Peer Exchange Summary Report

Nature-Based Solutions for Coastal Highway Resilience

Figure 1. A stone sill breaks waves generated by wind and boat traffic, allowing marshes to re-establish along a shoreline at Morris Landing Preserve, north of Wilmington, NC. This is one of several nature-based solutions that FHWA peer exchange participants viewed and discussed. Photo credit: FHWA

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16. Abstract To inform the development of an implementation guide, FHWA conducted four regional peer exchanges in Spring 2018 on nature-based solutions that improve coastal highway resilience. This peer exchange summary provides a synthesis of the key examples of nature-based solutions and recommendations for successful planning and implementation. In addition, the report discusses challenges that can arise across planning, permitting, partnerships and engagement, engineering and design, and monitoring and maintenance. Similar challenges were identified at all four peer exchanges, including, for example: uncertainty around the performance of nature-based solutions; insufficient understanding of the costs and benefits of nature-based solutions and funding available for them; lengthy permitting processes; and complexities associated with the broad coordination required to implement and maintain nature-based solutions.		
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Contents

1 Background

The Federal Highway Administration (FHWA) is developing an implementation guide on using nature-based solutions to improve coastal highway resilience. To be released in Summer 2019, the implementation guide will draw in part upon:

- Five pilot projects completed in Oregon, Maine and New Hampshire, Mississippi, Delaware, and New Jersey.[1]
- A white paper that succinctly summarizes the current state of knowledge and practice regarding the use of nature-based solutions for coastal highway resilience.[2]
- Four regional peer exchanges held around the country to solicit local expertise and perspectives on the needs of State Departments of Transportation (DOTs).

Nature-based solutions are approaches to problems (in this case, coastal highway flood damage and/or disruption) which mimic characteristics of natural features, including habitats, but are created by human design, engineering, and construction. There are many other terms (e.g., green infrastructure, living shorelines) used to describe the same concepts. Examples include marshes, beaches, wetlands, and dunes.

The results and discussions of the four regional peer exchanges are summarized in this report, which provides a synthesis of key examples of nature-based solutions and recommendations for successful planning and implementation.

2 Introduction and Overview

Between February and April 2018, FHWA convened four one-day peer exchanges on topics related to nature-based solutions for coastal highway resilience. The peer exchanges were held at the following locations on the dates listed:

- Mobile, Alabama – February 15, 2018
- Oakland, California – April 10, 2018
- Lewes, Delaware – April 17, 2018
- Wilmington, North Carolina – April 19, 2018

The purpose of the peer exchanges was to facilitate an exchange of ideas among a diverse range of professionals working in transportation, natural resources, coastal engineering, coastal ecology, coastal geology, and coastal management and planning. The exchanges provided opportunities to gather insights and lessons learned regarding how nature-based solutions have been and could be used to increase the resilience of highways exposed to coastal hazards,

[1] More information about the pilots can be found online at: https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/green_infrastructure/index.cfm.

[2] Available online at: https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/green_infrastructure/nature_based_solutions/.

including sea level rise. Peer exchange discussions also covered challenges to implementing nature-based solutions.

FHWA convened these peer exchanges with a regional focus to collect diverse experiences from around the country and capture some of the unique challenges and considerations of DOTs when it comes to implementing nature-based solutions. Figure 2 shows participants at the exchange in Wilmington, NC.

Figure 2. Participants at North Carolina Peer Exchange. Photo by Brenda Dix

The format of the peer exchanges included initial presentations to clarify goals and define the scope of the discussions to follow. Structured breakout sessions and activities prompted participants to discuss successful examples and lessons learned, and then to dig into specific topic areas including: policy and project opportunities and constraints, planning processes, appropriate selection of nature-based approaches, and design and monitoring procedures. Additional information on the agenda can be found in Appendix A – Example Agenda. Additionally, FHWA invited participants at each peer exchange to participate in an optional site visit to see and discuss local examples of nature-based solutions. At the Delaware peer exchange, participants visited several sites including the Lewes Ball Field Living Shoreline shown in Figure 3. A summary of the site visits can be found in Appendix D – Peer Exchange Site Visits.

Figure 3. Lewes Ball Field Living Shoreline Project in Delaware. Photo by Tina Hodges

Despite the diversity of locations and affiliations represented, similar challenges were identified at all four peer exchanges, including, for example: uncertainty around the performance of nature-based solutions; insufficient understanding of the costs and benefits of nature-based solutions and funding available for them; lengthy permitting processes; and complexities associated with the broad coordination required to implement and maintain nature-based solutions.

This summary report highlights some of the key themes and lessons learned from the peer exchanges, including examples of successful nature-based solutions and gaps in information and guidance that would be useful to include in the implementation guide. It includes the following sections:

- *Section 3 – Lessons Learned from Peer Exchanges* highlights examples of nature-based solutions mentioned at the peer exchanges along with recommendations for

successful planning and implementation. Additionally, the section summarizes peer exchange participant comments about the challenges that can arise across planning and funding, permitting, partnerships and engagement, engineering and design, and monitoring and maintenance.

- *Section 4 – Summary and Next Steps* provides an overview of participant feedback and a discussion of the topics under consideration for inclusion in the implementation guide.

Appendices A and B contain an example peer exchange agenda and participant lists, respectively. Appendix C includes a list of example nature-based projects. Appendix D provides descriptions of the site visits attended at each of the peer exchanges.

3 Lessons Learned from Peer Exchanges

3.1 Defining Success

At each of the peer exchanges, participants were asked to consider the characteristics of a successful nature-based solution and craft a headline touting those benefits. A few illustrative examples included:

1. "State tested – mother nature approved"
2. "Triple win for the Cape Region – people, nature, wildlife: making room for the future"
3. "Friends don't let friends build seawalls"
4. "Green infrastructure keeps Dauphin Island open during Hurricane Zena"
5. "New living shoreline project resolves homeowner lawsuit, neighbors now best friends"

Through that activity, participants identified characteristics of successful nature-based projects, yielding the following list:

- Protect the environment, infrastructure, and communities
- Reduce impacts from extreme events (e.g., storms, flooding)
- Include a plan for monitoring and maintaining the project
- Preserve natural areas for people to enjoy
- Implement strategies consistent with and built into adjacent habitat
- Consider the complete coastal system throughout all project stages
- Provide a clear return on investment that can be communicated to decision makers and analyzed within a cost-benefit framework
- Offer an alternative that will provide long-term value, including reduced maintenance and repair costs and additional co-benefits (ecological, recreational, etc.)
- Garner support from a wide range of stakeholders
- Engage and educate the public on nature-based solutions
- Involve the correct types of expertise in the design (e.g., coastal engineers, coastal scientists, ecologists)
- Include flexibility to adapt under future conditions (e.g., for addressing sea level rise)

- Incorporate an adaptive management approach[3] into design and construction

3.2 Examples of Nature-Based Solutions

At every peer exchange, participants emphasized the need for more successful demonstration projects and case studies of nature-based solutions in practice, and improved communication of the lessons learned. While there are many examples of nature-based solutions, there are fewer examples of projects that have been constructed specifically to protect a roadway. Real-world examples can demonstrate the viability of such options and inform the design of new projects. Without examples of successful projects, it is hard to convince agencies and elected officials to invest in these projects. At the exchanges, participants shared numerous examples of nature-based solutions, including some that demonstrate how nature-based solutions have been used to protect transportation infrastructure.

Project Databases and Resources

The following resources were identified through the peer exchanges to learn about nature-based projects implemented around the country:

- FHWA Pilot Projects: https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/green_infrastructure/index.cfm
- The Nature Conservancy Coastal Restoration and Natural Infrastructure Project Database: http://projects.tnc.org/coastal/
- National Oceanic and Atmospheric Administration Green Infrastructure Effectiveness Database: https://coast.noaa.gov/gisearch/#/search
- USACE Engineering With Nature: https://ewn.el.erdc.dren.mil/#
- Naturally Resilient Communities Case Studies: http://nrcsolutions.org/strategies/#case_studies
- Living Shorelines Academy: https://www.livingshorelinesacademy.org/
- Case Studies of Natural Shoreline Infrastructure in Coastal California: http://coastalresilience.org/wp-content/uploads/2017/11/tnc_Natural-Shoreline-Case-Study_hi.pdf
- Alabama Coastal Restoration Database: http://www.alabamacoastalrestoration.org/View-Approved-Projects
- Florida Living Shorelines: http://floridalivingshorelines.com/

[3] Adaptive management is an iterative process of decision making that allows project teams to adjust in response to changing conditions. Through monitoring, projects can be improved, and this allows projects to account for uncertainty.

Project Profiles

Below are four illustrative examples of nature-based projects. Additional examples are tabulated in Appendix C – Example Nature-Based Projects.

Florida SR A1A Reconstruction after Hurricane Matthew

Project Location: Flagler Beach, FL from S. 28th to south of Osprey Drive

Project Partners:

- City of Flagler Beach
- Flagler County
- City of Beverly Beach
- U.S. Army Corps of Engineers (USACE)
- Florida Department of Environmental Protection
- U.S. Fish and Wildlife Service
- Florida Fish and Wildlife Conservation Commission
- National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries
- Federal Highway Administration

Dates of Implementation:

- Hurricane Matthew hits Flagler Beach October 7, 2016
- Feasibility Study – October 2016 – December 2016
- Potential Funding Requests – Spring 2017
- Concept Design –March 2017 – June 2017
- National Environmental Policy Act (NEPA) & Permitting –March 2017 - June 2018
- Final Design –July 2017 – July 2018
- Begin Construction – September 2018

Description: SR A1A was originally constructed within the Coastal Construction Control Line (CCCL)[4] and is both an evacuation route and a scenic highway through Flagler Beach. This section of SR A1A has sustained storm damage from hurricanes and nor'easters since 1981. Over the years, Florida DOT has conducted maintenance on the roadway. Figure 4 shows the damage caused to dunes and the northbound lane of A1A by Hurricane Matthew in 2016. Subsequent nor'easters

Figure 4. Damage caused to SR A1A by Hurricane Matthew. Source: FL DOT

[4] The Coastal Construction Control Line (CCCL) program regulates structures and activities built along the coasts of Florida that could cause beach erosion, destabilization of dunes, damage to nearby properties, or reduced public access to beaches. https://floridadep.gov/water/coastal-construction-control-line

resulted in additional loss of dune and vegetation threatening the loss of the roadway.

A feasibility study was conducted to look at a number of solutions including relocating SR A1A outside of the CCCL. However, moving the road from its current location was not supported by the local agencies.

The final project design is divided into 3 segments (construction has not yet occurred):

- Segment 1 – S. 28th St. to S. 22nd Street
  - This section was originally planned as a rock revetment but was later revised to include placing sand and vegetation in order to rebuild the dune.
- Segment 2 – S. 22nd St. to S. 9th St.
  - Work in this section will consist of rebuilding the road, sloping pavement towards the inside median, and adding a French drain. By sloping the water to the inside the stormwater will drain to the west of the northbound lane rather than towards the dune as it previously did.
- Segment 3 – N. 18th St. to Osprey Drive
  - This section will include a buried secant pile wall which will be covered with sand and vegetated. The wall will be placed 50 to 75 feet westward of the mean high water line. It was designed as close to the roadway as possible to meet safety standards.
  - The original design included a buried sheet pile wall with rock at the toes. The new design does not require the rock toe and is constructed using poured concrete and fiber rebar reinforcements to withstand the coastal environment.

Lessons Learned:

- The project has not been constructed yet, so lessons learned are limited to planning and funding.
- Implementers raised funding from a wide range of sources and collaborated with the community by hosting community meetings.
- In conjunction with the dune systems, bike lanes, medians, and sidewalks were added to increase multi-functionality.

Cardiff Beach Living Shoreline Project

Project Location: Encinitas, CA

Project Partners:

- City of Encinitas
- California State Parks
- California State Coastal Conservancy
- San Elijo Lagoon Conservancy
- Ocean Protection Council
- California Coastal Commission
- San Diego Association of Governments

Dates of Implementation: Planned for Fall of 2018 (3 months construction, September 15 – December 15, 2018)

Description: The Pacific Coast Highway (Highway 101) has been damaged repeatedly by extreme wave events and high tides. The rock revetment has failed many times and the road has been undermined and flooded. Flooding is expected to occur more frequently with sea level rise. The planned hybrid nature-based solution project includes retrofitting existing, un-engineered rock revetment; adding native cobble materials in front of rip rap, building sand dunes using native sand material from the adjacent lagoon dredging activities, and planting with native and rare dune species.

This living shoreline dune restoration project, as shown in Figure 5, will protect the Cardiff State Park and Highway 101 from sea level rise, in addition to improving wildlife habitat.

Figure 5. Cardiff Beach Living Shoreline Project. Source: City of Encinitas
http://www.cityofencinitas.org/Government/Departments/City-Manager/Environmental-Management/Coastal-Zone-Management

Lessons Learned:

- Lessons regarding agency and local coordination include:
  - Having all of the permitting, funding, and land-owning agencies involved from the very beginning is key.
  - Compromises had to be made on the gray-side and green-side of this hybrid approach.
  - The road is owned/maintained by the City instead of Caltrans, and the City was interested in advocating for a nature-based approach.
  - Seed funding from the State Coastal Conservancy provided momentum for the project.
  - The regional Science Advisory Committee helped to develop a scientific monitoring program.
  - Education programming through San Elijo Lagoon Conservancy will teach the community about living shorelines.
- Construction has not yet occurred and, thus, not resulted in lessons learned on performance.

Delaware Coastal Protection, Indian River Inlet Sand Bypassing Plant

Project Location: Indian River Inlet, Sussex County, DE

Project Partners:

- Delaware Department of Natural Resources and Environmental Control (DNREC)
- USACE

Dates of Implementation: Operated from 1990 to present

Description: Inlet jetties built in the 1930s disrupted the natural flow of sand from south to north along Delaware's Atlantic Ocean coastline. Sand accumulates up-drift of the inlet, on the south side of the southern jetty; conversely there is a sand deficit down-drift of the inlet, north of the northern jetty. Delaware State Route 1 runs approximately parallel to the beach immediately landward of the dune line near the inlet, and is vulnerable to damage due to the sand deficit caused by the Inlet.

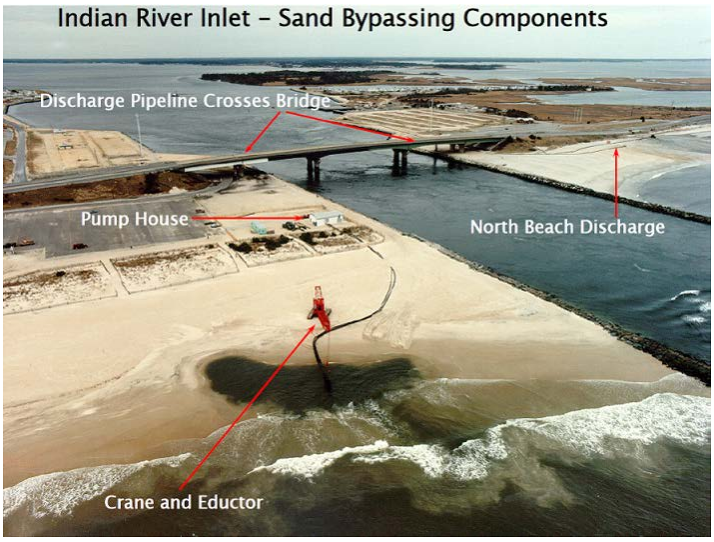

Figure 6. Annotated Photo of the Sand Bypassing Components at Indian River Inlet. Photo provided by: Jesse Hayden

Since the inlet's construction, a number of nature-based projects were completed to replenish sand on the beach from various inshore and offshore sources. Eventually, a Bypass Plant was built to recreate the natural flow of sand that would occur if the inlet jetties were not there by dredging sand from the nearshore zone on the south side of the inlet, pumping it over the SR-1 bridge, and discharging it on the north side of the inlet. Nourishment is also required on the feeder beach. Figure 6 shows the components of the bypassing system. The project's goal is to bypass approximately 100,000 cubic yards of sand annually, a figure that was calculated to best match the average longshore transport of that reach of shoreline.

Lessons Learned: Optimal operation of the system requires adaptive management in the intake and discharge practices. For example, the Indian River Inlet Bridge was replaced in 2012 with a higher and longer span, which required an update of some system components.

Plumb Beach

Project Location: Brooklyn, NY

Project Partners:

- USACE
- New York State Department of Environmental Conservation and Department of State
- National Park Service

- New York City Department of Parks & Recreation
- New York City Department of Environmental Protection
- New York City Department of Transportation

Dates of Implementation: Phase 1 was constructed in 2012; Phase II was completed in 2013.

Description: Plumb Beach, shown in Figure 7, is a popular recreation area that has experienced excessive erosion since the 1930s. The erosion threatened critical infrastructure, including an emergency evacuation route for New York City, buried utilities, in addition to recreational walking trails and a bike path.

Figure 7. Topography of Plumb Beach, NY. Source: Silveira, Tanya & Psuty, Norbert & P, Dennehy & N, Apostolou. (2010). Coastal geomorphology of the ocean shoreline, Gateway National Recreation Area: natural evolution and cultural modifications, a synthesis.

USACE and partners completed a Feasibility Study and then developed a coastal management project. The project included constructing a beach berm with sections of dune grass, two terminal groins, and a breakwater to minimize long-term erosion and reduce the need for future re-nourishment of the berm. Completed prior to Hurricane Sandy, Phase 1 protected critical infrastructure such as the Belt Parkway from significant damage. Phase II involved the construction of the stone groins and the breakwater.

San Francisco Bay Living Shorelines Project

Project Location: San Rafael, Marine County, California

Project Partners:

- CA State Coastal Conservancy
- CA Wildlife Conservation Board
- EPA
- NOAA
- San Francisco State University
- UC Davis
- USGS
- ESA
- The Nature Conservancy (landowner)

Dates of Implementation: Constructed in 2012 with monitoring 2012-2017.

Description: In 2012, the San Francisco Bay Living Shoreline Project was constructed to examine how the creation of native ecosystems can reinforce the shoreline, minimize coastal erosion, and maintain coastal processes while protecting and enhancing natural habitat for fish, aquatic plants, and wildlife. The living shoreline project included a pilot-scale, experimental approach to establish native oysters and eelgrass on property owned by The Nature Conservancy and the Wildlife Conservation Board. Monitoring was conducted to determine how various types of treatment (e.g., oyster reefs, eelgrass, or combinations) influenced habitat values differently. Additionally, the project implementers used the living shoreline to evaluate the potential for subtidal restoration to enhance functioning of intertidal mudflats, creeks, and marsh habitats by providing resources for species to move among habitats. This type of treatment may also reduce water flow velocities, attenuate waves, and increase sedimentation. Full design information and monitoring reports are available at www.sfbaylivingshorelines.org.

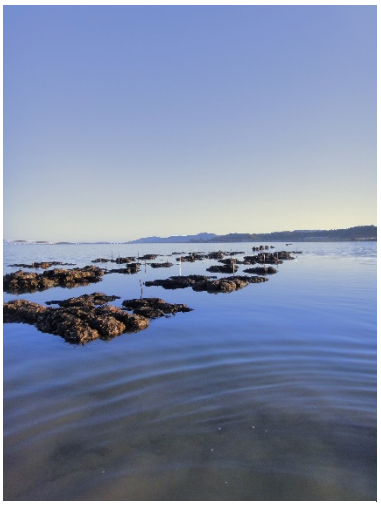

Figure 8. Oyster and eelgrass elements at San Francisco Bay Living Shorelines Project. Photo provided by: Marilyn Latta, State Coastal Conservancy

Lessons Learned: Based on the 5-year Monitoring Summary, the results demonstrated the following successes:

- Native oysters grew successfully on the reef structures. It is estimated that the reefs increased the number of oysters in the region by two orders of magnitude.
- Sedimentation has occurred adjacent to both the eelgrass reefs and oyster shell bag mound units.
- The reefs dissipate approximately 30% more wave energy than the mudflat alone.
- Eelgrass is growing better inshore from the oyster reefs, perhaps due to better matching of fine sediment conditions.
- Trapping with minnow and oval traps indicated an early response of species reliant on the physical structure, including bay shrimp, Dungeness crabs, red rock crabs and red crabs.
- Densities of Black Oystercatcher increased in treatment plots in comparison to pre-installation and control densities. The Forester's terns and wading birds such as egrets and herons began using the treatment plots post-installation. The site is used primarily for foraging at low tide, and non-foraging (resting, preening, etc.) behaviors at high tide.

3.3 Challenges and Recommendations for Implementation

At each of the peer exchanges, participants divided into topical breakout groups where they discussed the following topics.

- **Planning Process**, including when and where nature-based solutions should be considered in the transportation planning process and the valuation of ecosystem services. The group included mostly transportation-related professionals.

- **Planning/Policy Constraints**, including challenges due to planning and policy constraints, such as right-of-way, permitting, coastal restrictions, and local constraints. The group included transportation professionals and coastal management professionals.
- **Selecting Nature-Based Solution Approaches**, including topics related to nature-based solution selection, such as level of protection, costs, maintenance requirements, and designing for the local ecology and morphology. The group included mostly engineers and coastal management professionals.
- **Design and Monitoring**, including engineering tools (existing or desired) to aid in the design of nature-based solutions and in determining the level of protection. The group included mostly researchers, scientists, and engineers.

The main points made during these breakout sessions and other related discussions during the peer exchange can be divided into the following five categories:

1. Planning and Funding
2. Permitting
3. Partnerships and Engagement
4. Engineering and Design
5. Monitoring and Maintenance

Additionally, a common theme underlying these topics is education. Participants brought up the importance of educating stakeholders including engineers, permitting agencies, and the public about nature-based solutions to build participation and buy-in from key stakeholders.

The following sections summarize key takeaways within each of these categories, including recommendations for success, challenges faced, and suggestions for topics to include in the implementation guide.

3.3.1 Planning and Funding

Planning and Funding Key Takeaways

Integrate nature-based solutions into long-range planning.

Peer exchange participants noted that nature-based solutions should be considered in long-range planning. For example, nature-based solutions should be included in comprehensive and long-range transportation plans (LRTP), coastal master plans, coastal zone management (CZM) plans, asset management plans, and stormwater management plans. Also, sites where nature-based solutions may be appropriate could be pre-identified during hazard mitigation planning, corridor planning, asset management planning (e.g., areas with repeated maintenance expenditures) or as a standalone study. For example, the Louisiana Coastal Master Plan includes nature-based solutions as a central element. This type of plan could serve as a resource for State DOTs.

Integration of nature-based solutions into any of these planning processes can provide an opportunity to educate internal staff, stakeholders, and the public about climate change impacts and opportunities for nature-based solutions. Including nature-based solutions when developing long-term plans integrates these strategies into the vision for the future of the region, which can be a catalyst later when trying to develop and get approval for a project.

Another way of ensuring that nature-based solutions are considered is through inclusion in pre-engineering documentation. For example, Caltrans requires projects to explain on their pre-engineering forms what climate change vulnerabilities were considered. A similar approach could be used to ensure that engineers consider whether nature-based solutions are feasible before submitting their documentation. Alternatively, the Living Shoreline Act in Maryland requires a permittee to demonstrate, first, that a living shoreline could NOT work before a permit for a hard structure (bulkhead, seawall, revetment, etc.) is provided.

When nature-based solutions meet multiple objectives, they may be easier to fund.

In every peer exchange, participants brought up funding constraints as a major challenge when implementing nature-based solutions. It can be more difficult to convince management to fund a nature-based solution rather than traditional (and more widely implemented) "gray" solutions, even though nature-based solutions are eligible expenses for federal transportation funding. The hesitancy to fund non-traditional solutions is partially due to a lack of knowledge of successful demonstration projects, a lack of technical design procedures and methods, uncertainty about long-term performance and maintenance needs, permitting hurdles, and other challenges DOTs face. Additionally, there is a prevailing assumption among the public that nature-based solutions will cost more, which is not always the case. In fact, according to information from NOAA and USACE, greener shoreline stabilization options tend to be cheaper than grayer ones.[5] Participants recommended that funding be set aside or prioritized for the enhancement of nature-based solutions, and to cover additional costs above those of gray infrastructure, where applicable.

Participants discussed using nature-based solutions to address other agency needs, in order to pool resources and justify spending. For example, the potential for solutions to earn credits for National Pollutant Discharge Elimination System (NPDES)[6] permits and Total Maximum Daily Load (TMDL)[7], impervious surface credits,[8] or environmental mitigation credits[9] could provide access to additional funding sources. However, there are barriers to this approach. For example, most environmental mitigation is required to occur on a single project. Participants noted that establishing a way to bank mitigation credits across multiple projects could be effective, as has been done for freshwater wetlands in many states, for many years.

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[5] NOAA and USACE. 2015. Natural and Structural Measures for Shoreline Stabilization. SAGE Resilient Shorelines Thriving Communities. https://coast.noaa.gov/digitalcoast/training/living-shorelines.html.

[6] Under the Clean Water Act, anyone without the National Pollutant Discharge Elimination System (NPDES) permit is prohibited from discharging pollutants into U.S. waterways. The permit limits what you can discharge, and requires monitoring and reporting to ensure that discharge does not hurt water quality and health.

[7] Total Maximum Daily Load (TMDL) is the calculation of maximum amount of pollutant allowed to enter a waterbody to meet the water quality standards. Also, it determines a pollution reduction target.

[8] Impervious surface credit or stormwater credits provide encouragement for features that reduce the quantity and improve the quality of surface runoff. New living shorelines could be eligible for these credits to help offset the cost.

[9] A mitigation bank is a wetland, stream, or other resource area that has been restored, enhanced, or preserved to counteract unavoidable impacts to other aquatic resources. Find more at: https://www.epa.gov/cwa-404/mitigation-banking-factsheet

Funding is needed for continued management.

The budgeting cycle in many places does not support nature-based projects, which often take longer to get under way and complete. It is difficult to complete a phased project over several years when project planners receive annual budgets and are unsure whether they will receive enough funding for the next stage. Participants noted that while funding may be available for implementation, there is a lack of funding for the upfront costs associated with planning and the follow-up costs related to monitoring, evaluating the success of the project, and adaptive management. The continued management of nature-based solutions may require sustained funding, which could burden State DOTs. Participants recommended that tying projects to NPDES, mitigation credits, etc. may ease the burden. Also, DOTs could form partnerships with other agencies and groups to share maintenance costs and responsibilities. For example, substantial opportunities for coordination exist between State DOTs and USACE for federal shore protection projects that improve the resilience of adjacent transportation infrastructure, including evacuation routes.

Participants would like to see greater federal leadership to promote planning for resilience.

Participants recognize that there is a federal funding gap when it comes to resilience. They mentioned how FHWA does not provide a dedicated funding stream for preventative measures to build resilience before a storm (though this is an eligible expenditure of federal funds). Participants are interested in using FHWA's Emergency Relief Program for building in resilience after an emergency event. Those who had tried to apply to the program raised concerns, however, about the requirements for presenting the economic returns of the project in the application. These requirements pose a challenge for nature-based solutions, since many of the benefits (e.g., environmental benefits, social benefits) cannot be quantified in the economic justification.

Participants also noted that the Federal Emergency Management Agency (FEMA) should be more involved in the conversation around nature-based solutions and hazard mitigation/ emergency relief and provide more information to states on nature-based hazard mitigation options. FEMA pre-disaster mitigation funding could be used for nature-based solutions to build resilience ahead of time. After a disaster, however, FEMA has limitations on how funding is used. Infrastructure must be built back the same way, even if future conditions will make that system insufficient for dealing with hazard events.

FEMA has a funding program for storm damage maintenance and repair for beaches. For qualifying beach nourishment projects, namely those having a beach management plan and annual monitoring data, post-disaster aid can be used to make repairs or saved for future projects. A similar program could be made available for nature-based solutions.

Although participants knew of some FEMA funding mechanisms available for resilience projects, many who had tried to use the application found that it was difficult to use for nature-based projects. Reaching a cost-benefit ratio high enough to be considered for funding is very challenging due to the difficulty in accounting for the costs and benefits of nature-based solutions.

DOTs need better methods of quantifying the costs and benefits of nature-based solutions to attract funding and garner support.

Peer exchange participants shared information on the ease of implementing gray infrastructure solutions, which makes it more difficult to shift the paradigm from gray infrastructure to hybrid or nature-based solutions. Currently, State DOTs generally address erosion by placing rip rap. Rip rap is a low cost, effective solution that is quick to implement. The funding for rip rap is included in maintenance budgets, which shortcuts the lengthy design, planning, approval, and permitting process associated with projects that use other funding sources.

DOTs do not have a robust understanding of the costs and benefits of nature-based solutions, nor how to present that information to decision-makers and the public. Knowledge on the full range of potential benefits (including ecosystem services and socio-economic benefits) is limited. Even the language of "ecosystem services"[10] can be confusing. Developing improved methods of quantifying the costs and benefits, and comparing them to gray infrastructure solutions, is critical for encouraging DOTs to use nature-based approaches.

In some cases, the best solution may be retreat or relocation of the infrastructure rather than trying to protect it in place.

Letting nature take back an area is another form of nature-based solutions. However, making this decision has significant political implications and many stakeholders may resist. A community may depend on an access road that is threatened by hazards to the road. There also may be issues with relocation or retreat if the land behind the road is not available. Alternatively, participants discussed the option of elevating a road on a causeway, allowing natural processes to occur under the causeway (e.g., vegetation can grow, dunes can form, etc.) while maintaining the function of the roadway. In either case, it is important to consider the long-term sustainability of a project early in the planning process.

Planning Suggestions for the Implementation Guide

Peer exchange participants indicated that they would like information on the following topics in the implementation guide.

- Costs and benefits of nature-based solutions
- Funding streams and sources
    - Grants and other available funding sources
    - Opportunities for cost-sharing
    - Incentives for choosing nature-based solutions
    - Break down of funding for implementation, research, planning, and monitoring
- Entry points for integrating nature-based solutions in the planning process
- Decision matrix to assist with:
    - Determining how to reduce costs and increase benefits ratio
    - Selecting the right application for the right location

[10] Ecosystem services include the outputs and processes of natural systems that benefit humans directly or indirectly. Nature-based solutions provide ecosystem services, including habitat for plant and animal species, improving water quality, and protecting infrastructure from flooding and erosion. Find more at: https://www.britannica.com/science/ecosystem-services

- Identifying where nature-based solutions are a viable alternative and where they provide similar protection to traditional solutions

3.3.2 Permitting

Permitting Key Takeaways

Participants face challenges receiving approval and permitting for nature-based projects, particularly those outside of the DOT right-of-way.

The permitting process for building in the coastal zone is lengthy, varies from state to state, and the required approvals are often contradictory across different permitting processes. In some places, there is a lack of political will to implement projects and/or local regulations that limit the use of nature-based solutions. For example, there may be limitations on the types of infrastructure that can be built in particular areas. For example, the Bay Conservation and Development Commission does not allow any fill to be used in the San Francisco Bay, which hinders the development of living shorelines. This is because, historically, people filled in wetlands to develop new land, which degraded habitat and ecosystems. While using fill for living shorelines is to create wetlands, rather than fill them in, they are still subject to restrictions.

Also, participants expressed frustration that it is often easier to receive approval for gray infrastructure than for nature-based solutions. In some places like Florida, they are in the early stages of establishing "green tape" options that flag nature-based projects and move them through the approval process more quickly. In places where these systems were not in place, participants recommended that "extra credit" could be provided for nature-based solutions in grant applications. Some states hoping to achieve these goals want to move toward having nature-based solutions as the default permitting option.

Involving regulatory agencies early in the design processes can smooth the approval process.

It would be beneficial if transportation agencies and permitting agencies worked together to define nature-based solutions goals and objectives that could be used across projects rather than struggling through the same issues multiple times. Pointing to those broader goals could help focus everyone on the big picture and could help develop better coordination across projects.

Participants mentioned strategies that could help guide DOTs through the permitting process. While developing a project, the team can attend permitting agency meetings to discuss project development and get them involved early. In some places, Joint Planning Committees (JPC) or coastal managers can review and provide advice on project plans to help identify potential obstacles that will need to be overcome. Many participants emphasized the importance of involving the permitting agencies early in the project planning process so that they could receive comments and build relationships that would help them throughout the permitting process. This often takes the form of pre-application site visit with as many of the regulatory agencies and stakeholders as possible.

Many regulatory agencies are constrained in their approach to nature-based solutions.

In many cases, permitting agencies are rightly cautious in their approval decisions and are hesitant to approve projects that change the natural system that is currently in place. Changes in ecology could vary the use of the site by natural species. This concern limits the ability of DOTs to receive approval for projects that are considered an enhancement of the natural area. However, hard structures may have greater negative impacts on the environment, and the different options must be compared accordingly. Overcoming this difference in priorities requires changing ways of thinking to create more acceptance of nature-based approaches for infrastructure protection. One way DOTs can help with this is to include a write-up in the permitting application dedicated to explaining the scientific background of the project to educate the permitting agencies on the specifics of the approach. Also, this is an area where agencies can work together to overcome conflicting priorities and present the best case for their projects.

Permitting Suggestions for the Implementation Guide

Peer exchange participants indicated that they would like information on the following topics in the implementation guide.

- An explanation of how this work fits with other guidance (e.g., HEC-25 Highways in the Coastal Environment, FHWA's Integrated Ecological Framework)
- Simplified permitting flow chart, acknowledging that there are differences from state to state

3.3.3 Partnerships and Engagement

Partnerships and Engagement Key Takeaways

Building partnerships and involving stakeholders is a key component of project success, but also a major challenge.

There are often many stakeholders who could be impacted by or interested in a project. Trying to engage all of them can be overwhelming for many project teams. While there was general agreement among peer exchange participants that projects should engage as many stakeholders as possible, some recommended working closely with smaller core groups and keeping the larger stakeholder group informed at key decision points. If a project is anticipated to be controversial, it is vital to alert everyone who is going to be interested early in the process.

Below is a general list of the types of agencies and stakeholders that would be interested in participating in these projects.

- Federal agencies (e.g., FHWA, FEMA, U.S. Fish & Wildlife Service (FWS), U.S. Army Corps of Engineers (USACE))
- State agencies
    - Department of Transportation
    - Department of Health
    - Department of the Environment

    - Department of Game and Fisheries
    - Department of Water Resources
    - Coastal managers
- State legislature
- Cities and counties
- Regional transportation agencies
- Local communities
- Parks and recreation
- Universities and research institutions
- Non-governmental organizations (NGOs) and volunteer organizations
- Management departments if the road of interest serves major facilities (e.g., military, airports)
- Engineers (especially coastal engineers)
- Scientists (e.g., biologists and ecologists)
- Real estate agents
- Environmental groups

However, forming partnerships with other agencies and the public is a major challenge for DOTs. Many agencies act in silos and these barriers must be dismantled to form inter- and intra-agency partnerships. For example, Virginia DOT's environmental group offered to participate in the initial site planting and provide maintenance support for a nature-based solutions project to encourage buy-in from the maintenance division.

The Delaware Living Shoreline Committee has built partnerships around nature-based solutions and has sub-committees on policy, outreach/education, standards of practice, implementation, and engineering and design. They provide trainings on living shorelines and educational materials for the public on current projects.

Many people resist experimentation and innovative approaches.

There is continued doubt about the efficacy of nature-based solutions and many would prefer to use tested, traditional strategies. For example, if someone buys coastal property, they will often look at the coastal protection used by their neighbors, and engineers are likely to use the same approaches they have used their whole careers. Since most are using gray solutions, they feel comfortable doing the same and know where to find needed contractors. It is challenging to show people that nature-based solutions can offer the same level of protection and to then find contractors who can do the work well. Most people do not want to be the first one to try something new. Also, in some places, there have been instances where nature-based solutions have failed. These failures have degraded trust and made communities more resistant to nature-based projects.

Education and outreach can create a more supportive environment for these types of projects.

Participants expressed concerns about public misunderstanding and skepticism of nature-based projects. Participants shared examples of beach nourishment projects that replenished sand on a beach that was then washed away by a storm. This outcome was seen by the public as a failure, while, in reality, the project achieved its intended purpose and protected the infrastructure behind the beach. This demonstrates the importance of outreach and

communicating clearly with stakeholders about the objectives of the project and managing expectations. Defining "success" for a project from the beginning will make it easier to demonstrate how the project fulfills its purpose.

Figure 9. Educational sign for DNREC living shoreline. Photo by Tina Hodges

For example, educational signs can help inform the public explaining that just-finished projects may not look like much since the vegetation takes time to establish itself. Additionally, the Delaware Living Shoreline Committee provides "before" and "after" images of living shoreline sites to demonstrate to the public how the site has been changed and further educate them about these types of solutions. Figure 98 shows an educational sign in front of a Delaware Department of Natural Resources and Environmental Control living shoreline project stating, "Pardon Our Mess: Living Shoreline Installation in Progress." Similarly, the Outreach Committee of the Living Shorelines Committee in Delaware put up signs at their finished sites saying, "Living Shorelines Site: Protecting Shorelines Naturally: Preventing Erosion; Providing for Wildlife; Improving Water Quality". These measures help increase public awareness of living shorelines and help them realize how they are being used.

To engage with the public, participants recommended having a local (e.g., county, city) champion committed to the project. The champion can help bring in additional project partners and increase public support as a trusted advisor. Additionally, encouraging the public to participate in site visits can allow people to gain a better understanding of what nature-based solutions are and how they are used.

Partnerships and Engagement Suggestions for the Implementation Guide

Participants indicated that they would like information on the following topics in the implementation guide.

- List of stakeholders, actors, resources, institutions, or agencies for partnerships.
- Guidance on building partnerships.

3.3.4 Engineering and Design

Engineering and Design Key Takeaways

Participants identified tools and data available to use when designing nature-based solutions.

These include:

- Coastal engineering tools for geomorphological processes and structural design.
    - However, participants expressed a need for improved geomorphological databases for coastal areas. Since there is a lack of knowledge of data on

projects that are working well, it is difficult to develop new models for nature-based solutions. Some databases are available to find these examples (refer to Examples of Nature-Based Solutions).

- Suitability models
  - Virginia and Maryland both have GIS layers that help determine whether a site is a suitable candidate for a particular type of project and could also be used to screen for funding availability.
  - The Nature Conservancy hosts the coastal resilience mapping portal which provides information on coastal hazards in certain locations and suitability for different types of living shorelines. Figure 10 demonstrates the type of information available from the Coastal Resilience tool.

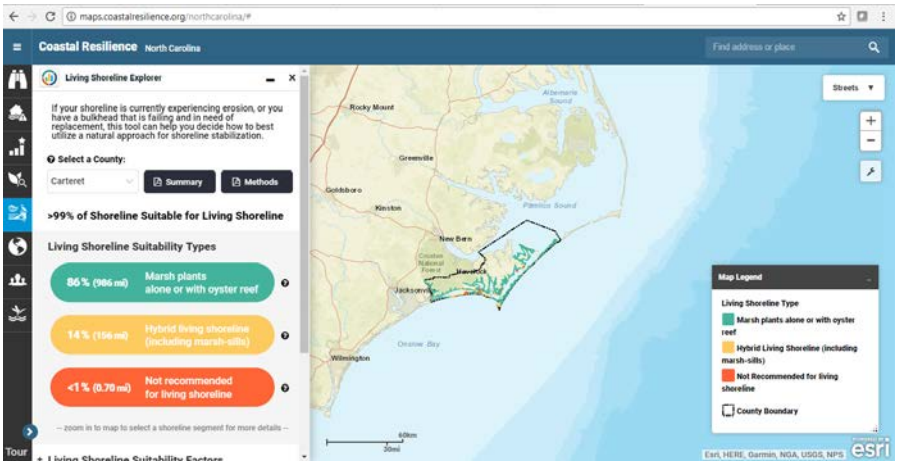

Figure 10. Coastal Resilience Tool Demonstration. Source: http://maps.coastalresilience.org/network/

- GIS-based wave atlas (for North Carolina)
- TNC handbook on oyster restoration
- livingshorelinesacademy.org
- Excel-based tool with economic impacts of different scenarios of flooding and inundation (being developed for Hampton Roads region by U.S. DOT Volpe Center[11])
- Data (some of it is available, depending on the site. However, it must be corrected for seasonality)
  - Biological indicators
  - Oceanographic characteristics (tide range, wave exposure)
  - Sedimentary characteristics (grain size, beach slope, sediment supply)

Integration of design tools and performance information is needed.

Generally, there are coastal engineering and science tools that have been available for many years that aid in the design of components of nature-based solutions. For example, there are mature tools for estimating wave transmission through rubble mound structures like sills and breakwaters. The tools for designing pocket beaches are similarly mature and well-tested. The wave tolerance of smooth cordgrass (*Spartina alterniflora*) is also known and serves as a

[11] More information available online at: https://rosap.ntl.bts.gov/view/dot/12379.

fundamental requirement in determining the size and geometry of a structure needed to attenuate wave energy. However, DOT engineers still lack quantitative information regarding long-term performance and the risk reduction provided during extreme events.

Participants expressed a need for federal guidance for transportation engineers on how to design and construct nature-based solutions. Additionally, transportation engineers do not have performance metrics to draw upon, and it may seem riskier to use nature-based approaches rather than traditional approaches. More pilot projects, monitoring, and shared data from demonstration projects can help improve design guidance. Engineers can draw on the successes and lessons learned for future designs, but only when demonstration projects are designed to accomplish stated goals (e.g., 50% reduction in wave height, 20% reduction in rate of retreat, etc.). It is comparatively difficult to develop lessons learned for demonstration projects that lack appropriate engineering and/or ecological design upfront.

DOTs lack in-house expertise on how to design nature-based solutions.

Many DOT representatives indicated that they lack in-house expertise in coastal science, ecology, and coastal engineering, all of which are critical for designing nature-based solutions. In State DOTs, there are few or no coastal engineers on staff. Without this expertise, important design variables can be overlooked. For example, development of a nature-based solution in one location may cut off sediment transport elsewhere. Coastal engineers or geomorphologists are needed to ensure the system-level impact of changing the shoreline is properly considered. Coastal ecologists are similarly needed to ensure habitat continuity and appropriate ecological function is maintained.

For many DOTs, their experienced civil engineers play a significant role in the development of projects and they are more comfortable with traditional coastal engineering approaches for which design guidance exists. Encouraging continued training in this area could help raise awareness. For example, FHWA offers a course on coastal engineering through the National Highway Institute, and USACE has some classes in their “Purple Book.”

Participants also recommended encouraging more training and developing partnerships with universities to ensure that they are training the next generation of young engineers who can participate in this work. State DOTs could engage with students to encourage them to specialize in areas of study in demand by DOTs. These types of education programs have worked in the past to shift thinking on designing for stormwater management and seismic concerns.

Most DOT projects will be a mix of green and gray solutions.

Transportation engineers often design gray solutions because it is what they know best. They may be hesitant to design nature-based solutions because they need to ensure the roadway will be protected in storm events. Thus, DOTs can consider integrating green and gray solutions into the same project and use nature-based components as a “resilience multiplier” to complement gray infrastructure. Hybrid solutions can maximize benefits by combining the strengths of green and gray strategies. Monitoring and assessing the successes and challenges of these projects will help build up the knowledge base on performance metrics. Over time, engineers may become more comfortable with nature-based solutions and the level of protection they provide, particularly if they can point to successful projects in their area.

Some participants expressed concerns that small or superficial "green" components could be added to gray solutions to make them more appealing to decision-makers without adding true ecological benefits. This type of "green washing" should be avoided. Additionally, participants emphasized that hybrid solutions should be carefully designed to account for the resilience benefits provided by the nature-based components and to proportionally decrease the design of the gray components, rather than overbuilding the solution. Figure 11 shows the range of green to gray solutions, which demonstrate that there is a spectrum of solutions that could be used.

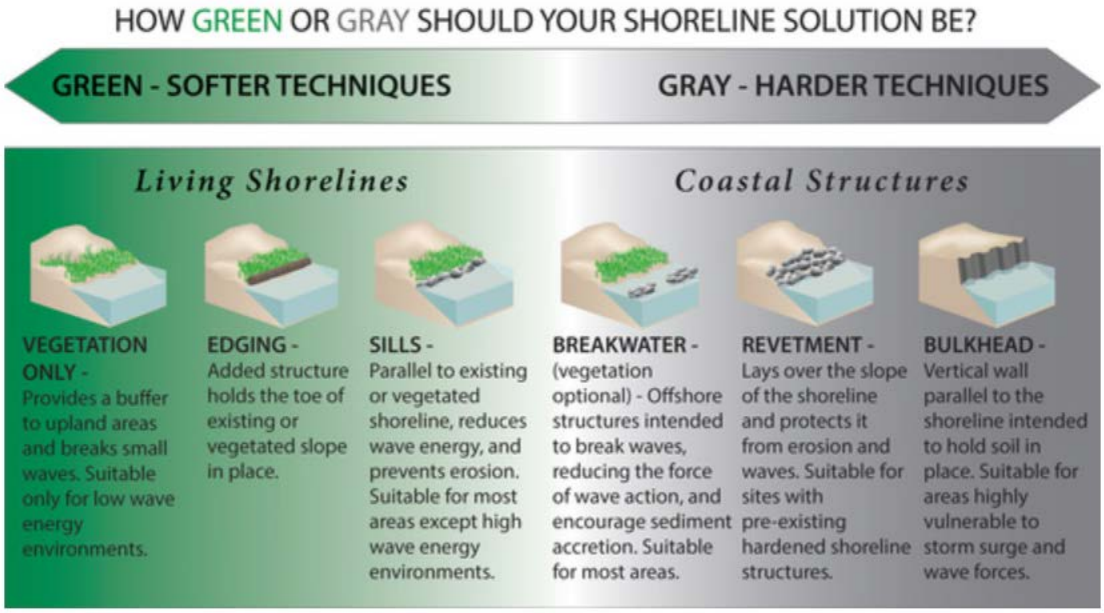

Figure 11. Coastal shoreline continuum from green to gray infrastructure solutions. Source: https://www.fisheries.noaa.gov/insight/living-shorelines#what_is_a_living_shoreline

Climate data are used inconsistently in the design process.

According to participants, sea level rise is infrequently considered in design at the project level. A lot of states do not have guidance and, even if they do, it is not always clear what decisions should be made based on that information. In States that do not have guidance, engineers may not be familiar with how to select sea level rise scenarios that match their agency's risk tolerance. Additionally, DOTs may lack certainty on how to use relative sea level rise during project design. In other places, there is resistance in using sea level rise in designs at all.

Some participants have faced challenges within their organizations when others do not view sea level rise as an immediate concern. Participants recommended that, in some jurisdictions, it can be more effective to point to recent extreme events as evidence for the need for resilience measures. Since some states do not have local guidance on how to use and interpret climate data, NOAA extension agents could help State DOTs interpret local climate science. NOAA has on-the-ground extension agents through the sea grant program who provide technical and science-based information to communities in which they reside. Also, online sea level rise guidance is available from NOAA and others, including the Sea Level Rise Viewer (https://coast.noaa.gov/digitalcoast/tools/slr.html).

Engineering and Design Suggestions for the Implementation Guide

Peer exchange participants indicated that they would like information on the following topics in the implementation guide.

- Examples and lessons learned from successful and unsuccessful projects in all types of environments (e.g., marshes, beaches)
- Design templates and design criteria
    - Links to local resources with design templates
    - Guidance for land-based vs. water-based construction
- Graphics that show clearly what different solutions look like in practice, including diagrams and cross sections
- Information and data on the performance of nature-based solutions
- Technical fact sheet on nature-based solutions
- Baseline and performance metrics
- Straightforward guidance for engineers on climate considerations to use in design
- Guidance on when/where nature-based solutions might be appropriate
    - Checklist of what to look for and what may or may not be feasible

3.3.5 Monitoring and Maintenance

Monitoring and Maintenance Key Takeaways

Participants find it difficult to secure funding for the monitoring and maintenance costs of nature-based projects.

Nature-based solutions require a different level of monitoring and maintenance than traditional gray infrastructure (although most DOTs do not keep good records of gray infrastructure maintenance costs at the project level). Participants expressed concern about receiving sufficient funding to cover maintenance costs over time and about who takes on the responsibility of performing maintenance. Participants explained that while they may be able to get funding for implementation using the same funding streams they use for traditional projects, there is insufficient funding for planning, monitoring, and maintenance. Additionally, since many DOTs have little experience implementing nature-based solutions, the long-term maintenance requirements might not be known up front. Often, transportation agencies are uncomfortable with this level of uncertainty. Also, politically, those who are in office when a project requires monitoring may not be those who provided the initial funding and, if they are not supportive, they may resist providing additional funding for long-term maintenance. Participants repeatedly discussed the need for more pilot projects, across different geographies and conditions to demonstrate the performance and document the costs of nature-based solutions over time. State DOTs themselves should be empowered to conduct their own pilot projects which will provide a diversity of examples and lessons to draw on.

Often, the maintenance division at a DOT becomes responsible for a project by default.

DOTs have struggled to delegate responsibility for monitoring and maintenance activities, leaving the maintenance division responsible. However, they may not know how nature-based solutions work; some issues have arisen due to improper maintenance. For example, at one

living shoreline site, the maintenance team mowed the site as they would grass at other locations, killing all the planted vegetation. Participants acknowledged that alternative training or maintenance solutions are needed. One way to address this concern would be to engage nonprofits or other volunteer organizations who could bring teams of volunteers to assist with maintenance or even initial project construction (e.g., national estuary programs or consortiums). Alternatively, living shoreline construction and maintenance services could be bundled similar to landscaping contracts, which would ensure proper maintenance and create a viable business model for the private sector.

DOTs need more realistic monitoring and adaptive management plans.

In some places, participants noted that regulatory agencies have high monitoring requirements that can be a barrier to implementation. Ideally, project teams would monitor shoreline position, elevation, erosion, stem density, and species. The results of the monitoring program can be translated into project design considerations for future projects and contribute to an adaptive management approach. Although engineers may understand the performance and characteristics of each component of the project, monitoring helps build a knowledge base on performance of the full systems.

Monitoring and Maintenance Suggestions for the Implementation Guide

Peer exchange participants indicated that they would like information on the following topics in the implementation guide.

- Adaptive management and monitoring guidance
- Maintenance considerations and recommendations, such as contract guidance, coordinating with others, expectations, communication with maintenance staff, etc.

4 Summary and Next Steps

4.1 Participant Feedback

Participant feedback from the peer exchanges was overwhelmingly positive. Many people were grateful to see FHWA leading discussions across the country on the topic of nature-based solutions. There are many local agencies working on nature-based solutions, but participants expressed desire for more support regionally and federally to tie all of the work together.

Participants expressed their appreciation for an opportunity to engage with other practitioners across disciplines and to form a network of people throughout their region. Participants were interested to learn that people in other states and from other types of organizations were dealing with many of the same issues. Some participants saw opportunities to develop common guidance on these shared concerns, such as maintenance and performance metrics. Those outside of the transportation sector learned about issues faced by transportation agencies and about how their organizations could partner in the future. Also, sharing experiences across states provided insight into new solutions to the challenges participants faced.

Participants valued the site visits as opportunities to see examples of nature-based solutions, both successful and otherwise. Many participants felt that the lack of known demonstration

projects hindered the implementation of projects; seeing how they worked in practice was valuable.

The participants are interested in the outcome of the implementation guide and would like to see data and resources compiled and accessible to their organizations. Many participants took notes with the intention to go back to their organizations and share the lessons that they learned with their colleagues. Many participants also indicated that they wanted to stay involved throughout the development of the implementation guide.

4.2 Topics for Inclusion in the Implementation Guide

In the first two peer exchanges, participants were asked to provide suggestions for what topics should be covered in the final implementation guide. For the last two peer exchanges, the previous suggestions were aggregated and participants (including non-transportation agencies) voted on which ones they would like to see. The following table shows the top-ranked topics for inclusion in the implementation guide.

Topic	Participant Votes
Costs and benefits of nature-based solutions (particularly in relation to traditional projects)	37
Adaptive management and monitoring guidance	28
Technical design templates and design criteria	27
Examples of successful projects for all types of environments (e.g., marshes, beaches)	23
Funding streams and sources	22
Decision matrix for selecting nature-based solutions	18
Maintenance considerations and recommendations	17
Information and data on the performance of nature-based solutions (+ performance standards)	17
Lessons learned (particularly from projects that have not worked out)	15
Guidance on how to screen and select projects	13
List of stakeholders, actors, resources, institutions, or agencies for partnerships. Guidance on building partnerships.	10
Show how this work fits with other guidance (e.g., HEC 25, Ecological)	7
Graphics that clearly show what different solutions look like in practice	6
Entry points for integrating nature-based solutions into the planning process	6
Technical fact sheet on nature-based solutions	5
Permitting flow chart	4

The results of these polls will be taken into consideration when determining what will be included in the implementation guide along with input from the project's technical advisory committee, FHWA, and the project team's broader understanding of State DOT's needs.

5 Appendices

Appendix A – Example Agenda

This appendix provides the agenda from the Mobile, AL, peer exchange. All the peer exchanges followed a very similar format.

NATURE-BASED SOLUTIONS FOR COASTAL HIGHWAY RESILIENCE

FEBRUARY 15, 2018

8:30 AM TO 4:30 PM CENTRAL TIME

ALABAMA DEPARTMENT OF TRANSPORTATION SOUTHWEST REGION OFFICE

PEER EXCHANGE AGENDA	
8:30 AM	Check-In
Setting the Stage	
8:45 AM	**Welcome/Introductions** (Facilitated by Susan Asam, ICF) Welcoming remarks Participant self-introductions Housekeeping (overview of agenda, plan for lunch, facility details)
9:15 AM	Introduction to Project and Goals of this Meeting (Remarks by Tina Hodges, FHWA) Overview of this effort, its objectives, expected outcomes, and how this meeting fits into goals
What Do We Know?	
9:30 AM	Defining Success – Using Nature-based Solutions to Increase Coastal Highway Resilience (Facilitated by Susan Asam, ICF) Define "nature-based solutions" and discuss what success looks like for these solutions.
10:10 AM	Break
10:20 AM	**Sharing experience from the field** (Facilitated and documented by Scott Douglass, Bret Webb, Susan Asam, Brenda Dix) Hear from participants about their experiences with nature-based solutions in practice.
12:00 PM	Lunch
What Challenges Remain?	
1:00 PM	**Digging into the details** (Facilitated and documented by Scott Douglass, Bret Webb, Susan Asam, Brenda Dix)

PEER EXCHANGE AGENDA	
	Topical breakout groups
2:30 PM	Break
2:45 PM	Knowledge Gaps and Implementation Challenges (Facilitated by Susan Asam, ICF) • What local and regional implementation challenges have you faced (may range from technical to regulatory)? • What are your stumbling blocks and outstanding questions? • What would you want to see in the implementation guide to help you plan and implement nature-based solutions?
Meeting Wrap Up	
3:45 PM	**Lessons Learned** (Facilitated by Susan Asam, ICF) Discuss key takeaways from the day, drawing out lessons learned.
4:15 PM	**Closing (**Remarks from Tina Hodges, FHWA)

Appendix B – Participant Lists

Mobile, Alabama – February 15, 2018

Participants

Name	Affiliation
Vince Beebe	Alabama DOT
Danielle Blackshear	FHWA
Darryl Boudreau	The Nature Conservancy
Just Cebrian	Dauphin Island Sea Lab
Renee Collini	Dauphin Island Sea Lab
Mandy Farmer	Mississippi DOT
Beth Fugate	Florida Department of Environmental Protection
Kevin Harrison	South Alabama Regional Planning Commission
Wade Henry	Alabama DOT
Alison Maulhardt	New Orleans MPO
Saul Nuccitelli	Texas DOT
Laura Phillips	FHWA, Louisiana Division
Jeffrey Pollack	Corpus Christi MPO
Rebecca Prado (Becky Roland Prado)	Florida Department of Environmental Protection
Melody Ray-Culp	U.S. Fish and Wildlife Service
Tina Sanchez	Mobile County
Jeff Shelley	FHWA, Alabama Division
Amy Sirmans	Florida DOT
Peter Smith	Texas DOT
LaDon Swann	Mississippi-Alabama Sea Grant Consortium
Duncan Greer	Taylor Engineering, Inc.

Facilitators

Name	**Affiliation**
Susan Asam	ICF
Thomas "Beau" Buhring	South Coast Engineers
Brenda Dix	ICF
Scott Douglass	South Coast Engineers
Tina Hodges	FHWA
Bret Webb	South Coast Engineers

Oakland, California – April 10, 2018

Participants

Name	Affiliation
Karen Bamfield	Caltrans
Robert Battalio	Environmental Science Associates (ESA)
Russ Boudreau	Moffatt & Nichol
Julia Biggar	Caltrans
Chuck Carlson	Caltrans
Marilyn Latta	California State Coastal Conservancy
Patrick Crist	NatureServe
Geoff Crook	Oregon DOT
Dick Fahey	Caltrans
Joel Gerwein	California State Coastal Conservancy
Brian Holt	East Bay Regional Park District
Stefanie Hom	San Francisco Bay Area Metropolitan Transportation Commission
Lanh Phan	FHWA California Division
Sarah Newkirk	The Nature Conservancy
Alyssa Newton Mann	USC Sea Grant
Brenda Powell-Jones	Caltrans
Dave Revell	Revell Coastal
Carol Lee Roalkvam	Washington State DOT
John Rozum	National Oceanic and Atmospheric Administration (NOAA)
Evyan Sloane	California State Coastal Conservancy
Lesley Ewing	California Coastal Commission
Justin Vandever	AECOM
Jessica Davenport	California State Coastal Conservancy

Facilitators

Name	Affiliation
Susan Asam	ICF
Thomas "Beau" Buhring	South Coast Engineers
Brenda Dix	ICF
Scott Douglass	South Coast Engineers
Robert Hyman	FHWA

Lewes, Delaware – April 17, 2018

Participants

Name	Affiliation
Rick Bennett	U.S. Fish and Wildlife Service
Silvana Croope	Delaware DOT
Eric Freidly	Maryland DOT, State Highway Administration
Elizabeth Habic	Maryland DOT, State Highway Administration
Jessica Hammond	The Nature Conservancy
Jesse Hayden	Delaware Department of Natural Resources and Environmental Control
Charles Hebson	Maine DOT
Roselle Henn Stern	U.S. Army Corps of Engineers (USACE)
Maria Honeycutt	National Oceanic and Atmospheric Administration (NOAA)
David Kidwell	National Oceanic and Atmospheric Administration (NOAA)
Jeff King	USACE
Kelly Leo	The Nature Conservancy
Joy Liang	FHWA, Delaware Division
Nicole Maher	The Nature Conservancy
Tim Mallette	New Hampshire DOT
Rebecca Martin	New Hampshire DOT
Pam Mason	Virginia Institute of Marine Science (VIMS)
Kim McKenna	Stockton State
Peter Murdoch	U.S. Geological Survey (USGS)
Shawn Norton	National Park Service
Kim Penn	National Oceanic and Atmospheric Administration (NOAA)
Tony Pratt	Delaware Department of Natural Resources and Environmental Control

Emily Seldomridge	Delaware DOT
Bhaskar Subramanian	Maryland Department of Natural Resources
Lee Weishar	Woods Hole Group

Facilitators

Name	**Affiliation**
Eric Brown	FHWA
Thomas "Beau" Buhring	South Coast Engineers
Charlotte Cherry	ICF
Brenda Dix	ICF
Tina Hodges	FHWA
Becky Lupes	FHWA
Bret Webb	South Coast Engineers

Wilmington, North Carolina – April 19, 2018

Participants

Name	Affiliation
Paul Atkinson	North Carolina DOT
Sam Belfield	Hampton Roads Transportation Planning Organization (HRTPO)
Victor Dang	FHWA, Georgia Division
Jenny Davis	National Oceanic and Atmospheric Administration (NOAA)
Katherine Filippino	Hampton Roads Planning District Commission
Rachel Gittman	Northeastern University
C. Scott Hardaway	Virginia Institute of Marine Science (VIMS)
Tracey Harmon	Virginia DOT
Kevin Jones	FHWA, VA Division
Andy Jordan	North Carolina DOT
Mike Kozlosky	Wilmington MPO
Abby Lorenzo	Wilmington MPO
Ron Lucas	FHWA NC Division
John Matthews	Virginia DOT
Andy McDaniel	North Carolina DOT
Brett Morgan	Myrtle Beach-Socastee SC/NC MPO
Robert Neal	Moffatt & Nichol
Spencer Rogers	North Carolina Sea Grant
Brad Saxon	Georgia DOT
Beth Sciaudone	North Carolina State
Tracy Skrabal	North Carolina Coastal Federation
Jay Twisdale	North Carolina DOT

Facilitators

Name	Affiliation
Susan Asam	ICF
Eric Brown	FHWA
Thomas "Beau" Buhring	South Coast Engineers
Brenda Dix	ICF
Tina Hodges	FHWA
Heather Holsinger	FHWA
Bret Webb	South Coast Engineers

Appendix C – Example Nature-Based Projects

Table 1 describes some selected examples of nature-based solutions.[12]

Project Name	Location	Implementing Entities	Design Notes	Observations and Lessons Learned
Crown Beach	Alameda, CA	City of Alameda	**Resource Protected:** Shoreline Drive Sandy beach nourishment stabilized by some terminal groins at each end.	This legacy project has performed according to the design objectives.
Cardiff Beach Living Shoreline Project	Northern San Diego, CA	City of Encinitas, California State Parks, California State Coastal Conservancy, San Elijo Lagoon Conservancy, Ocean Protection Council, California Coastal Commission, San Diego Association of Governments	**Resource Protected:** Pacific Coast Highway/Highway 101 The Highway and Cardiff State Park has been damaged repeatedly by extreme wave events and high tides. Sea-level rise will increase the frequency and severity of flooding and damage. The project includes retrofitting rock revetments, adding native cobble, building sand dunes, and planting dune species. The sand used is dredged from the adjacent coastal lagoon as part of the restoration of that lagoon.	This project is under construction (sand pumping began in April 2018). Project implementation required extensive collaboration from the beginning. Compromises made to create a hybrid approach. http://scc.ca.gov/webmaster/ftp/pdf/sccbb/2015/1503/20150326Board08_Cardiff_State_Beach.pdf

[12] The table includes only information mentioned during the peer exchanges and, therefore, the information available for each example is not consistent or comprehensive.

Project Name	Location	Implementing Entities	Design Notes	Observations and Lessons Learned
Ocean Beach	San Francisco, CA	San Francisco Public Utilities Commission (SFPUC)	**Resource protected:** Lake Merced Tunnel, critical wastewater infrastructure, and Sloat Boulevard. Impacted by chronic erosion problems. Phase 1 (2015-2021) involves short-term strategies to reduce erosion while long-term strategies are implemented. Managed retreat, beach nourishment, and low-profile protection structures to reduce coastal erosion.	Once natural infrastructure is in place, the previously installed boulder revetments can be removed. https://www.spur.org/news/2015-08-13/coastal-engineering-study-validates-ocean-beach-master-plan-vision http://sfwater.org/index.aspx?page=1216
Surfers Point Managed Shoreline Retreat	Ventura, CA	California Department of Parks and Recreation, The Surfrider Foundation, California Coastal Commission, California State Coastal Conservancy	**Resource Protected:** A bike path and portion of a parking lot removed and relocated. Preserved access to the area via Shoreline Drive. Relocated erosion-damaged infrastructure inland instead of building a seawall. Natural shoreline processes were restored by replacing a stretch of paved beachfront bike path and parking lot with a cobble berm covered by vegetated dunes.	Constructed berm and dunes resisted erosion through two winters and survived a major storm with less damage than surrounding areas. Documented in *Case Studies of Natural Shoreline Infrastructure in Coastal California*. https://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/california/ca-green-vs-gray-report-2.pdf?redirect=https-301

Project Name	Location	Implementing Entities	Design Notes	Observations and Lessons Learned
				http://www.adaptationclearinghouse.org/resources/surfer-s-point-managed-shoreline-retreat-project.html
Dewey Beach Pilot Project	Dewey Beach, DE		**Resource protected:** SR 1 protected by the beach Addressing coastal flooding and drainage issues. A sand bypassing plant near the Indian River Inlet bridge restores the natural sand flow that is interrupted by the jetties. The plant was put in place in 1990.	Implementation has been successful, but it does require substantial annual maintenance costs.
Delaware Coastal Protection, Indian River Inlet Sand Bypassing Plant	Sussex County, DE	Delaware Department of Natural Resources and Environmental Control (DNREC), USACE	**Resource Protected:** Beach at Indian River Inlet and Delaware State Route 1 Bridge USACE constructed inlet jetties in the 1930s that disrupted the flow of sand from south to north along the coastline. SR-1 is vulnerable to damage from the sand deficit. The Sand Bypassing Plant was built to recreate the natural sand flow.	Operation requires adaptive management to respond to changing conditions.
Milford Neck	Milford, DE	The Nature Conservancy	**Resource protected:** Saltwater marshes and wildlife habitat	Restoration has occurred since 1998 to maintain habitat protection.

Project Name	Location	Implementing Entities	Design Notes	Observations and Lessons Learned
			Several agencies in Delaware have been working to manage and restore wildlife habitat. Efforts include forest restoration to create habitat for bird species. Marsh and beach restoration protects habitat for birds and waterfowl. Near Route 1 and Tub Mill Pond Road. http://delmarva-almanac.com/index.php/content/article/milford_neck_wildlife_area_preserve/	Example of cooperation between public and private agencies working to protect the ecosystem.
Prime Hook National Wildlife Refuge	Milton, DE	U.S. Fish and Wildlife Service	**Resource Protected:** Restores tidal marsh/barrier beach ecosystems Marsh and beach nourishment/restoration completed in 2016. The wetland restoration provides habitat for key species and improves the marshes resilience to future storms and sea level rise. Also provides natural and economic benefits for nearby communities.	https://www.fws.gov/hurricane/sandy/projects/PrimeHookBarrierBeach.html

Project Name	Location	Implementing Entities	Design Notes	Observations and Lessons Learned
Niceville 5 Oyster Reef Site	Choctawhatchee Bay, Niceville, FL		**Resource Protected:** Five properties adjacent to the site experiencing severe erosion caused by wind and wave action Breakwater using oyster reefs were installed and plants were placed above the MHW line to break waves. http://www.gcrc.uga.edu/PDFs/Living%20Shorelines%20in%20the%20Southeast.pdf	Volunteers of the Choctawhatchee Basin Alliance (CBA) helped build the oyster reefs. https://coastalanglermag.com/volunteers-build-oyster-reefs-choctawhatchee-bay/
Florida SR A1A	Flagler Beach, FL	City of Flagler Beach, Flagler County, City of Beverly Beach, USACE, Florida Department of Environmental Protection, U.S. Fish and Wildlife Service, NOAA, Florida Fish and Wildlife Conservation Commission, FHWA	**Resource Protected:** State Route A1A, which is an evacuation route and scenic highway. SR A1A has experienced storm damage since 1981. Project included adding rock revetment, which was later replaced with sand and vegetation. The road was rebuilt with improved drainage. A pile wall was built and covered with sand and vegetated.	Project has not been constructed yet. Demonstrated the value of working with locals and getting funding in place. Collaborated with the community through community meetings and public decided to take a more resilient approach. Includes bike lanes, median improvements, and sidewalks, in addition to road protection.
Project GreenShores	Pensacola Bay, FL	DEP of Florida, City of Pensacola, Escambia County,	**Resource Protected:** Habitat restoration effort along the urban	This community-based environmental restoration project has received support

Project Name	Location	Implementing Entities	Design Notes	Observations and Lessons Learned
		Ecosystem Restoration Support Organization, EPA Gulf of Mexico Program, FWS, NOAA, Gulf Power, local agencies, businesses, and volunteers	shoreline. Restored oyster reef, salt marsh and seagrass habitat Site 1 completed in 2003 with 15 acres Site 2 constructed in 2007 with two submerged breakwaters that will also serve as living oyster reef.	from many organizations and volunteers. https://floridadep.gov/fco/aquatic-preserve/content/project-greenshores
Gibson Road	St. Mary's County, MD		**Resource Protected:** There was an erosion problem causing the road to collapse. Implemented solution to move pressure off the toe DNR suggested going out into the water and built a rock sill 6 in. above mean high water. Put sand behind it and planted 2 native species.	The shoreline has been eroding 2-3 ft. per year. The project did not stop erosion, but it has slowed it. Maintains natural processes. The natural slope should be 10:1 for marshes in Maryland.
NOAA's Pivers Island Living Shoreline Project	Beaufort, NC	NOAA, Duke University, North Carolina Department of Natural Resources	**Resource Protected:** Living shoreline on each side of the island protects the island infrastructure, including Pivers Island Road which is the only access route to the island. Established a marsh using cordgrass with oyster sill.	Reduced erosion of beach. Created habitat value for a valuable fishery and bird habitat. Improves water quality. Sequesters carbon.

Project Name	Location	Implementing Entities	Design Notes	Observations and Lessons Learned
			https://ncdenr.s3.amazonaws.com/s3fs-public/document-library/HurricaneImpactsPiversIsland.pdf	https://www.habitatblueprint.noaa.gov/living-shorelines/beaufort/
Plumb Beach	Brooklyn, NY	USACE, New York State Department of Environmental Conservation and Department of State, National Park Service, New York City Department of Parks & Recreation, New York City Department of Environmental Protection, New York City Department of Transportation	**Resource Protected:** Protected critical transportation artery during Sandy (Belt Parkway). USACE and partners developed a coastal management plan. Includes constructed beach berm with sections planted with dune grass, two terminal groins, and a breakwater to reduce erosion and reduce need for future nourishment.	http://www.nan.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/487400/fact-sheet-plumb-beach/
Cape Lookout State Park	Tillamook, OR		Dunes, cobbles San Rafael – 1-acre oyster reef and eel grass beds.	If oysters are too high in the wave zone they will suffer heat stress. Had to replant eel grass but the oysters returned on their own. Impacted by salinity changes.

Project Name	Location	Implementing Entities	Design Notes	Observations and Lessons Learned
				Holistic system and the components depend on one another.
Chincoteague National Wildlife Refuge Living Shoreline/Living Reef	VA	U.S. Fish and Wildlife Service, The Nature Conservancy, Virginia Marine Resources Commission (VIMS)	**Resource Protected:** Access roads that experience flood damage due to flooding. Oyster reefs were built at Tom's Cove and Assateague Beach as the foundation for living shoreline designs. The strategically placed oyster reef increases the resilience and stability of the road/tidal interface by creating a living barrier (oysters) that grow and adapt (height and area) as sea level rises over the long term. This project responded to extensive damage caused by Hurricane Sandy. https://www.fws.gov/hurricane/sandy/projects/ChincoteagueLivingShoreline.html	The project provides highly visible examples of how human needs can be met by working with nature-based solutions to help mitigate the impacts of climate change, particularly sea level rise and coastal flooding. Volunteers helped build the oyster reefs. http://coastalresilience.org/new-oyster-reefs-at-chincoteague-national-wildlife-refure-to-help-protect-coastlines/
Water Street Pocket Beaches	Yorktown, VA	County of York	**Resource Protected:** Water Street, which often experienced flooding. Sand fill and rock breakwaters were used to establish a series of pocket beaches to protect 0.3 miles of	Virginia DOT participated in project formulation and provided funding proportional to the road protection capacity.

Project Name	Location	Implementing Entities	Design Notes	Observations and Lessons Learned
			coastal highway along the York River. Additionally, it provides recreational areas along the waterfront.	The project performed well and provided protection to the road and infrastructure behind the road, in addition to providing habitat and recreational opportunities.

Appendix D – Peer Exchange Site Visits

Each of the four peer exchanges included an optional site visit led by a local partner to view nature-based solutions projects in the vicinity. This helped set the stage for discussion and illustrate practical considerations for nature-based solutions implementation. While several of the projects were built to protect habitat, housing, or structures other than roads, similar techniques may be effective in protecting roads at some sites.

FHWA is grateful to each of the individuals and local organizations that led the site visits: Scott Douglass of South Coast Engineers (Mobile, AL); Marilyn Latta of California Coastal Conservancy (Oakland, CA); Alison Rogerson of Delaware Department of Natural Resources and Environmental Control (Lewes, DE); and Tracy Skrabal of North Carolina Coastal Federation (Wilmington, NC).

Mobile, Alabama

The group visited a constructed living shoreline project along Alabama Highway 193, south of Alabama Port. The project was designed to restore and protect marsh between Mobile Bay and Highway 193. It consists of offshore breakwaters submerged at high tide. Unfortunately, the project did not take into account all of the critical sediment transport processes in the area. The project inadvertently starved the shoreline immediately to the south of sediment, resulting in accelerated erosion near the road and Alabama DOT needing to take action to protect Highway 193 with a rock revetment. This illustrates the need to include a coastal engineer on the project team and to ensure a full understanding of the coastal processes at the site.

Figure 12. Bret Webb of South Coast Engineers and Rob Kafalenos of FHWA discuss erosion along Highway 193. Rock revetment visible in background. Photo credit: FHWA

Participants then viewed a successful living shoreline project along Mobile Bay consisting of oyster reefs, rock headlands, and pocket beaches protecting private homes. The homeowner enthusiastically showed the project to the group along with the oyster cultivation small business she started in conjunction with the living shoreline.

Figure 13. Rock headlands and pocket beaches protecting private homes from erosion and flooding. Photo credit: FHWA

Oakland, California

Write-up provided by California Coastal Conservancy

Figure 14. Marilyn Latta of California Coastal Conservancy and Matt Graul from East Bay Regional Park District discuss the Dotson Family Marsh Project with transportation practitioners. Photo credit: FHWA

Participants viewed three living shoreline project examples between Point San Pablo and Point Pinole on the North Richmond Shoreline. Each illustrated various stages of shoreline condition and habitat restoration progress, as well as strong community-based involvement including nearby underserved communities.

First, participants visited estuarine headlands and a derelict wharf and creosote piling removal project at Point San Pablo, just north of the Richmond-San Rafael Bridge. Derelict creosote pilings impact Pacific herring, the last commercial fishery in San Francisco Bay, and a variety of other species that use subtidal habitats in the estuary. More than 33,000 derelict pilings have been mapped at low tide, and an additional 30,000 are estimated to be laying on the bay floor. The CA State Coastal Conservancy is working with the City of Richmond, National Fish and Wildlife Foundation, Ducks Unlimited and other partners on

the San Francisco Bay Creosote Piling Removal and Pacific Herring Restoration Project at this site. Phase One of the project included a baywide site assessment to identify the highest density piling removal opportunities that also matched Pacific herring spawning locations, and also with feasible conditions for native Olympia oyster and eelgrass bed restoration. Demolition of the former Red Rocks Warehouse and removal of more than 420 tons of debris and 460 creosote pilings occurred in Fall 2016 as part of Phase Two. Phase Three will happen in Spring-Summer 2018 and includes construction of a living shoreline that includes eelgrass plantings and three types of oyster reefs for restoration. There is a second wharf at the site that includes more than 2,500 concrete and creosote pilings that is slated for removal in Fall 2019.

Next, participants visited the Dotson Family Marsh on the North Richmond Shoreline, which is an innovative example of sea level rise adaptation design coupled with substantial public access. The phased 2015-2017 project restored formerly filled wetlands on a mixed-use shoreline. The restoration design includes multiple habitat types along the newly created shoreline elevational gradient- tidal wetlands and sloughs, upland habitat transition zones, and the use of on-site clean fill to create seasonal wetlands that are expected to become tidal over time as sea level rises. The restoration resulted after 20 years of major community involvement efforts including the underserved and diverse community of Parchester Village, which housed workers of the former WWII shipyards, who pushed for habitat restoration and open space in heavily urbanized and industrial Richmond. The project is managed by East Bay Regional Park District, with support from U.S. Fish and Wildlife Service, NOAA, CA State Coastal Conservancy, and many others.

Finally, participants used the new public access boardwalk to walk from Dotson Family Marsh to the third and final stop at Giant Marsh, and view the area of a future Giant Marsh Living Shorelines Project to be constructed in phases between Spring 2018 and Fall 2020. Giant Marsh is actually a fairly small marsh, but named for the former town of Nitro-Giant which was formed in 1892 by the Giant Powder Company which was the first company in America to produce dynamite. The area is now part of Point Pinole Regional Shoreline managed by East Bay Regional Park District. The project directly incorporates monitoring data and lessons learned from the Coastal Conservancy's 2012 living shorelines project across the bay in San Rafael, and the design includes multiple habitat types ranging from subtidal to supratidal-eelgrass plantings, native Olympia oyster reefs, tidal marsh and sandy habitat plantings, trellising with woody plant material for high tide refugia, and upland ecotone treatments. Partners include San Francisco State University, UC Davis, USGS, and ESA. Drone based aerial imagery and digital elevation data, coupled with boat-based bathymetry data and substantial pre-construction site monitoring, informed the experimental design that helps implement regional priority habitat recommendations.

Lewes, Delaware

The Delaware Department of Natural Resources and Environmental Control (DNREC) showed peer exchange participants four shoreline restoration sites and explained the problems addressed, techniques used, and monitoring information for each.

Figure 15. Living shoreline site at the DNREC training facility. Photo credit: FHWA

Participants viewed the living shoreline project adjacent to the DNREC training facility where the peer exchange was held. There, DNREC installed a stone breakwater and planted marsh to protect the site from erosion from boat wakes. The design included gaps in the breakwaters to allow for more flow of water and sediment to the marsh. Additional, smaller breakwaters were then placed landward of the main breakwater to provide protection for the areas with the gaps. DNREC has observed scour around the inlets in the breakwaters and this site has required adaptive management to maintain function.

Figure 16. Rebecca Martin of New Hampshire DOT and Becky Lupes of FHWA discuss the Lewes Ball Field Living Shoreline. Photo credit: FHWA

The Little League baseball field in Lewes, DE sits across the canal from a marina and the area is subjected to boat wakes from traffic at the marina. The existing salt marsh shoreline between the canal and the ball field was being undercut by boat wakes and deteriorating. The site has relatively low energy, so standard vegetated living shoreline tactics were selected. The slope of the eroding shoreline required two tiers of coconut fiber (coir) logs staked on top of each other to reach the optimal elevation for Spartina grass. The first round of coconut fiber matting and logs were positioned in the intertidal zone before being staked down and tied in place. Oyster shell

bags were then arranged in front of the coir logs to further armor the shoreline and absorb wave energy. The next step was to allow sediment to fall out of the naturally turbid water into the cells created by the coconut fiber logs. Installed in 2014, the total cost for the project was $4,138, or $49 per foot. More info on the Lewes Ball Field Living Shoreline is available at: http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Documents/Lewes%20LS%20Handout.pdf

Figure 17. The marsh provides habitat for bivalves, crabs, snails, horseshoe crabs, and other species. Photo credit: FHWA

DNREC restored two shoreline areas at the Indian River Marina, near the Indian River Inlet Bridge in Rehoboth Beach, DE. The group visited one of these, an 84 linear foot restoration site close to a loading dock, which was built along a sandy shoreline as an option for "greening-up" an existing rip-rap structure. DNREC positioned coconut fiber matting and logs in the intertidal zone and then staked them down and tied them in place. DNREC then arranged oyster shell bags in front of the coir logs to further armor the shoreline and absorb wave energy. Clean sand fill then brought the site up to the desired graded elevation for planting smooth cordgrass (Spartina alterniflora). The total costs for the site was $3,411 ($41/linear foot). Unexpectedly, horseshoe crabs found the new habitat desirable and decided to use it to crawl onto the shore and lay their eggs. Unfortunately, the spiny bodies of the horseshoe crabs tore up some of the coir logs. DNREC placed more oyster bags as adaptive management to protect the shoreline while still allowing the horseshoe crabs and other species to access the area. More information is available at: http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Documents/Indian%20River%20LS%20Handout5.15.pdf

The final site that participants visited demonstrated some of the challenges that arise in meeting the needs of multiple sectors and agencies in a complex and dynamic coastal environment. As shown in the photo below, the site is at the Indian River Marina, with DelDOT's Indian River Inlet Bridge visible in the background and a U.S. Coast Guard facility visible in the foreground. The Indian River Inlet is manmade; the U.S. Army Corps of Engineers created the inlet in the early 20th century to enable farmers to transport their products to

market. Because the inlet is narrow, strong tidal currents pass between the ocean and the back bay at this point. This caused deep scouring of the bridge piers of the 1965 steel girder bridge, requiring frequent surveillance, strengthening with riprap, and a structurally deficient rating. To solve the problem, DelDOT built a new cable-stayed bridge, with the pylons on land to avoid the need for bridge piers in the inlet that would be subject to scour. The new bridge opened in 2012.

Sand shoals in the inlet channel shift over time, redirecting forces. Due to the strong currents and a sand shoal directing currents towards it, the sheetpile bulkhead protecting the U.S. Coast Guard Facility at the site began to fail. In addition, the shoreline by recently built DNREC public cottages for rent was eroding. In coordination with the other agencies, the U.S. Coast Guard removed the helipad on the site to shorten the length of land jutting out into the water and reduce the total land area needing bulkhead protection. USACE built rip rap protection in front of the DNREC cottages and up to the U.S. Coast Guard Site. DNREC built and planted sand dunes behind the rip rap for extra protection, habitat, and aesthetic value.

Figure 18. From background to foreground: Indian River Inlet Bridge, U.S. Coast Guard Facility, sheetpile bulkhead, rip rap, newly planted dunes, and fencing to catch sand and divert pedestrians off the dunes. Photo credit: FHWA

Wilmington, North Carolina

Participants viewed and discussed multiple living shoreline projects at the Morris Landing Preserve, located 35 miles north of Wilmington. North Carolina Coastal Federation purchased the property in 2004 in order to restore salt marsh and oyster habitat, enhance public access and recreation, and improve water quality. Between 2005 and 2016, the Federation built multiple living shoreline projects demonstrating a variety of techniques that attenuate waves and reduce erosion, including stone sills, vegetation, oyster reefs, and marsh plantings.

Figure 19. Tracy Skrabal of North Carolina Coastal Federation discusses a Morris Landing living shoreline site with FHWA North Carolina Division staff member Ron Lucas. Photo credit: FHWA

Figure 20. Waves from a recreational boat traveling through the Intracoastal Waterway at Morris Landing. Note the large waves outside the oyster sill. The wave energy is absorbed by the oyster sill and only small ripples reach the marsh. This allows the marsh to thrive rather than erode in an environment with frequent, large boat wakes. Photo credit: FHWA

Figure 21. Three oyster castles in the background with oyster bags in the foreground. Photo credit: FHWA

Figure 22. Left: Brett Morgan from Myrtle Beach – Socastee SC/NC MPO examines oyster shell bags at the Morris Landing Preserve. Right: Marl, lightweight stones, stockpiled at Morris Landing. Photo credit: FHWA

North Carolina Coastal Federation discovered that they could build oyster reefs at lower cost using limestone marl for the bottom layers of the reef and oyster shell bags for the top layers rather than oyster shell bags throughout. This is because the oysters only adhere to the top layers, so it is not necessary to have the bottom layers be oyster shell bags. Limestone marl is cheaper. It also weighs significantly less. Consequently, NC Coastal Federation finds it easy to find volunteers to heft and place marl bags but difficult to find volunteers willing to lift the heavier shell bags.

More information is available at: https://www.nccoast.org/project/morris-landing/