22 ft, before the 17 ft wide 1.1 m tall *Spartina alterniflora* zone (extending from 23-40 ft). The % cover of *Spartina alterniflora* was rather low, only 30 %. The pool between the *Spartina alterniflora* zone and the breakwater had now widened to seven ft and was 40 cm deep. On the last transect we laid out (#4), we found a patch of *Baccharis halimifolia* from 0-6 ft from the toe of the bank, then a low swale from 6-11 ft, followed by a five ft wide ditch (from 11-16 ft). Adjacent to the ditch was an 18 ft wide *Phragmites australis* community (2 meters in height) adjacent to a 15 ft wide *Spartina alterniflora* dominated marsh which was 90 cm tall. The pool behind the breakwater was ten feet wide (extending from 45-55 ft from the base of the bank and was 40 cm deep. The stake at the top of the rock berm was 59 ft from the base of the bank (see figure 23, below).

Figure 23. David Burke & Eva Koch, west end of London Town Breakwater, June 2004.

Overall the relatively high breakwater had provided much better protection for the bank and the *Spartina alterniflora* marsh (than the low sill had afforded downstream at South

River Farm Park), but it may have some drawbacks. The height most likely was a factor in the creation of the pool immediately behind it. The pool itself had noticeably warmer water than the shallows immediately outside. Since the water in the pool was not flushed with every tide, we viewed this as a serious design limitation in terms of animal habitat. This could be easily remedied by removing some of the rock in places to create gaps for the exchange of water and organisms. The large pool behind the breakwater may promote denitrification, due to the high residence time of the water and the elevated temperatures in spring and summer would enhance microbial activity in the surficial sediments. However, since the upland watershed is forest at London Town (see figure 10, above), nutrient reduction does not appear as important as it would be at the edge of more developed watersheds (e.g. Epping Forest) or agricultural watersheds (e.g. Wye Is).

Jefferson Patterson Museum and Park

The last site we assessed was on the Calvert County side of the lower Patuxent River which is now the location of a Museum and Park named after the last land owner, Jefferson Patterson, formerly the U.S. Ambassador to Uruguay. This scenic spot has long been cherished by Marylanders and was the plantation of Richard Smith during the 1600s, who served as Attorney General for the Province. Indeed artifacts that have been unearthed along the shoreline date to the period Smith had his plantation there and in addition this land was later a key position in the Battle of St Leonards Creek during the War of 1812. In view of the importance of historic and prehistoric sites on this 570 acre waterfront property, shoreline stabilization was viewed as imperative by State of Maryland archeologists who also have their conservation laboratory at this location. We began our assessment of this project on the south end of the property at Peterson Point, where St Leonard's Creek empties into the Patuxent River (figure 24, below). This area is particularly exposed in the northwest direction where the maximum fetch is slightly over six miles. Also Peterson Point is vulnerable from the southern direction, with a maximum fetch there in the range of five miles, and not surprisingly erosion has been noted here since the colonial period.

Transect #1 was laid out beginning at the northern edge of the base of an old chimney aside a little rustic building Jefferson Patterson had apparently erected on the site before his death to use as a bayside picnic house. The transect extended bayward over sandy ground having "dune grass" *Ammophila breviligualata* and then through one of the three tombolo structures that were constructed several years ago. We found *Ammophila breviligulata* on the first four feet of the transect and *Spartina patens* was dominant from 4-18 ft. Both these species can tolerate very dry conditions on sand dunes. From 18-62 ft there was no vegetation at all indicating severely stressed conditions up to the waters edge. The transect re-emerged at 124 ft (from the chimney) on the backside of the tombolo which was twenty feet wide and had a few 1-2 m tall "Black Locusts", *Robinia pseudoacacia* interdispersed among *Spartina patens* on the top. The *Spartina patens* cover was almost 100% on most of the tombolo and it was 80 cm tall. The vegetation appeared to be healthy, but the tombolo was too high to be considered a wetland and animal habitat may have been limited to groundhogs or other burrowing animals. There was no SAV observed behind or in front of the tombolo in the shallows, but the beach was obviously excellent terrapin nesting and horseshoe crab habitat.

The second transect was laid out in the vicinity of the old Philadelphia Academy of Sciences research pier that had been badly damaged by Hurricane Isabel at the north end of the property. The transect began at a "Cherry Tree", *Prunus serotina*, at the base of 25 ft high cliff and the marsh zone extended for 25 ft to the beginning of the stone on the breakwater (figure 25, below). The marsh was a mix of *Spartina patens* which graded into *Spartina alterniflora* which combined to give an estimated 100% vegetative cover. In terms of habitat there were abundant periwinkle snails, *Littorina irrorata*, on the rocks of the breakwater as well as on the *Spartina alterniflora* culms. However, this may not be the best sign for the plants. Silliman and Zieman (2001) have reported that *Littorina irrorata* can disrupt the epidermis of *Spartina* allowing fungal and other pathogens to damage leaves which can result in significant losses in productivity. Also we noted a considerable amount of *Ulva lactuca* in the vicinity of the breakwater, but unfortunately no SAV was evident nearby.

Figure 24. Marsh and dune vegetation on tombolo at Peterson Point on Patuxent River.

Figure 25. Breakwaters, northern end of the Jefferson Patterson Park & Museum site.

We laid out vegetation Transect #3 north of Transect #2 and this had 2 ft of wrack just below the toe of the bank (marked with a stake and a rock) before we noted any vegetation. We concluded that this had been deposited by Isabel in September of 2003. *Spartina patens* was then the dominant from 2-8 ft (from the stake), although there was *Baccharus halimifolia*, *Amaranthus cannabinus* and *Hibiscus moscheutos* nearby. The *Spartina patens* was particularly robust and the decumbent culms were 75 cm long. Possibly subsurface groundwater was available and high in nitrate from the adjacent agricultural fields. After the *Spartina patens* zone, there was a 3 ft bare area, then a *Spartina alterniflora* zone (mixed with some Spartina patens) extended from 11-24 ft before hitting the sill. Curiously, in view of the obvious robustness of the Spartina patens, the Spartina alterniflora was only 70 cm tall. Again periwinkles were noted in the marsh and they were also on the rocks of the breakwater (along with barnacles). Transect #4 was much like Transect #3 with Spartina patens from 0-6' from the toe of the bank with some *Baccharus halimifolia* shrubs scattered about. This transect was unique because it was the only area we noted much *Distichlis spicata* mixed in with the *Spartina patens* from 6-22 ft from the toe of the bank. The next marsh zone seaward (extending 22-31 ft) was co-dominated by *Spartina alterniflora* and *Spartina patens*. The culms of *Spartina alterniflora* were not particularly tall (60 cm high) and *Spartina patens* was not as robust (only 45 cm) as it was on Transect #3. Animal utilization that we noted on Transect #4 included muskrat and a caterpillar on the *Baccharus*.

Overall, the project at Jefferson Patterson Park did very well in terms of arresting shoreline erosion. The tombolos at the south end of the project were effective in promoting a variety of sandy edge habitats beneficial to a large diversity of estuarine organisms than simply a marsh edge, while the shift in design in the north towards breakwaters of varying heights made them more valuable as a habitat than if they were kept at one level. Also the narrow gaps and layering of rocks (see figure 25 above) in various locations, managed to protect the shore from high energy waves as well as to provide access to the marsh by aquatic organisms. This access feature plus the fact that this fringe marsh was in an ideal location to intercept surface runoff and groundwater from the adjacent agricultural fields, gave this project particularly high marks in terms of multi-functional design. Although the nutrient reduction associated with the southern end of the project was minimal (because of the high tombolos), there was no need for nutrient buffering since it was the southern end of a wooded peninsula.

B.2. SAV historical presence and habitat suitability

Submersed aquatic vegetation (SAV) is an important component of coastal ecosystems as it provides a diversity of ecosystem services such as wave attenuation and sediment stabilization. Therefore, SAV could be a vital part of a healthy living shoreline. The more waves are attenuated by SAV before they reach the shoreline, the less armoring of the shoreline is required. It is possible that the massive loss of SAV in the Chesapeake Bay in the 1970's contributed to shoreline erosion. Unfortunately, such data do not yet exist and we can only speculate about this lost ecosystem service of SAV in Chesapeake Bay.

Due to their contribution to wave attenuation and, therefore, a healthy living shoreline, we evaluated the presence/absence and abundance of SAV at each site. As the SAV distribution was markedly different on the eastern and western shore, they will be addressed separately.

Eastern shore SAV communities

The only SAV species observed at all 4 sites on the eastern shore (Phase I) was *Zanichellia palustris*, a freshwater/mesohaline plant. At these study sites, it occurred at very low densities (Wye NRMA, Aspen 96 and 98) if at all (Eliott R.). At the Wye NRMA site, *Z. palustris* occurred at relatively high depths (0.6 to 1.0 m) at transects 2, 3 and 4 but the percent cover did not exceed 10% (quite low). This species also occurred at Aspen 96 (transects 2 and 3) and 98 (transects 6 and 7), again at what would be considered the maximum depth of distribution of SAV in Chesapeake Bay (1 m) and at very low densities. No SAV was found growing at Eliott R. although some floating plant material was observed.

It was somewhat surprising to find SAV at the study sites on the eastern shore as the Chesapeake Bay Program (VIMS mapping program) has reported all 4 study sites as devoid of SAV for more than 10 years. Only in 1997 and 1998 was SAV reported for the bay just south of Aspen 98. It is possible that the mapping techniques (aerial photograph) are unable to detect SAV densities as low as those observed during the site visits or the aerial photos may have been taken at a time that the dominant SAV species are not at their peak biomass.

It was also quite unexpected that, when present, SAV on the eastern shore occurred at or near its maximum depth of distribution (approximately 1 m) but not closer to shore. As light is the main limiting factor to SAV distribution in Chesapeake Bay, it would be expected that SAV would be more abundant in shallower waters (less light attenuation through the water column) nearshore. Therefore, something seems to be limiting SAV from colonizing these shallower waters. It could be desiccation at extreme low tides or turbidity generated by shoreline erosion. Despite the cause, during the site visits, the water quality in the Wye River (where the eastern shore sites were located), did not seem to be favorable to support the growth of extensive SAV beds. Measurements of Secchi depth were used to calculate light extinction coefficients (K_d) and percent light at one meter depths (Table 9). The percent light available at one meter depth was well below the suggested minimum SAV light requirement established by the Chesapeake Bay Program (Technical Synthesis II). This low light availability is a result of high water turbidity, a result of high nutrient concentrations, suspended solid (TSS) concentration, and/or phytoplankton (Chl a) concentration.

At the Aspen sites both dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) concentrations were relatively low (Figure 26) and did not exceed the threshold required for SAV as suggested by the Chesapeake Bay Program. The combination of low nutrients and low light penetration suggests that benthic macroalgae may be drawing down the nutrient concentration. Thick algal layers were observed covering the few *Z. palustris* shoots at Aspen and also covered the epiphytic strips deployed at the sites (Figure 27).

Table 9. Water column light characteristics and requirements at eastern shore sites.

Site	Observed Secchi Depth (m)	Calculated K_d (m^{-1})	Calculated Light (%) at 1 m depth	Light Requirement (% of surface light)
Aspen 96	.55	2.6	7.2	> 22
Aspen 98	.63	2.3	9.8	> 22
Eliott R.	.40	3.6	2.7	> 22
Wye NRMA	.68	2.1	11.7	> 22

At the Eliott Robertson and Wye NRMA sites, DIN was relatively high and exceeded the suggested SAV habitat requirement (Figure 26). DIP was also above the SAV habitat requirement at Eliott Robertson but not at Wye NRMA. The Eliott R. site is characterized by fine and highly organic sediments while Wye NRMA is immediately adjacent to a farm. These are likely the causes for the elevated nutrient concentrations, especially DIN at these sites. High concentrations of DIN or DIP can spur increased phytoplankton and epiphytic growth which can lead to a reduction in light availability to SAV.

Epiphytic cover was monitored as an environmental indicator of water quality. Accumulation rates of epiphytes (attached algae and bacteria) on artificial substrates are dependent primarily on water column nutrients but also take into account the entire surrounding environment including water column irradiance levels, temperature, presence of grazers, and wave and current dynamics. High rates of epiphyte growth are an indication of poor SAV growing conditions as epiphytes block the light that would normally reach SAV leaves.

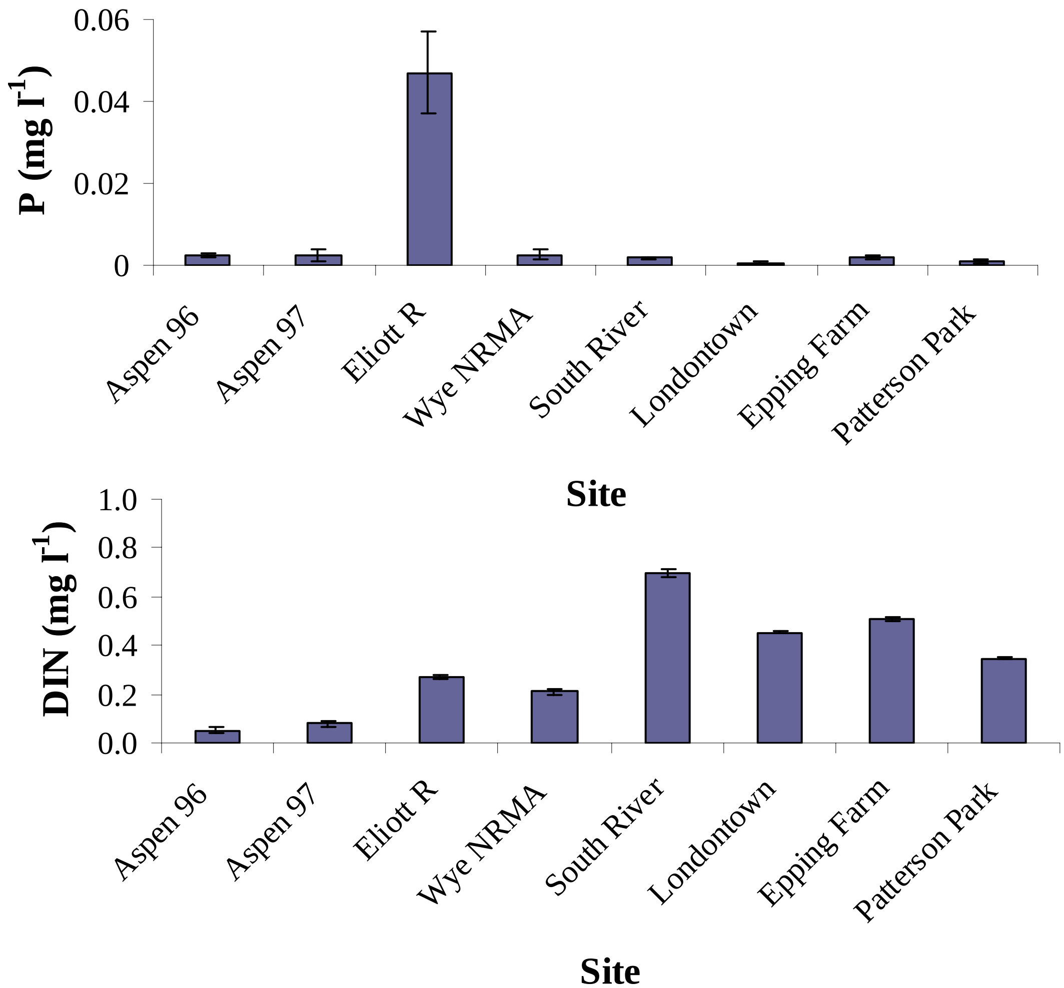

Figure 26. Nutrient (DIN and P) concentration at the study sites. Note the high P concentration at the site with the finest and most organic sediments, Eliott R and the relatively high DIN concentrations on the western shore.

At each of our sites, despite a high degree of variability, epiphyte accumulation was high (Figure 27). No distinct patterns between nutrient concentration and epiphyte accumulation were observed. The Eliott Robertson and Wye NRMA sites exhibited a larger inorganic portion to the overall epiphyte load. At the Eliott Robertson site, which is dominated by fine grain particles, these particles may be incorporated into the epiphyte mix during resuspension or runoff events. The Wye NRMA site, which is exposed to higher wave activity, may experience more resuspension which could contribute to increased incorporation of particulates into the epiphyte mix. The high rates of epiphyte accumulation at each of these eastern shore sites yields further evidence that these sites generally do not and will not support robust SAV growth unless some action is taken to improve water quality.

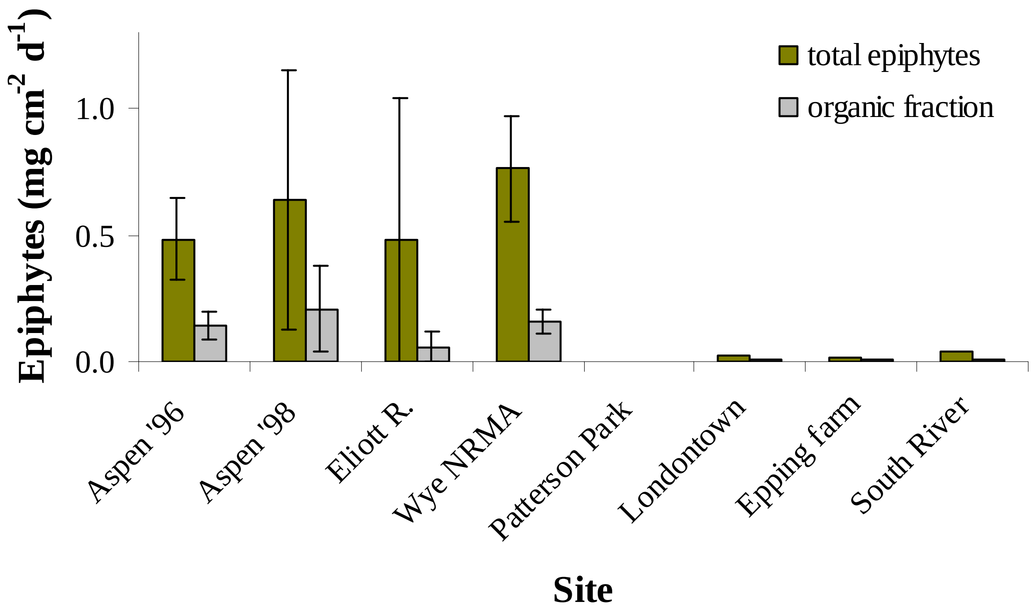

Figure 27. Epiphytic growth rates at each site. Note the significantly higher growth at the eastern shore sites.

Western shore SAV communities

All sites on the western shore (Phase II) except JPPM were vegetated. The shallows adjacent to Epping Forest were mainly colonized by *Ruppia maritima* although some *Potamogeton perfoliatus* was also observed. This vegetation was relatively sparse but appeared healthy. Perhaps the relatively long fetch is responsible for the patchy distribution. A medium density SAV bed was found adjacent to the South River Farm project. There, an extensive and healthy bed was flowering at the time of sampling but its density was not as high as that of a *Zannichellia* bed adjacent to the London Town project. The London Town bed occupied the entire water column and most likely contributed to wave attenuation in the area but the vegetation tended to decrease in density at the northern end of the sill.

According to annual aerial surveys by the Virginia Institute of Marine Science, all western shore sites have been vegetated at some point during the past decade, again with the exception of JPPM. SAV was present at the Epping Forest site from 1997 to 1999 and again in 2002. The species found there were *R. maritima*, *Z. palustris*, *P. perfoliatus*, and *M. spicatum*. This bed has ranged from approximately 4,000 m^2 to 6,700 m^2. *Ruppia* and *Zanichellia* were also observed at both the London Town and South River Farm Park site every year from 1994 to 1998. At the South River Farm Park site, SAV was also present in 2001 and 2002. At London Town, *Z. palustris* was present at high densities at the time of sampling (2004). Over the past decade, the SAV beds at the South River Farm Park site ranged in area from approximately 64,000 m^2 to 85,000 m^2. The SAV beds at London Town were smaller over the same time period, ranging from 12,000 m^2 to 19,000 m^2. JPPM has been unvegetated during the past decade though in some nearby locations (2-5 km away) small beds of *Z. palustris* and *R. maritima* appeared in 1994, 1997, and 2002. In summary, the presence of SAV at the study sites has been sporadic and its density has been quite variable.

The lack of SAV at JPPM may be due to the turbidity of the water leading to reduced light availability (Table 10) in combination with the relatively high depths (> 1.5 m) immediately adjacent to the structures. At the vegetated sites on the western shore, light availability tended to be above 15% of incident surface light (although 22% is recommended) but at JJPM light availability was only 6%. Perhaps the long fetch, relatively high waves and steep shore faces are the cause for high local turbidity at JPPM. In areas at JPPM where the wave energy was reduced via the construction of attached breakwaters, the habitat suitable to SAV (shallower than 1.5 m) has been covered by macroalgae as these are being trapped in the more quiescent waters. The large abundance of macroalgae is an indication of high nutrient concentrations, mainly DIN (Figure 26). Although DIN concentrations were also high at the other western shore sites (Table 26), SAV were relatively healthy, a reflection of the higher light availability when compared with JPPM (Table 10).

Table 10. Water Column Light Characteristics and Requirements at western shore Sites

Site	Observed Secchi Depth (m)	Calculated K_d (m^{-1})	Calculated Light (%) at 1 m depth	Light Requirement (% of surface light)
Epping	0.9	1.61	20.0	> 22
South River				> 22
London Town	0.82	1.78	16.9	> 22
Jefferson	0.50	2.9	5.5	> 22

Epiphytic loading on our test strips was significantly higher on the eastern shore than on the western shore (Figure 27) which is counterintuitive considering the higher DIN concentration in the west (Figure 26). The fast uptake of nutrients in the water by phytoplankton and other algae has been previously listed as a mechanism that alters water chemistry. Perhaps the epiphytes growing on all substrates are reducing water column nutrient levels. This would suggest that epiphytes are a better indicator of water quality as they integrate the long-term nutrient signal in the water column instead of just measuring a water nutrient concentration at one location in time. If that is the case, the water quality on the western shore sites is better than on the eastern shore. The light availability data and SAV populations confirm that. In summary, the poor water quality encountered at the eastern shore study sites did not support the growth of extensive SAV beds and, thereby, the sites did not benefit from the ecosystem service of SAV wave attenuation which could have contributed to a healthy living shoreline.

At most sites on the eastern and western shores (except Eliott R.) the sediment seems to be suitable for SAV growth. Therefore, a reduction in water column turbidity via nutrient and sediment resuspension control could aid the recovery of SAV. Individual living shoreline projects may help locally (marsh nutrient uptake and shoreline stabilization) but larger scale (watershed) efforts are required for a river-wide recovery of SAV. Only then will SAV be able to contribute to a healthy living shoreline. Meanwhile, reducing the impact of boat generated waves on shoreline erosion and shallow water sediment resuspension could be a first step towards attaining better water quality (lower turbidity) for SAV growth.

Section C: Summary of Physical/Biological Effectiveness & Overall Conclusions

The eight living shoreline sites we examined had variable erosion and marsh stability responses reflecting the basic purpose of the project and the degree of structural protection associated with the fringe marsh component. Two projects were designed more for habitat benefits than erosion control. These “habitat first” projects, including South River Farm Park and Epping Forest and have the greatest risk of shoreline or bank erosion; and marsh stress or direct loss. These sites used different, very low profile sill configurations to protect the fringe marsh areas. The two stone groin projects, including Eliott R. and Wye NRMA, had a moderate degree of marsh stress or loss. The remaining four sites used sills and a breakwater system to achieve erosion control first and habitat creation as a secondary benefit. As a class of projects, the “erosion control first” group had the least erosion and habitat loss. These include: Aspen ’96 and ’98; London Town; and Jefferson Patterson Park & Museum.

A few key factors contributed to the relative success of the “erosion control first” sites. These sites generally deployed more massive, higher elevation sill structures and a breakwater system to attenuate wave energy and achieve a more stable environment where little or no bank or shoreline erosion occurred and the marsh communities were mostly healthy. In contrast, at the “habitat first” sites and groin sites, a number of variables including: bank erosion; higher average fetch; substrate conditions; boat wakes; steepness of marsh gradients; marsh shading; movement of groin structures; and littoral drift patterns intervened to present additional stress to the marsh community, causing greater loss of overall vegetated area and shifts in plant species. However, it should be noted that one “habitat first” site, Epping Forest , is very young in age and should be examined at a later date to assess performance characteristics. Beyond this individual case, the availability of “as built” data on all Phase I sites further supports the relative success of the “erosion control first” sites. For example, changes in sill elevation data at the Aspen sites (“as-built” to current conditions) showed largely “no meaningful change” – indicating a variation of less than 0.5’. The marsh community generally supported greater plant coverage and robustness than the two locations at Wye NRMA and Eliott R. which used stone containment groins. While erosion of some areas of the marsh at Wye NRMA was evident from “micro-scarp” conditions of the marsh edge and detachment of remnant marsh areas, the shoreline did not experience significant erosion. Similarly, at the Eliott R. site, significant marsh erosion was absent.

Although the availability of Phase I “as built” data provided a strong basis for the conclusions reached in this report, some problems were evident. The lack of survey control points from the initial land survey particularly at Wye NRMA, reduces our confidence that a direct and highly accurate comparison of “as-built” conditions with current day conditions was really possible. How well the as-built and current surveys compared with respect to Mean Low Water was of particular concern. While it is perhaps understandable why this occurred; when these projects were initiated, there was no intention of establishing detailed and costly benchmarking to allow future comparisons. The two Aspen sites and Eliott R. had better survey control points. Establishing such control points at a select number of new sites, earmarked for on-going monitoring, is critical to our understanding of the basic processes involved in success and failure. Nonetheless, the overall patterns and observations gained from having an accurate elevation profile of current conditions along with a relative abundance of collateral data from all eight sites provided sufficient information to raise some important questions for future consideration.

Can periodic maintenance at theses study sites enhance their longevity and function? Maintenance might include actions such as: removal of excessive wrack deposits or debris that may prevent marsh growth. However wrack deposition may increase accretion and actually help these marshes maintain themselves under increasing sea-level scenarios. Can select tree limbing help in providing more sunlight to marshes which are now shaded for portions of the day? There is, unfortunately little or no experimental evidence bearing on light limitation issues for marsh plants. Could replanting of appropriate marsh species in areas that are devoid of vegetation help, or have these systems reached equilibrium where physical changes are needed to promote these wetlands ? Beyond simple maintenance work, three sites will likely require more intensive physical intervention measures such as providing additional sand fill material to adjust the gradient or width of the marsh; and the addition of strategically placed stone to further attenuate wave energy. These sites include: Wye NRMA; South River Farm Park; and Epping Forest. Without intervention, the effective life of these projects may be short—especially if we have a strong hurricane and/or series of Nor’easters hit the Bay.

An obvious conclusion from our assessment is the confirmation that sill structures appear to have the potential to retain more sediment than the groin structures from sources both landward and channelward of the sill. In several instances, at the Aspen sites, either the marsh surface elevation was slightly elevated or the gradient had become somewhat flatter at a short distance from the base of the sill– matching or exceeding the original design standard. Raised surface elevations became more consistent on the Aspen ’98 site, where bank elevations exceeded 10ft in height. Deposition of bank soils in the upper *Spartina patens* zone was especially evident in some instances. We noted a combination of sloughing of the bank face; and wave driven sediment “overwash” likely caused the marsh gradient adjustments. For example, the South River Farm Park site dramatically demonstrated how even a low profile sill can play a critical role in retaining massive amounts of eroding bank sediment from reaching the water column. Unfortunately, in the process, the large overburden of sediment caused considerable mortality of both *Spartina alterniflora* and it was unclear how fast it will naturally recover. Conversely, sediment accumulation was not observed at the two groin projects on the Eastern Shore, where the trend was a steepening of marsh gradients and a lowering of the marsh surface. Because of the continuous effect of sea level rise and the predicted decline or disappearance of many fringe marsh systems in the Chesapeake Bay, sills clearly offer greater longevity than groins.

Also, we noted that because sill structures reduce flushing considerably they may be more nutrient retentive and could be favorably situated with respect to upland non-point pollution sources. Further, we envision that future designs may be formulated to combine sill structures with detention ponds to focus sediment and nutrients into wetlands along the shoreline for additional buffering of the Bay. Sills should however have at least some narrow openings to provide free exchange with tidal waters, making the quiescent pools more open to fish and other aquatic organisms. Certainly the size and number of openings in a sill/breakwater system is important for the biological friendliness of the structure. Too few openings can restrict water circulation leading to high temperatures shoreward of the sills (as at London Town) and prevent normal migration of aquatic organisms. However, there is obviously a trade-off in some instances (e.g. where soft sediments; steeper nearshore gradients; or boat wakes may be problems) between having narrower openings with larger stone sill structures, which provides additional longevity, and having slightly less habitat value, (for example at the northern end of Jefferson Paterson Park and Museum).

Although SAV could (and should) be an integral part of a healthy living shoreline, due to its’capacity to attenuate waves and thereby protect the shoreline, water quality needs to be improved to support this component of a living shoreline. This was especially obvious in the lower Patuxent River. However, even in this well studied tributary, where nutrient reduction was viewed as essential; water quality improvement has been lagging in recent years. Management involves a long-term commitment at the watershed level and a more concerted effort to use living shoreline projects for nutrient buffering around sensitive tributaries. Until this commitment is made, a reduction in boat-generated waves may help in the reduction of turbidity in shallow SAV habitats and shoreline erosion. One of the most important findings in our assessment was that the construction of coastal structures such as sills and groins did not appear to have a negative effect on adjacent SAV populations and they may indeed be much more helpful if implemented to buffer nutrients and sediment inputs.

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Appendix

Photos

Figure . Epping Forest, low tide

Figure . Epping Forest, Section 1

Figure . Epping Forest, Section 1, bank erosion

Figure . Epping Forest, Section 1, full

Figure . Epping Forest, Section 1, left

Figure . Epping Forest, Section 1, back

Figure . Epping Forest, Section 1, left root damage

Figure . Epping Forest, Section 1, left roots recover

Figure . Epping Forest, Section 1, roots

Figure . Epping Forest, Section 2

Figure . Epping Forest, Section 2, bank erosion

Figure . Epping Forest, Section 2, bank

Figure . Epping Forest, Section 2, across

Figure . South River, Station 1+32, bank

Figure . South River, Station 1+32, water

Figure . South River, Station 3+82, bank

Figure . South River, Station 3+82, water

Figure . South River, Station 7+04, across

Figure . South River, Station 11+47, full view

Figure . South River, Station 11+47, across

Figure . South River, Station 11+47, bank

Figure . South River, Station 11+47, buried *S. alterniflora*

Figure . South River, Station 14+90, bank

Figure . South River, Station 14+90

Figure . South River, Station 14+90, water

Figure . London Town, Station 2+00

Figure . London Town, Station 3+00, bank

Figure . London Town, Station 3+00, water

Figure . London Town, Station 4+00

Figure . JP Park, Station 48+60, left

Figure . JP Park, Station 48+60, right full view

Figure . JP Park, Station 48+60, back

Figure . JP Park, Station 48+60, planter breakwater

Figure . JP Park, Station 48+60, middle

Figure . JP Park, Station 48+60, *S. alterniflora*

Figure . JP Park, Station 28+11

Figure . JP Park, Station 28+11, sill window

Figure . JP Park, Station 2+03, high tide

Figure . JP Park, Station 2+03, mid tide

Figure . JP Park, Station 2+03, low tide

Figure . JP Park, Station 0+50, low tide

Figure . JP Park, Station 0+50, mid tide

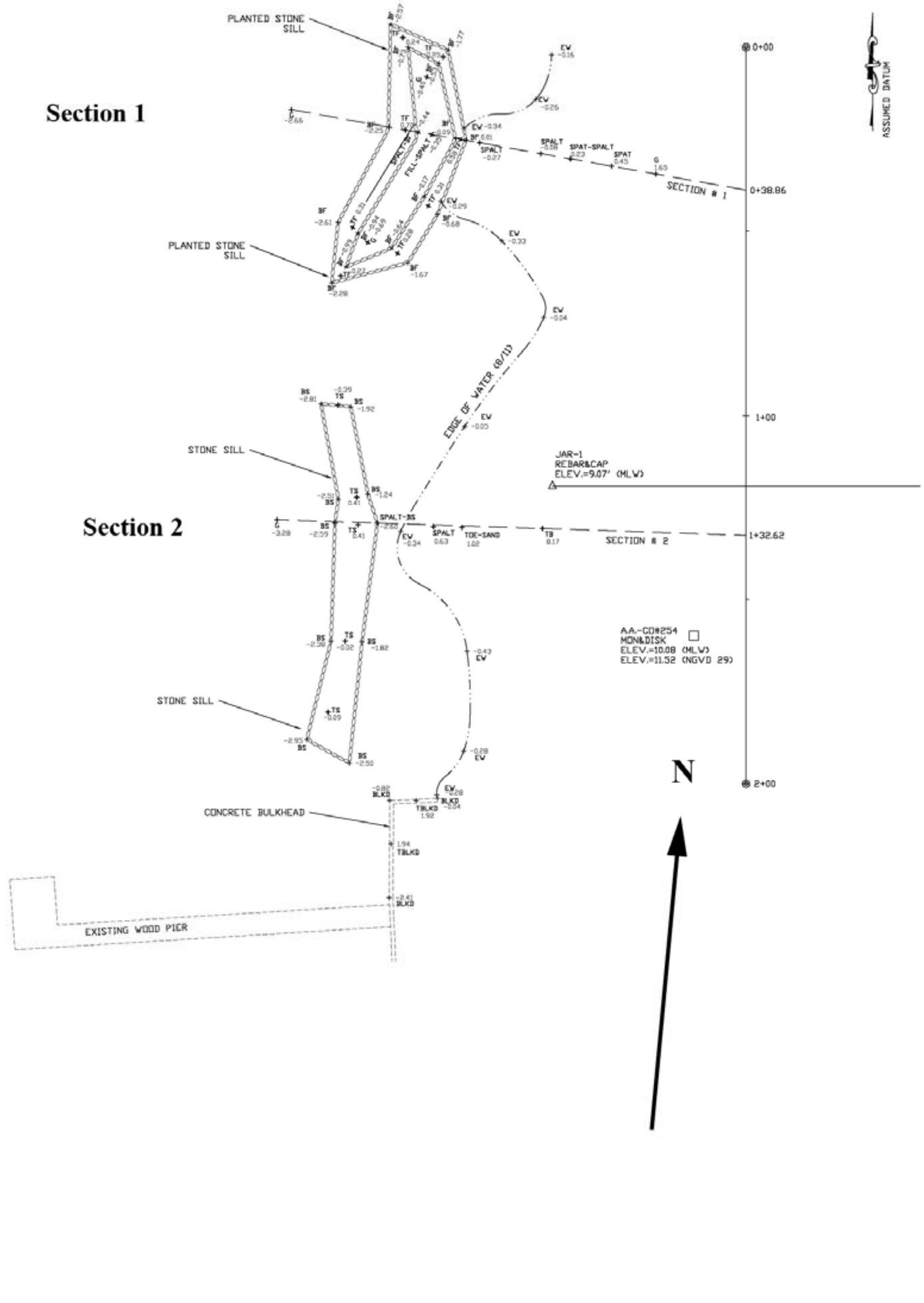
Appendix

Appendix

Overhead View

Appendix

Figure . Epping Forest



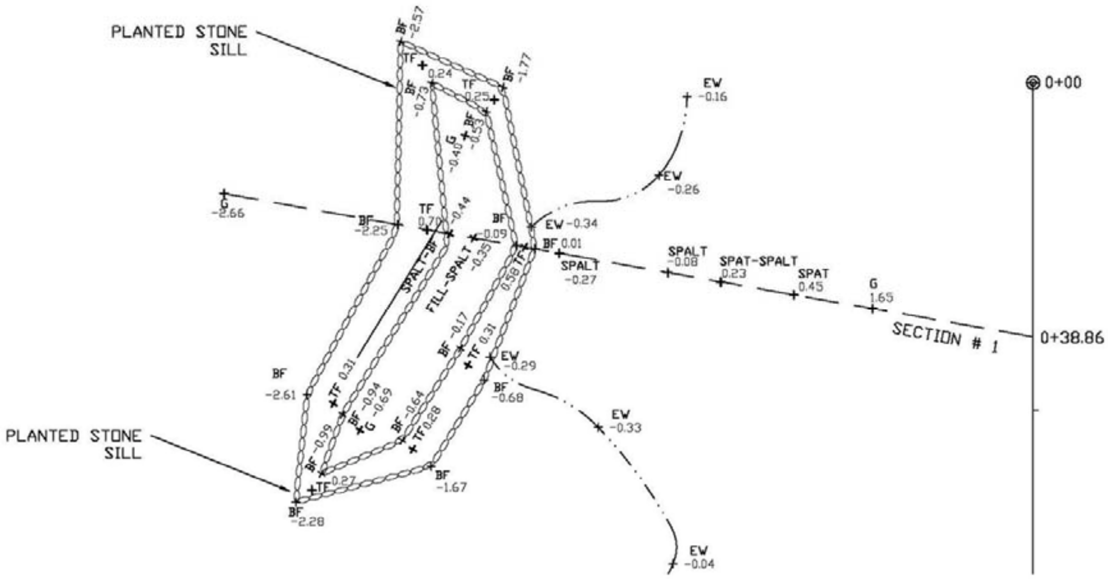


Figure . Epping Forest, Section 1

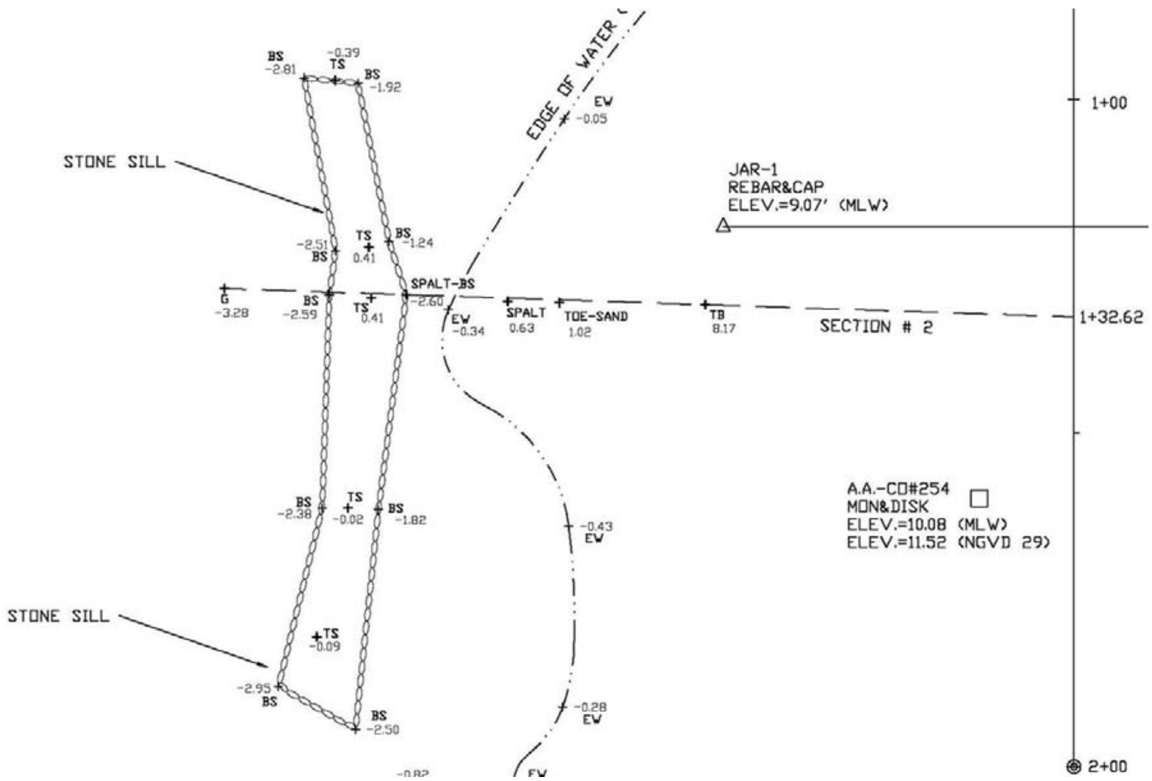
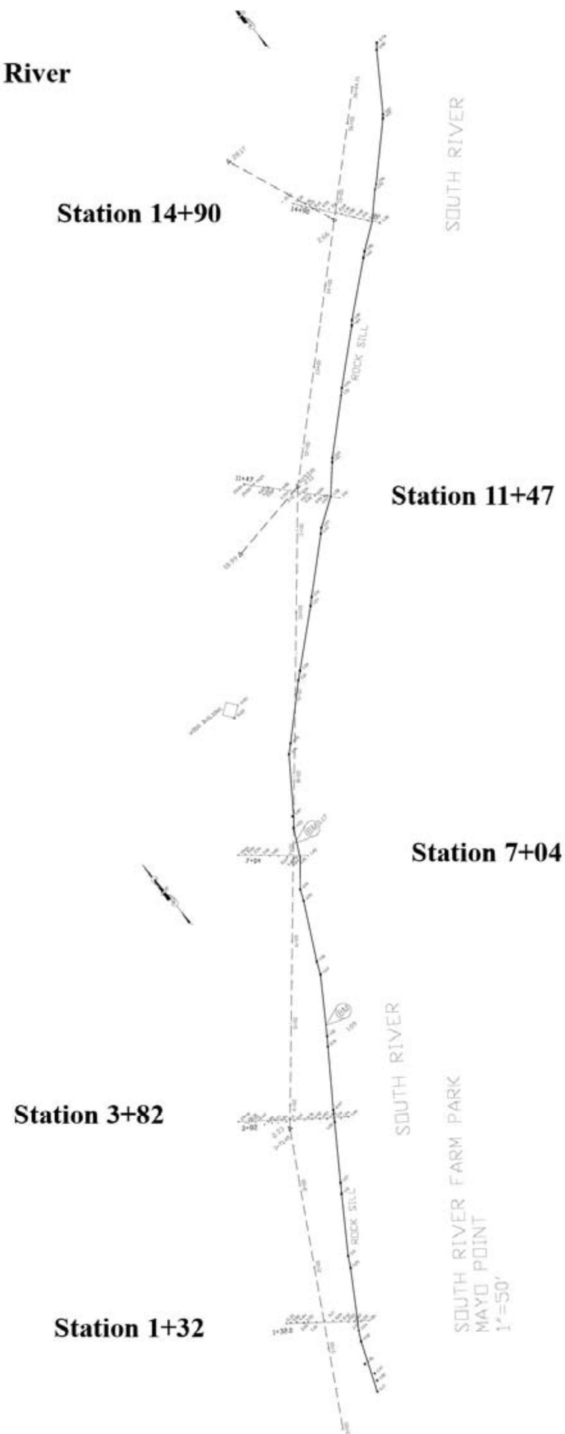


Figure . Epping Forest, Section 2

Appendix

Figure . South River



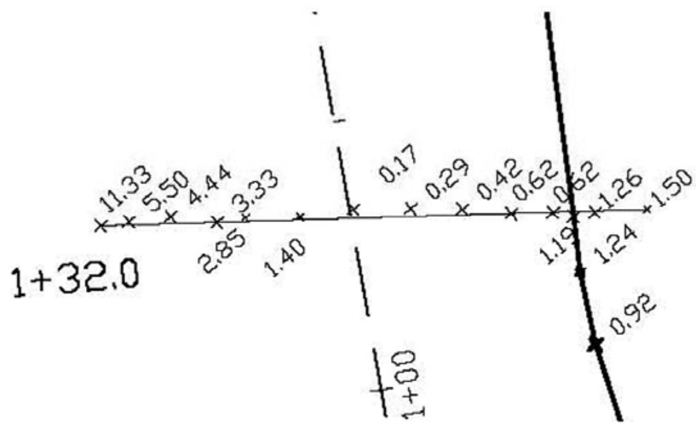


Figure . South River, Station 1+32

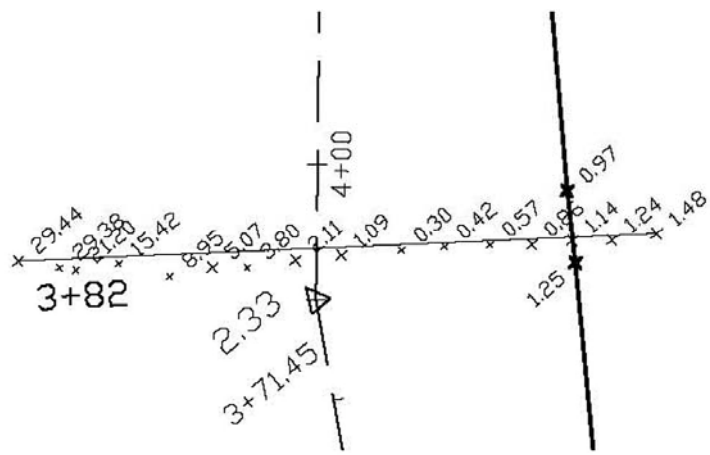


Figure . South River, Station 3+82

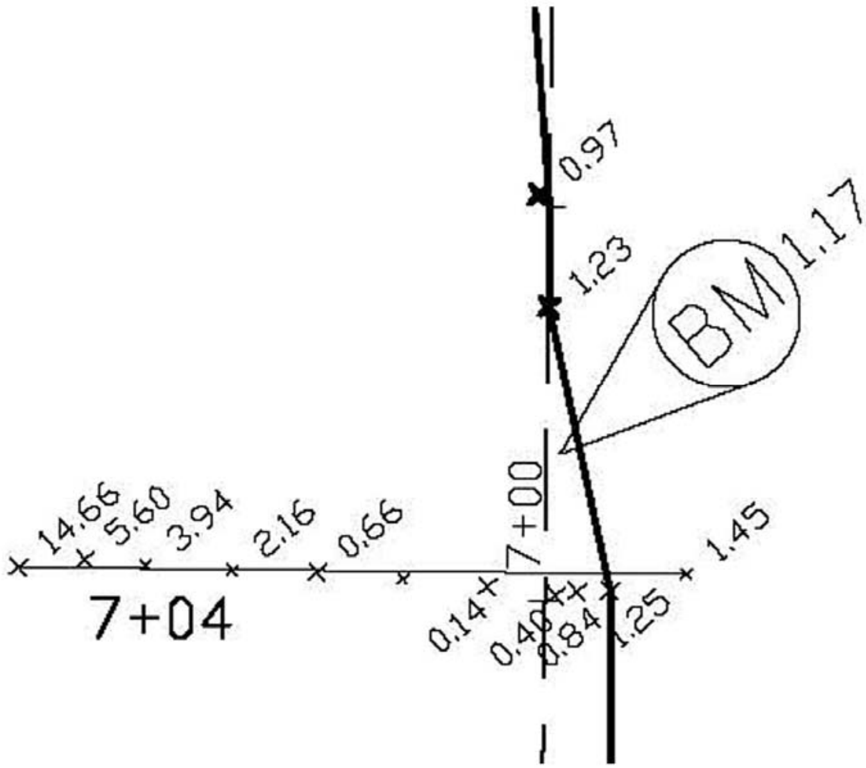


Figure . South River, Station 7+04

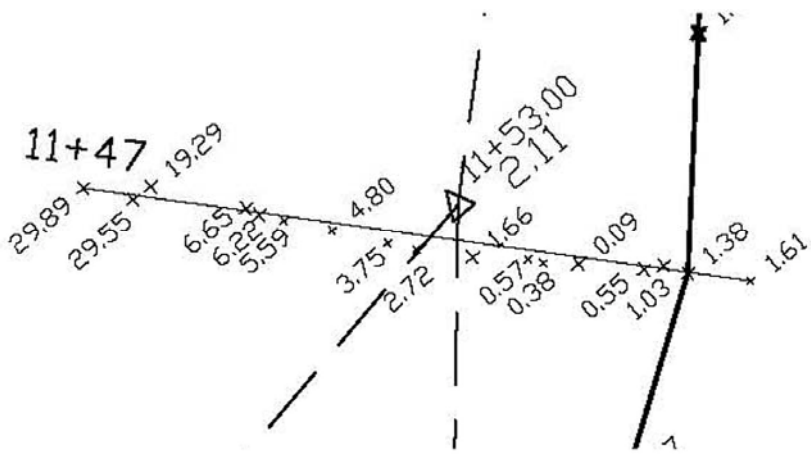


Figure . South River, Station 11+47

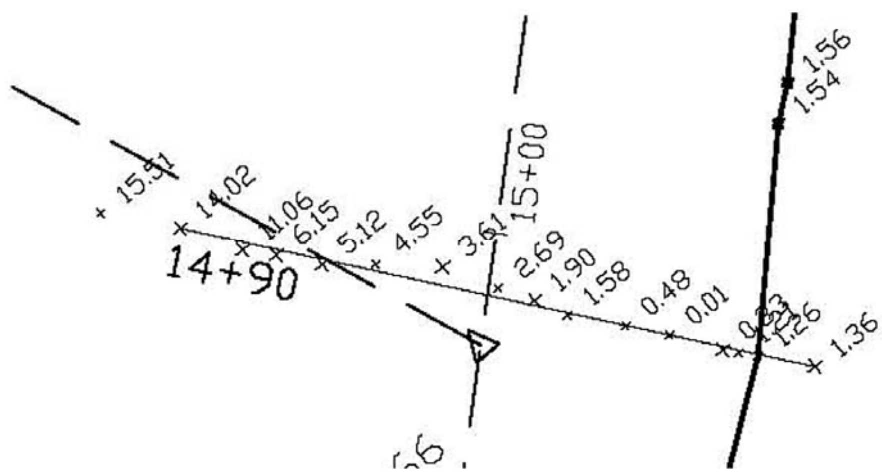
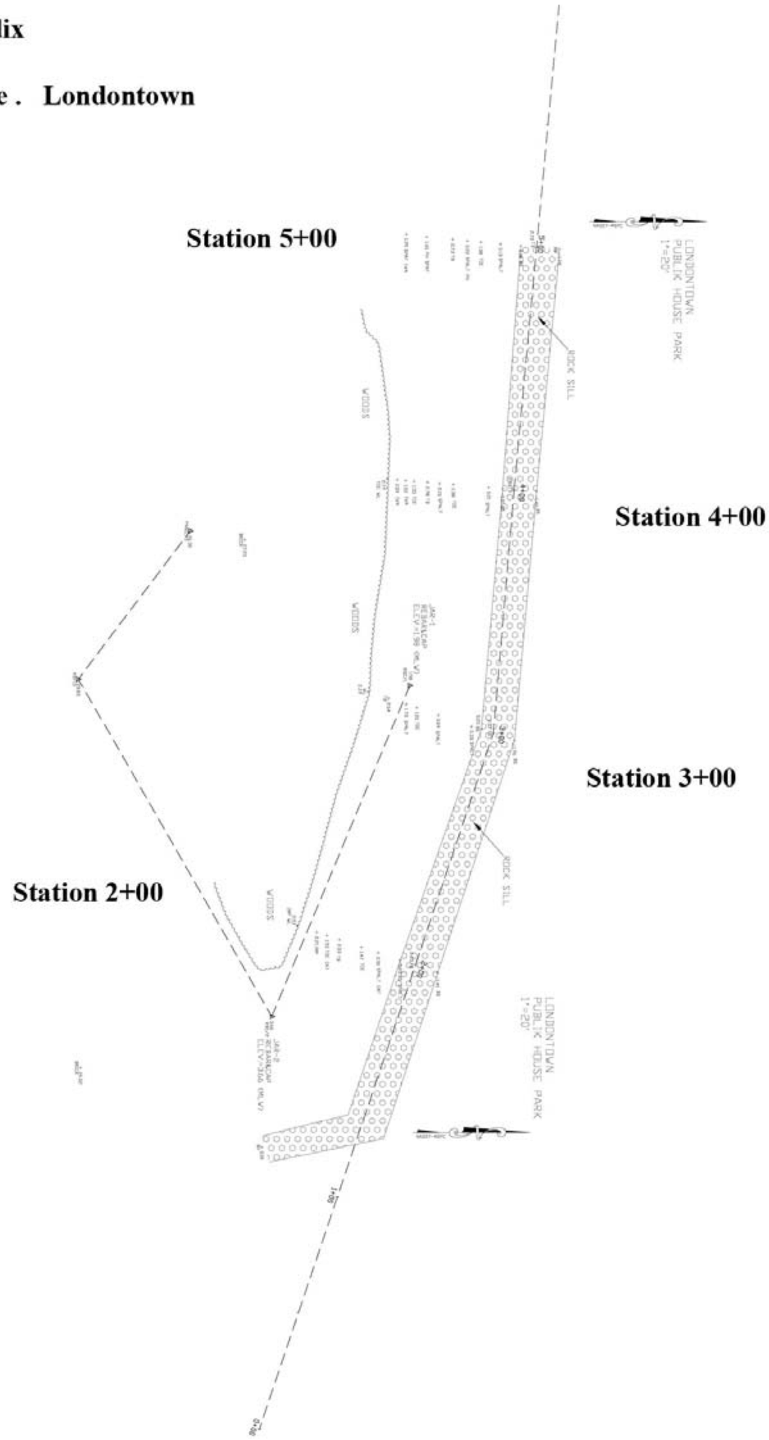


Figure . South River, Station 14+90

Appendix

Figure . Londontown



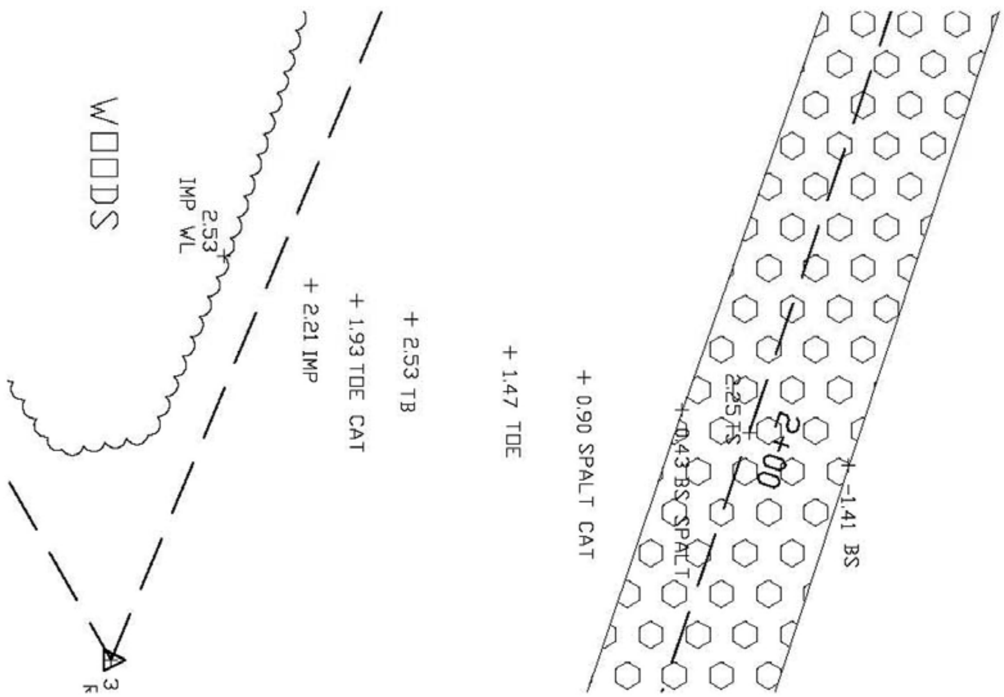


Figure . London Town, Station 2+00

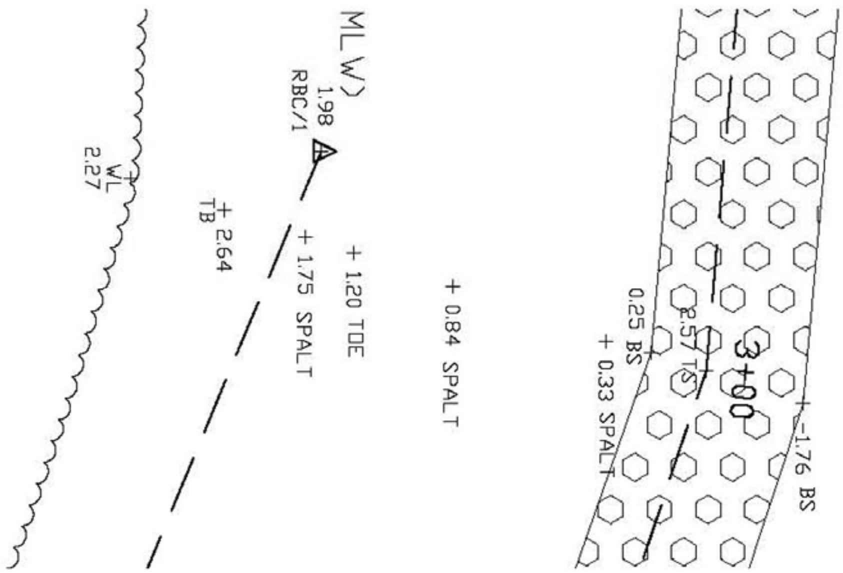
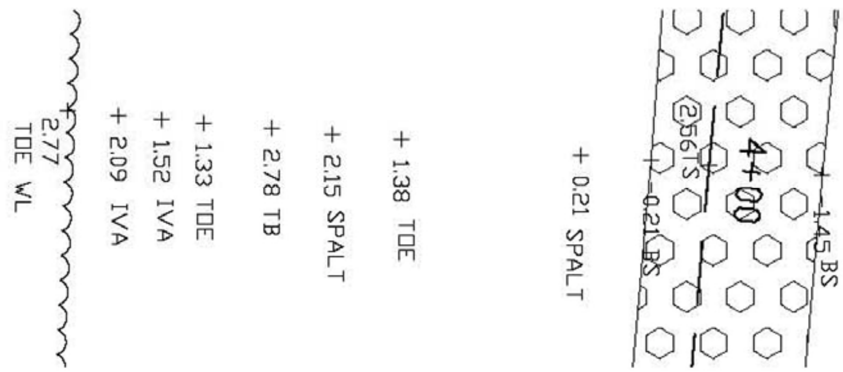


Figure . London Town, Station 3+00



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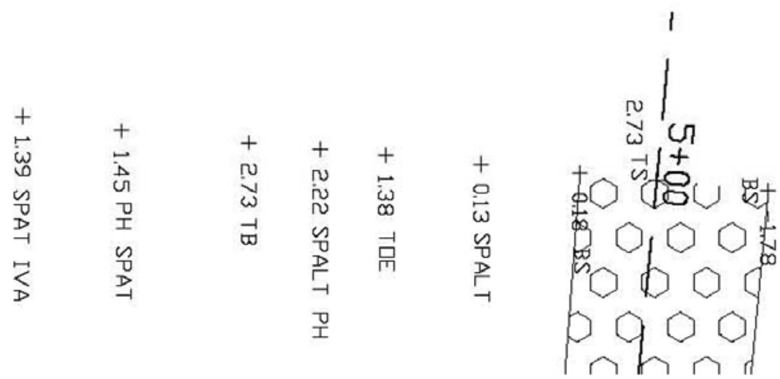


Figure . London Town, Station 5+00

Appendix

Figure . Jefferson Paterson Park

Part 1. North Section

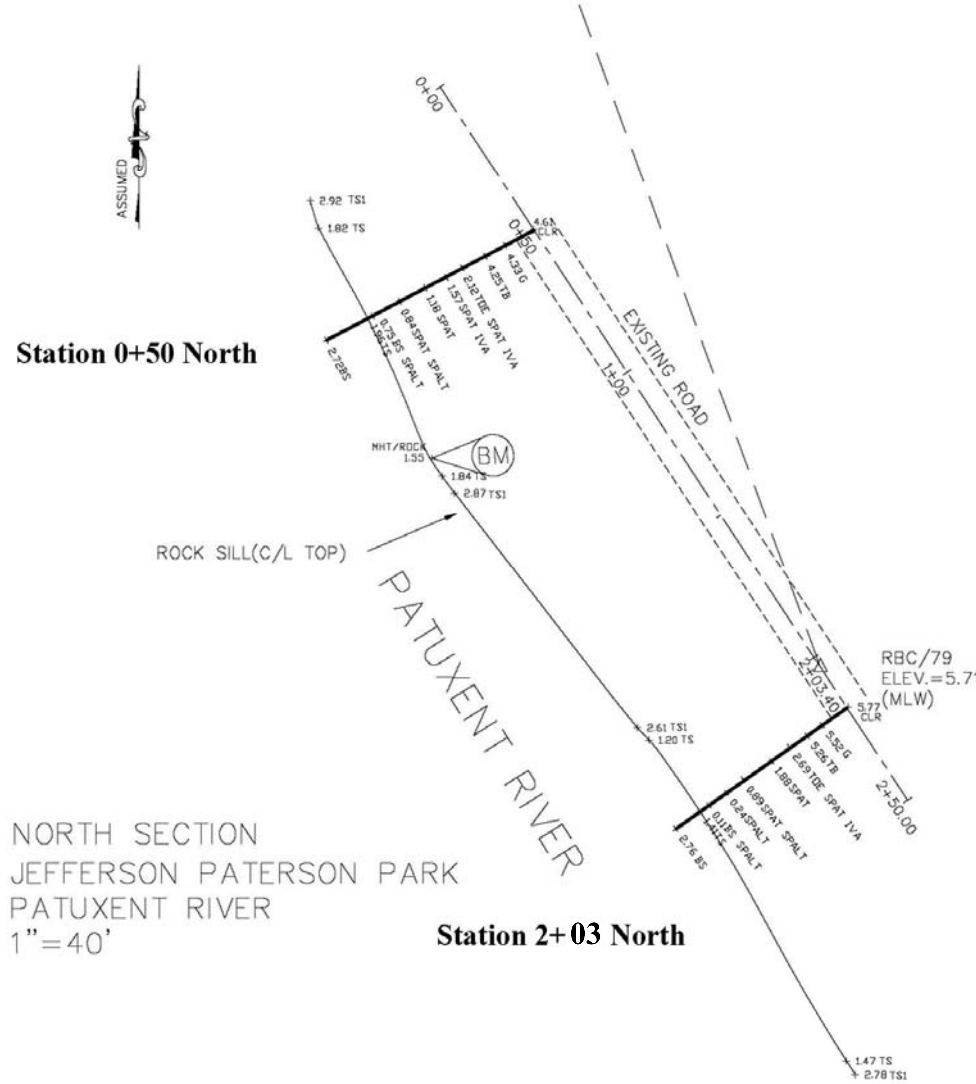


Figure . Jefferson Paterson Park

Part 2. Station 28+11

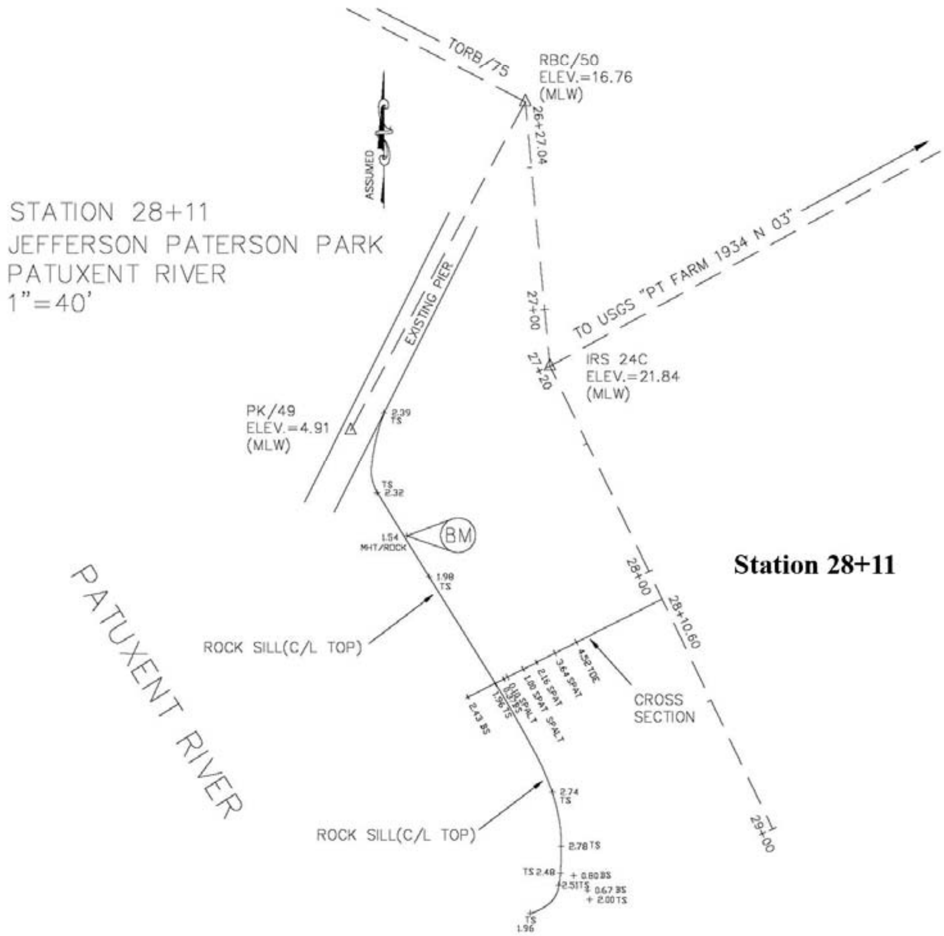
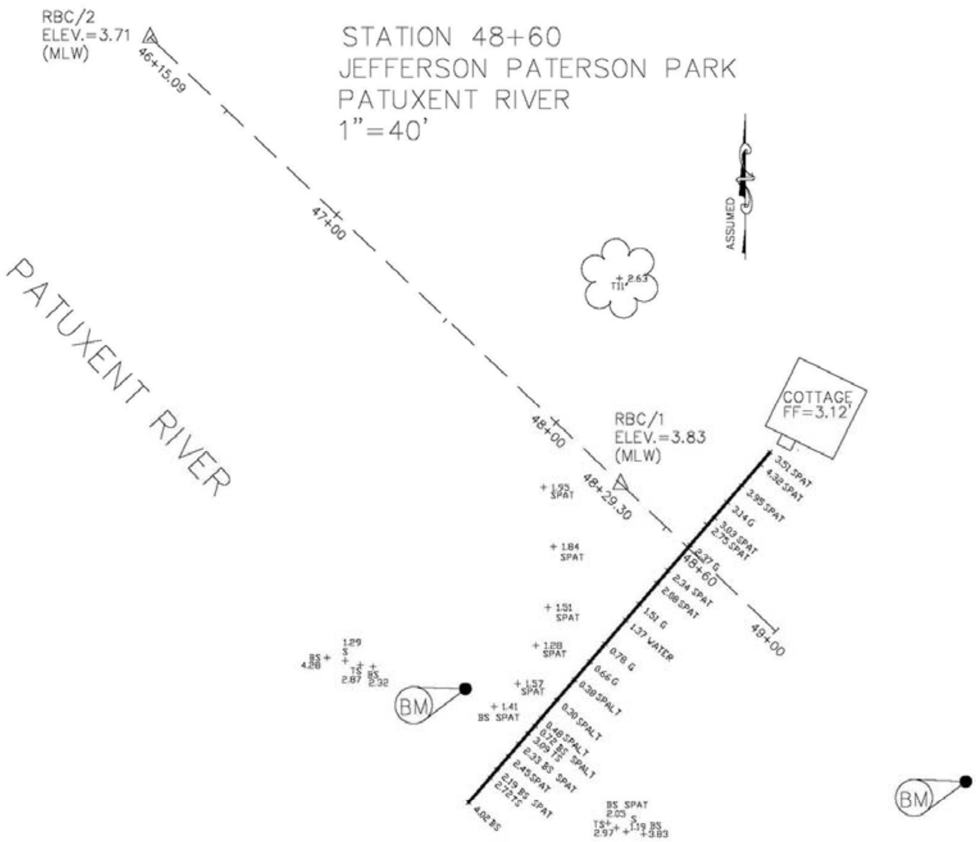


Figure . Jefferson Paterson Park

Part 3. Station 48+60



Appendix

Cross Sectional View

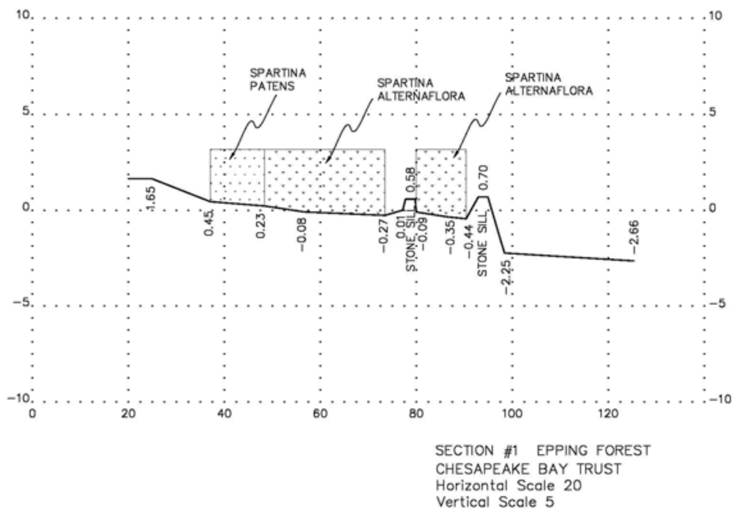


Figure . Epping Forest, Section 1

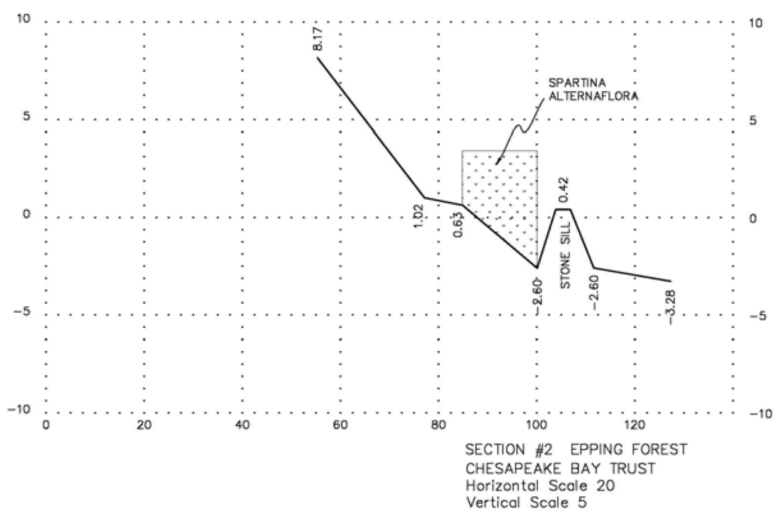


Figure . Epping Forest, Section 1

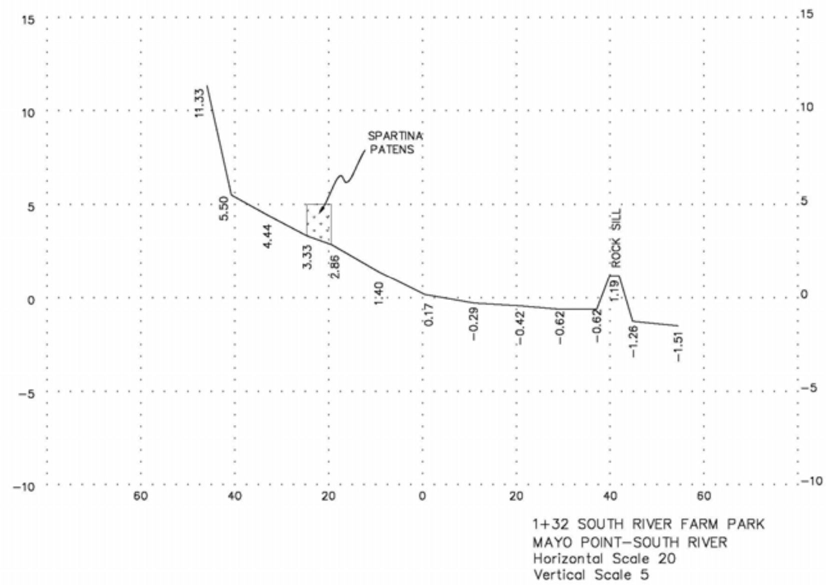


Figure . South River, Station 1+32

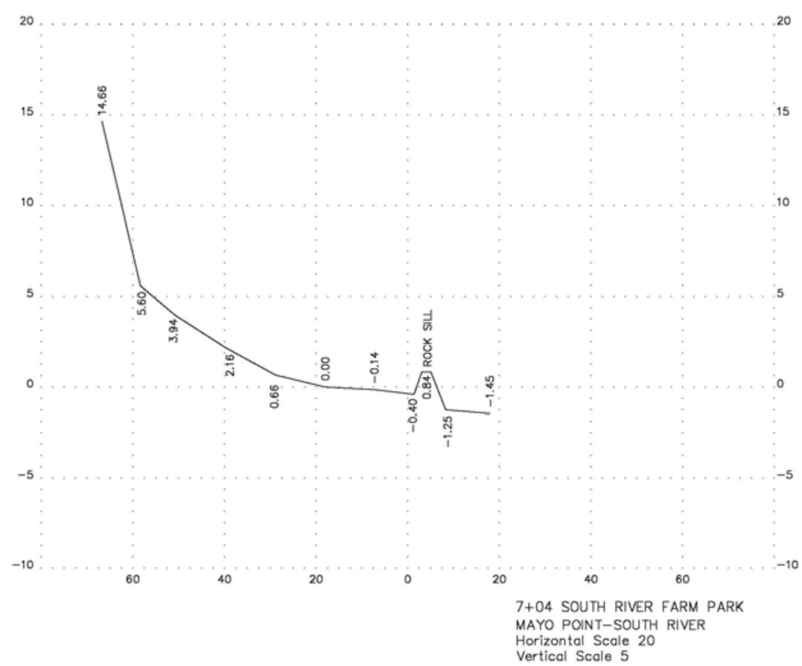


Figure . South River, Station 7+04

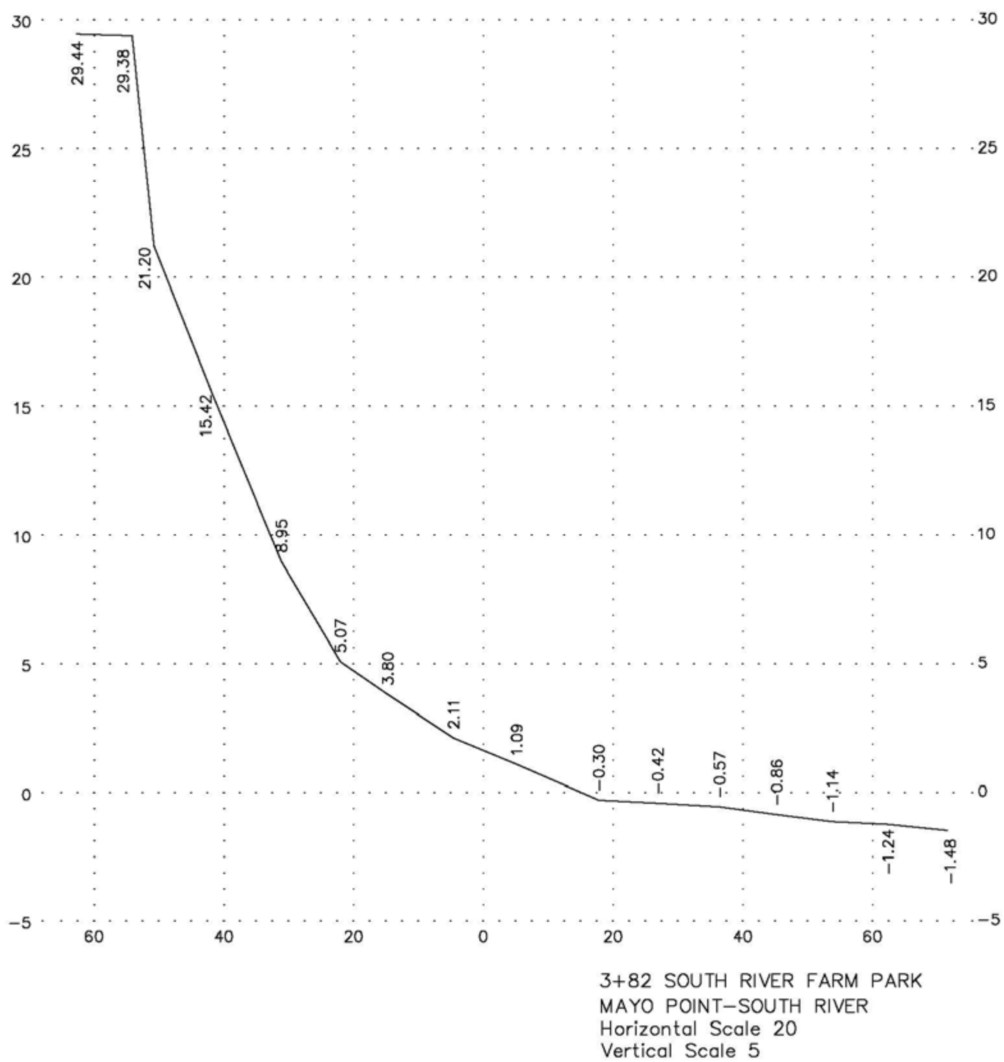


Figure . South River, Station 3+82

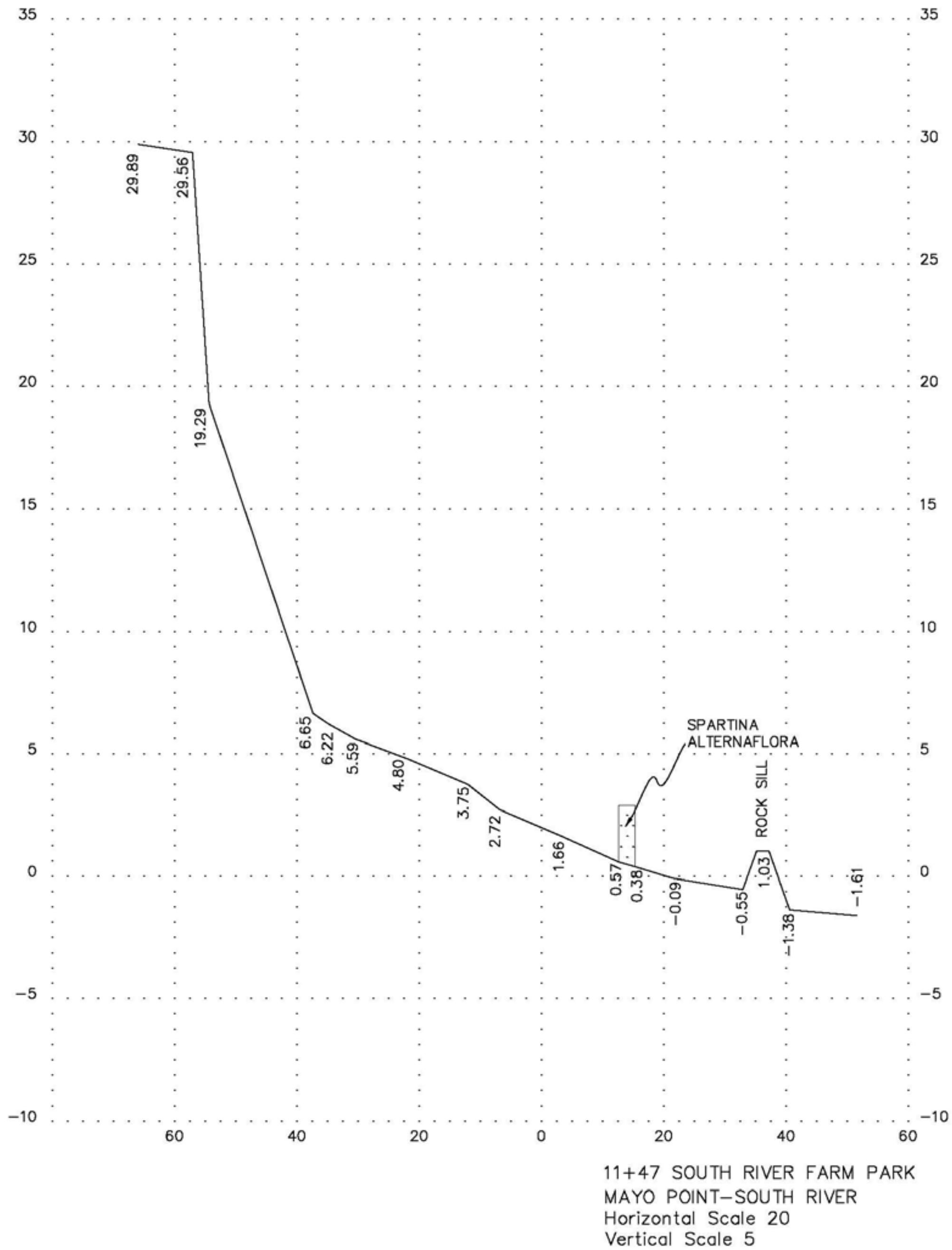


Figure . South River, Station 11+47

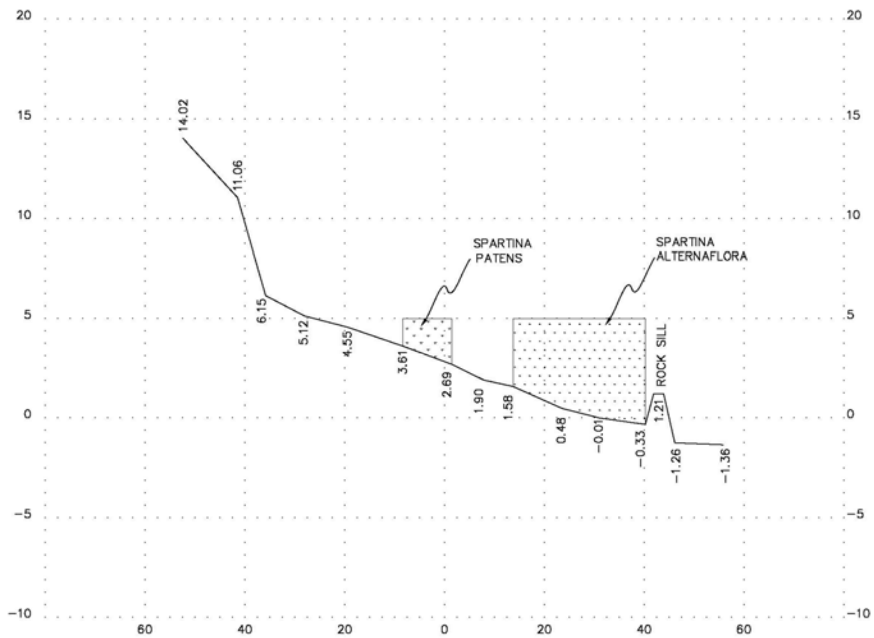


Figure . South River, Station 14+90

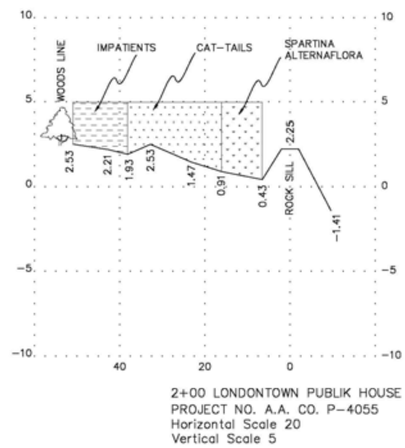


Figure . London Town, Station 2+00

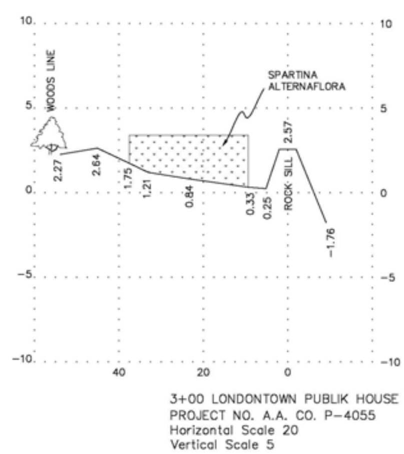


Figure . London Town, Station 3+00

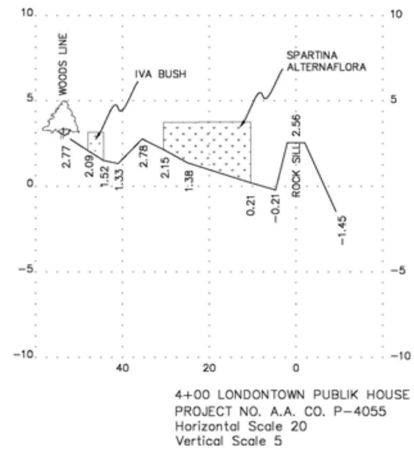


Figure . London Town, Station 4+00

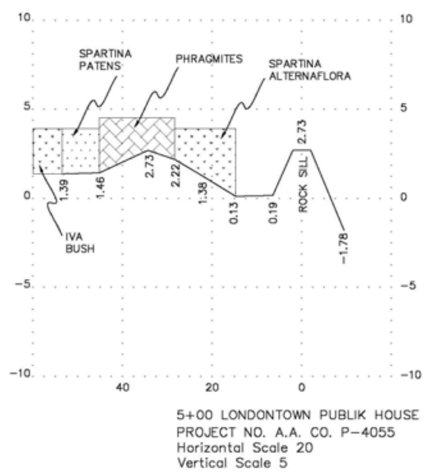


Figure . London Town, Station 5+00

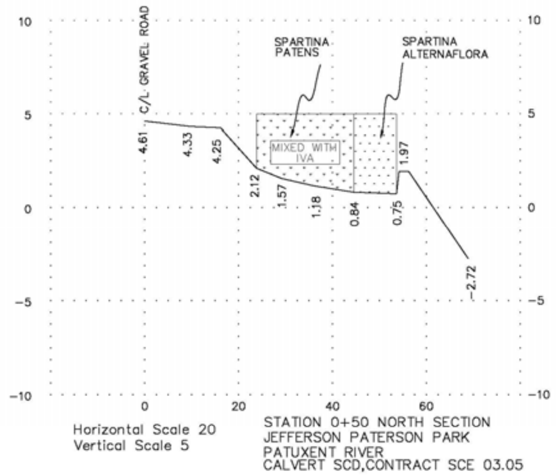


Figure . Jefferson Patterson Park, Station 0+50

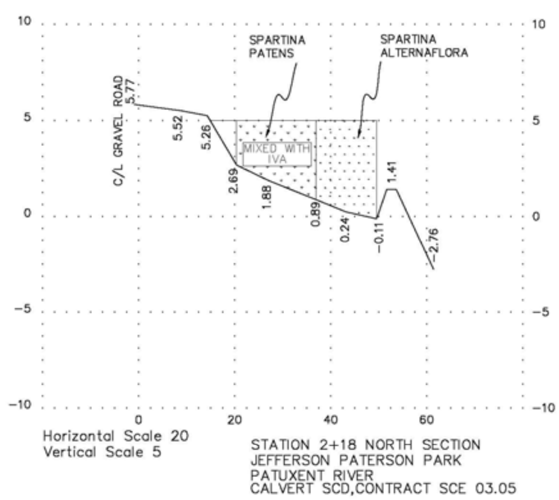


Figure . Jefferson Patterson Park, Station 2+03

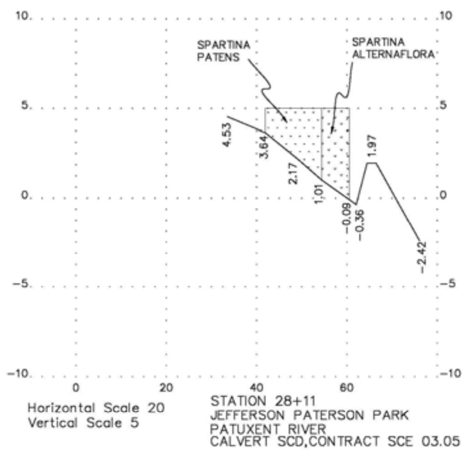


Figure . Jefferson Patterson Park, Station 28+11

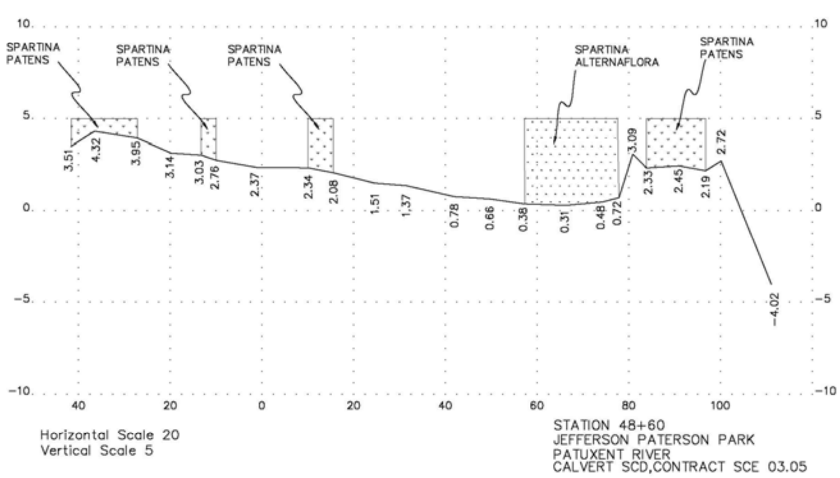


Figure . Jefferson Patterson Park, Station 48+60