Engineering with Nature for Coastal Resilience – Application to Natural and Nature-Based Features

Dr. Todd S. Bridges

Senior Research Scientist, Environmental Science
U.S. Army Engineer Research and Development Center,
U.S. Army Corps of Engineers
todd.s.bridges@usace.army.mil

USACE-NOAA NNBF Meeting

March 1-3, 2016

U.S.ARMY

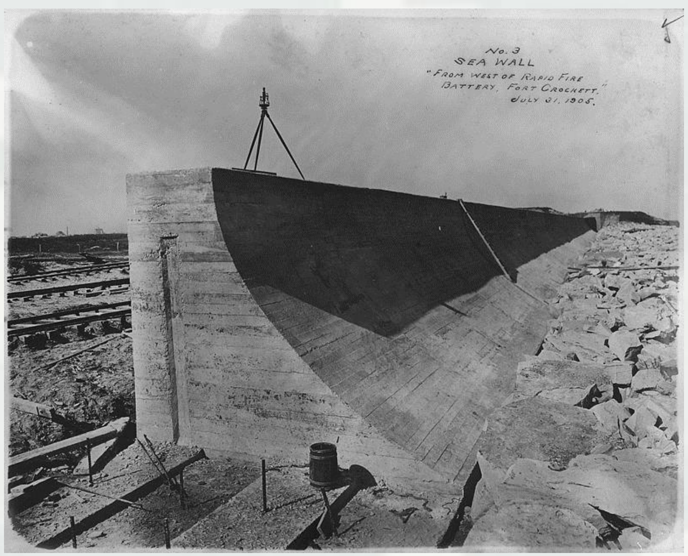
US Army Corps of Engineers®

ERDC
Engineer Research and Development Center

Coastal Resilience is Serious Business: Lives are at Stake

Galveston Hurricane (1900)

- Landfall 8 September 1900
- Estimated Category 4 Hurricane
  - 145 mph winds
- Estimated death toll: 6,000-12,000
- Galveston Seawall
  - Constructed:1902-1963
  - >10 miles long

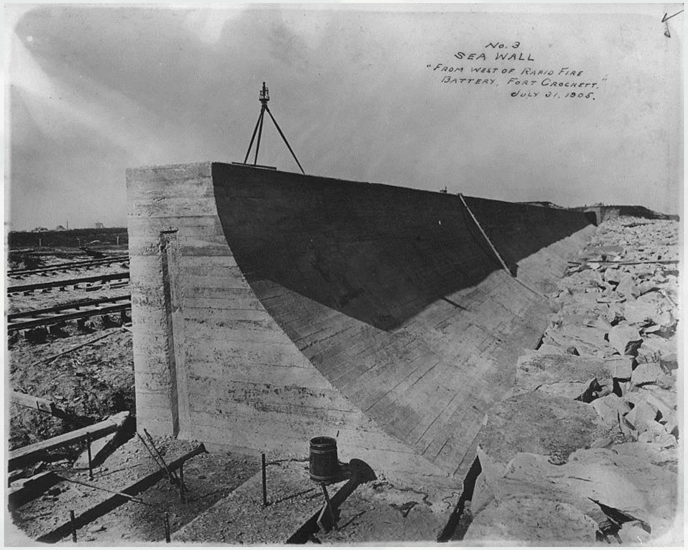


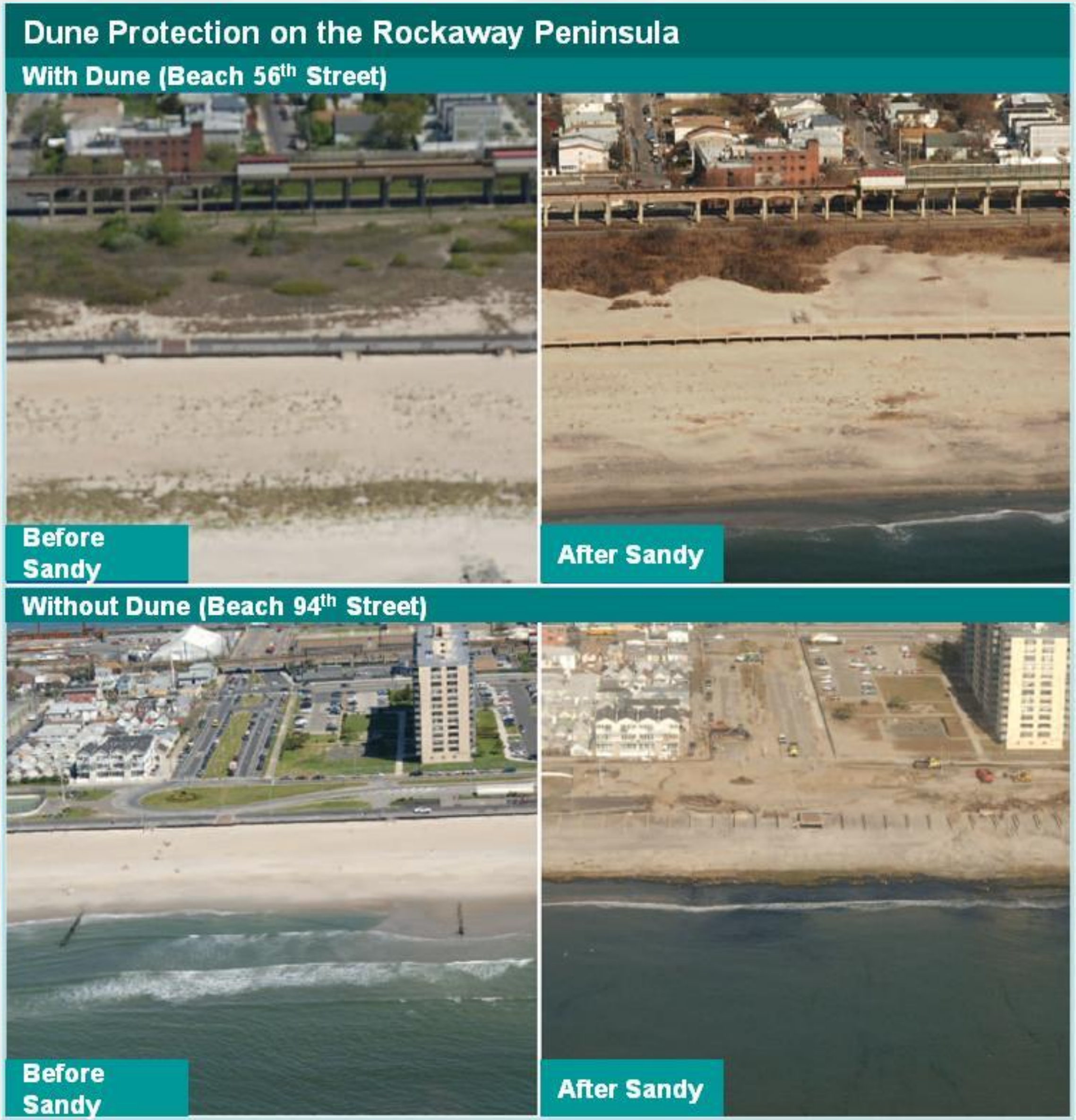
Coastal Resilience is Serious Business: Lives are at Stake

Galveston Hurricane (1900)

- Landfall 8 September 1900
- Estimated Category 4 Hurricane
  - ► 145 mph winds
- Estimated death toll: 6,000-12,000
- Galveston Seawall
  - ► Constructed:1902-1963

Nature-Based Features Perform During Hurricane Sandy (2012)



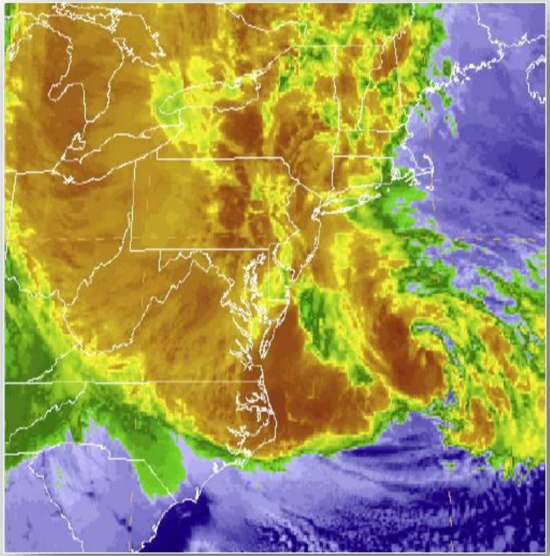


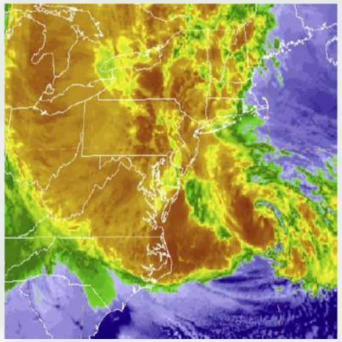
http://www.nyc.gov/html/sirr/html/report/report.shtml

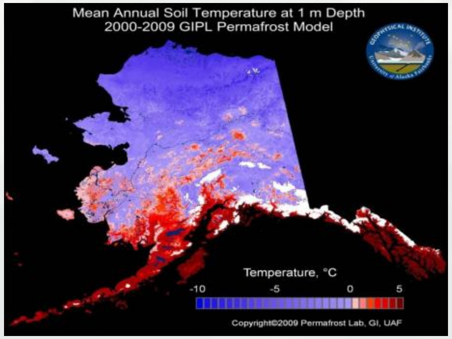
Hurricane Sandy

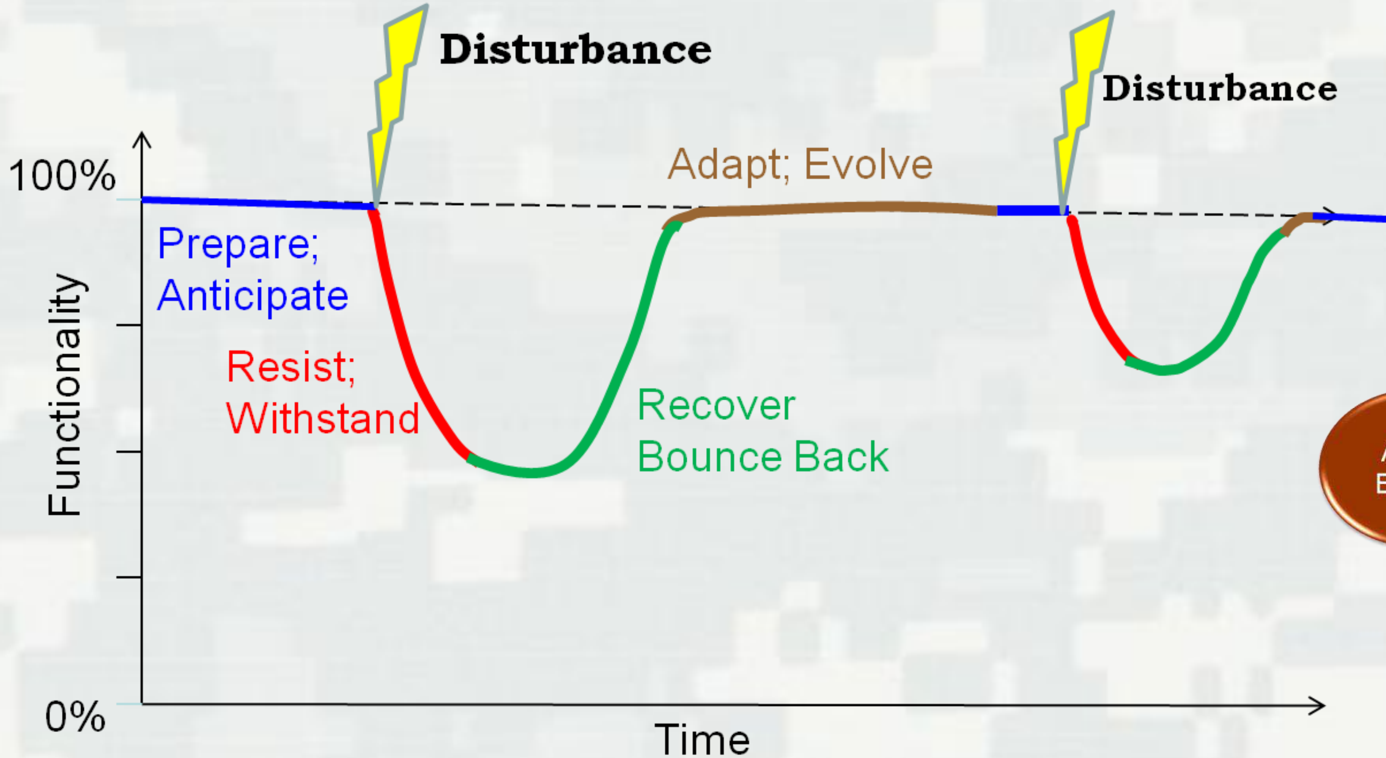
Storm Impacts and Damages: 22-29 October 2012

- **Human**
  - 286 people killed (159 in the US)
  - 500,000 people affected by mandatory evacuations
  - 20,000 people required temporary shelter
  - Extensive community dislocations – continuing today in some areas
- **Economic**
  - $65B in damages in the U.S.
  - 26 states affected (10 states and D.C are in the NACCS study area)
  - 650,000 houses damaged or destroyed









Resilience: the ability of a ***system*** to **Prepare for**, **Resist**, **Recover**, and **Adapt** to achieve functional performance under the stress of disturbances through time.

Engineering Performance: Nature-Based Features Work in Different Ways

Natural and Nature-Based Infrastructure at a Glance

GENERAL COASTAL RISK REDUCTION PERFORMANCE FACTORS:
STORM INTENSITY, TRACK, AND FORWARD SPEED, AND SURROUNDING LOCAL BATHYMETRY AND TOPOGRAPHY

Dunes and Beaches

Benefits/Processes

Break offshore waves

Attenuate wave energy

Slow inland water transfer

Performance Factors

Berm height and width

Beach Slope

Sediment grain size and supply

Dune height, crest, width

Presence of vegetation

Vegetated Features: Salt Marshes, Wetlands, Submerged Aquatic Vegetation (SAV)

Benefits/Processes

Break offshore waves

Attenuate wave energy

Slow inland water transfer

Increase infiltration

Performance Factors

Marsh, wetland, or SAV elevation and continuity

Vegetation type and density

Oyster and Coral Reefs

Benefits/Processes

Break offshore waves

Attenuate wave energy

Slow inland water transfer

Performance Factors

Reef width, elevation and roughness

Barrier Islands

Benefits/Processes

Wave attenuation and/or dissipation

Sediment stabilization

Performance Factors

Island elevation, length, and width

Land cover

Breach susceptibility

Proximity to mainland shore

Maritime Forests/Shrub Communities

Benefits/Processes

Wave attenuation and/or dissipation

Shoreline erosion stabilization

Soil retention

Performance Factors

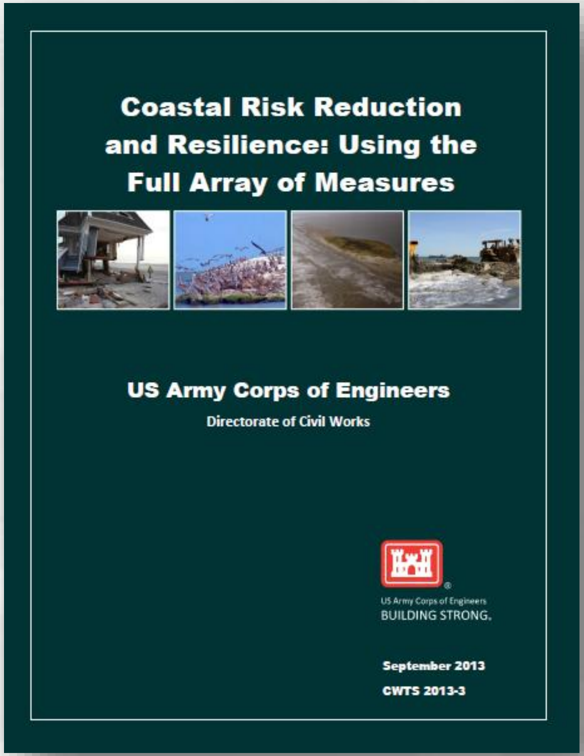
Vegetation height and density

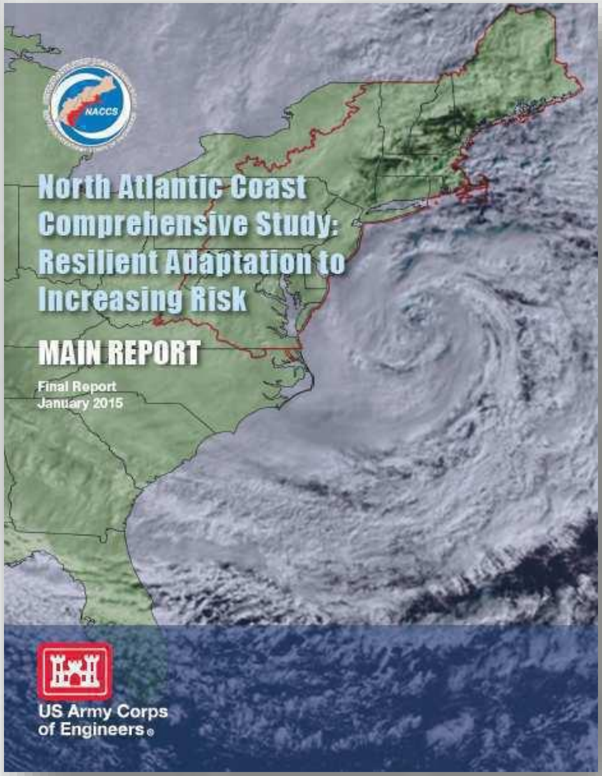
Forest dimension

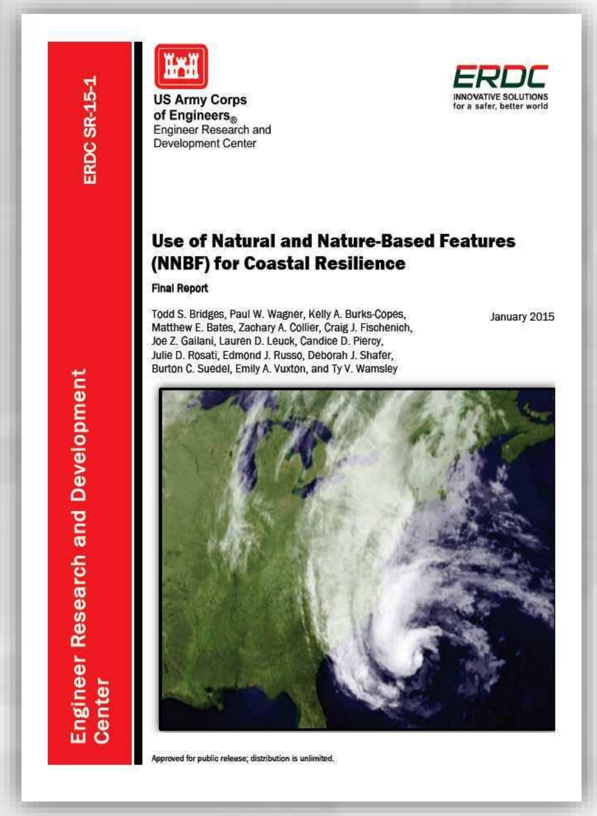
Sediment composition

Platform elevation

The North Atlantic Coast Comprehensive Study



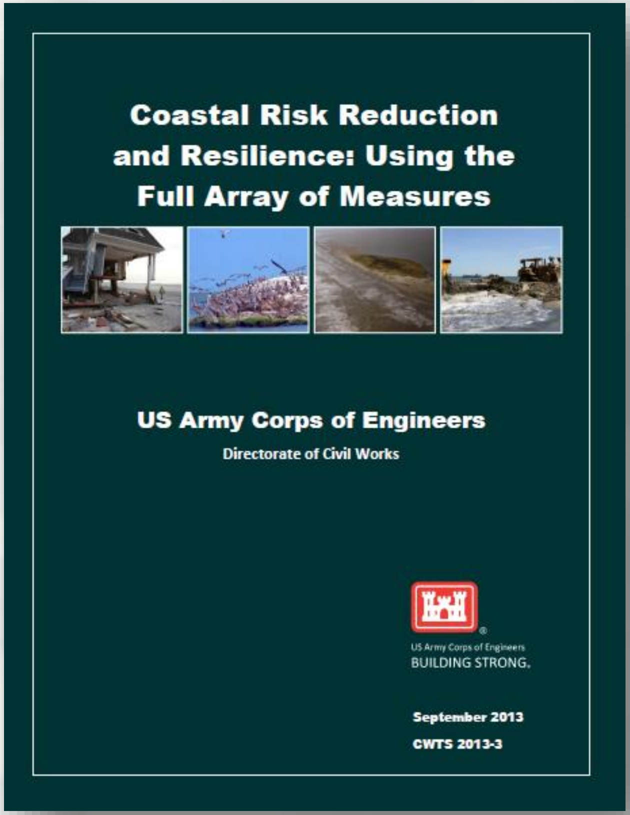




http://www.nad.usace.army.mil/CompStudy

A Systems Approach: Coastal Risk Reduction and Resilience

"The USACE planning approach supports an ***integrated approach*** *to reducing coastal risks and increasing human and ecosystem community resilience through a combination of* ***natural, nature-based, non-structural and structural measures****. This approach considers the engineering attributes of the component features and the dependencies and interactions among these features over both the short- and long-term. It also considers the* ***full range of environmental and social benefits*** *produced by the component features."*



http://www.corpsclimate.us/docs/USACE_Coastal_Risk_Reduction_final_CWTS_2013-3.pdf

Exploring nature-based solutions: the role of green infrastructure in mitigating the impacts of weather- and climate change-related natural hazards

- "…instead of automatically defaulting to grey solutions like dikes and pipes for flooding, we first should look at restoring floodplains or wetlands. Rather than building sea walls, we need to think about conserving sand banks...Planners should compare green to grey and identify new opportunities for investing in nature, including a combination of green and grey approaches when nature-based solutions alone are insufficient. As planners explore how to accommodate infrastructure demands in the future, the lesson is clear: think about green before investing in grey."


EEA Technical report | No 12/2015

Exploring nature-based solutions

The role of green infrastructure in mitigating the impacts of weather- and climate change-related natural hazards

ISSN 1725-2237

European Environment Agency

EEA Technical Report No 12/2015

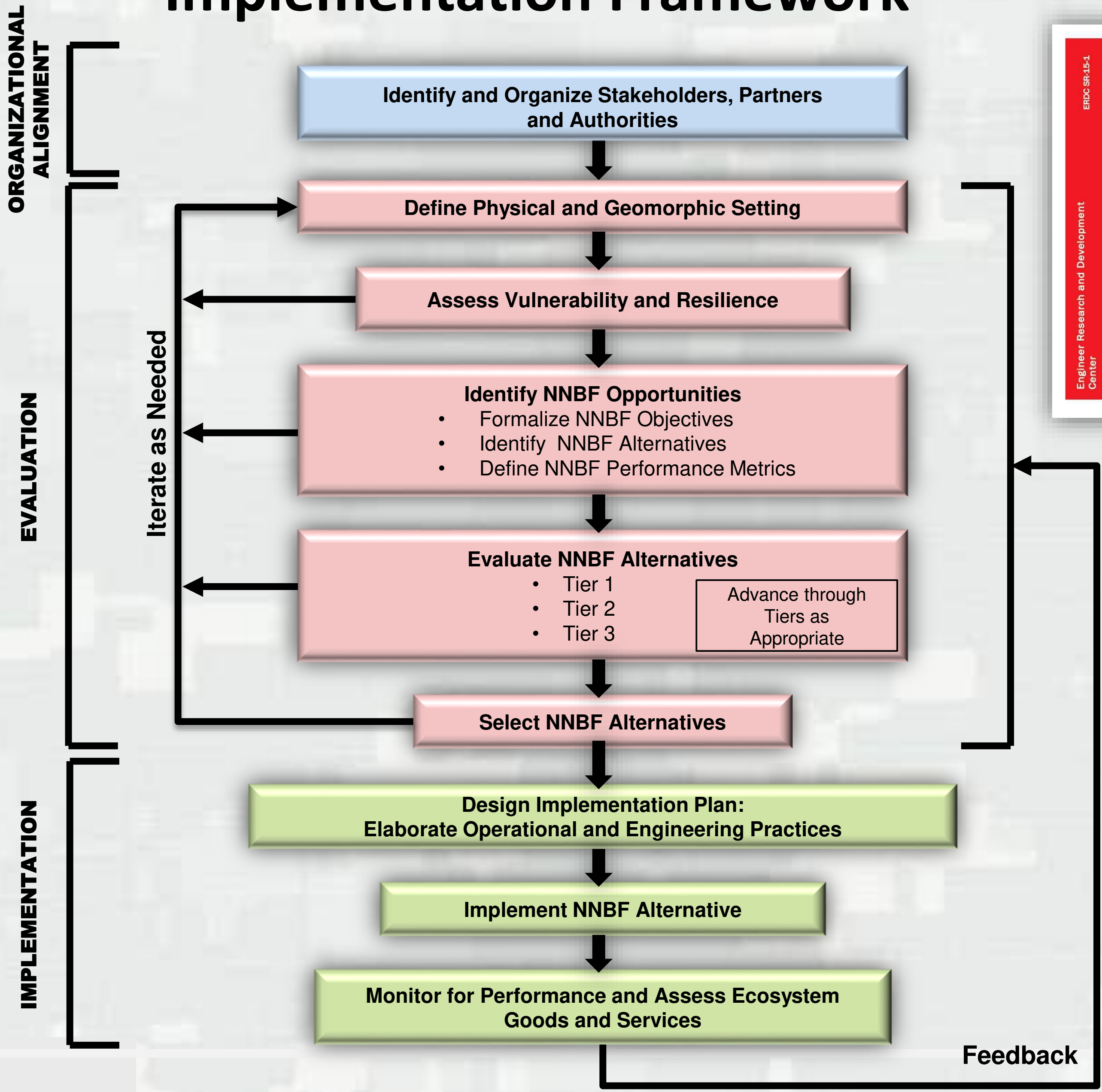
Caterpillar Corporation's
Restoring Natural Infrastructure Summit
4 November 2015, New York City

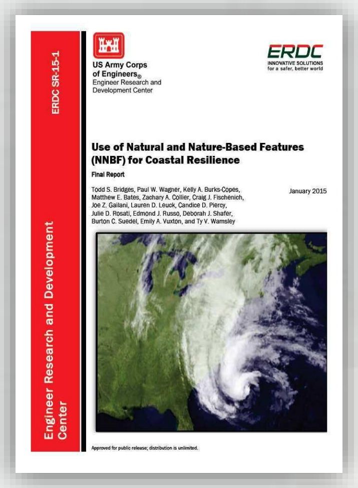
In the Context of Coastal Resilience…

- What opportunities are there for achieving better alignment of natural and engineered systems?
  - Can improved alignment reduce risks to life and property?
  - What range of services can be produced through such alignment?
  - What are the science and engineering needs in order to achieve better alignment?

Sustainable Solutions Vision: "Contribute to the strength of the Nation through innovative and environmentally sustainable solutions to the Nation's water resources challenges."

Natural and Nature-Based Features Evaluation and Implementation Framework

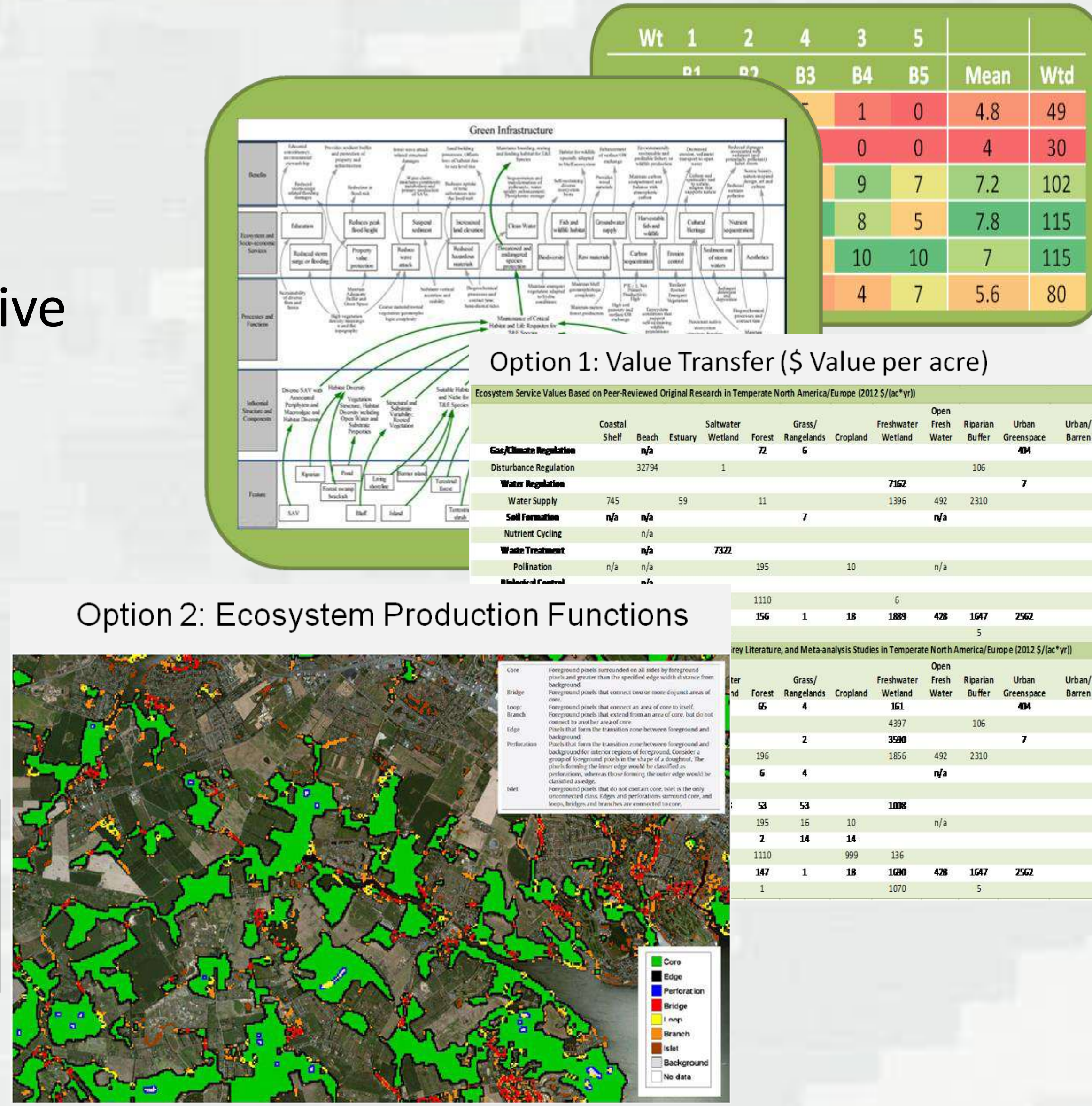




System Performance Evaluation

- **Level 1** – Qualitative characterization of performance
- **Level 2** – Semi-quantitative characterization of performance
- **Level 3** – Quantitative characterization of performance

72 individual performance metrics identified for NNBF



North Atlantic Coast Comprehensive Study: Identifying NNBF Ecosystem Services

Metric	Average	Stdev	Max	Min	Relative Mean	Median	n
Reduce storm surge and related flooding	81.2	25.9	100	0	7%	95	47
Reduce wave attack	80.0	26.8	100	0	7%	90	47
Erosion protection and control	78.6	24.7	100	15	7%	85	47
Reduce the peak flood height and lengthen the time to peak flood	75.9	29.3	100	0	7%	90	47
Habitat for fish and wildlife provisioning	69.9	32.4	100	0	6%	90	47
Threatened and Endangered species protection	66.6	32.4	100	0	6%	80	47
Clean water provisioning	64.7	31.3	100	0	6%	75	47
Biological diversity	64.3	32.0	100	0	6%	70	47
Recreation	61.2	27.4	100	5	5%	60	47
Property value protection	56.8	33.3	100	0	5%	70	47
Reduce hazardous or toxic materials in water or landscape	55.9	32.3	100	0	5%	60	47
Nutrient sequestration or conversion	52.6	31.2	100	0	5%	60	47
Increase or maintain land elevation and land-building	52.2	32.6	100	0	5%	50	47
Education and scientific opportunities	49.1	31.3	100	0	4%	50	47
Commercial harvestable fish and wildlife production	48.7	32.8	100	0	4%	50	47
Aesthetics	47.6	28.8	100	0	4%	50	47
Provision and storage of groundwater supply	47.4	31.2	100	0	4%	50	47
Carbon sequestration	46.8	30.1	100	0	4%	50	47
Maintain background suspended sediment in surface waters	45.0	26.6	80	0	4%	50	47
Cultural heritage and identity	44.3	29.1	100	0	4%	50	47
Raw materials production	22.3	25.6	100	0	2%	10	47

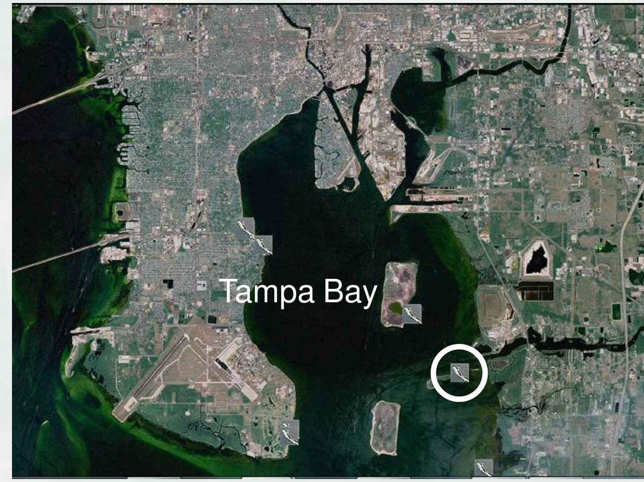
North Atlantic Coast Comprehensive Study (NACCS)

Case Studies from NNBF Report

1. Proof of concept analysis
   - Quantify benefits of environmental restoration projects using an ecosystem goods and services (EGS) analysis framework
2. Hurricane Sandy case study
   - Use extreme event to improve understanding of restoration effectiveness & benefits
3. Focused on two general types of services:
   - Flood damage Reduction
   - Wildlife Habitat (emphasis on T&E species)
4. 3 Study Sites
   - Jamaica Bay
   - Cape May Meadows
   - Cape Charles South

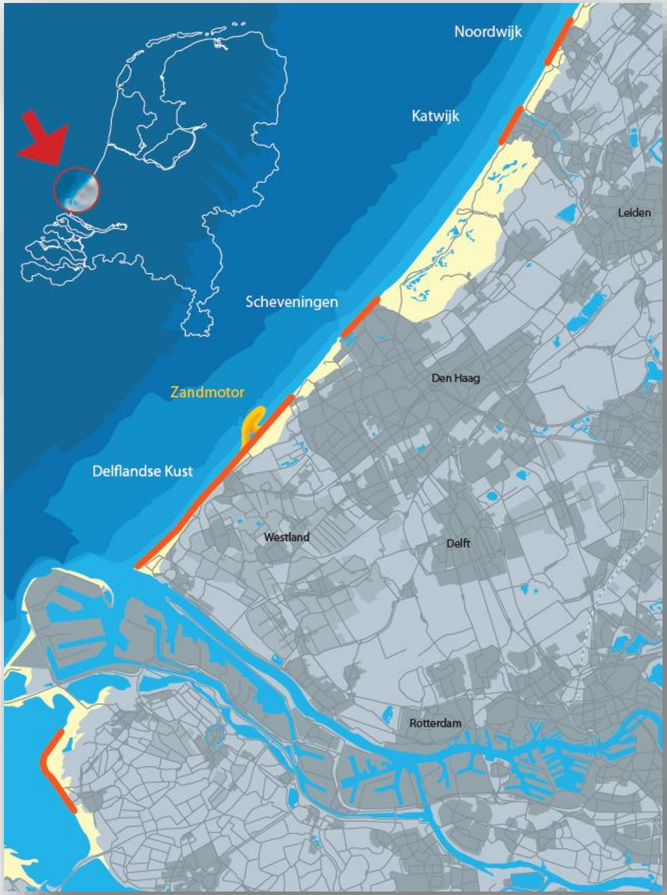
Alafia Banks Bird Sanctuary, FL

- 8000 lb reef module breakwaters (930 ft)
- Shore protection for Audubon bird sanctuary islands
- Help restore oyster populations
- Provide habitat



www.reefball.org

Dutch Sand Engine

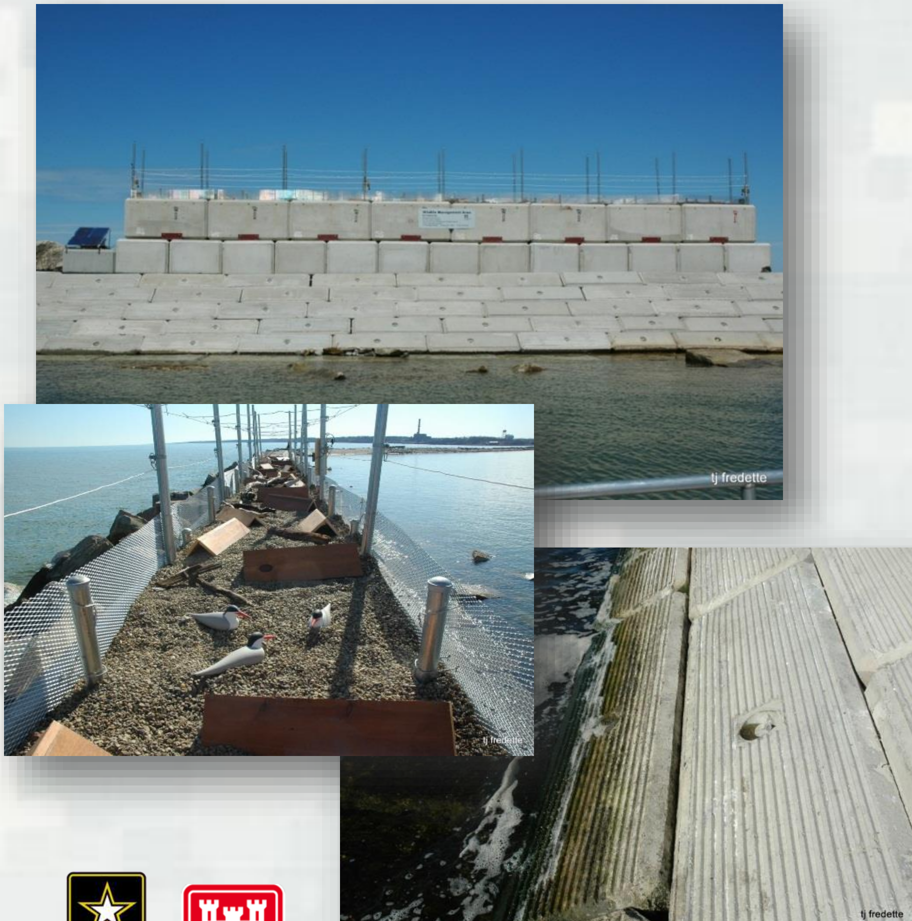


- 2011 construction
- 21.5 mcm of sand

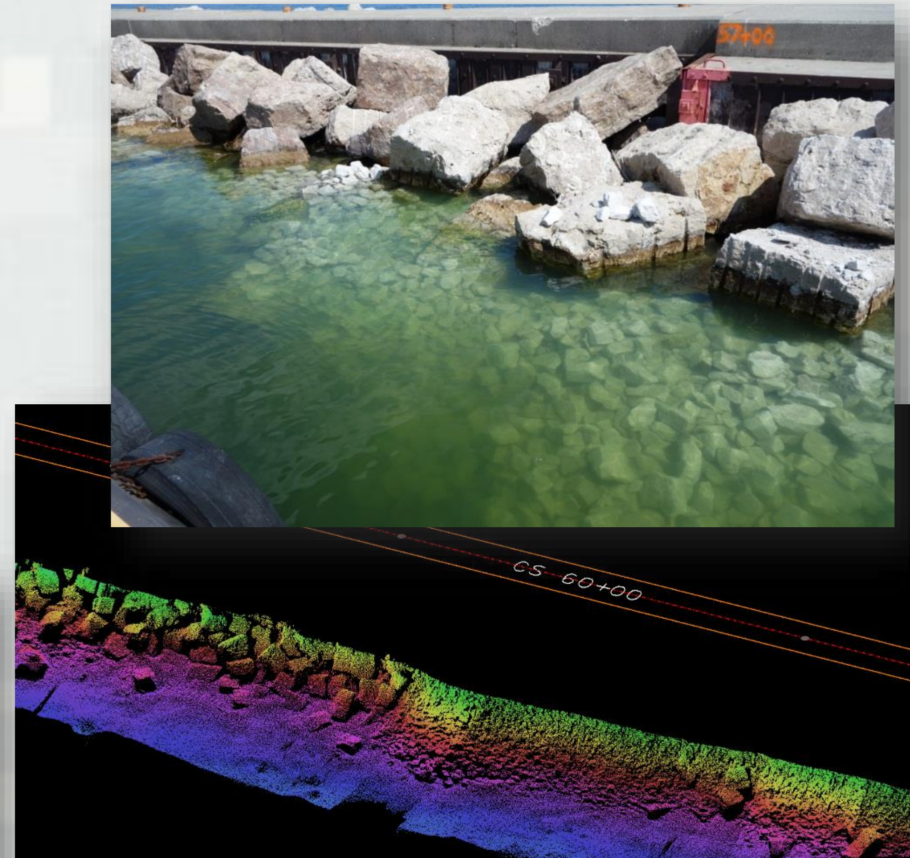
Fort Pierce City Marina

Example EWN Solutions: Green Breakwaters

Ashtabula Harbor



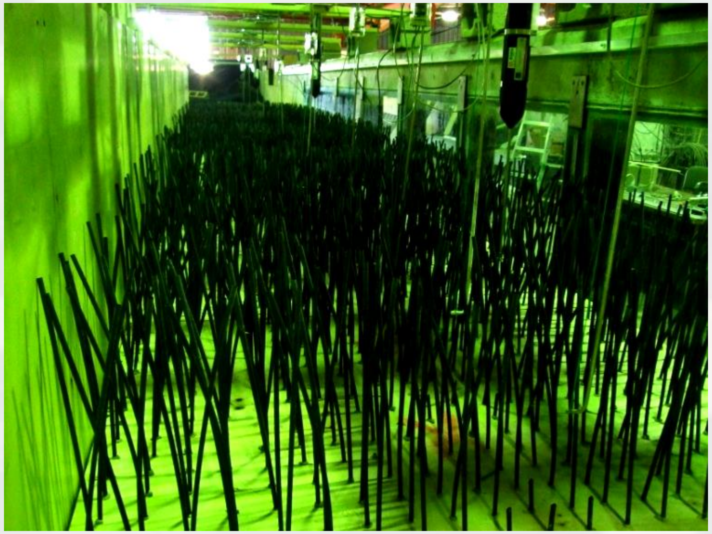
Milwaukee Harbor

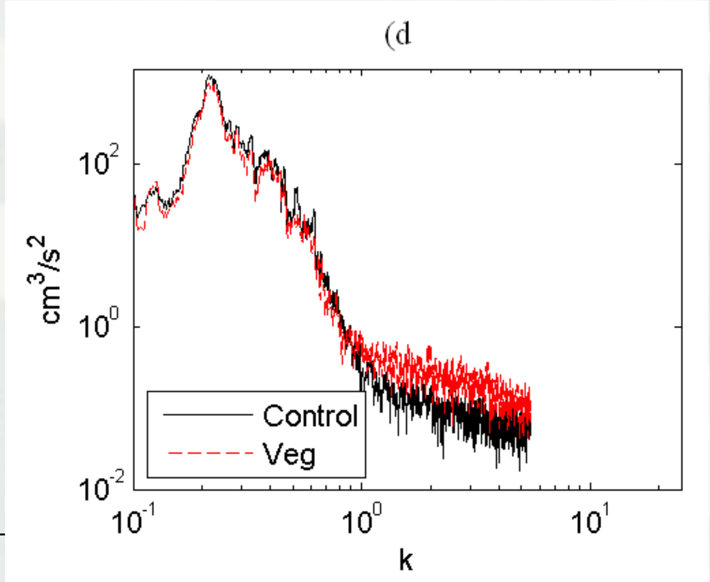


Coastal Dunes
Piha, New Zealand

R&D Example: Engineering Performance of NNBF

- What are the engineering benefits of wetlands with respect to waves?
- Studies being performed in the 10 ft flume
  - Complemented with field studies
- Wave attenuation was found to:
  - increase with stem density
  - increase with submergence ratio
  - slight increase with incident wave height
- Sedimentation processes:
  - Reduced velocity, but increased turbulence



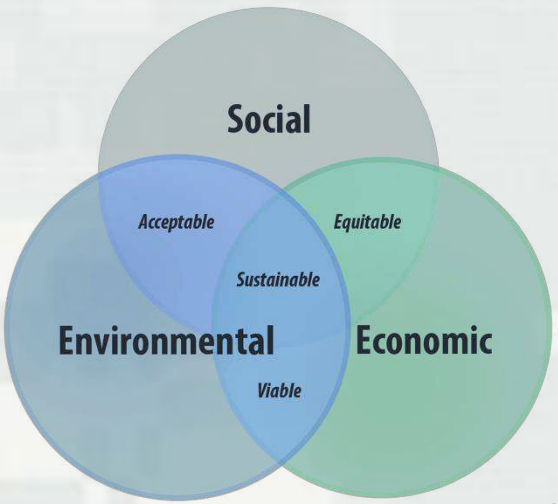


Engineering With Nature…

…the intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental and social benefits through collaborative processes.

Key Elements:

- Science and engineering that produces operational efficiencies
- Using natural process to maximum benefit
- Broaden and extend the benefits provided by projects
- Science-based collaborative processes to organize and focus interests, stakeholders, and partners



EWN Status

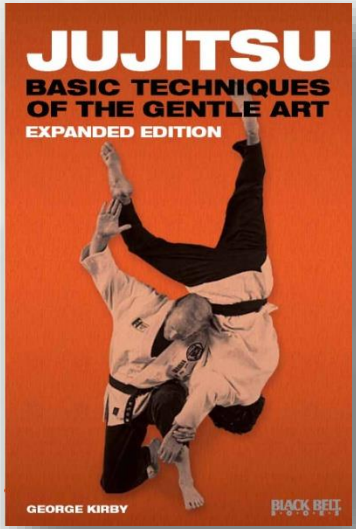
- *Engineering With Nature* initiative started within USACE Civil Works program in 2010. Over that period we have:
  - Engaged across USACE Districts (23), Divisions, HQ; other agencies, NGOs, academia, private sector, international collaborators
    - Workshops (>20), dialogue sessions, project development teams, etc.
  - Implementing strategic plan
  - Focused research projects on EWN
  - Field demonstration projects
  - Communication plan
  - District EWN Proving Grounds established
  - Awards
    - 2013 Chief of Engineers Environmental Award in Natural Resources Conservation
    - 2014 USACE National Award-Green Innovation

www.engineeringwithnature.org

ERDC

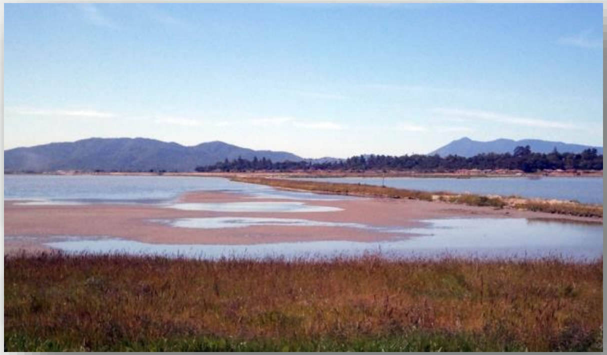
Opportunities to *Engineer With Nature*

- **Key Factors, the 4 Ps**
  - Processes
    - Physics, geology, biology…
    - Foundation of "coastal engineering Jujitsu"
  - Programmatic context
    - Planning, engineering, constructing, operating, or regulating
  - Project scale
    - Individual property owner to an entire coastal system
  - Performance
    - Configuring the system
    - Quantifying the benefits



EWN Action Demonstration Projects, 1

- Sediment Retention Engineering to Facilitate Wetland Development (San Francisco Bay, CA)
- Realizing a Triple Win in the Desert: Systems-level Engineering With Nature on the Rio Grande (Albuquerque, NM)
- Atchafalaya River Island and Wetlands Creation Through Strategic Sediment Placement (Morgan City, LA)
- Portfolio Framework to Quantify Beneficial Use of Dredged Material (New Orleans and New England)
- Engineering Tern Habitat into the Ashtabula Breakwater (Ashtabula, OH)
- Living Shoreline Creation Through Beneficial Use of Dredged Material (Duluth, MN)
- A Sustainable Design Manual for Engineering With Nature Using Native Plant Communities



EWN Action Demonstration Projects, 2

- Landscape Evolution of the Oil Spill Mitigation Sand Berm in the Chandeleur Islands, Louisiana
- Guidelines for Planning, Design, Placement and Maintenance of Large Wood in Rivers: Restoring Process and Function (Collaboration with BoR)
- The Use and Value of Levee Setbacks in Support of Flood Risk Management, Navigation and Environmental Services (a strategy document)
- Strategic Placement of Sediment for Engineering and Environmental Benefit (an initial guide to opportunities and practices)
- Use of Activated Carbon to Manage Contaminant Exposures Associated with Open-Water Placement

Horseshoe Island EWN Project
Atchafalaya River

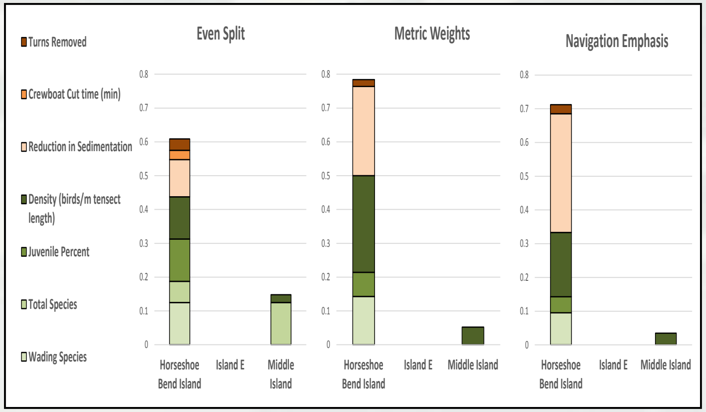
- Options for managing dredged material via shore-based wetland creation were exhausted
- Strategic placement of sediment (0.5-1.8 mcy/1-3 yrs) was used to create a ~35 ha island

- Producing significant environmental and engineering benefits
- Project won WEDA's 2015 Award for Environmental Excellence

Using Dredged Material Best Practices and Nature to Create River Island Habitat in Coastal Louisiana, USA

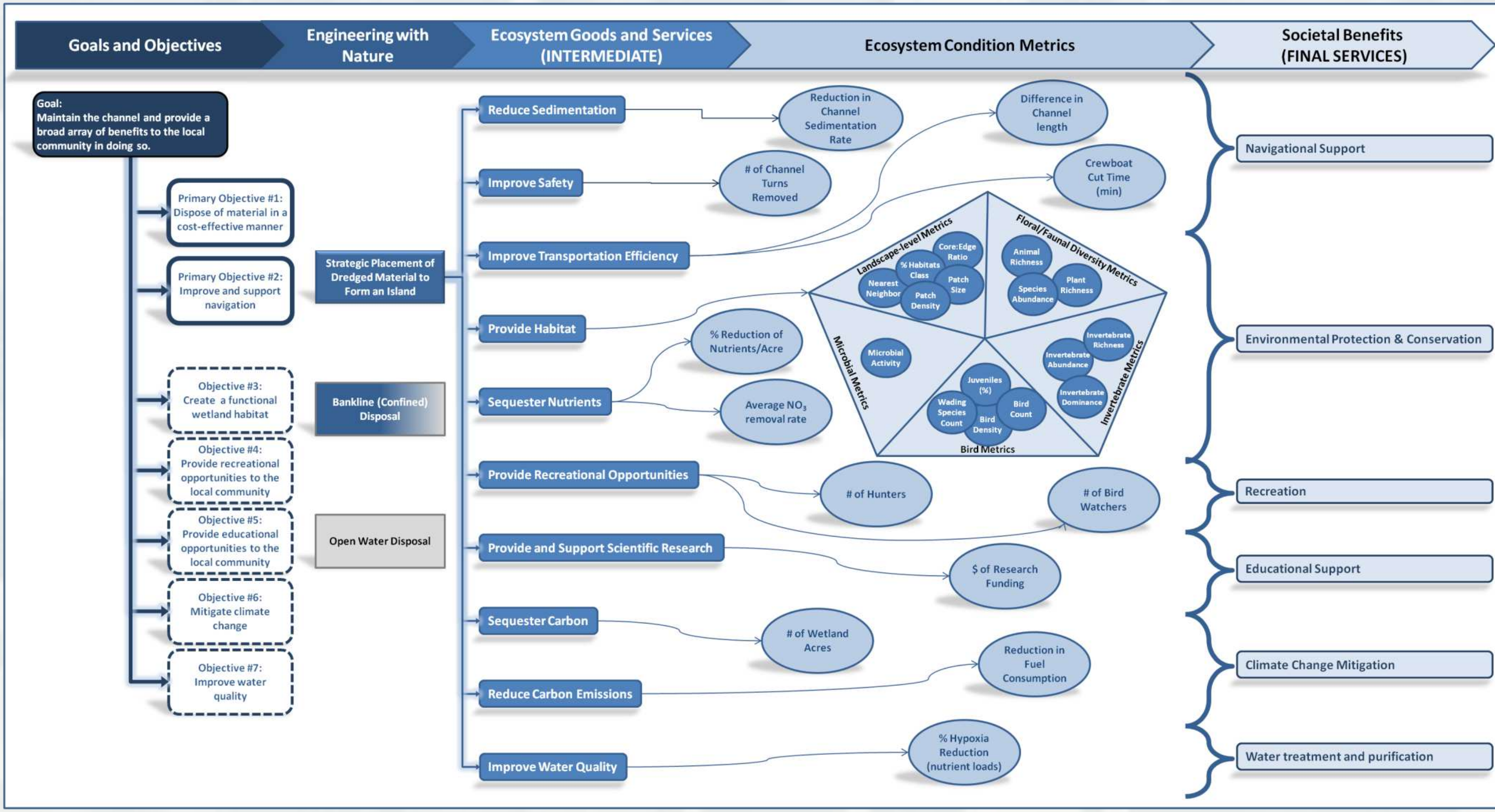
Approach

1) **Generate** a short list of EGS
2) **Develop metrics** to quantify the EGS benefits using readily available data
   - Species-based
   - Hydrological
   - Landscape-level
3) **Calculate** and **compare** benefits from Horseshoe Island vs. control sites (both natural and artificial)
4) **Develop** and **apply** a tool to perform tradeoffs transparently



Ecosystem Goods and Services	Description	Potential Metrics
Habitat Value	The maintenance of ecosystems' structural and functional qualities and resilience to adapt to change over time. Includes all non-use or passive use services (existence, intergeneration bequest, or altruistic values) derived from the diversity or condition of species, or ecosystems.	acres of habitat added
Water Treatment & Purification	The filtration and removal of excess nutrients or pollutants by ecosystems from inland, coastal or marine waters.	mass of nitrogen absorbed by the created landscape, that would otherwise pass downstream
Carbon Sequestration	Ecosystem moderation of adverse climate effects through sequestration of greenhouse gases.	difference in kg of carbon contained at the site before and after placement
Recreation Opportunities	Quantity and quality of recreational opportunities.	annual visits for fishing opportunities
Natural Hazard Mitigation	Ecosystem reduction of risk of or vulnerability to natural hazards that threaten property, infrastructure, human safety, or natural resources. Threats include storms, floods, landslides, fires and droughts.	incremental difference in property risk from flooding
Human Health	Ecosystem reduction of the risk of or vulnerability to health hazards other than water quality. Includes changes in air quality, environmental stressors, and animal or insect disease vectors.	*value of incremental change in health for people benefitting from hazard mitigation*
Cultural, Spiritual & Educational Support	Maintenance of opportunities arising from sites and landscapes that have spiritual or religious significance, contribute to a 'sense of place,' or sustain cultural heritage, including traditional ways of life. Also includes opportunities for scientific discovery and education.	number of classes visiting the site annually
Navigation Maintenance	Ecosystem maintenance and regulation of unobstructed transport of goods and people provided by water bodies.	change frequency of necessary dredging
Raw Goods & Materials Provisioning	Provisioning of or contribution to raw goods and materials.	value of annual harvest
Food Provisioning	Provisioning of or contribution to commercial or subsistence production of food and the ecosystem conditions that support it.	value of additional fish resulting from creating of spawning grounds

Ecosystem Services Causal Chain



USACE Galveston, Buffalo, Philadelphia Districts: EWN "Proving Grounds"

- EWN Proving Ground Kick-Off Workshops
  - October (SWG) and December (LRB) 2014
  - ~70 participants
  - SWG, SWD, LRB, ERDC, IWR and HQ
- Identified opportunities to implement EWN within current and future programs and projects
- Emphasis on solution co-development

Coastal NJ, Philadelphia District

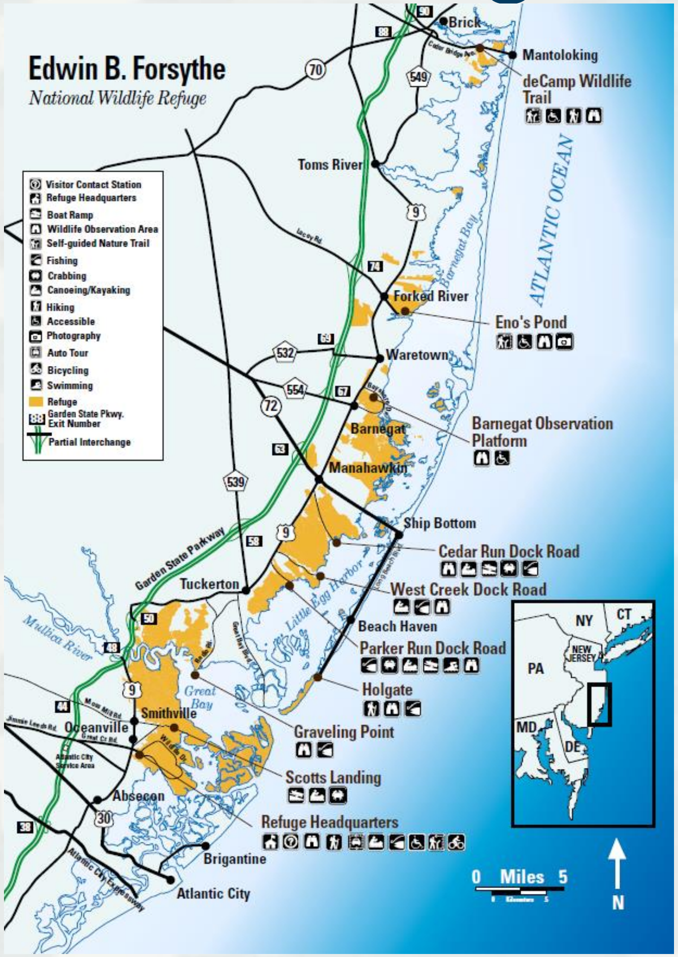
December 2014

Stone Harbor

Avalon

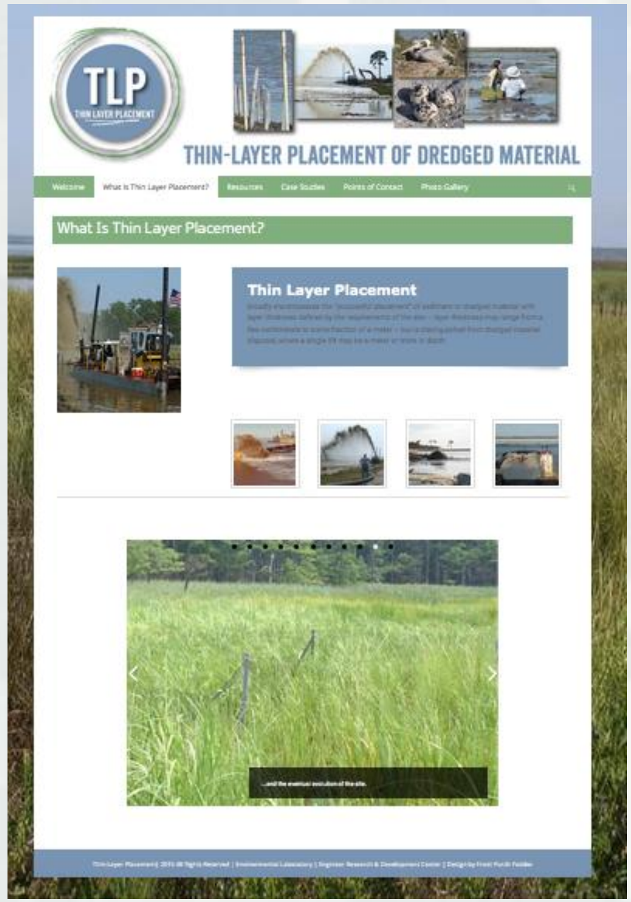
US Fish and Wildlife Service Forsythe National Wildlife Refuge

- Forsythe NWR: >40,000 acres of wetlands and other habitat in coastal NJ
- Collaboration objective: Enhance ecosystem resilience through engineering and restoration
- Means: Smart use of sediment resources and EWN principles and practices



Thin-Layer Placement Website

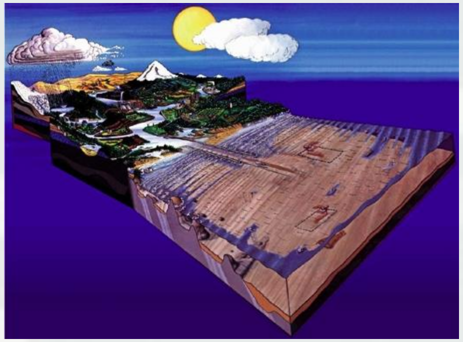
Coming soon to www.engineeringwithnature.org



Regional Sediment Management…

…a systems approach to deliberately manage sediments in a manner that maximizes natural and economic efficiencies to contribute to sustainable water resource projects, environments, and communities.

- Recognizes sediment as a valuable resource
- Regional strategies across multiple projects and business lines guide investments to achieve long-term economic and environmental value and benefits
- Enhances relationships with stakeholders & partners to better manage sediments across a region (local actions with regional benefits)
- Share data, tools, technology, and lessons learned



Science, Engineering, Technology Research Targets

- Fundamental processes
  - Sediment transport through and around NNBF
  - Long-term engineering and environmental performance of features
  - Environmental Services provided by engineered features and structures
  - Processes contributing to system-scale resilience
- Modeling systems that support broad-scale application
  - Planners, stakeholders and decision-makers
  - Engineering design
  - Operations and maintenance
- Reliable, cost-efficient monitoring technologies
  - Measuring system evolution
  - Infrastructure/feature performance
- Demonstration/pilot projects to innovate, evaluate, and learn at relevant field scales
  - Facilitate necessary collaboration
  - Evolve organizational culture and practice
  - Produce credible evidence of success
  - Fuel the "power of the story"

Next Steps for Science and Engineering…

- How will integrated infrastructure systems evolve over time in dynamic coastal environments?
- What processes and engineering requirements are critical to performance?
- How can integrated systems be assembled to reduce long-term operations and maintenance?
- How can field-scale demonstration projects be used to accelerate progress?

High Points

- Conservation of existing natural infrastructure can support future resilience
  - Incentivizing and financing
- Development of new nature-based features can enhance system resilience
  - Incentivizing and financing
- Elevate communication about advancing practice
- Accelerate progress through co-development of solutions
  - Across government
  - Between government and industry
  - Among government, industry, academia, and NGOs