the management of invasive species, and weedy or invasive species often need to be controlled before and after installation of native plant material. Control methods may include manual, mechanical, chemical, biological, and cultural components. Thorough site evaluation is important to determine the life-cycle characteristics of the invasive species and the effects of control methods on native plant and animal species and on water resources. When limited resources, species-specific challenges, or the degree of infestation make eradication unattainable, a more realistic management goal may be to control the invasive species by reducing the density and abundance to levels that allow native species to eventually dominate to a degree that provides for a healthy ecosystem. Many State agencies maintain lists of invasive plant species.

5.6 Monitoring, Maintenance, and Public Access Needs

The overall project design should include design elements that will be needed to facilitate monitoring and maintenance. Examples include implementation of temporary pathways or boardwalks through the habitat during the maintenance and monitoring period to avoid trampling; delineation of temporary staging areas for equipment and vehicles; specifying ingress/egress areas; specifying the timing of maintenance and monitoring events to avoid disturbance during sensitive breeding, nursery, and nesting times; and restrictions on noise, smoking, and animals.

Public use of natural areas may include activities such as general day use, picnicking, birdwatching, fishing, hiking, biking, and boating. Public use of natural areas often results in degradation of the natural habitat because of a variety of factors, including trampling of vegetation and disturbance of wildlife, introduction of trash, and contamination of water and soils by humans and pets—all of which can result in erosion and project failure. Use of boats in some areas may introduce wakes that are larger than waves caused by wind. The expected use and frequency of public recreation; the expected size, use, and frequency of vessels in the area; and the proximity of the site to a boat launch, a marina, or navigational channel are important design considerations for nature-based solutions.

5.7 Design Examples

Nature-based solutions come in many different configurations. The design elements depend on the system components, hydrodynamic conditions, terrestrial setting, and ecological needs—the key parameters from Section 2 . This section shows some design examples and cross-sections of nature-based solutions. Their purpose in this document is to convey, graphically, their scale and composition. These selected examples are not an exhaustive list of nature-based solutions, and some of them are conceptual and have not yet been implemented. However, these design examples illustrate the diversity of nature-based solutions and their application to coastal highway resilience.

Pocket Beach: Yorktown, Virginia

Region: Mid-Atlantic
Coastal Risks Addressed: Waves, erosion, flooding

Along Water Street in Yorktown, VA (37.2370ºN 76.5068ºW), York County led a shoreline protection project that placed clean sand fill and rock breakwaters to form a series of pocket beaches—beaches stabilized by artificial or natural headlands (see location overview on Figure 5-15). The project provides protection to approximately 1,600 feet of Route 1020 (Water Street) along the York River and serves as a recreational amenity for the Yorktown waterfront. This shoreline experiences an average fetch of 10 miles across the mouth of the York River and wave energy from across Chesapeake Bay, with a maximum fetch totaling 30 miles. Figure 5-16 shows positions of the shoreline before and many years after construction.

The County of York was the primary sponsor of this project, which was completed as part of a historic waterfront revitalization in conjunction with the Virginia Board on Conservation of Public Beaches. Virginia DOT participated in the project formulation and provided funding proportional to the extent of the State-maintained highway mileage that was previously exposed at the east end of the project.

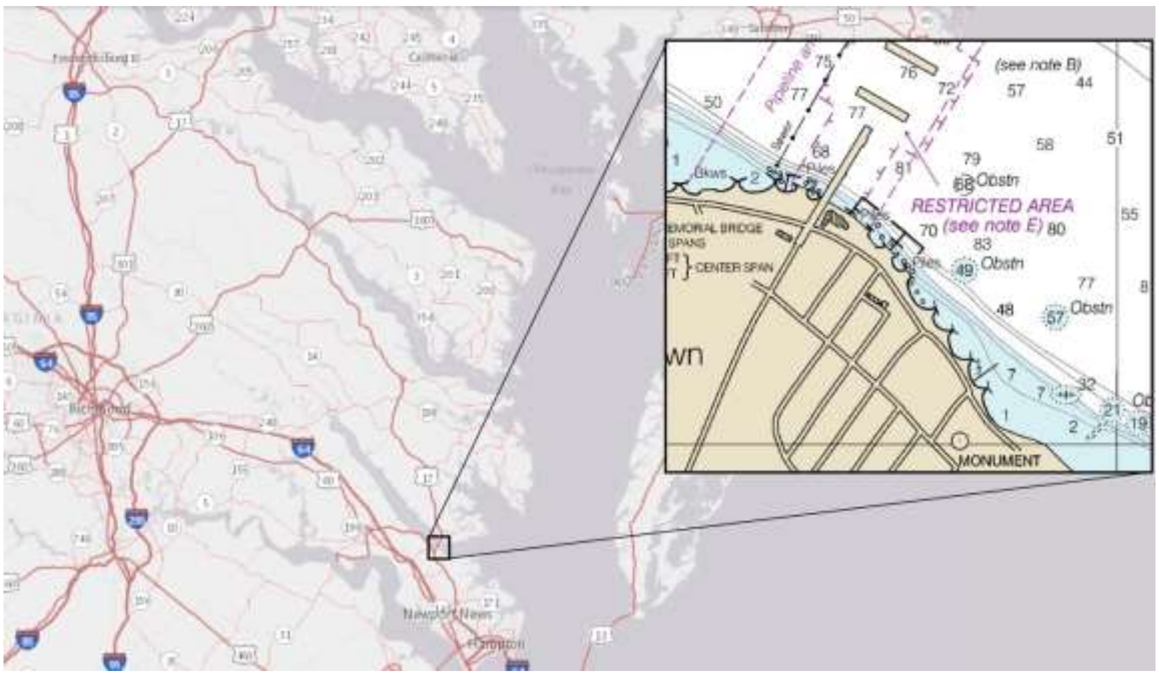

Figure 5-15. Yorktown, VA, location overview (NOAA Nautical Chart 12241 inset, depths in feet).

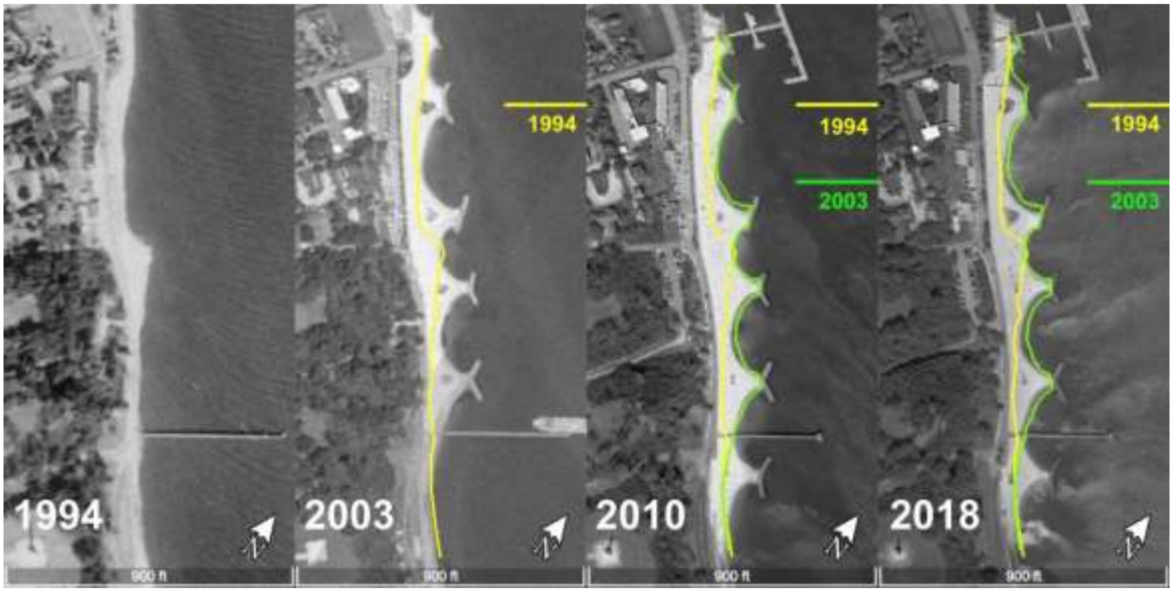

Figure 5-16. Recent history of shoreline positions at Yorktown, VA (photo courtesy of Google Earth).

Figure 5-17 shows a general cross-section schematic of the pocket beach. The first three breakwaters and sand beach fill were constructed in September 1994, and the rest were added over the next 10 years as the success of the initial project became clear. The original breakwaters, 7,500 cubic yards of beach fill, and planted *Spartina alterniflora* and *Spartina patens* cost $260,000 for protection of 1,350 feet of shoreline for an average cost of $193 per linear foot (Milligan 1996). The project was designed for a 50-year return period storm. Hurricane Isabel (2003), an approximately 100-year return period storm event for this area, resulted in sand losses and local scour, but without significantly affecting project performance. The beach required an additional 3,500 cubic yards of sand to re-establish its pre-storm condition (Milligan et al. 2005). During Hurricane Isabel, the project successfully decreased wave energy that would have otherwise damaged upland commercial infrastructure.

The project has performed well by providing protection to the road and the infrastructure behind the road, while also providing a sandy beach for tourists and locals for more than two decades. The beach and vegetation provide intertidal habitat and shore bird habitat. The addition of a raised stone wall running parallel to the sidewalk mitigates flooding of Water Street during storms. Storms have not damaged the sidewalks and roads since construction of the original pocket beach project (Milligan 1996).

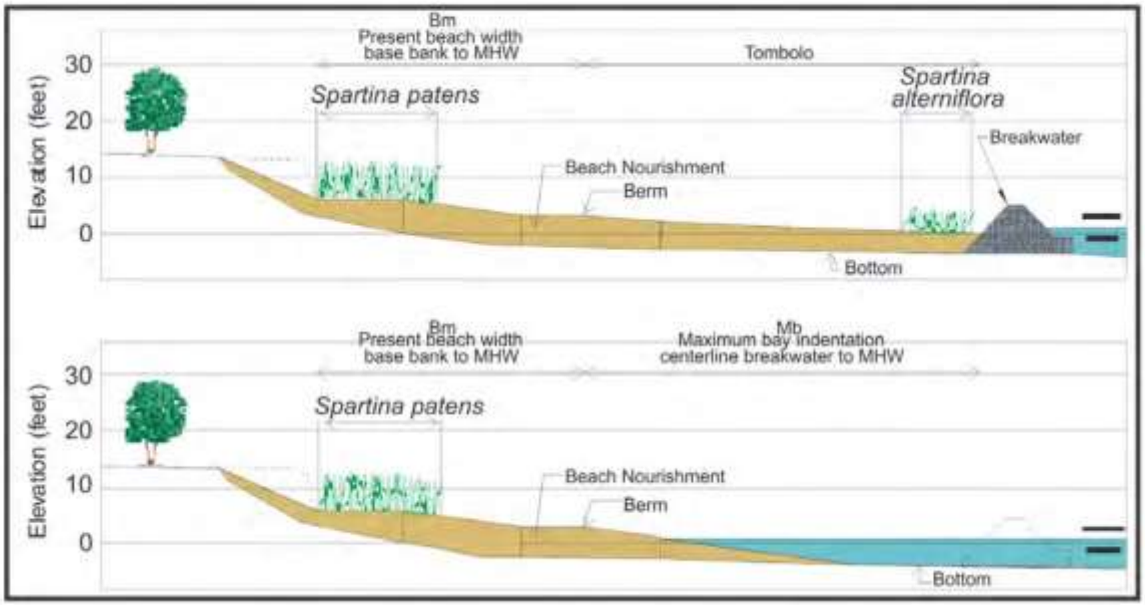

Figure 5-17. Conceptual cross-section of the Yorktown Pocket Beach (Hardaway and Byrne 1999).

Constructed Marsh With Breakwaters: Mobile Bay, Alabama

Region: Gulf Coast
Coastal Risks Addressed: Erosion, waves

Alabama DOT considered a nature-based solution as part of a bridge replacement and highway realignment project across Mobile Bay, AL (see location on Figure 5-18). The replacement of an existing bridge necessitates a new eastbound alignment and bridge to carry U.S. 98 across the confluence of the Tensaw River with the Mobile Bay estuary. The proposed realignment will alter approximately 2,200 feet of bay shoreline within the project footprint. Establishment of the new alignment will result in the loss of benthic habitat, aquatic resources, and SAVs (~1 acre). Alabama DOT considered the use of a nature-based solution in order to enhance the resilience of U.S. 98 and to potentially offset unavoidable impacts on aquatic resources. The existing shoreline is hardened with a vertical concrete seawall.

Shorelines within the study area are subject to a small tide range (~1.5 feet), considerable water level fluctuations as a result of storms, and considerable exposure to wave energy. The wave energy exposure is high because of the 30+-mile-long fetches that stretch to the south. Large shoals are directly offshore from the study area and water depths beyond are typically shallow (< 9 feet). The intertidal and nearshore slopes here are both low. This part of the estuary exhibits low salinity levels and nearby shorelines are a combination of sand and intertidal marsh vegetation. Submerged vegetation exists in shallow water depths adjacent to the site.

The resilience requirements for this highway included shoreline and embankment stabilization during minor to extreme events. Alabama DOT considered using a continuous rock revetment from the edge of the pavement down to the existing bay bottom on a slope of 3:1 (H:V).