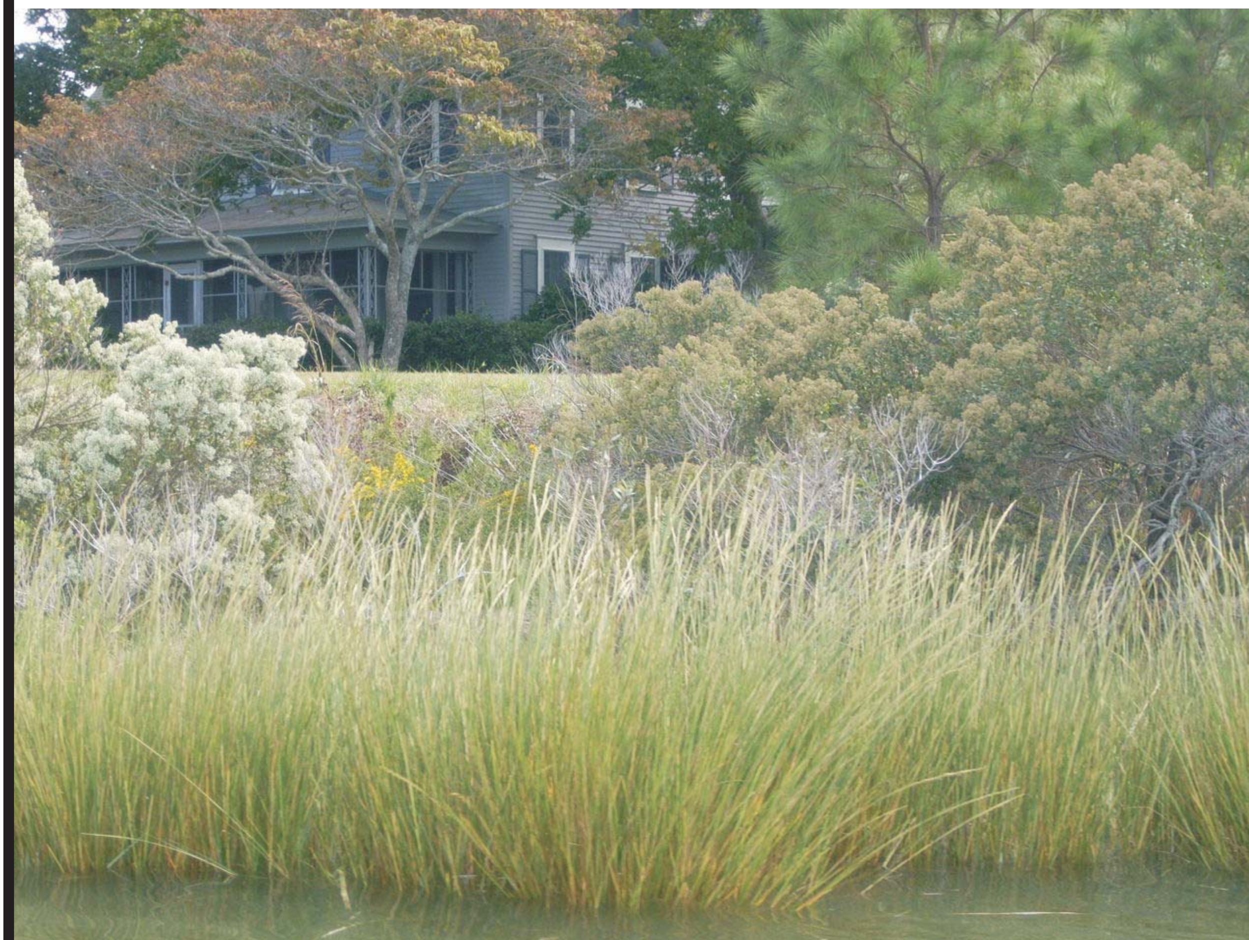
OCCOHANNOCK CREEK
Shoreline Erosion Assessment and Living Shoreline Options Report



Virginia Institute of Marine Science
College of William & Mary
Gloucester Point, Virginia

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Shoreline Erosion Assessment and Living Shoreline Options Report

Prepared for
Eastern Shore of Virginia
Resource Conservation & Development Council

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Landowner's Summary

This summary of the "Occohannock Creek Shoreline Erosion Assessment and Living Shoreline Options" report was provided by the Resource Conservation and Development Council to landowners at an informational meeting at the conclusion of the project.

1. Why was this shoreline erosion assessment performed?

Occohannock Creek is one of the most beautiful Creeks on the Eastern Shore Bayside. It is about 6 miles long from the confluence of Chesapeake Bay to its upper reaches, where the Creek narrows to about 100 feet or less. There are 31 miles total miles of shoreline. The northern side of the Creek is largely in Accomack County, while land on the southern side is in Northampton County. Overall, the Creek shoreline is fairly stable and erosion is minor by Bay standards, averaging between 0 and 1 feet per year. Erosion is more likely to occur near the mouth of the Creek and the Bay which has longer fetch exposures and higher wave energy than the eastern or tributary areas.

This study provides information to Occohannock Creek property owners to help them assess their shoreline stability and their options if erosion is a problem. In the past, shoreline erosion control options were typically limited to rip-rap, groins, or bulkheads. These hard structures often destroyed marsh and other habitat and may not have provided the protection desired. Other methods of erosion control now exist that have been used in a variety of conditions and evaluated for their durability and performance. The alternative techniques incorporate vegetation and are referred to as Living Shoreline designs. Conditions on Occohannock Creek make it a very good place to use Living Shoreline techniques to stabilize areas that are losing land or fringe marsh. All segments of Occohannock Creek can achieve some benefit by planting new marsh grasses or enhancing those already present to improve habitat, trap sediment, and reduce the erosive force of waves.

The specific design varies depending on the level of wave energy, which is usually a function of fetch (distance to nearest shore) and size of boat wakes. Shorelines in low energy environments may be stabilized entirely with vegetation, while increasing levels of wave energy require additional structural protection. Hybrid designs incorporate low stone structures called sills to protect the exposed edge of a marsh and may require sand fill and planting of additional marsh. In higher energy areas, offshore stone breakwaters constructed in segments can help retain fill sand or trap sand already moving along the shore.

In May of 2005, the Eastern Shore Resource Conservation and Development (RC&D) Council conducted two informational sessions on Living Shorelines. They were well attended and generated a lot of interest. Because there are a limited number of companies with experience designing Living Shorelines, RC&D contracted with Virginia Institute of Marine Science to perform a study and develop a report with conceptual design recommendations for sixteen segments of Occohannock Creek. Occohannock Creek was chosen for this demonstration shoreline assessment because increasing productive marsh and reducing shoreline erosion here will benefit the environment and the residents of both counties.

The resulting document presents shoreline management strategies keyed to each of these segments. The recommendations are based on physical and hydrodynamic characteristics such as fetch, depth of water offshore, vegetation, land use, bank condition and height. These designs are conceptual and each individual project will still require a site survey, geotechnical evaluation, and detailed design by a qualified engineer or contractor to address site-specific conditions. In addition, each project may have requirements for permits depending on the resources impacted by construction or fill.

In the end, it is the landowner who makes the decision on how to protect their shoreline. Besides evaluating the technical merits of different options, they have to consider factors such as cost, maintenance, environmental benefits, and permitting difficulty.

2. Existing Shoreline Conditions

Along Occohannock Creek, year-to-year erosion rates may vary widely for a property. Shoreline loss is most significant during storms, when water levels and wind make the wave action very damaging. Severe northeasters and hurricanes, rather than gradual processes, are what cause dramatic changes in shorelines. Typically waves undercut banks or the edge of a fringe marsh, or remove soil from a bank face, causing landward retreat of the bank or vegetation.

Geology shaped Occohannock Creek's modest-sized upland banks, which range from 5 to 25 feet high with intermittent marsh fringes and sandy backshore. The land drops from about +25 feet to about +10 feet going from east to west at a scarp that marks the contact boundary for two geologic formations. The upland bank heights along the Creek's shoreline show where this geological transition occurred.

Much of the land bordering the Creek has trees, shrubs or fields, and many of the residences are located back from the shoreline to preserve the natural environment. Marsh grasses along the shoreline provide a protective buffer where they grow densely and extend out several meters from the shore. Much of this shoreline habitat protects water quality, fish and shellfish and provides cover and food for birds. In areas where the landside vegetative buffers are not as wide, there may be overland or subsurface flow from rainfall that can worsen erosion. Water seeping through a bank face also makes sediment more like to erode through slumping or wave attack.

Erosion is often accelerated where overhanging bank vegetation shades and kills marsh grasses. Sometimes the sediment eroding from a bank face provides additional substrate for marsh expansion. The width of a marsh (or beach), along with the site's orientation, fetch, and hydrodynamic elements determine the stability of an upland bank on the landside of the marsh/beach fringe.

An unstable base of the bank (BOB) is usually the first indicator of shore erosion. Instability of the bank face is the second indicator. If both the vertical bank face and base are exposed, there is probably active erosion. If there is no undercutting at the base of the bank, and the bank face is fully vegetated, then both are likely stable. These two extremes are readily identified. It is intermediate or transitional cases that are harder to determine. Generally, along the main stem of Occohannock Creek, the wider the marsh/beach fringe, the more stable the upland bank. Narrow (<5 ft) marshes or beaches have less ability to absorb wave energy than wide (>15 ft) marshes or beaches. Some action to manage the shoreline is recommended where the banks are actively eroding and the marsh or beach fringes are narrow.

3. Shorezone Management Considerations

Wherever it is possible to preserve a continuous connection between the vegetation of the upland, the marshes, and the aquatic vegetation, high quality ecosystem can be maintained which benefits the fish, crabs, and wildlife that make waterfront living desirable. Occohannock Creek has a high percentage of natural or unhardened shoreline. Along most of its shoreline, Occohannock Creek has little or no erosion and no action is needed.   Most of the areas with serious erosion have already been riprapped or bulkheaded. A number of landowners have taken steps to maintain their marsh and understand the importance of controlling overland flow and trees at the edge of unstable banks. A large scale Living Shoreline project has even been created on the Creek.

Trees grow along much of the shoreline, above the elevation of tidal wetlands. Some parcels have woodlands or riparian forests. Trees and shrubs act as riparian buffers to trap and filter sediments, nutrients, and chemicals from surface runoff and shallow groundwater. Their roots can stabilize a Creek bank and microbes in organic forest soils convert nitrate, especially from agricultural land, into nitrogen gas through denitrification. However, tree roots exposed by an eroding bank can accelerate land loss if the tree falls and takes part of the bank with it. Trees that shade marsh grasses can kill them.

Managing trees and shoreline vegetation to stabilize an exposed and eroding bank face may require trimming, removal, or other measures to obtain a grade slope that will be more stable. Tree work, bank grading, and planting with the appropriate vegetation is best done with assistance from experts who can plan, permit and/or perform the job. To find out what permits are required, check with local planning departments and wetlands boards.

4. Shoreline Management Measures

The first thing a landowner should do before taking any action is to observe what is happening to their shoreline and their neighbors' shoreline. If possible, take measurements and photographs spanning the season when storms are more likely to occur. Note the type, location and density of vegetation, its orientation to the sun, and particularly the hours of sunlight reaching marsh grasses. Observations at low and high tide, from the shore or from a boat offshore, can be helpful. Look at historic photographs of your property, available in this report. This information will be helpful in understanding the shoreline process on a specific property, deciding if you have a problem that requires action, and working with consultants or contractors if erosion must be addressed.   If a shoreline needs stabilization, consider how to incorporate the principles of Living Shoreline design into the project.

The Living Shoreline techniques described here have been used successfully in many other areas of the Bay. Sills and breakwaters must be designed for the site conditions and wave energy and constructed using techniques and materials specified by the engineer or designer. All shoreline structures and plantings require maintenance from time to time.

All of the Creek will benefit from landowners maintaining their marsh. It is beneficial to remove dead plant material or debris that might smother marsh plants. Trees may need to be limbed or thinned to make sure the marsh gets adequate sunlight. Results from these simple measures can be dramatic in the smaller tributaries and Creeks where wave forces are limited. Obtain permits if you intend to cut trees or disturb soil.

After trimming overhanging trees that can kill marsh grasses, another option is to plant existing substrate or bottom with *Spartina alterniflora*. Along the eastern-most portion of Occohannock Creek and tributary Creeks where the fetch is short and the waves are lower in energy, this may be all that is needed. As one proceeds westward toward the confluence of the Creek and Chesapeake Bay, fetch increases and it may be necessary to add sand and stabilize it with groins or rock sills in order to establish a marsh. Permits are required if fill is going onto state-owned bottom (below mean high water).

Sills can be high or low, depending on the energy level. They give newly planted marsh the opportunity to get solidly established. Intermittent breaks, or windows in the sills, may aid tidal flushing and movement of marine fauna. The goal is to create conditions where high and low marsh grasses can both grow along the shore. The higher energy areas at the mouth of the Creek may require offshore breakwaters.

Properties with stable banks and bank faces usually have an existing marsh fringe that is wide enough to offer shore protection. However, many of the marsh fringes along the main stem of Occohannock Creek are being eroded and as they get narrower they provide less protection to the upland bank. An eroding marsh that is still wide enough to absorb wave energy can be stabilized with a low sill and perhaps only a little sand. This is sometime referred to as a marsh toe revetment although the sill is a freestanding structure.

Where a property has eroding upland banks, grading and replanting may be required. If a bank face is vegetated and stable, but the base of the bank is being undercut, fill to establish a protective marsh fringe can help prevent further undercutting.

Generally, along the main trunk of Occohannock Creek, the narrower marsh/backshore width, the greater the potential for upland bank erosion. On open Creek shorelines with an erosional or transitional base of bank (BOB) and bank face (BF), if a shoreline needs stabilization, this report recommends stone sill systems with plantings. In a few places, a breakwater system or sand fill with groins was recommended. No bulkheads or seawalls were recommended. The areas with immediately threatened infrastructure have already been hardened.

The shoreline specific management recommendations for Occohannock Creek are shown on a series of maps in Plates 1 through 16, Appendix C of this report. Generally, only structural recommendations are shown. Where no recommendation is shown and no structure presently exists, it is understood that the recommendation is Marsh/Buffer Management.

The sill systems recommended for Occohannock Creek varied in size depending on the level of protection desired and the height of the upland bank. Based on a wave climate assessment, the level of the 2 year, 10 year and 50 year storm surges are 4.2 feet, 6.5 feet and 8.5 feet, respectively. This becomes an issue on the more exposed sections of Occohannock Creek when fetch exposures exceed 2,000 feet. For Occohannock Creek, the design level of protection should be at least the 10 year water level which is about +6.5 feet MLW.

Here are more specific guidelines for applying Living Shoreline techniques along Occohannock Creek. Maintenance is always required. Marsh grasses and even sand may need to be replaced after storm events.

- **Marsh Management**: Appropriate in very fetch limited creeks (F=<1,000 feet) but may work in more open shores where the existing marsh fringe is narrow or absent and the base of bank is exposed. <u>Considerations:</u> Watch year to year as the erosion rate may be minimal; trim overhanging tree limbs; and plant bare areas of existing intertidal substrate, usually *Spartina alterniflora*.

- **Add sand with structures**: As fetch exposures increase beyond about 1,000 feet, the intertidal marsh width may not be sufficient to attenuate wave action. In these cases, the addition of sand can increase the intertidal substrate as well as the backshore region. The simple addition of sand is usually not enough and a sand retaining structure such as short groins or a low sill will be required. Any addition of fill, sand or rock beyond mean high water will require a permit.

- **Stone sills**: The general cross-section (Figure 5) shows the sand for the wetlands substrate is on about a 10:1 slope from the base of the bank to the back of the sill. The elevation of the intersection of the fill at the bank and the sill will determine, in part, the dimensions of the sill system. The size of the sill systems recommended are related to what is threatened, residential vs agricultural or wooded.

- **Breakwater System**: Although single breakwaters can be used, two or more are recommended to address several hundred feet of coast. Breakwaters can also have varying levels of protection where increased dimensions generally correspond to increased increased fetch exposure and where a beach/dune shoreline is desired.

Four typical cross-sections are shown in Figure 16. The condition of the bank, fetch, and landuse were used to assign a sill size to a given reach. With both high and low banks in Occohannock Creek, three sill systems are given for the higher banks and one typical cross-section is depicted for the low bank situation. High banks offer a "backstop" to the sand fill. The low sill system for high banks is indicated for a site usually with and an existing marsh fringe that is too narrow to adequately protect the base of bank even thought the bank face is stable or transitional. As fetch and the "need" for greater protection increases, the sill system can be elevated in both sand elevation and stone sill elevation to the medium and high sill systems. Low banks might have the same approach except the "back stop" effect is limited to the height of the bank. Bank grading is recommended where needed, usually with the high sill since it generally has a greater fetch exposure.

Bank condition indicators for sills include in descending order where #1 is most severe:
1. Eroding Base of Bank, Eroding Bank Face
2. Eroding Base of Bank, Transition Bank Face
3. Eroding Base of Bank, Stable Bank Face
4. Transitional Base of Bank, Transitional Bank Face
5. Transitional Base of Bank, Stable Bank Face

Landuse condition indicators for sills include in descending order:
1. Residential
2. Lawn
3. Agricultural land
4. Woodland

The low sill option was most recommended structural option along Occohannock Creek. At these sites, an existing but narrow fringe marsh usually existed, but it needed some level of enhancement. The upland was generally either agricultural or wooded. Low sill systems were also recommended for residential properties in lower energy realms and/or with low banks. Medium sill systems were recommended where there were high eroding banks. Only one high sill system was recommended.

Two breakwater systems were recommended, one along an eroding upland bank with an existing groin field and another along the west coast of Morley's Wharf. A typical breakwater system for this type of coastal setting is made of 60 foot breakwater units, 60 feet offshore with 60 foot gaps. Three sand with groin segments were recommended, one up Shields Cove where the narrow intertidal width needs enhancement.

Managing shorelines to slow down erosion and maintain marsh and aquatic habitat requires an understanding of the conditions of a site and how the various options perform under specific conditions. Eastern Shore Resource Conservation and Development (RC&D) Council, the sponsor of this study, believes that if waterfront landowners have good information, they will consider using Living Shoreline techniques if their property needs protection. Most people who live on the water do so because they enjoy the beauty and recreational opportunities of their location. Those natural assets depend on the intertidal and aquatic grasses which Living Shorelines aims to protect.

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Cover Photo: Occohannock Creek shoreline, 2 October 2007 by Shoreline Studies Program, VIMS

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1 Introduction

1.1 The Shoreline Erosion Assessment and Living Shoreline Options Report

Occohannock Creek is located along the boundary between Northampton County and Accomack County on the Virginia's Eastern Shore (Figure 1). The creek is about 6 miles long from the confluence of Chesapeake Bay to the where the creek narrows to about 100 feet or less. About 31 miles of shoreline occur along both sides of the creek. The shorelines of Occohannock Creek are surrounded by modest-sized upland banks 5-25 feet high with intermittent marsh fringes. Over time, the marsh fringes have advanced and grown upon eroded sediments then decreased in width from wave action especially along the western half of the creek where the fetch exposures increase. The result is increasing erosion of the upland or fastland banks. Landowners often will install bulkheads or stone revetments to halt the land loss from wind-driven wave action.

Although effective for shore erosion control, the hardening of the coast does not create an environmental edge. Research has shown that shoreline erosion can be controlled by re-establishing marsh fringes to the "proper" dimensions. If too much wave action is an issue, a low stone sill can be built along the outboard side of a planted marsh to insure long-term stability. Intermittent breaks, or windows, are created in the sill to allow better tidal flushing and the ingress and egress of marine fauna. This vegetative approach is often referred to as Living Shoreline methodology.

In order to evaluate the appropriate shoreline strategy along estuarine coasts, a Shoreline Erosion Assessment is a very effective planning tool for the creeks and rivers of Chesapeake Bay. It ties the physical and hydrodynamic elements of the targeted shorelines to the various shoreline protection strategies available including Living Shoreline options.

1.2 Previous Research on Sills as " Living Shorelines"

Marshes are an integral part of the Chesapeake Bay ecosystem because they provide habitat for many plant and animal species, filter sediment which can improve water quality, and can protect property from storm damage by lessening the impact of surge. Using Living Shorelines to stabilize the shoreline provides the additional benefits of enhancing the Bay ecosystem. However, marshes can not be created everywhere; they can only be installed in low energy areas where wave action and boat wake are minimal.

In order to evaluate the effectiveness of Living Shorelines, Bosch *et al.* (2006) assessed 80 man-made tidal wetlands in Maryland. Of those sites surveyed, the average permitted dimensions were 23 feet wide and 207 feet long, while the average actual dimensions of the sites were 18 feet wide by 200 feet long which relates to a 23% decrease in area between permitted and actual. About 90% of the marshes had additional structures (such as sills) as part of the erosion control project. Forty three of the marshes had sills, and of those, fifteen had gaps in the sill. Also, 24 of the projects had groins and six had biologs.

Bosch *et al.* (2006) ranked the marshes as very successful, successful, moderately successful, or unsuccessful according to three factors: vegetation, wildlife, and erosion. Of the 80 sites visited, 14 sites, or 18%, received an unsuccessful ranking. Twenty one marshes (26%) a moderately successful ranking. Thirty one sites (38%) earned a successful rating. Finally, 14 projects (18%) scored a rating of very successful.

After the sites were ranked, the sites were evaluated in relation to their fetch and the presence of sills. The only relationship observed for overall marsh ranking was only marginally significant reduction of rank with increasing longest shore fetch for sites with sills. Because no significant relationships were observed for wildlife or erosion rankings, the pattern observed for marsh rank is likely due to the decrease in vegetation rank with increasing fetch for sites with sills. However, there is considerable variation in rank, with sites with low and high fetch having both low and high rankings, independently of the presence or absence of sills (Bosch *et al.*, 2006).

In order to determine the marshes general characteristics, Bosch *et al.* (2006) evaluated the site rankings for low or high ranked projects. Low-ranked sites tended to have little or no vegetation, were poorly constructed or designed, or were built directly adjacent to eroding cliffs. High-ranked sites tended to have established marsh vegetation and preventing erosion. High-ranked sites tended to be wider and longer than lower-ranked sites. The study did not find that fetch vs. sills were a strong determinant of whether a site was ranked as high or low.

More specifically, low-ranked sites tended to have low vegetation cover (<30%) while high-ranked sites had high cover (>70%). Additionally, low-ranked sites tended to have only high or low marsh, but not both, while high-ranked sites generally had an equitable distribution of high and low marsh. Hurricane Isabel negatively impacted some of the low-ranked sites. High-ranked sites also tended to have higher plant diversity, but some of these had bare patches, Phragmites australis, or experienced herbivory of plantings (Bosch *et al.*, 2006).

Low-ranked sites had low numbers of organisms observed or collected in dip nets, and either had no access for wildlife or little or no wildlife habitat. Highly-ranked sites, on the other hand, generally supported abundant and diverse wildlife based on observation or dip-netting. However, some of these sites provided good terrestrial or aquatic habitat, but not both. Organisms observed or reported included waterfowl, fish, crabs, snakes, turtles, snails, frogs, fish, and miscellaneous aquatic invertebrates. Clearly these observations show that constructed wetland sites can provide valuable habitat for aquatic and terrestrial organisms (Bosch *et al.*, 2006).

Lower ranked sites tended to exhibit erosion or clearly offered little protection from erosion, particularly due to a lack of established vegetation. Highly-ranked sites appeared to be stable or accreting sediment from incoming waves (*i.e.* not from an adjacent eroding cliff, as was observed in some cases). Vegetation again appeared to be important in reducing or stabilizing against erosion (Bosch *et al.*, 2006).

Another interesting component of the Bosch *et al.* (2006) report was the homeowner's opinion of the project. The study reported that "*homeowners were generally amenable to talking about their projects, and had favorable impressions of them. Homeowners seemed happy with the aesthetic benefits that their marsh added, commenting on the lush and colorful addition that marshes made to their property. Often these homeowners felt that in comparison, structural projects felt very sterile and incompatible with the natural environment of a Chesapeake Bay home. Homeowners connected with their marsh in a way that made each marsh seem like their own personal bay-restoration project. This gave them a sense of stewardship and empowerment that might be missing with a less environmentally-conscious project.*

Homeowners in particular were enthusiastic about the relationship their marshes had with wildlife. Seeing fish spawn or birds nest was a thrilling occasion for homeowners. Many homeowners felt that the added benefit of attracting wildlife to their yard far outweighed the monetary difference between a non-structural shoreline erosion control project and a structural one.

Not all homeowners were completely satisfied with their marshes, however. Many environmentally conscious homeowners felt that they were misled or even strong-armed into adopting projects that were not in keeping with their ideas over what was the best way to protect their property as well as preserve Bay habitat. A common complaint of homeowners was that the marshes were forced upon them even though the main problem they were facing was the erosion of a large cliff due to factors that were inadequately addressed by the addition of a marsh. Government was particularly distrusted, as the bewildering maze of agencies that have authority over these projects often failed to respond in an acceptable manner in the opinion of some homeowners. Despite these misgivings, the feelings of homeowners were overwhelmingly in favor of non-structural solutions to preventing Bay erosion."

Bosch *et al.* (2006) also made additional site observations that could be used for construction recommendations.

- *Sunny*. The marsh plantings should get sun-without sufficient sunlight, they will not be able to grow and form a healthy project. It is important, especially on cliff properties, to trim back trees limbs so that the *Spartina* grasses can get enough sunlight.
- *Proper Filling*. Proper filling is important for the stability of the marsh and the health of the flora and fauna. Placement of the inappropriate substrate (lacking in sand) can lead to sinkholes forming in the marsh and plants will not be able to take root.
- *Protected shoreline*. One of the most serious threats to a wetland is the action of waves. Boat wakes and waves propagated by long fetches can wash away all traces of a marsh. When the grasses are newly planted and have not yet developed a strong root system, a sill can be essential in protecting a marsh.
- *Staggered or dog-legged vents in sills*. While sills are often essential for a successful project, it is helpful when they are constructed in such a way that allows for flushing and wildlife access to the shore. Large obtrusive sills without vents prevent proper flushing of marsh and trap sediment and dead vegetation, which can strangle the marsh, in addition to blocking wildlife access. However, vents can facilitate erosion where the wave action is persistent. Therefore, in areas with large fetch (greater than 1600 feet), it is recommended that vents are constructed such that there is no unprotected shoreline, but in a doglegged or staggered system.

- *Independently stabilized cliff*. In properties with high cliffs, the marsh will not prevent the top of the cliff from eroding due to run off. This erosion may ultimately bury the marsh with eroded sediments. The cliff should be stabilized with either a re-grading and upland plant stabilization or a structural solution such as a retaining wall or ground mesh to hold back erosion. With the cliff stabilized, the marsh can then be used to prevent undercutting at the base of the cliff.
- *Proper grading and sill placement*. When the site is not properly graded and the sill is placed too close to the shore, there is danger of "sillvetment" formation, where the sill becomes a revetment as the marsh and sediment builds up behind the rock wall. Additionally, the low marsh should extend to the lowest tide line. If the sill is placed too close to the mean high water line, then the marsh will trap sediment without flushing, and will ultimately accrete to the point where the marsh doesn't flood during high tide and the low marsh does not get enough water. Then, the sill turns into a revetment and the marsh turns into an upland/high marsh region. If possible, the sill should be placed about one meter from plantings.
- *Proper maintenance*. As with any shoreline erosion control project, a certain amount of maintenance is necessary to keep the project working effectively and to sustain it in the long term. Three main things need to be done for marsh projects: keep the marsh clear of debris; refrain from the use of chemical lawn treatments; and keep marsh free of unwanted, alien plant and animal invaders. Dead vegetation from the year before can accumulate in such density that it buries new growth and can kill off marsh grasses. This problem is especially pressing in *Spartina patens* high marshes. It is important to ensure that new plant growth is not choked off by last year's die-off or any debris that washes onto the shore. Chemical lawn treatments can kill *Spartina alterniflora*. Even neighboring use can be damaging to the marsh plants. It is very important to refrain from using chemical lawn treatments that can run off into the marsh. It is important to note that chemical treatments can and should be used on individual undesirable plants, such as Phragmites australis. It is very important to keep the marsh free of unwanted alien invaders-both flora and fauna. *Polygonum perfaliatum* (mile-a-minute weed), *Cuscuta gronovii* (dodder), and *Phragmites australis* can take over man-made marshes and render them inhospitable to desired plants and wildlife. It is important to make sure that the marsh is kept free of these invasive flora; for example, by using specific applications (use hypodermic to prevent poisoning of *Spartina*) of Roundup® or Rodeo® to kill *Phragmites australis*. Unwanted fauna such as Mute swans or Canada geese can be kept from the marsh with the use of geese fencing. This is especially important while grasses are young and have not taken root.

Based on their research, Bosch *et al.* (2006) portrayed the traits consistent with healthy marsh creation projects on the Chesapeake Bay many of which are embodied in the sill shown in Figure 2. A severely eroding cliff bank is independently stabilized. The marsh plants are planted in a 50/50 *Spartina patens* to *Spartina alterniflora* ratio corresponding to a 50/50 split between high and low marsh. The marsh is free of shade and gets mostly full sun. It is planted in proper filling with a 10:1 gradient. Mean high water line falls between the high and low marsh plantings. A three foot space between the low marsh and the sill will break wave action but not trap all sediment, prevent wildlife access or proper flushing.

Duhring *et al.* (2006) researched the effectiveness of 36 marsh protection structures that were used to protect existing tidal marshes with eroding edges. A marsh toe revetment is defined as a structures placed immediately against the erosion scarp of a tidal marsh while a marsh sill is a free-standing structure offset from the marsh edge. Twenty projects (56%) were considered to be consistent with the principles of living shoreline treatments, with some room for improvement. These improvements might be additional tidal openings may be needed at long, continuous structures or increasing the stone size, crest height and marsh width in the design at medium energy settings. Twenty projects were determined to be very effective for both erosion control and for supporting living resources and connections between habitats.

In general, the marsh protection structures were very effective for both upland and marsh erosion control. Upland bank erosion observed before the structures were placed was reduced (Duhring *et al.*, 2006). Future upland erosion may be prevented reducing landward retreat of a wide, protective marsh. Both high and low marsh components were present in most cases, although eight sites included only high marsh vegetation. The marsh condition was generally stable with a high percent cover of vegetation in almost all cases. Tidal marsh condition appeared good in almost all cases, but the effects of the structures on tidal flushing, primary productivity, nekton access and other wildlife utilization were not evaluated.

Fetch models alone may not be sufficient to predict the necessity for structures in low energy settings (Duhring *et al.*,2006). The widest fetch was less than 0.5 mile at 20 out of 36 sites, which is typically considered a wave climate suitable for non-structural methods alone. Yet only one marsh protection structure project was considered to be excessive and unnecessary for erosion control purposes. Boat wake influence appears to be the underlying cause for this observation.

Duhring *et al.* (2006) listed the common characteristics of the twenty projects that were determined to be very effective for both erosion control and for supporting living resources and connections between habitats. These common characteristics included:

- Marsh toe protection structures provided effective erosion reduction where a non-structural approach would not be effective
- Tidal marsh was the primary erosion control treatment with no additional upland structures
- Tidal marsh width was greater than 15 feet
- No or minor erosion of upland bank and marsh was evident after structure was placed
- Appropriate structures were designed with a revetment base width generally <8 feet in low energy settings and <15 feet in medium energy settings
- Tidal exchange was provided either by a crest height <1 ft above MHW and/or strategically placed tidal connections

Hardaway *et al.* (2007) researched the effectiveness of a sill with marsh at St. Mary's City, Maryland. The project, installed in 2002, has about 1,000 ft of shoreline with a gapped sill. The windows or gaps in the sill were encouraged to allow more free flow of marine fauna to utilize the created marsh fringe, particularly turtles and fish. However, when the sill is opened to allow marine fauna ingress and egress, the local wave climate also comes in as well. The result was twofold: 1) during storms, the waves could impact the upland bank which the sill was designed to protect, and 2) the waves would create a "beach" berm around the perimeter of the opening thereby closing the marsh fringe off and reducing access to the adjacent marsh. In fact, sill openings will create small pocket beaches which are important estuarine habitat themselves. These factors have been addressed by numerous creative opening designs including varying the opening or gap, offset on side to the other, turning the sills offshore to create small spurs, using cobble instead of sand in adjacent to the openings, and others. The effectiveness of each window design type was analyzed.

The sill site has evolved over the past five years to a be a viable system for shore protection and habitat creation (Hardaway *et al.*, 2007). Variations in landscape due to increases and decreases in elevation only serve to diversify site vegetation communities. The site has been impacted by several high water events that significantly exceeded the design elevations. This has caused only minor bank scarping, mostly within some of the window areas with no evidence of bank failure. Overall, the 2002 sill installation has performed well as a shore protection system, enduring Hurricane Isabel (September 2003) and Tropical Storm Ernesto (September 2006) with minimal base of bank scarping. Although the water levels were well up on the upland bank during these storms, only modest wave action impacted it due to relatively short fetch distances and sheltering from the main storm winds

The type of window with a backshore revetment, appears to be the best of the gap types installed at St. Mary's in terms of maintaining tidal flow across and adjacent to the opening and providing for protection of the bank in the midbay region (Figure 3). The inclusion of cobble and gravel enhanced shore protection and allowed much less berming around the bay perimeter than those windows with the standard sand fill requirement (Hardaway *et al.*, 2007).

The flushing model (Unstructured, Tidal, Residual Intertidal, and Mudflat model (UnTRIM)) for these types of systems showed that more windows allow for better flushing if there is no interchange through the sills. The seepage model allows for significant exchange between the river and silled marsh. The reality is that water moves through the rock void and that the porosity of the rock is as important, if not more important, than the window opening. Oversized stone may even be preferred (Hardaway *et al.*, 2007).

The ecological services provided by a stone sill system is significant, especially from a fisheries perspective. Access to the fringe marsh behind the sill (Figure 4) occurs through three pathways: 1) the sill windows, 2) macro-pores in the sill, and 3) overtopping by tidal waters. Results indicate that marsh minnows reside within the filled pore spaces of the St. Mary's sill during low water and move with rising water into the intertidal marsh region. Aggregating within the sill structure during low water conditions may serve as a behavioral adaptation to minimize predation risk. Having some part of the sill below mean low water may be an important design component for sills (Hardaway *et al.*, 2007).

Maryland developed design guidelines for marsh creation which outlines various ways to construct marsh fringes for shore erosion control (Luscher and Hollingsworth, 2006). Figure 5 shows the general dimension of a typical sill system and state guidelines for installation. However, it is unclear as to how high the sand fill goes up onto the base of the eroding bank but at a 10:1 it would be about 3 ft above MLW. In Maryland, if you keep the system within 35 feet of MHW, the permitting process is simpler. Adding sand fill elevation and a 10:1 slope would push the structure further offshore; this allows more shore protection but adds to permitting review. It also would add to the marsh width thereby increasing habitat.

1.3 Shorezone Management Considerations

Shore erosion is the process by which wind-driven waves impact the coast and cause the bank sediments to be undercut and transported away from the source. The result is a landward retreat of the bank, berm, or line of vegetation. The process is more severe during periods of high water and high winds, *i.e.* a storm, when wave energies are highest and impacts to upland banks are the greatest. Shore erosion on a daily basis is minimal.

Shore change along the coast of Occohannock Creek is relatively low compared to open bay shorelines. Nonetheless, exposed bank and land loss is often an unwanted process by many landowners who chose to install traditional shore protection structures such as bulkheads or stone revetments. These defensive strategies are effective shore protection but often cause loss of intertidal wetlands both vegetated and non-vegetated. These structures, particularly bulkheads, intersect the coast profile and make it difficult to establish a coastal profile as shown in Figure 6.

The word *riparian* refers to anything connected with or immediately adjacent to the banks of a stream or other water body. Creek side woodlands are riparian forests. These areas occur naturally or are managed as buffers. Riparian buffers trap and filter sediments, nutrients, and chemicals from surface runoff and shallow groundwater. The frame work of tree roots stabilizes the creek bank and microbes in the organic forest soils convert nitrate, (especially from agricultural land) into nitrogen gas through denitrification.

The riparian buffer along the shorelines of Occohannock Creek is occurs above the zone of tidal wetlands and is typically occupied by scrub/shrub and trees. Riparian buffers are often being eroded as the upland banks recede as seen by displaced trees along the shoreline. When shoreline erosion strategies are employed one must consider how to interface with the riparian edge. If the bank face is relatively stable, the riparian edge might remain as is but if the bank face is fully exposed and actively eroding, then bank grading might be required. Graded banks should be replanted with the proper native vegetation.

VIMS' Center for Coastal Resources Management developed a water quality and habitat model (Figure 6) which incorporates aspects of the entire cross-shore environment from upland development to subaqueous habitats (CCRM, 2007). The model integrates habitat features such as riparian landuse, intertidal zone, and subaqueous habitats through a cross-section of the coastal landscape. Natural landuse helps stabilize the bank reducing erosion and sediment introduction into the waterway and provides native or unaltered habitat for terrestrial and avian species and generally has a high diversity whereas agricultural land has reduced availability of suitable habitat for a wide variety of creatures. Developed landuse may result in reduced available habitat and increased human disturbance.

In the intertidal zone, beaches interact with dunes and serve as habitat of animals and plants living on or in the sand (Figure 6). Dunes themselves are a transitional area between marine and terrestrial habitats providing essential habitat and are protective barriers from flooding and erosion resulting in decreased sediment and nutrient input. Marshes provide habitat for both aquatic and terrestrial animals and reduce erosion by intercepting run-off, filtering groundwater, and holding sediment in place. Bulkheads, boat ramps may stabilize the shore reducing sediment input, but they have an adverse impact on habitat because they displace native environments and interrupt the marine-terrestrial interface (CCRM, 2007).

In the subaqueous zone, submerged aquatic vegetation (SAV) and oyster reefs are becoming increasingly rare in Chesapeake Bay and the surrounding watersheds (Figure 6). They are important components of the coastal ecosystem for a wide variety of estuarine species (CCRM, 2007). They also have limited capabilities to dampen waves and stabilize nearhsore sediments and may help reduce excess nutrients. Breakwaters, sills, and jetties provide attachment surfaces for aquatic animals, but they are not native habitats since they cover the existing bottom. They also stabilize the shoreline reducing sediment input. Marinas have an adverse impact on habitat because they cover subaqueous bottom and increase shading and introduce pollutants associated with boating.

1.4 Shoreline Management Strategies

In developing the Living Shoreline options for effective shoreline management, the following objectives have been given consideration:

- Prevention of loss of land and protection of upland improvements.
- Protection, maintenance, enhancement, and/or creation of wetlands habitat both vegetated and non-vegetated.
- Management of upland runoff and groundwater flow through the maintenance of riparian and vegetated wetland fringes.
- For a proposed shoreline strategy, address potential secondary impacts within the reach which may include impacts to downdrift shores through a reduction in the sand supply or the encroachment of structures onto subaqueous land and wetlands.
- Providing access to and/or creation of recreational opportunities such as beach areas.
- Align costs with goals.

These objectives must be assessed in the context of a shoreline reach. While all objectives should be considered, they will not carry equal weight. In fact, satisfaction of all objectives for any given reach is not likely as some may be mutually exclusive.

Suitable living shoreline strategies for Occohannock Creek are recommended:

1) Marsh Management: Usually in very fetch limited creeks (F=<1,000 feet) but may include more open shores where the existing marsh fringe is narrow or absent resulting in exposed base of bank (Figure 7). Narrowing of the marsh can be due to shading by trees.

Recommended Strategies:
- do nothing, the erosion rate is probably minimal
- trim trees
- plant bare areas of existing intertidal substrate, usually *Spartina alterniflora*, no permit required.

2) Add sand with groins: As fetch exposures increase beyond about 1,000 feet, the intertidal marsh width may not be sufficient to attenuate wave action. In these cases, the addition of sand can increase the intertidal substrate as well as the backshore region (Figure 8). The simple addition of sand is usually not enough because, although the increased marsh fringe offers increased wave protection, the sand often will be transported away from the site. This usually requires the inclusion of some sand retaining structures such as short groins or a low sill. Any addition of fill, sand or rock beyond mean high water will require a permit.

These types of shore management solutions must have maintenance before and after the project. The project at Wye Island is degrading because trees had grown over the marsh through time and shaded out the plants (Figure 9). This allowed wave action to directly impact the bank. Sand that was protecting the bank is deflated and now the bank is eroding again. Trees must be trimmed if they shade the marsh over time. Marsh grasses and potentially even sand may need to be replaced after storm events. Property owners need to understand their shoreline and recognize when it may be in distress.

3) Stone sills: The stone sill has been used extensively in Chespeake Bay over the years especially in Maryland (Figure 10A). The general cross-section (Figure 5) shows the sand for the wetlands substrate is on about a 10:1 slope from the base of the bank to the back of the sill. The elevation of the intersection of the fill at the bank and the sill will determine, in part, the dimensions of the sill system.

4. Breakwater System: Although single breakwaters can be used, two or more are recommended to address several hundred feet of coast (Figure 10B). Breakwaters can also have varying levels of protection where increased dimensions generally correspond to increased increased fetch exposure and where a beach/dune shoreline is desired.

2 Methods and Plan Development

2.1 Shoreline Condition Survey

2.1.1 Introduction

The Comprehensive Coastal Inventory Program (CCI) has developed a set of protocols for describing shoreline conditions along Virginia's tidal shoreline. The assessment approach uses state of the art Global Positioning Systems (GPS), and Geographic Information Systems (GIS) to collect, analyze, and display shoreline conditions. These protocols and techniques have been developed over several years, incorporating suggestions and data needs conveyed by state agency and local government professionals (Berman and Hershner, 1999).

Three separate activities embody the development of a Shoreline Inventory: data collection, data processing and analysis, and map generation. Data collection follows a three tiered shoreline assessment approach described below. Data are portrayed on maps in Appendix A.

2.1.2 Three Tiered Shoreline Assessment

The data inventory developed for the Shoreline Inventory is based on a three-tiered shoreline assessment approach. This assessment characterizes conditions in the shorezone, which extends from a narrow portion of the riparian zone seaward to the shoreline. This assessment approach was developed to use observations that could be made from a moving boat. To that end, the survey is a collection of descriptive measurements that characterize conditions. GPS units log location of conditions observed from a boat. No other field measurements are performed.

The three tiered shoreline assessment approach divides the shorezone into three regions: 1) the immediate riparian zone, evaluated for land use; 2) the bank, evaluated for height, stability, cover, and natural protection; and 3) the shoreline, describing the presence of shoreline structures for shore protection and recreational purposes. Each tier is described in detail below.

Riparian Land Use: Land use adjacent to the bank is classified into one of ten categories (Table 1). The categories provide a simple assessment of land use, and give rise to land management practices that can be anticipated. GPS is used to measure the linear extent along shore where the practice is observed. The width of this zone is not measured. Riparian forest buffers are considered the primary land use if the buffer width equals or exceeds 30 feet. This width is calculated from digital imagery as part of the quality control in data processing.

Table 1. Tier One - Riparian Land Use Classes.

Land Use	Description
Forest	stands greater than 18 feet high / width greater than 30 feet
Scrub-shrub	stands less than 18 feet high*
Grass	includes grass fields, and pasture land*
Agriculture	includes cropland*
Residential	includes single or multi family dwellings*
Commercial	includes small and moderate business operations, recreational facilities*
Industrial	includes large industry and manufacturing operations*
Bare	lot cleared to bare soil*
Timbered	clear-cuts*
Paved	areas where roads or parking areas are adjacent to the shore*
Unknown	land use undetectable from the vessel*

* forest fringe along the shore is present in conjunction with the dominant land use

Bank Condition: The bank extends off the fastland, and serves as an interface between the upland and the shore. It is a source of sediment and nutrient fluxes from the fastland, and bears many of the upland soil characteristics that determine water quality in receiving waters. Bank stability is important for several reasons. The bank protects the upland from wave energy during storm activity. The faster the bank erodes, the sooner the upland will be at risk. Bank erosion can contribute high sediment loads to the receiving waters. Stability of the bank depends on several factors: height, slope, sediment composition and characteristics, vegetative cover, and the presence of buffers to absorb energy impact to the bank itself.

The bank assessment in this inventory addresses four major bank characteristics: bank height, bank cover, bank stability, and the presence of natural (beach, marsh) buffers at the bank toe (Table 2). Conditions are recorded continuously using GPS as the boat moves along the shoreline. The GPS log reflects any changes in conditions observed.

Bank height is described as a range, measured from the toe of the bank to the top. Bank cover is an assessment of the percent of either vegetative or structural cover in place on the bank face. Natural vegetation, as well as structural cover like riprap is considered "cover". The assessment is qualitative (Table 2). Bank stability characterizes the condition of the bank face. Banks that have exposed root systems, down vegetation, or exhibit slumping of material qualify as a "high erosion". Those showing erosion signs only at the base may be noted as undercut. At the toe of the bank, natural marsh vegetation and/or beach material may be present. These features offer protection to the bank and enhance water quality. Their presence is noted in the field. Sediment composition and bank slope cannot be surveyed from a boat, and are not included.

Table 2. Tier 2 - Bank Conditions.

Bank Attribute	Range	Description
bank height	0-5 ft	from the toe to the edge of the fastland
	5-10 ft	from the toe to the edge of the fastland
	10-30ft	from the toe to the edge of the fastland
	> 30 ft	from the toe to the edge of the fastland
bank stability	low erosion	minimal erosion on bank face
	high erosion	includes slumping scarps exposed roots
	undercut	erosion at the base of the bank
bank cover	bare	<25% cover; vegetation or structural cover
	partial	25-75% cover; vegetation or structural
	total	>75% cover; vegetation or structural
marsh buffer	no	no marsh vegetation along the bank toe
	yes	fringe extensive or embayed
beach buffer	no	no sand beach present
	yes	sand beach present
Phragmites australis	no	no Phragmites australis present on site
	yes	Phragmites australis present on site

Shoreline Features: Structures added to the shoreline by property owners are recorded as a combination of points or lines. These features include defense structures, constructed to protect the shoreline from erosion; offense structures, designed to accumulate sand in transport; and recreational structures, built to enhance public or private use of the water (Table 3). The location of these features along the shore is surveyed with a GPS unit. Linear features are surveyed kinematically without stopping the boat. Structures such as docks, and boat ramps are point features, and a static six-second GPS observation is collected at the site. Table 3 summarizes shoreline features surveyed. Linear features are denoted with an "L" and point features are denoted with a "P." The glossary describes these features, and their purpose along a shore.

Table 3. Tier 3 - Shoreline Features.

Feature	Feature Type	Comments
Control Structures		
riprap	L	
bulkhead	L	
breakwaters	L	first and last of a series is surveyed
groinfield	L	first and last of a series is surveyed
jetty	P	
debris	L	can include tires, rubble, tubes, etc.
unconventional	L	composed of non-traditional materials
marsh toe revetment	L	placed in front of an eroding marsh
Recreational Structures		
pier/wharf	P	includes private and public
boat ramp	P	distinguishes private vs. public landings
boat house	P	all covered structures, assumes a pier
marina	L	includes piers, bulkheads, wharfs

2.1.3 Data Collection/Survey Techniques

Data collection was performed in June 2007 from a small, shoal draft vessel, navigating at slow speeds parallel to the shoreline. To the extent possible, surveys take place on a rising tide, allowing the boat to be as close to shore as possible. Data is logged using the handheld Trimble GeoExplorer III, GeoExplorer XT, or GeoExplorer XH GPS unit. GeoExplorers are accurate to within 4 inches of true position with extended observations and differential correction. Without post processing, these units can achieve accuracies around 3 ft (1 meter). Both static and kinematic data collection is performed. Kinematic data collection is a collection technique where data is collected continuously along a pathway (in this case along the waterway). GPS units are programmed to collect information at a rate sufficient to compute a position anywhere along the course. The shoreline data is collected at a rate of one observation every five seconds. Land use, bank condition, and linear shoreline structures are collected using this technique.

Static surveys pin-point fixed locations that occur at very short intervals. The boat actually stops to collect these data, and the boat operator must hold the boat against tidal current, and surface wind waves. Static surveys log 6 GPS observations at a rate of one observation per second at the fixed station. The GPS receiver uses an averaging technique to compute one position based on the 6 static observations. Static surveys are used to position point features like piers, boat ramps, and boathouses.

2.1.4 Data Processing

Data processing occurs in two parts. Part one processes the raw GPS field data and converts the data to GIS coverages. Part two corrects the GIS coverages to reflect true shoreline geometry. Differential correction of GPS field data improves its accuracy by including other "known" locations to refine geographic position. A National Geodetic CORS GPS base station within 124 miles of the field site was used for the data processing on Occahanncock Creek. Differential correction is the first step to processing GPS data. Trimble's Pathfinder Office GPS software is used. The software processes time synchronized GPS signals from field data and the selected base station. Differential correction improves the position of the GPS field data based on the known location of the base station, the satellites, and the satellite geometry. Although the Trimble hand-held units are capable of about 4 inch accuracy, the short occupation of sites in the field reduces the accuracy to 16 feet. In many cases the accuracy achieved is better, but the overall limits established by the program are set at 16 feet. This means that features are registered to within 16 feet or better of their true position on the earth's surface. In this case, positioning refers to the boat position during data collection.

The final step in GPS processing converts the files to three separate ArcInfo® shape files. These are converted into three coverages: a land use and bank condition coverage (occah_lubc), a shoreline structure coverage (lines only) (occah_sstru), and a shoreline structure coverage (points only) (occah_astru).

The second phase of processing is in GIS. GIS processing includes one major step that combines ESRI's ArcInfo® GIS software, and ERDAS' Imagine® software. Several data sets are integrated to develop the final inventory products. The processing is intended to correct the new GIS coverages so they reflect conditions at the shoreline, and not along the boat track. All attributes summarized in Tables 1, 2, and 3 are included. A digital shoreline coverage is generated to use as a basemap. For this inventory, a digital shoreline data set generated as part of the 2002 Virginia Base Mapping Program (VBMP) was used as the projects baseline shoreline. This shoreline is not referenced to a tidal datum but is the most recent available data and developed from a very high resolution product. The shoreline is extracted from the digital terrain model.

The GIS processing under goes a rigorous sequence of checks to insure the positional translation is as accurate as possible. Each field coverage; land use, bank condition, and shoreline condition, is processed separately. The final products are three new coded GIS shoreline coverages; occah_lubc (depicting land use and bank cover), occah_sstru (depicting linear structures), occah_astru (depicting point structures). Quality control and assurance measures require that each coverage be checked twice onscreen by different GIS personnel. Draft hardcopy maps are printed and reviewed in the third and final QA/QC step. The data are then ready for incorporation into other GIS products, maps and analyses.

2.2 General Wave Climate Analysis

The wave climate is the overall wave energy that impacts the project shoreline averaged through time. The wave climate along any given shoreline is a function of fetch and nearshore bathymetry. Fetch is defined as the distance over water that wind can blow and generate waves and was determined for 22 fetch locations. The individual reach locations are shown in Figure 11. The 2002 image mosaic from Virginia Base Mapping Program and its corresponding shoreline were used to determine the starting point of each fetch location, while a bay wide shoreline from NOAA and a 30 meter bathymetric DEM from NOAA were used to establish the end shoreline locations.

The shoreline and fetch centerline shapefiles and the DEM information were input to an AML program running in ArcInfo Workstation which produced two sets of 6 additional vectors for each fetch location. The additional vector lines were spaced at 6 degree intervals on either side of the original centerline, starting at the same point as the corresponding centerlines and extending to the opposite shoreline. At each of the 22 sites, the NOAA bathymetric DEM was used to compute the average depth along the resulting 15 vector lines. The average depth and distance to the opposite shore were exported into a separate dbf table for each of the 22 locations. The average depth of the entire fetch window was calculated as well. Each section of Occohannock Creek's shoreline has varying fetches which are shown in Table 4. Generally, fetches decrease up the creek.

While wave climate is fetch limited, select storm wave conditions can be portrayed along each subreach using the wind/ wave growth program developed as part of the ACES (Veritech, Inc., 2008) modeling package. ACES predicts wave height and period based on input fetch and wind conditions. Three storm scenarios were modeled: 1) a two year event with 25 mph sustained winds and a 4.2 ft MLW surge, 2) a ten year event with 35 mph sustained winds and a 6.5 ft MLW surge, and 3) a 50 year event with a 55 mph sustained wind and an 8.2 ft MLW surge. The wind direction was assumed to come from the direction of the longest fetch. Surge levels were added onto the average depth of the fetch window.

Data from Norfolk International Airport, summarized for the time period 1960-1990 in Table 5, show the long-term wind frequencies. The north component is dominant followed by the south, southwest, and northeast while the west and northwest components are minor. Westerly winds can generate storm waves that travel through the mouth of the creek. However, shoaling on the sand shoals will greatly reduce Bay-generated waves. The other parts of the Creek have only local winds generated due to limited fetches and relatively shallow depths.

Table 4. Individual reach fetch lengths.

Fetch Line	Fetch (ft)	Fetch Window Avg Depth (ft)	Fetch Line	Fetch (ft)	Fetch Window Avg Depth (ft)
N1	73,955	-13.9	S1	68,550	-19.3
N2	2,579	-2.4	S2	2,736	-3.7
N3	41,908	-11.6	S3	4,625	-4.1
N4	2,781	-5.2	S4	2,394	-2.2
N5	3,385	-4.5	S5	3,213	-5.2
N6	3,422	-4.1	S6	3,167	-4.4
N7	4,515	-4.3	S7	3,845	-4.2
N8	11,264	-5.9	S8	2,679	-4.3
N9	2,721	-4.3	S9	2,103	-3.6
N10	2,588	-4.3	S10	2,607	-2.3
N11	2,283	-3.5			
N12	2,289	-3.4			

Table 5. Summary wind conditions at Norfolk International Airport from 1960-1990.

		WIND DIRECTION								
Wind Speed (mph)	**Mid Range (mph)**	**South**	**South west**	**West**	**North west**	**North**	**North east**	**East**	**South east**	**Total**
< 5	3	5497* 2.12[+]	3316 1.28	2156 0.83	1221 0.47	35748 13.78	2050 0.79	3611 1.39	2995 1.15	56594 21.81
5-11	8	21083 8.13	15229 5.87	9260 3.57	6432 2.48	11019 4.25	13139 5.06	9957 3.84	9195 3.54	95314 36.74
11-21	16	14790 5.70	17834 6.87	10966 4.23	8404 3.24	21816 8.41	16736 6.45	5720 2.20	4306 1.66	100572 38.77
21-31	26	594 0.23	994 0.38	896 0.35	751 0.29	1941 0.75	1103 0.43	148 0.06	60 0.02	6487 2.5
31-41	36	25 0.01	73 0.03	46 0.02	25 0.01	162 0.06	101 0.04	10 0.00	8 0.00	450 0.17
41-51	46	0 0.00	0 0.00	0 0.00	1 0.00	4 0.00	4 0.00	1 0.00	0 0.00	10 0.00
Total		41989 16.19	37446 14.43	23324 8.99	16834 6.49	70690 27.25	33133 12.77	19447 7.50	16564 6.38	259427 100.00

*Number of occurrences [+]Percent

2.3 Shoreline Change Assessment

Historical aerial imagery was digitized in order to portray shoreline evolution since 1938 to the present. Understanding the long-term shoreline change is critical to assessing shoreline reaches in Chesapeake Bay. The method for this assessment involves digitizing historic shorelines into a database. Available aerial photos were orthorectified and the shoreline digitized. The years included 1904 (map), 1938, 1949, 1953, 1979, 1994, 2002, and 2006. The 1994 imagery was already processed and mosaicked by the United States Geological Survey, while the 2002 imagery was processed and mosaicked by the Virginia Base Mapping Program. The aerials for the remaining flight lines were processed and mosaicked by the VIMS Shoreline Study Program.

The images were scanned as tiffs at 600 dpi and converted to ERDAS IMAGINE (.img) format. They were orthorectified to a reference mosaic, the 1994 Digital Orthophoto Quarter Quadrangles (DOQQ) from USGS. The original DOQQs were in MrSid format but were converted into .img format as well. ERDAS Orthobase image processing software was used to orthographically correct the individual flightlines using a bundle block solution. Camera lens calibration data was matched to the image location of fiducial points to define the interior camera model. Control points from 1994 USGS DOQQ images provide the exterior control, which is enhanced by a large number of image-matching tie points produced automatically by the software. A minimum of four ground control points are used per image, allowing two points per overlap area. The exterior and interior models were combined with a 30-meter resolution digital elevation model (DEM) from the USGS National Elevation Dataset (NED) to produce an orthophoto for each aerial photograph. The orthophotographs that cover each USGS 7.5 minute quadrangle area were adjusted to approximately uniform brightness and contrast and were mosaicked together using the ERDAS Imagine mosaic tool to produce a one-meter resolution mosaic also in an .img format.

To maintain an accurate match with the reference images, it was necessary to distribute the control points evenly. This can be challenging in areas with little development. Good examples of control points are permanent features such as manmade features such as corners of buildings or road intersections and stable natural landmarks such as easily recognized isolated trees. The maximum root mean square (RMS) error allowed is 3 for each block.

Once the aerial photos were orthorectified and mosaicked, the shorelines were digitized in ArcMap with the mosaics in the background to help delineate and locate the shoreline. The edge of marshes and the toe of the narrow beaches are documented along the creek. These features generally can indicate the MLW position but can be very difficult to see due to tree cover. This was particularly the case in the smaller creeks. Tree cover and photo quality combine to make this very difficult in terms of characterizing the shore. The final format the shorelines are in shapefile format. One shapefile was produced for each year that was mosaicked. In areas where the shoreline was not clearly delineated on the aerial photography, the location was estimated based on the experience of the digitizer.

This methodology works well along the open shorelines of Chesapeake Bay. The more sheltered coast inside Occohannock Creek has not had nearly as much shoreline change. As such, the small amount of change that did occur between digitized shorelines may well be within the error associated with these methods. As such only the long-term trend will be displayed in this report. The 1949 photos have better clarity than the 1938 and will be used in conjunction with the 2002 photos to show the long-term shoreline change trends within Occohannock Creek. The other photo dates will be available in GIS.

2.4 Existing Marine Resources

Existing marine resources both natural and aquaculture areas are shown in GIS through existing databases. They are included as a layer in the existing conditions element of the plan. No new data has been created for this report. The existing source data are:

Tidal Wetlands Inventory - VIMS, Center for Coastal Resources Management, 1988

Tidal wetland data were collected through site visits to all tidal marshes in Virginia using aerial photography for assistance. The geographic boundaries of tidal marshes were digitized from USGS 7.5 minute topographic quadrangle maps (scale = 1:24000). Aerial photography was used to correct for obvious discrepancies in the boundaries observed. The community structure and composition were described through site visits to all tidal marshes in the Tidewater region of Virginia. Composition was based on estimated percent cover of wetland species observed during site visits. http://ccrm.vims.edu/gis_data_maps/data/index.html

Aquaculture Vulnerability Model - VIMS, Center for Coastal Resources Management, completed in 2007 but pulled existing data from various sources

The purpose of the AVM was to model risks to shellfish aquaculture. The model first considers basics physical and biological conditions necessary for aquaculture success, and second, the impacts that current land use and proposed local zoning have on suitable growing areas. The study uses data available from federal, state, and local government sources to derive salinity, bathymetry, submerged aquatic vegetation (SAV) distribution, water quality, land use, and local zoning. A vulnerability index is scaled to reflect current and projected conditions and the resulting impact to shellfish growing. http://ccrm.vims.edu/gis_data_maps/data/index.html

Blue Infrastructure - VIMS, Center for Coastal Resources Management

This online mapping tool integrates important aquatic resources that have been compiled for the coastal zone of Virginia using GIS technology. The data used for this tool represents archives from a variety of agencies and programs. Data from VIMS's Comprehensive Coastal Inventory Program (CCI) and Submerged Aquatic Vegetation (SAV) Program were layers plotted on the maps as were layers from the Department of Conservation and Recreation, the Department of Game and Inland Fisheries, Virginia Marine Resources Commission, and Virginia Commonwealth University. Layers include: aquaculture Sites (hard clams and oysters), public oyster grounds, private oyster leases, and mud flats.
http://ccrm.vims.edu/gis_data_maps/interactive_maps/blueinfrastructure/disclaimer_bi.html

SAV - VIMS, Submerged Aquatic Vegetation Program

The 2006 Chesapeake Bay SAV Coverage was mapped from 1:24,000 black and white aerial photography. Each area of SAV was interpreted on-screen from the rectified photography and classified into one of four density classes by the percentage of cover. The final 2006 SAV beds are stored as ArcInfo GIS coverages. http://www.vims.edu/bio/sav/

2.5 Shoreline Strategy Development

Living Shoreline strategies were recommended for each section of eroding coast. The initial recommendation was done by boat in October and December 2007 using similar procedures to the shoreline condition survey. A handheld GPS unit, the GeoExplorer XH, was used to store the recommended structures in the field. The data were downloaded, processed as raw data and in GIS to create the management recommendations. Once the data were compiled and evaluated, adjustments to the recommendations were made based on other collected data.

3 Results and Discussion

3.1 Shoreline Conditions

3.1.1 Hydrodynamic Setting

The mean tide range in Occohannock Creek is 1.7 feet. The storm surge frequency in Occohannock Creek was developed for this report from data published by the U.S. Army Corps of Engineers for Cape Charles, Virginia on the Eastern Shore. However, data on more recent storms also guided the development of the hydrodynamic setting. Using hourly water levels from NOAA's tide gauge at Windmill Point, the impact of recent storm surges could be qualified. Recent storms include Hurricane Floyd (September 1999), Tropical storm Ernesto (September 1, 2006) and the northeasters on October 10 and November 22, 2006. These storms had surges of 3.4 ft MLLW, 5.13 ft MLLW, 4.17 ft MLLW, and 3.49 ft MLLW, respectively. Hurricane Isabel impacted the region on September 18, 2003. The tide gauge at Windmill Point stopped recording at 3.24 ft MLLW. However, other gauges around the Bay indicated a much higher surge level.

Fetch is often used as a measure of potential wave climate. Two general fetch exposures exist along the Occohannock Creek sub-estuary based on its geomorphology. These fetches occur along the main trunk of the creek and along the small tidal tributaries. The width of these small creeks is generally less the 1,000 feet in any direction while averaging only a few hundred feet. The main trunk shorelines are exposed to fetches greater than 1,000 feet and as much as several miles or more particularly near the mouth of the creek at its confluence with Chesapeake Bay. Most of the wind driven shore erosion occurs along the main trunk. Minor bank erosion occurs up the small creeks where shading by overhanging trees can prevent a protective marsh fringe from existing. In these areas, there can be a perceived problem with an exposed base of bank (BOB). However, overall change is minimal.

Shore erosion is the process by which wind-driven waves attack the base of the upland banks rendering it unstable. With continued wave action against the base of bank, the bank face will eventually become unstable. This process is most active and effective during periods of high water and high wind conditions, *i.e.* storms. The less frequent events, severe northeasters and hurricanes can have the most significant erosive impacts.

3.1.2 Physical Setting

The condition or state of a given shoreline segment will dictate the management strategy that the landowner might employ. One purpose of this plan is to assess on a reach by reach basis the nature of the shoreline in terms of how it has evolved to its present state, what that state is and what factors influence the shore condition. This will, in effect, determine if erosion is an issue or whether the shore is stable and nothing is required. Intermediate situations also occur where the bank transitions to erosive or stable situation. This assessment is qualitative to a certain degree, and the landowner may see an erosion problem that may or may not be significant from a management perspective.

The Occohannock Creek watershed drains westward from head waters to Chesapeake Bay. The underlying geology is upper Pleistocene Formations including Kent and Nassawaddox (Figure 12). At the contact between these two formations, a scarp exists. Here the land drops from about +25 feet to about +10 feet going from east to west. This is reflected in the upland or fastland bank heights along the creek's shoreline

The shorelines along Occohannock Creek are a variety of low to medium height fastland banks between 5 to 25 feet high with intermittent marsh fringes and sandy backshores. The landuse of these upland areas include forested, agricultural and residential properties with one marina and one public landing. The key parameters measured during the field assessment include marsh/beach width, condition of the base of the bank, and condition of the bank face. The condition of the front edge of marsh also was assessed but not included in the final analysis.

The fringing marsh/beach along Occohannock Creek has varying histories as to how they were formed and influenced by littoral processes. It suffices to say that narrow marsh/beach features (<5 ft) will have less wave attenuation capabilities that wide marsh/beach features (>15 ft). We have included intermediate categories as well, 5-10 ft and 10-15 ft. The state of the upland bank on the land side of the marsh/beach fringe is determined largely by the marsh/beach width along with the site's orientation, fetch, and hydrodynamic elements.

The upland banks have two components that were assessed, the base of bank (BOB) and the bank face. The stability of the BOB is usually the first indicator of shore erosion. The bank face is the second. Vertically exposed bank face and exposed BOB are signs of active erosion. A stable bank face and BOB are indicated by no undercutting at BOB and a fully vegetated bank face. These two extremes are readily identified but the intermediate or transitional cases are a bit more subjective (Figure 13).

Generally, along the main stem of Occohannock Creek, the wider the marsh/beach fringe, the more stable the upland bank. The narrower marsh/beach fringes tend to occur in front of erosional banks and are usually the shore reaches where a proactive management strategy is recommended.

3.2 General Wave Climate Analysis

The results of the wave climate analysis are shown in Table 6. As expected the reaches, facing out of the mouth of the creek have larger potential wave energies impacting the shore due to exposure from waves from Chesapeake Bay (N1, S1, N3). All other shore reaches have average fetch exposures less than 5,000 ft except N8 which has an 11,000 ft effective fetch. Reach N8 is about 14,000 ft from the mouth of Occohannock Creek, but it is oriented such that it has a long fetch to the west. This results in a potential increase in wind/wave energy. Basically, the less the fetch exposure, the less the wave energy potential. Conversely, the higher the water levels, the higher the wave energy potential. Shore reaches up the smaller creeks were not assessed. This analysis is meant to provide landowners with the potential wave energies relative to the frequency of storm events so that shoreline management strategies and the level of protection they afford can be assessed.

Table 6. General wave climate analysis for Occohannock Creek.

	2 year		10 year		50 year	
Case	WaveHeight	WavePeriod	Wave Height	Wave Period	Wave Height	Wave Period
	(ft)	(sec)	(ft)	(sec)	(ft)	(sec)
N1	3.7	4.1	5.0	4.8	7.1	5.9
N2	0.8	1.7	1.2	2.0	1.9	2.5
N3	3.2	3.7	4.4	4.3	6.3	5.3
N4	0.7	1.6	1.0	1.8	1.7	2.3
N5	1.0	1.8	1.4	2.1	2.2	2.7
N6	0.9	1.7	1.2	2.0	2.0	2.5
N7	1.0	1.9	1.5	2.3	2.4	2.8
N8	2.0	2.9	2.8	3.4	4.3	4.1
N9	0.7	1.5	1.0	1.8	1.7	2.3
N10	0.8	1.6	1.2	1.9	1.9	2.4
N11	0.7	1.5	1.0	1.8	1.6	2.2
N12	0.7	1.5	1.0	1.8	1.5	2.2
S1	3.9	4.0	5.3	4.7	7.7	5.7
S2	0.7	1.5	1.0	1.8	1.6	2.2
S3	1.1	2.0	1.6	2.3	2.6	2.9
S4	0.8	1.6	1.1	1.9	1.8	2.4
S5	0.8	1.7	1.2	2.0	2.0	2.5
S6	0.7	1.6	1.1	1.9	1.7	2.3
S7	1.0	1.8	1.4	2.1	2.2	2.6
S8	0.8	1.6	1.1	1.9	1.8	2.3
S9	0.4	1.2	0.8	1.6	1.3	2.0
S10	0.7	1.5	1.0	1.8	1.7	2.3

3.3 Shore Change Assessment

The morphology of coastal shorelines are constantly evolving. Shore change along Occohannock Creek is often difficult to assess due to photo quality and inherent error in the orthorectification process. Nevertheless, those areas where shore change is obvious have been noted. Two shorelines, 1949 and 2002, were used in this analysis. The 2002 imagery is clear and already orthorectified. The 1949 imagery is relatively clear but harder to rectify. Other older imagery are intermittently fuzzy and clear. In order to keep the analysis relatively simple, the end point method, which gives a net change over a relatively long time for a given shore reach was employed. The photos, digitized shorelines, and calculated rates of shoreline change along the main stem of the Creek are shown in Appendix B. The average rate of change for most of Occohannock Creek is between 0 and -1 feet per year.

3.4 Assessment of Existing Marine Resources

Figures 14 and 15 show the existing marine resource databases available for Occohannock Creek. Areas of SAV as well public oyster grounds and private oyster leases are shown. In addition, the risk levels associated with oyster aquaculture in the Creek are also shown. In Figure15, the risks associated with clam aquaculture are shown.

3.5 Living Shoreline Strategies and Recommendations

In order to apply management strategies to the Occohannock Creek shorelines, it was necessary to establish some assumptions and boundaries regarding the cause and severity of erosion, what is threatened, and level of protection that will be provided. Generally, the shorelines along the main trunk of the creek were the focus of the plan because of greater fetch exposures and measurable historic shore change. As one proceeds into the small creeks, the erosion is much less. Shorelines up these smaller sub-watersheds might have an exposed base of bank, but the erosion is more a perception than land loss. Nevertheless, perception can move a property owner to action. The recommendations are offered accordingly although many situations might not seem to warrant protection in that the erosion is not really severe. However, it is impossible to anticipate what present day and/or future waterfront property landowners might desire.

3.5.1 Strategies

Do-Nothing:

The do-nothing option should be considered first. Many areas of the Occohannock Creek watershed have no erosion problems. Even areas with minimal erosion, the scale is so small that doing nothing may not significantly affect the stability of the shoreline.

Marsh/Buffer Management:

This requires the landowner to maintain and enhance an existing marsh fringe by planting more plants, removing smothering wrack material and/or providing adequate sunlight. The latter can be done by prudent limbing of trees and NOT the whole sale stripping of the riparian buffer and grading the bank. Marsh management applies to all the Occohannock Creek shorelines but particularly up the smaller creeks where wave forces are small. In these regions, marsh maintenance can be very effective. Generally, no permits are required as long as no fill is going into wetlands or onto state-owned bottom.

If the property has a stable bank and bank face, it is usually because of an existing marsh fringe that is wide enough to offer shore protection. However, many of the marsh fringes along the main stem of Occohannock Creek are themselves erosional and may with time be reduced in width and gradually (or suddenly) be rendered ineffective for shore protection. Therefore all waterfront landowners should take note of the condition of their coast and decide how to proceed. An eroding marsh, while still wide enough for wave attenuation can be stabilized with the low sill option with little or no sand component. This is sometime referred to as a marsh toe revetment although the sill is a freestanding structure.

Harden the Shore:

No bulkheads or seawalls were recommended because the areas with immediately threatened infrastructure already has been hardened.

Add Sand and Vegetate with Structure:

Generally, the narrower the wave attenuating marsh/backshore width, the greater the potential upland bank erosion. A rough correlation exists between marsh width and bank stability along the main trunk of Occohannock Creek. For the purpose of this plan, a specific recommendation is made (beyond do-nothing and marsh/buffer management) to those open creek shorelines with an erosional or transitional base of bank (BOB) and bank face (BF). This usually took the form of a stone sill system although a few breakwater systems and sand fill with groins were recommended.

3.5.2 Recommendations

The shoreline management recommendations for Occohannock Creek are shown on a series of maps in Appendix C. The recommendations are meant to offer alternatives to shoreline hardening along Occohannock Creek. They are shown at a conceptual level. Final design will require, a site survey and geotechnical investigations as well as fitting the project more closely to the coastal geomorphology.

Only structural recommendations are shown. Where no recommendation is shown and no structure presently exists, it is understood that the recommendation is Marsh/Buffer Management. The sill systems recommended for Occohannock Creek varied in size depending on the level of protection desired and the height of the upland bank. As shown in the wave climate assessment, the level of the 2 year, 10 year and 50 year storm surges are 4.2 feet, 6.5 feet and 8.5 feet, respectively. This becomes an issue on the more exposed sections of Occohannock Creek when fetch exposures exceed 2,000 feet. For Occohannock Creek, the design level of protection should be at least the 10 year water level which is about +6.5 feet MLW.

Generally, the size of the sill systems also were related to what is threatened. Four typical cross-sections are shown in Figure 16. The condition of the bank, fetch, and landuse were used to assign a sill size to a given reach. With both high and low banks in Occohannock Creek, three sill systems are given for the higher banks and one typical cross-section is depicted for the low bank situation. High banks offer a "backstop" to the sand fill. The low sill system for high banks is indicated for a site usually with an existing marsh fringe that is too narrow to adequately protect the base of bank even though the bank face is stable or transitional. As fetch and the "need" for greater protection increases, the sill system can be elevated in both sand elevation and stone sill elevation to the medium and high sill systems. Low banks might have the same approach except the "back stop" effect is limited to the height of the bank. Bank grading is recommended where needed, usually with the high sill since it generally has a greater fetch exposure. Examples of the types of shoreline where recommendations are shown in Figures 17 and 18.

Bank condition indicators for sills include in descending order where #1 is most severe:

1. Eroding Base of Bank, Eroding Bank Face
2. Eroding Base of Bank, Transition Bank Face
3. Eroding Base of Bank, Stable Bank Face
4. Transitional Base of Bank, Transitional Bank Face
5. Transitional Base of Bank, Stable Bank Face

Landuse condition indicators for sills include in descending order:

1. Residential
2. Lawn
3. Agricultural land
4. Woodland

As shown in Table 7, the low sill option was most recommended sill type around Occohannock Creek, with 52 segments. At these sites, an existing but narrow fringe marsh usually existed, but it needed some level of enhancement. The upland was generally either agricultural or wooded. Residential properties in lower energy realms and or low banks also qualified for low sill systems.

Eleven medium sill systems were recommended some of which were intermittently included within a low sill system or addressed high eroding banks. Only one high sill system was recommended between low sills at structure #25 where there was a high eroding bank on residential property. Individual shore segment management recommendations are shown in Table 8. Table 9 includes the breakdown of costs associated with building the various types of structures recommended in this report. These numbers include unit costs and per linear feet of shoreline costs. These numbers were calculated in 2008. Costs will vary in later time frames and may need to be updated. They do provide a ballpark number on which homeowners may make decisions regarding a system's cost.

Two breakwater systems are recommended. One along an eroding upland bank with an existing groin field and another along the west coast of Morley's Wharf. A typical breakwater system for this type of coastal setting is shown in Figure 18 with 60 foot breakwater units, 60 feet offshore with 60 foot gaps.

Three sand with groin segments were recommended, one up Shields Cove with a narrow intertidal width that needs enhancement.

3.5.3 *Other Considerations*

- Early sill systems used to be continuous but more recent designs have openings, windows or vents to presumably allow better ingress and egress for marine fauna and water exchange. Recent research points the latter may not be the case to a significant degree.
- The recommendations made will provide effective shore erosion control. However, it is up to the landowner to determine their needs and goals. They can do more or they can do less depending on personal factors. Landowners must understand their shoreline and stand ready to do maintenance on it.
- Each sill cross-section can have an increased level of protection by adding more sand and more stone. However, with each increase in protection, more encroachment onto State-owned bottom occurs, but, also, wetland habitat and riparian buffer increases.

Table 7. Summary of shoreline recommendations for Occohannock Creek.

Catergory	**Type**	**Number of Structures**	**Length (miles)**	**% of Total Shore Length**
Recommended	Breakwaters	2	0.34	1.1%
Structures	Marsh Man in small creeks	43	15.57	50.6%
	Low Sill	52	4.29	13.9%
	Medium Sill	11	0.73	2.4%
	High Sill	1	0.04	0.1%
	Sand and Groins	3	0.35	1.1%
	Marsh Man on open creek		7.29	23.7%
		Total	**28.60**	**93.0%**
Marsh Width	>15		3.91	12.7%
	10-15		3.66	11.9%
	5-10		14.52	47.2%
	<5		4.45	14.5%
Base of Bank	Erosional		4.01	13.0%
	Transitional		1.64	5.3%
	Stable		22.39	72.8%
Bank Slope	Erosional		2.57	8.4%
	Transitional		1.59	5.2%
	Stable		24.18	78.6%
Bank Graded	Yes		1.12	3.7%
Trim Trees	Yes		16.42	53.4%

Table 8. Individual shoreline recommendations for Occohannock Creek.

Structure Number	Structure Type	Bank Slope	Bank of Base	Marsh Width	Bank Grading	Erosion Categories
1	Low Sill	Stable	Erosional	<5	No	0 to -1
2	Low Sill	Stable	Erosional	<5	No	0 to -1
3	Low Sill	Erosional	Erosional	<5	No	Not Calculated
4	Low Sill	Stable	Transitional	5-10	No	Not Calculated
5	Low Sill	Transitional	Transitional	<5	No	Not Calculated
6A	Sand and	Erosional	Erosional	<5	No	0 to -1
6B	Low Sill	Erosional	Erosional	<5	No	-1 to -3
6B	Low Sill	Erosional	Erosional	5-10	No	0 to -1
6B	Low Sill	Transitional	Transitional	<5	No	0 to -1
7	Low Sill	Stable	Erosional	<5	No	0 to -1
8	Low Sill	Erosional	Erosional	5-10	No	0 to -1
9A	Low Sill	Erosional	Erosional	5-10	Yes	0 to -1
9B	Medium Sill	Erosional	Erosional	5-10	Yes	0 to -1
9C	Low Sill	Erosional	Erosional	5-10	Yes	0 to -1
9D	Medium Sill	Erosional	Erosional	5-10	Yes	0 to -1
9E	Low Sill	Erosional	Erosional	5-10	Yes	0 to -1
10	Low Sill	Transitional	Erosional	5-10	No	0 to -1
11	Low Sill	Transitional to Erosional	Transitional to Erosional	5-10	No	0 to -1
12	Low Sill	Transitional	Transitional	5-10	No	0 to -1
13	Low Sill	Transitional	Transitional	5-10	No	0 to -1
14	Low Sill	Erosional	Erosional	<5	No	0 to -1
15	Medium Sill	Erosional	Erosional	<5	Yes	0 to -1
16	Low Sill	Transitional	Transitional	5-10	No	0 to -1
17	Breakwater	Erosional	Erosional	<5	Yes	0 to -1
18	Low Sill	Transitional	Transitional	5-10	No	0 to -1
19	Low Sill	Transitional	Erosional	5-10	No	0 to -1
20	Low Sill	Transitional	Erosional	<5	No	0 to -1
21	Low Sill	Transitional	Transitional	<5	No	0 to -1
22	Low Sill	Transitional	Transitional	<5	No	0 to -1
23	Low Sill	Transitional to Erosional	Erosional	<5	No	0 to -1
24	Sand and	Stable	Erosional	<5	No	Not Calculated
25A	Low Sill	Stable	Erosional	<5	No	0 to -1
25B	High Sill	Erosional	Erosional	<5	Yes	0 to -1
25C	Low Sill	Erosional	Erosional	<5	Yes	0 to -1
26	Low Sill	Stable	Erosional	<5	No	0 to -1
27	Low Sill	Transitional	Erosional	<5	No	0 to -1
28	Medium Sill	Transitional	Erosional	<5	No	0 to -1
29	Low Sill	Stable	Erosional	<5	No	0 to -1
30	Low Sill	Stable	Transitional	<5	No	0 to -1
31	Low Sill	Stable	Transitional	5-10	No	0 to -1
32	Sand and	Stable	Erosional	<5	No	0 to -1
33	Low Sill	Transitional	Transitional	<5	No	-1 to -3
34	Low Sill	Erosional	Erosional	<5	No	-1 to -3
35	Low Sill	Erosional	Erosional	<5	No	-1 to -3
36	Low Sill	Transitional to Stable	Erosional	5-10	No	-1 to -3
37	Low Sill	Stable	Transitional	5-10	No	0 to -1
38A	Low Sill	Transitional	Transitional	<5	No	0 to 5
38B	Breakwater	Transitional	Transitional	<5	No	0 to -1
39	Medium Sill	Erosional	Erosional	<5	No	0 to -1

Table 8 (Continued). Individual shoreline recommendations for Occohannock Creek.

Structure Number	Structure Type	Bank Slope	Bank of Base	Marsh Width	Bank Grading	Erosion Categories
40	Medium Sill	Erosional	Erosional	<5	Yes	0 to -1
41A	Low Sill	Stable	Transitional	<5	No	0 to -1
41B	Medium Sill	Stable	Transitional	<5	Yes	-1 to -3
42A	Low Sill	Transitional to Erosional	Erosional	<5	No	-1 to -3
42B	Medium Sill	Erosional	Erosional	<5	Yes	-1 to -3
43A	Medium Sill	Erosional	Erosional	<5	Yes	-1 to -3
43B	Low Sill	Stable	Erosional	<5	No	0 to -1
44	Low Sill	Transitional to Erosional	Transitional to Erosional	5-10	No	-1 to -3
45	Low Sill	Erosional	Erosional	<5	No	0 to -1
46	Low Sill	Stable to Erosional	Transitional to Erosional	5-10	No	0 to -1
47A	Low Sill	Transitional	Transitional	5-10	No	0 to -1
47B	Medium Sill	Erosional	Erosional	<5	No	0 to -1
48	Low Sill	Erosional	Erosional	5-10	Yes	0 to -1
49A	Low Sill	Erosional	Erosional	5-10	No	0 to -1
49B	Medium Sill	Erosional	Erosional	5-10	No	0 to -1
49C	Low Sill	Transitional	Transitional	<5	Yes	Not Calculated
50	Low Sill	Erosional	Erosional	5-10	No	-1 to -3
51	Low Sill	Transitional to Erosional	Erosional	<5	No	-1 to -3
52	Low Sill	Erosional	Erosional	<5	No	-1 to -3
53	Low Sill	Stable	Stable	>15	No	-1 to -3

Table 9. Approximate costs of each structure type per linear foot of shoreline. These numbers generally are valid in 2008. Later time frames will need updated costs.

Type	Amount of Rock (Tons/ft)	Estimated Cost ($65-$75/Ton)	Amount of Sand (cubic yards/ft)	Estimated Cost ($25-$35/cy)	Total Estimated Cost ($/linear ft)
Low Bank Low Sill Full Fill	1.7	$110-$127	1	$25-$35	$135-$162 plus plants
High Bank Low Sill Full Fill	1.7	$110-$137	1	$25-$35	$135-$162 plus plants
Medium Sill	2	$130-$150	2	$50-$70	$180-$220 plus plants
High Sill	3	$195-$225	3.8	$95-$133	$290-$358 plus plants

4 Conclusions

Understanding the dimensions of the shore reach and those factors which influence it puts the problem into context for property owners. A primary goal of this project was to provide information and documentation on shoreline strategies that can be applied along Occohannock Creek as well as their limitations and consequences. The overarching theme of the shoreline erosion assessment is to provide an environmental edge along the Creek, particularly through marsh and beach creation and buffer management. The recommendations are meant to offer alternatives to shoreline hardening along Occohannock Creek and are shown at a conceptual level.

Many of the sites chosen for recommendations along the main stem of Occohannock Creek have a marsh fringe that is presently too narrow to offer shore protection. By enhancing the marsh with a sill and some fill, one can not only provide an increased level of protection but also provide wetland habitat. These strategies generally are acceptable to the local, state and federal permitting agencies. In fact, these Living Shorelines methods are encouraged in many localities Bay wide. However, encroachment onto state bottom with sand fill and structures and modification to the riparian buffer must be minimized. Reducing the impacts to these elements but attaining adequate shore protection requires a detailed evaluation of each site.

Except for a few areas, most of the shore change is minor by Bay standards. Landowners, especially those new to waterfront living may view an exposed bank as a problem that must be fixed. It is the landowner’s prerogative to do so and hopefully this document will help in the decision making process and provide local wetlands boards and planners a guide to shoreline development.

The management approaches and strategies recommended are intended to be informational for landowners and managers. Generally, the recommended strategies are the minimum needed for effective erosion control. Other types of approaches can and will work. This report presents the data necessary for those making decisions and designing systems to develop a project that meets their goals, expectations, and cost. Final design will require a site survey and geotechnical investigations as well as fitting the project more closely to the coastal geomorphology.

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Figure 1. Location of Occohannock Creek within the Chesapeake Bay estuarine system.

Figure 2. The Poster Child for Successful Marsh Projects. Photos taken at a community marsh in Anne Arundel County.This site received the highest overall marsh ranking and embodies many of the factors deemed essential to a successful project (from Bosch *et al*., 2006).

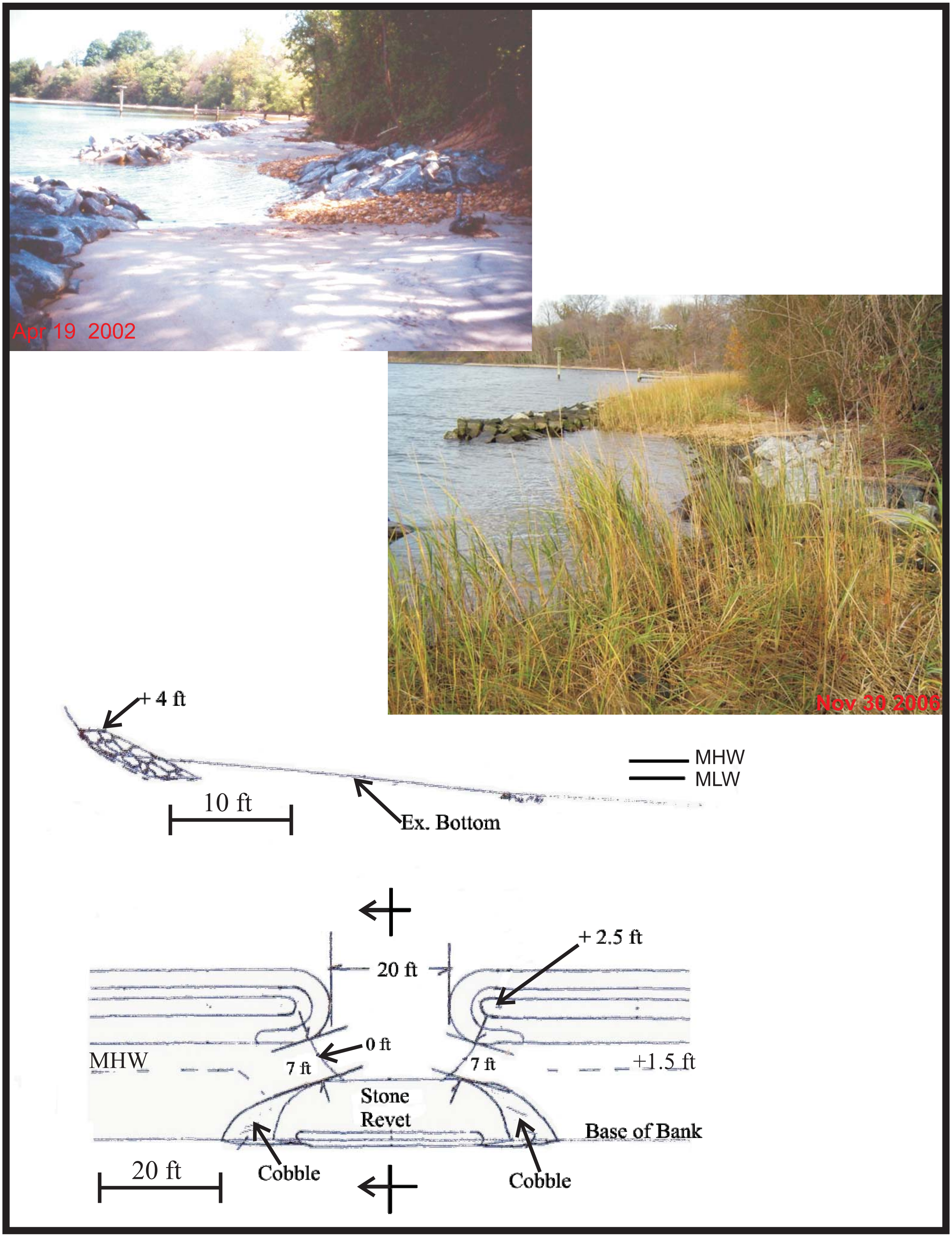


Figure 3. Photos showing a window in the Historic St. Mary's City sill post construction in 2002 and in 2006. The window 9 has a stone revetment along the backshore shown in the planform and cross-sectional design (From Hardaway *et al*., 2008).

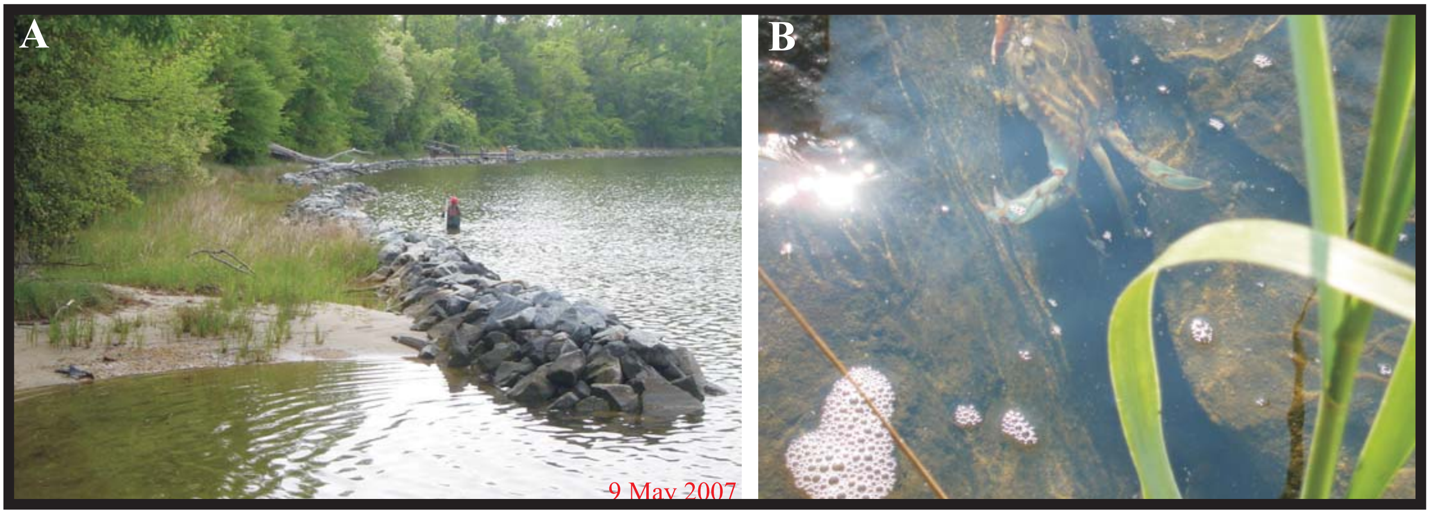


Figure 4. The sill at St. Mary's City at low tide depicting two of the access pathways including the A) sill windows and B) macro-pores in the sill (from Hardaway *et al*., 2008).

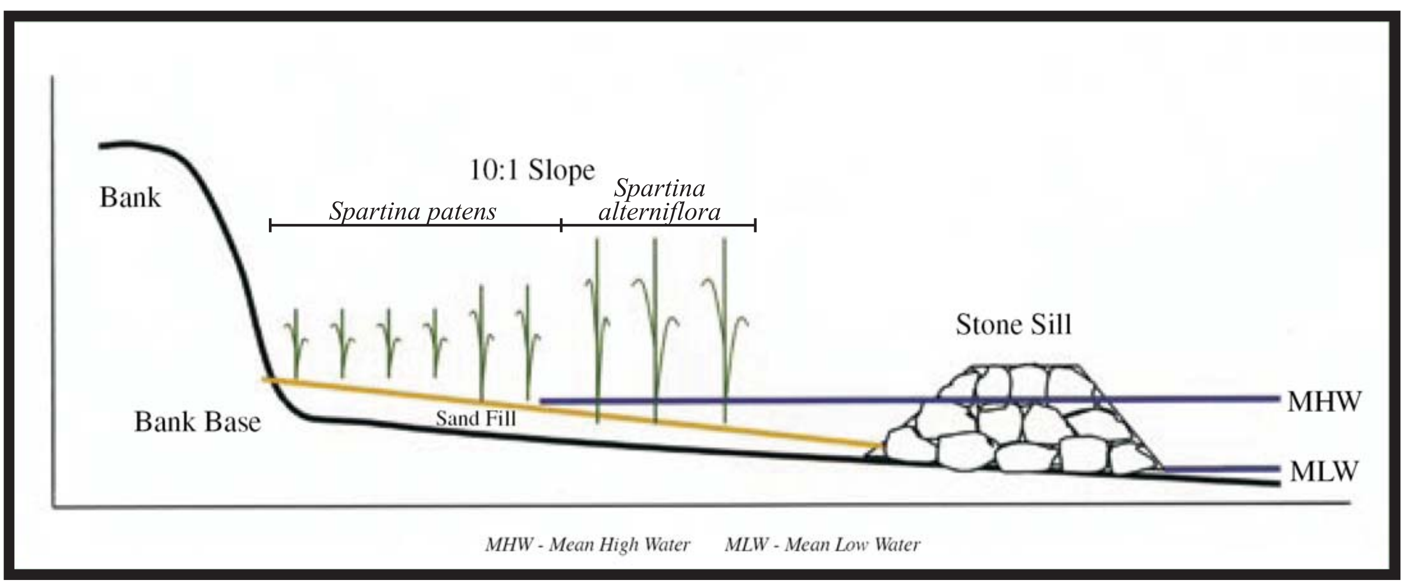
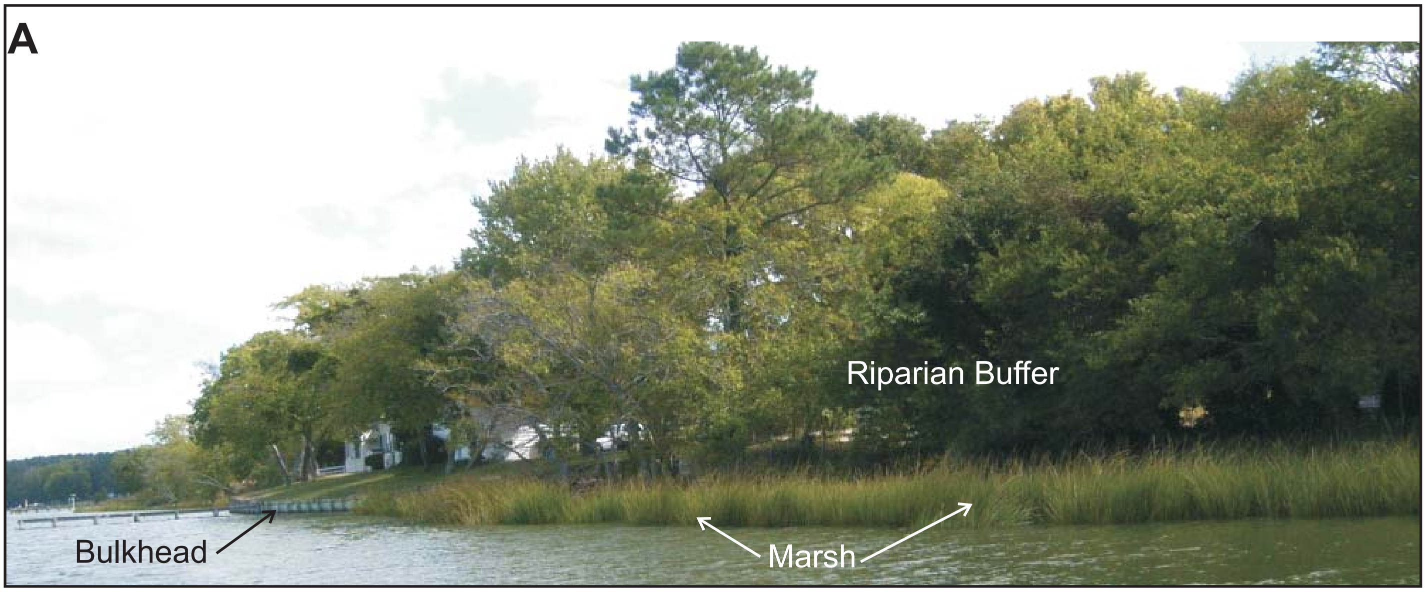
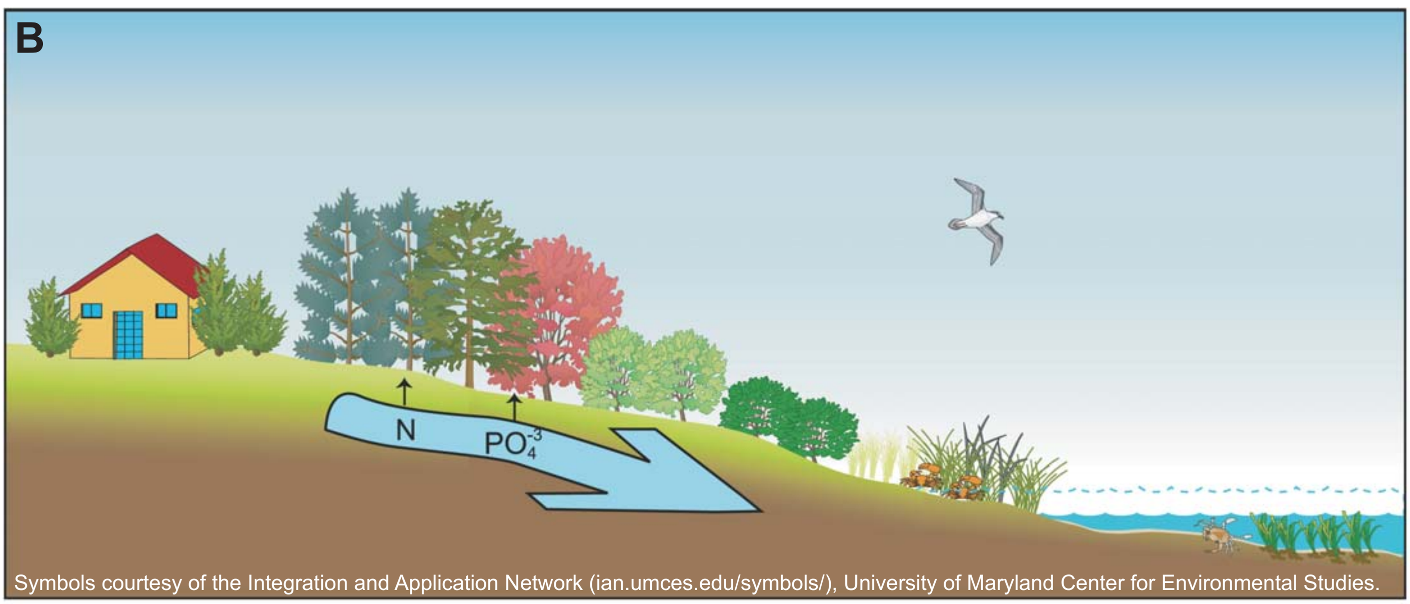


Figure 5. Profile of a typical marsh edge stabilization project used to prevent wetland edge loss (from Luscher and Hollingsworth, 2005).





	Upland Landuse	Riparian Landuse	Banks	Intertidal Zone	Subaqueous Lands
(+)	Trees, shrubs, tall grass	Trees, shrubs, tall grass	Vegetated, Stable	Marshes, Phragmites	Seagrass (SAV)
			Partial vegetation	Coastal Sand Dunes	Oyster Reefs
	Agriculture	Residential, Agriculture	Undercut	Riprap, Bulkheads	Aquaculture
(-)	Residential, Commerial	Industrial	Bare, Unstable	Boat ramps	Marinas

Figure 6. A) Photo taken along Occohannock Creek depicting aspects of the coastal profile, and B) an integrated shoreview of a water quality model that shows the relative contribution of different landscape elements to water quality and habitat, from positive (diverse habitat opportunities and improved water quality) to negative (few habitat opportunities and reduced water quality). B is reprinted courtesy of VIMS Center for Coastal Resources Management.

Figure 7. Photo taken along Lower Machodoc Creek, Westmoreland County, Virginia showing shading of the marsh by overhanging trees.

Pre-project shoreline on Wye Island, Kent County, Maryland (1988).

Marsh grass plantings with sand fill and short, stone groins 3 months after installation on Wye Island, Kent County.

Wye Island project four years after construction.

Figure 8. Photos showing a marsh construction project at Wye Island, Maryland before and after installation and after four years (Hardaway and Byrne, 1999).

Figure 9. Wye Island, Maryland on 29 November 2006 (18 years after installation) showing the erosion of the planted marsh and the upland bank.

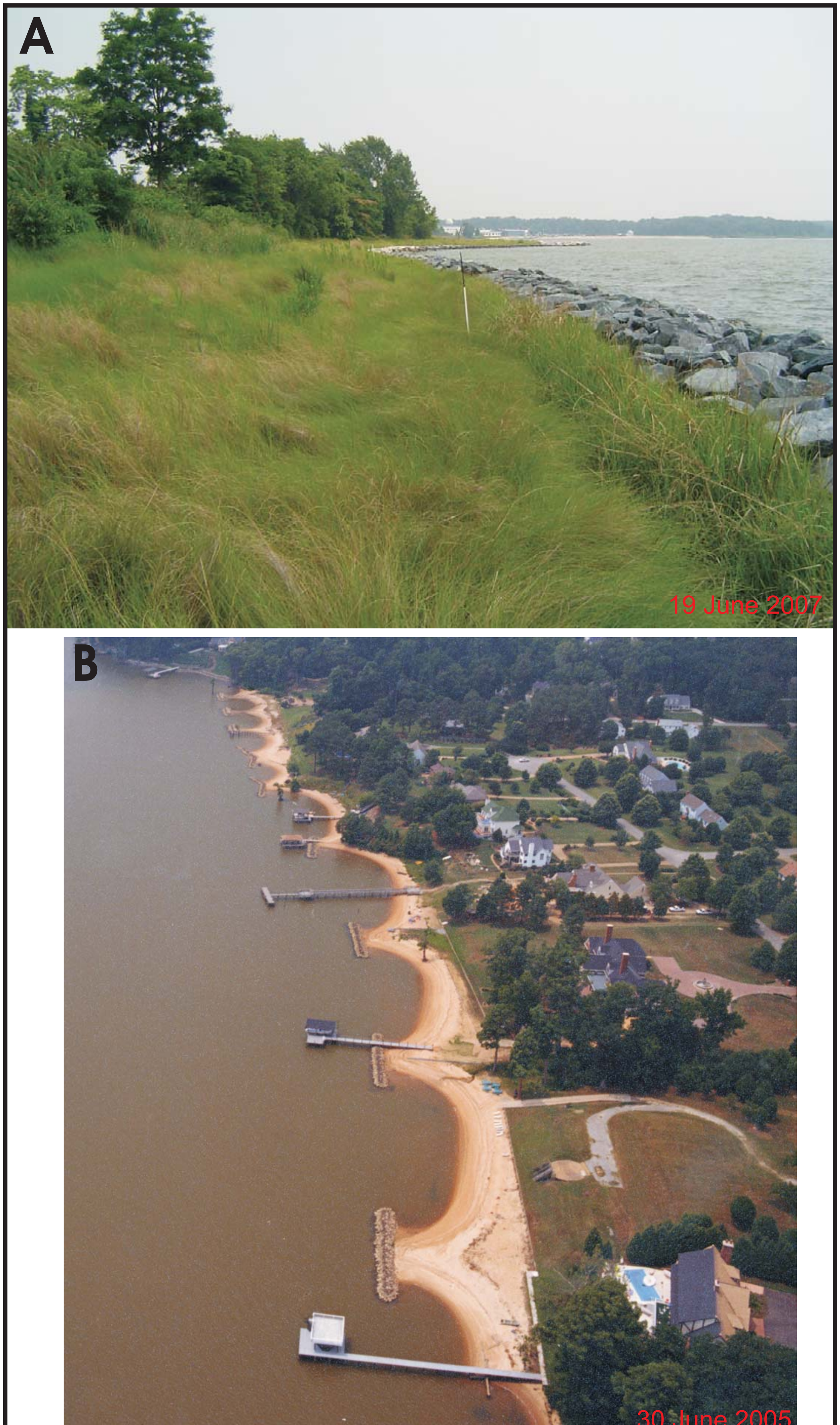


Figure 10. Photo of A) a sill project at Webster Field in St. Mary's County, Maryland and B) a breakwater system on the James River, Virginia.

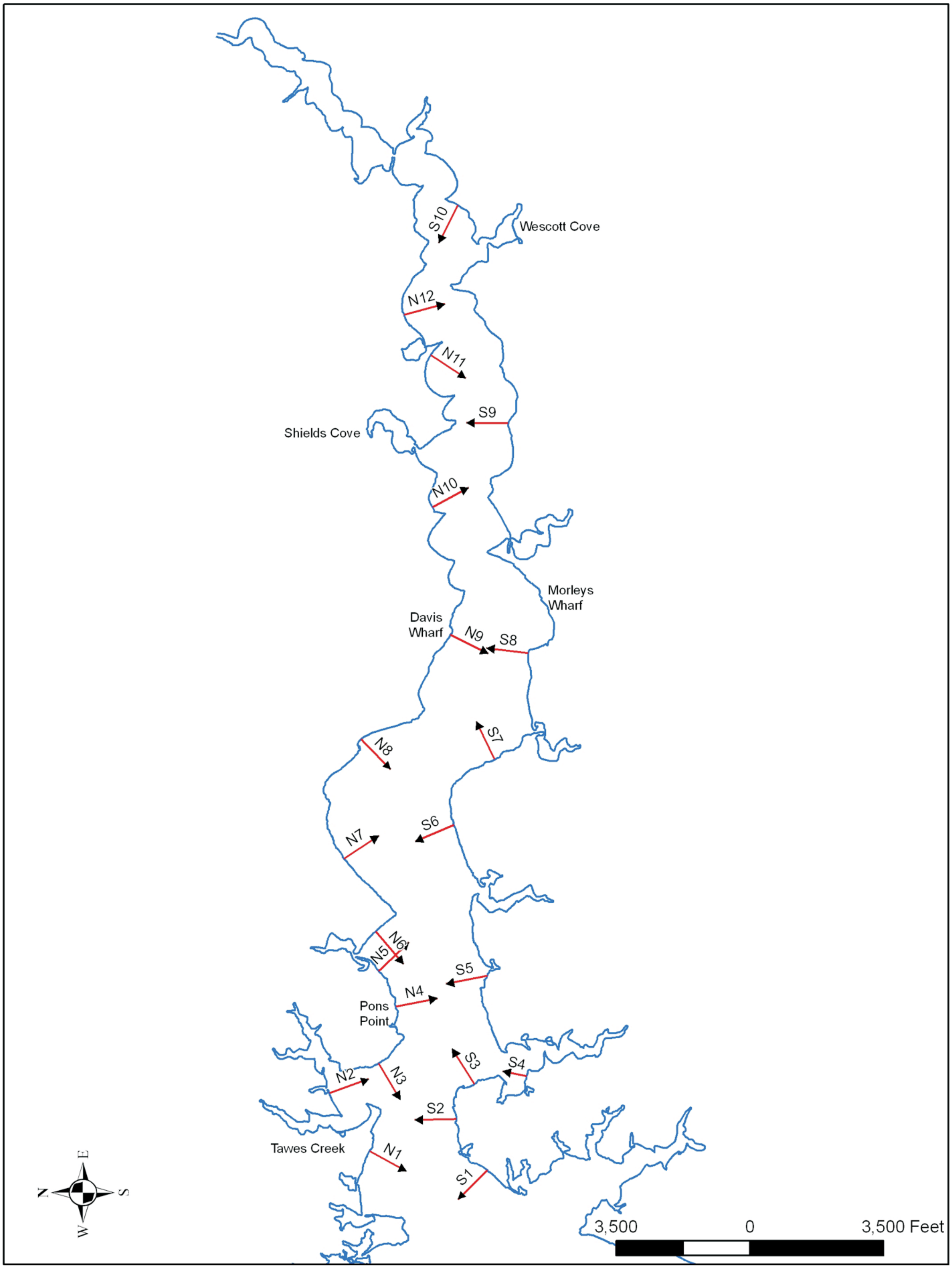


Figure 11. Fetch calculation locations for Occohannock Creek.

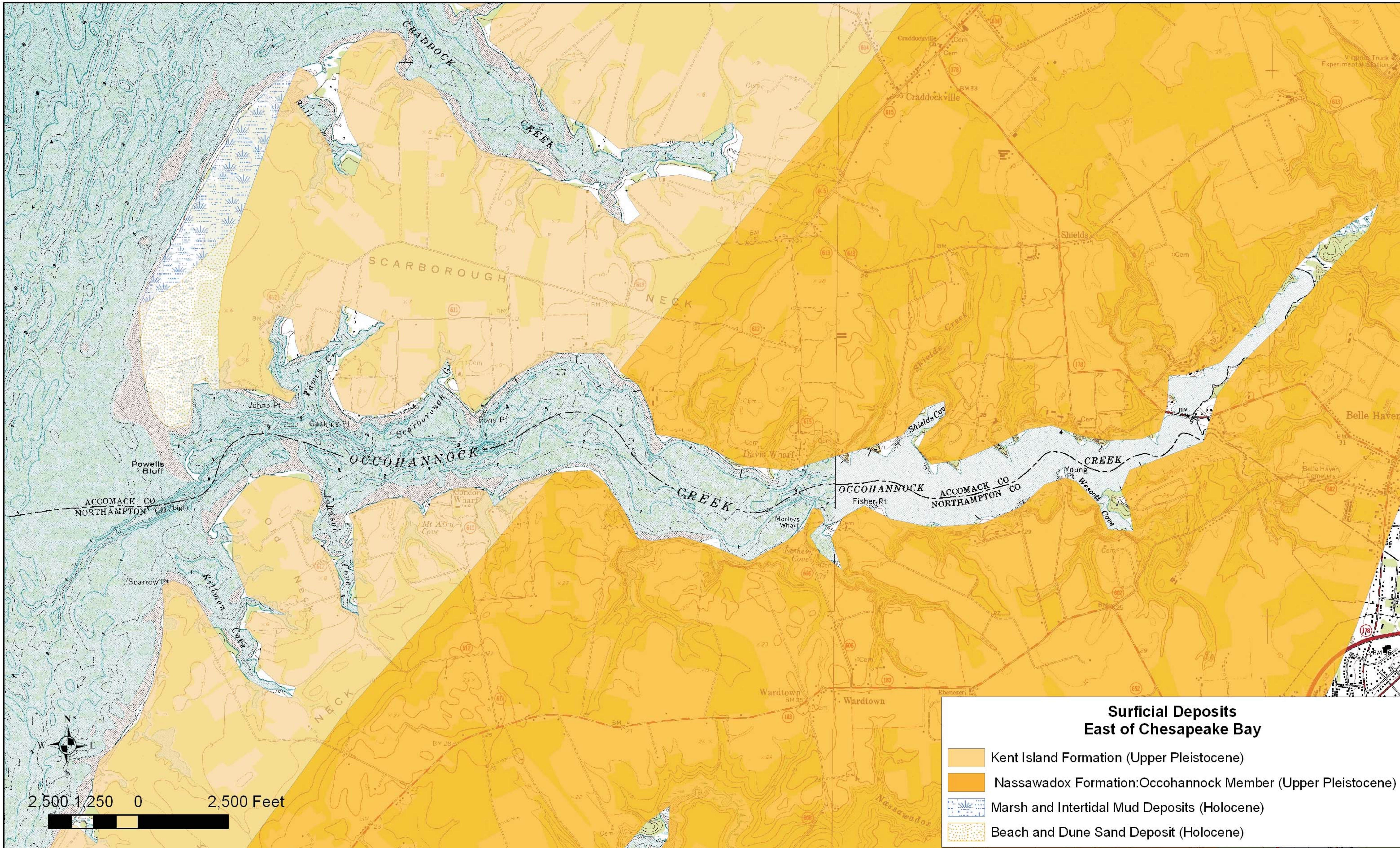


Figure 12. Geology of the region surrounding Occohannock Creek. Base map is a US Geological Survey topographic map of the area.

Figure 13. Photos depicting a stable, transitional, and erosional bank in Occohannock Creek.

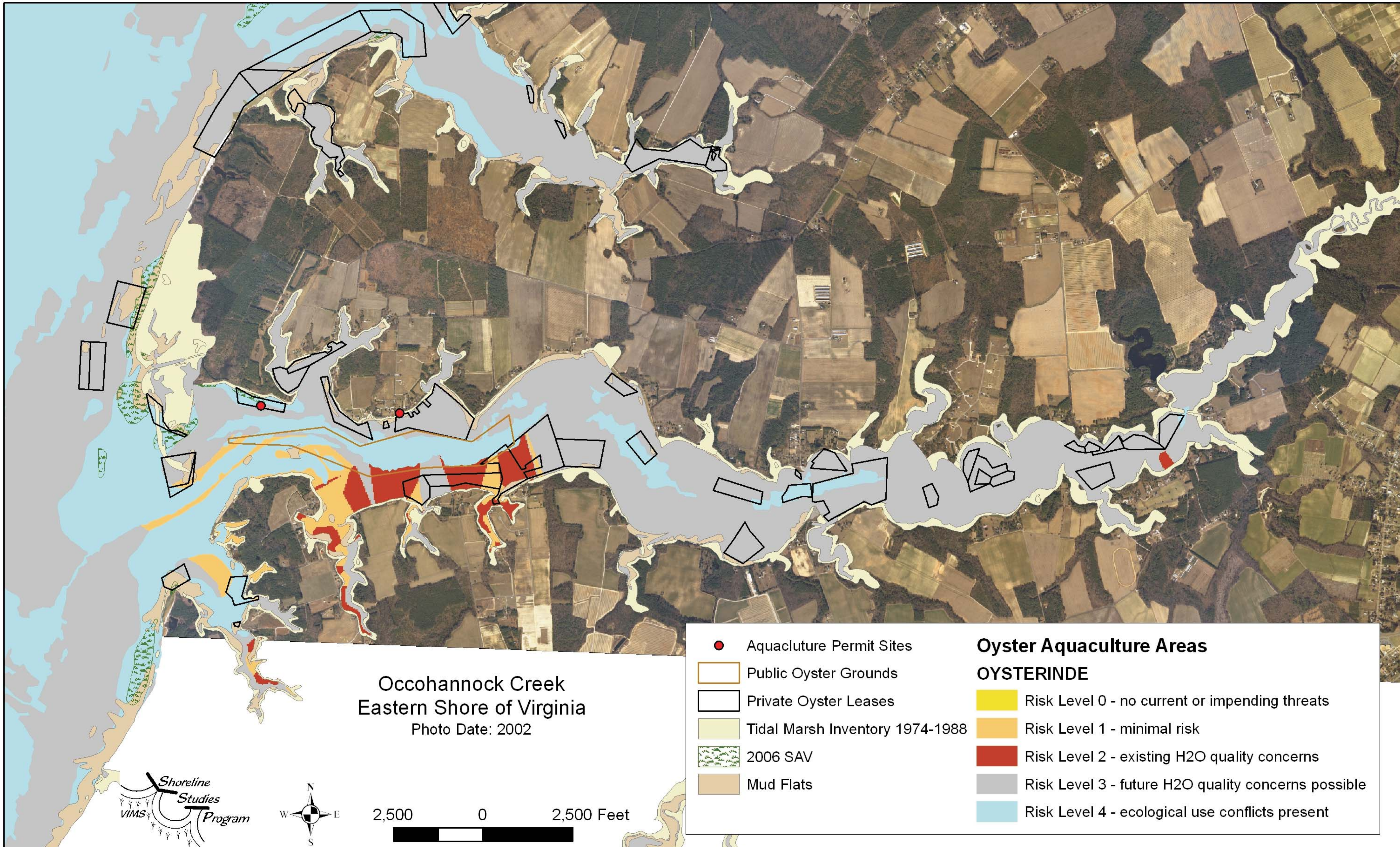


Figure 14. Existing marine resources including SAV and oyster aquaculture risk areas are shown for Occohannock Creek. The data comes from existing databases available on the VIMS website.

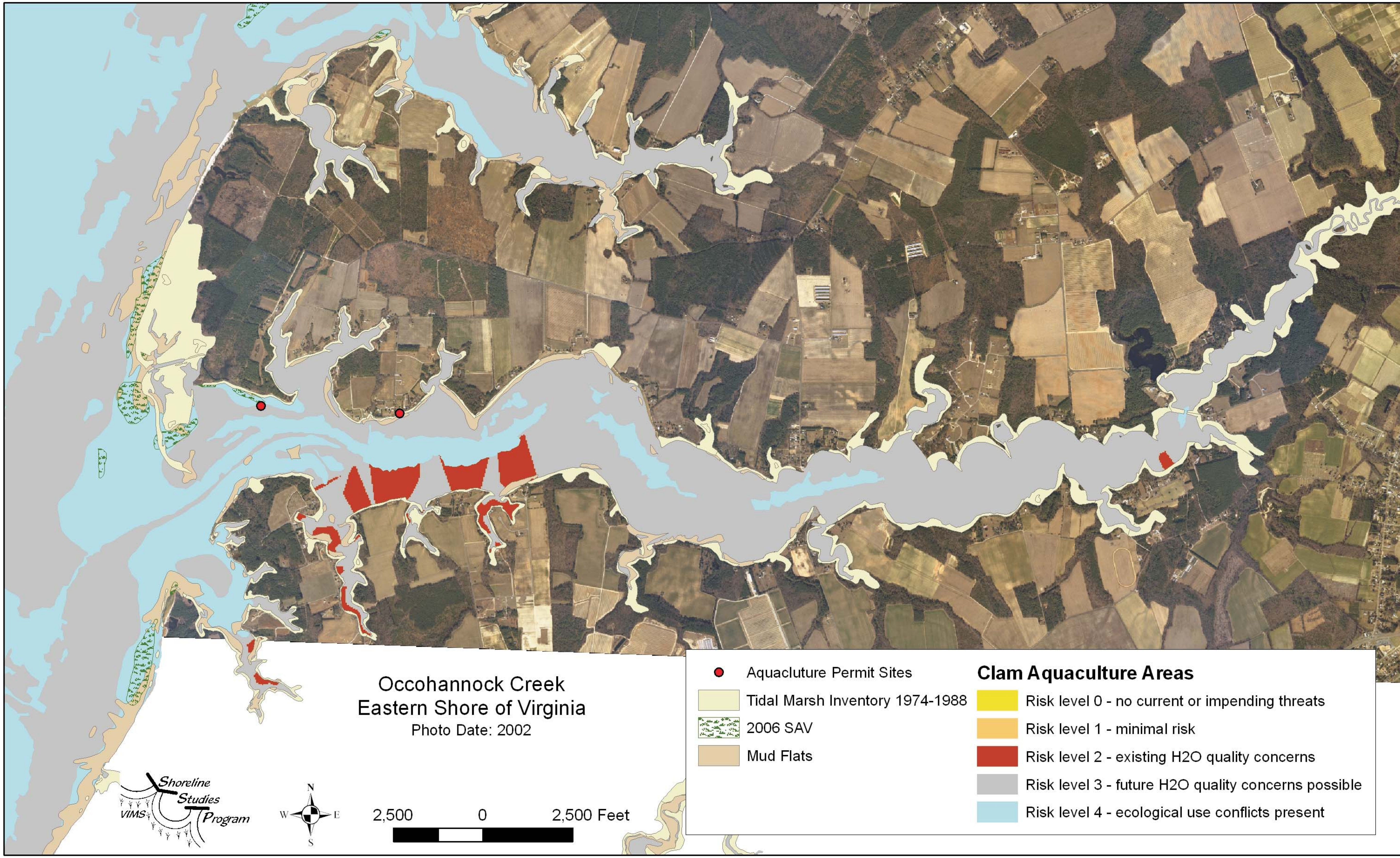
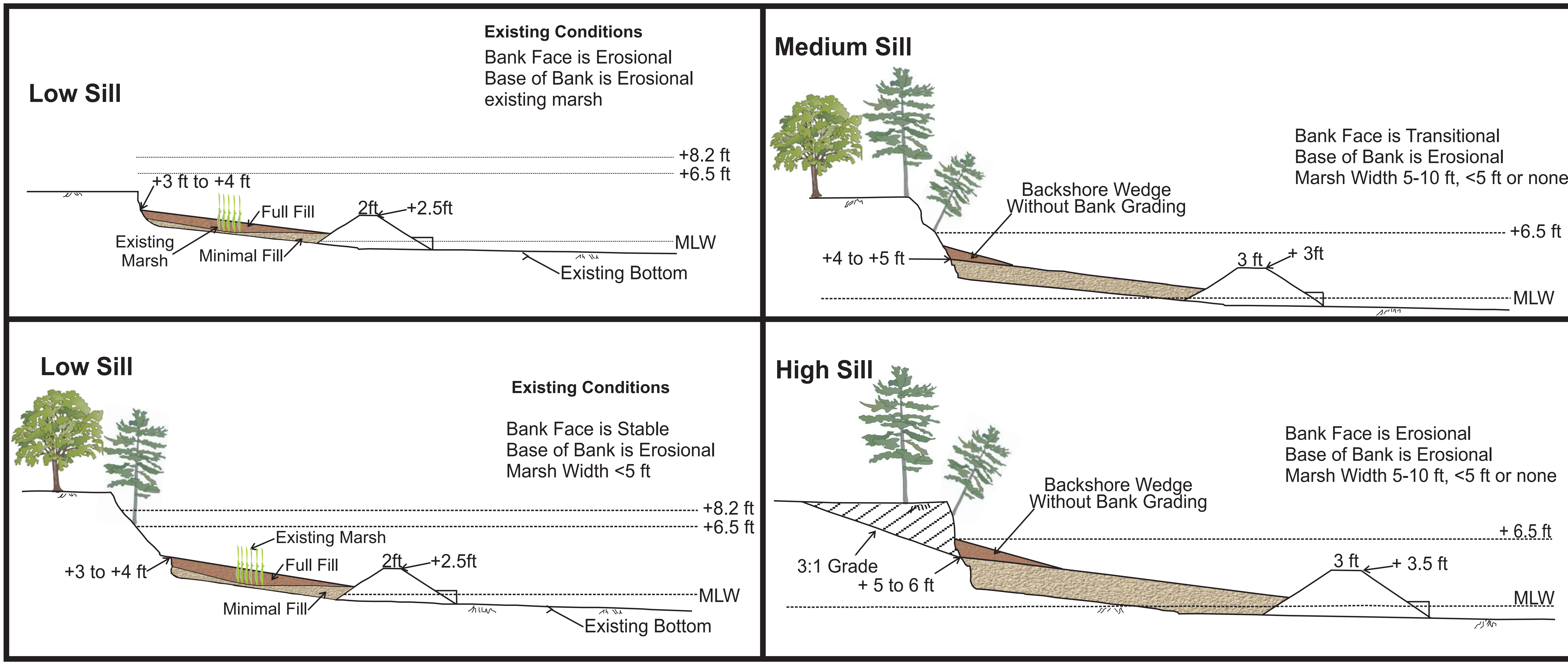


Figure 15. Existing marine resources including SAV and clam aquaculture risk areas are shown for Occohannock Creek. The data comes from existing databases available on the VIMS website.



+6.5 ft MLW 10 yr event
+8.2 ft MLW 50 yr event

Figure 16. Cross-sections of sill types proposed for the Occohannock Creek shoreline.

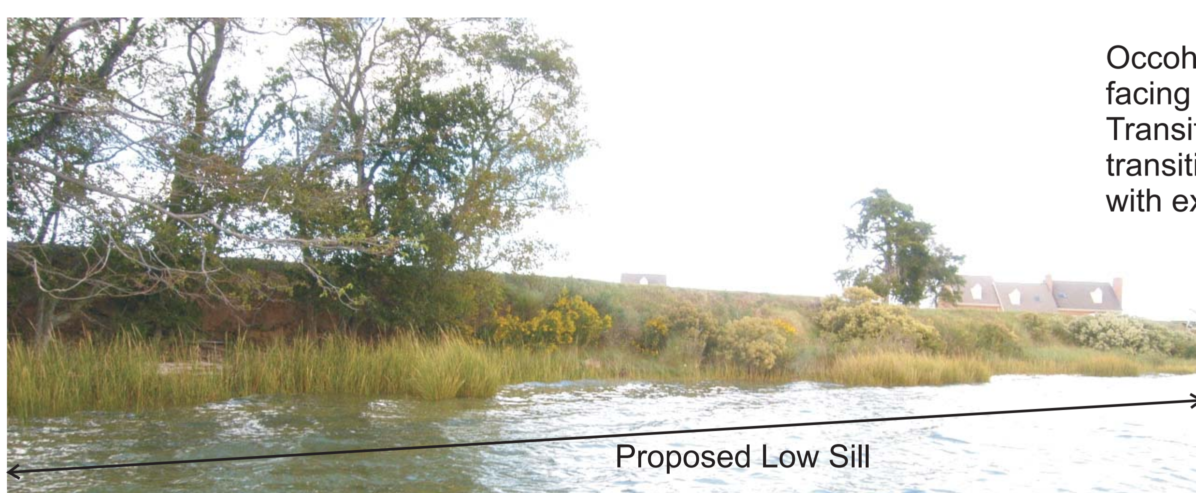


Figure 17. Example photos of existing shoreline conditions with the proposed management strategy noted. Location of proposed management strategies are approximate.

Figure 18. Photo of Knott in Kent County, Maryland on the Chester River showing an example of breakwaters that would be suitable for Occohannock Creek.

Click Here for
Appendix A. Existing Shore Conditions Maps

Click Here for
Appendix B. Shoreline Change Maps

Click Here for
Appendix C. Living Shoreline Option
Recommendations Maps