ENGINEERING WITH NATURE ON THE GREAT LAKES

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US Army Engineer Research and Development Center
Vicksburg, MS
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Program overview

Natural and nature-based features

Wetlands: waves, water levels, & design

Examples

Ways to work with USACE
The escalating costs of dredging
Sustainability

Sustainability is achieved by efficiently investing resources to create present and future value.
Engineering With Nature®

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

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® Overview

Engineering With Nature® began in 2010
- Engaging across USACE, other agencies, NGOs, academia, private sector, international collaborators
- Guided by a strategic plan
- Established through Proving Grounds
  - Galveston, Buffalo, Philadelphia
- Informed by focused R&D
- Demonstrated with field projects
- Advanced through partnering
- Shared by strategic communications
- Marking progress
  - 2013 Chief of Engineers Environmental Award in Natural Resources Conservation
  - 2014 USACE National Award-Green Innovation
  - 2015, 2017 WEDA Awards; 2017 DPC Award

www.engineeringwithnature.org
EWN® across USACE Mission Space

Navigation
- Strategic placement of dredged material supporting habitat development
- Habitat integrated into structures
- Enhanced Natural Recovery

Flood Risk Management
- Natural and Nature-Based Features to support FRM
- Levee setbacks

Ecosystem Restoration
- Ecosystem services supporting engineering function
- “Natural” development of designed features

Water Operations
- Shoreline stabilization using native plants
- Environmental flows and connectivity
Natural and Nature-Based Features

NNBF are landscape features that are developed to provide engineering functions relevant to flood risk management while producing additional economic, environmental and social benefits.
Leveraging nature for engineering value

Following Hurricane Sandy:
• Risk industry-based tools used to quantify the economic benefits of coastal wetlands
  – Temperate coastal wetlands saved more than $625 million in flood damages.
  – In Ocean County, New Jersey, salt marsh conservation can significantly reduce average annual flood losses by more than 20%.
**Why wetlands over concrete?**

**Co-benefits!!**

<table>
<thead>
<tr>
<th>Supporting</th>
<th>Sediments – trapping and formation</th>
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<tbody>
<tr>
<td></td>
<td>• Organic matter</td>
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<td>• Fodder</td>
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<td>• Water purification</td>
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<th>Supporting</th>
<th>Biological productivity</th>
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<tr>
<td></td>
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<td>• Biodiversity</td>
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<tr>
<th>Supporting</th>
<th>Coastal Protection</th>
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<tbody>
<tr>
<td></td>
<td>• Livelihoods (fishing, harvesting)</td>
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<td>• Eco-tourism</td>
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</table>

**Co-benefits**:
- Supporting Provisioning Regulating Cultural
- Sediments – trapping and formation
- Organic matter
- Fodder
- Water and Nutrients – recycling and storage
- Water
- Flood storage
- Water purification
- Biological productivity
- Food (fisheries)
- Wood (fuel, construction)
- Species-richness
- Biodiversity
- Coastal Protection
- Livelihoods (fishing, harvesting)
- Eco-tourism

**from Orvis**
Wetland NNBF: evidence for use

- wetlands and marshes are the most published NNBF in the context of reducing impacts of waves, surge, and erosion (Webb, University of Southern Alabama)
- **70+** studies encompassing:
  - **field**: measurements, observations
  - **laboratory**: isolating responses
  - **modeling**: mechanistic processes; regional, landscape applications; predictive capability

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**Pie Chart: Distribution of NNBF**

- Vegetated: 36%
- Maritime Forests: 16%
- Reefs: 8%
- Barrier Islands: 3%
- Rocks: 5%
- Multiple: 11%
- Other: 8%
- Dunes & Beaches: 13%
In what context do wetlands make sense?

- In an environment where wetlands can persist
  - Rocky coasts
  - Soft cliffs
  - Banks
  - Wetlands
  - Mudflats
  - Sandy beaches and dunes
  - Wetland erosion should be balanced with sediment accumulation

- Where they can provide the desired co-benefits
  - Co-benefits are not uniformly produced at all locations.

- Where they can provide the required engineering performance
  - Education, outreach, and guidance are required to ensure wetlands are accepted.

- Where they are accepted
  - Wetlands in some areas can reduce flood damages but may increase them in others.

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from Narayan and Beck 2017

from TNC Mangroves for Coastal Defence: Guidelines for coastal managers & policy makers
Modes of flood risk management

- Erosion reduction
  - Reduces future flood risk
  - Required area
    - Evidence base for use
  - We have evidence for all modes but as risks increase, the evidence base required increases. **Lives are at stake.**

- Accretion/adaptation
  - Maintains or decreases future flood risk
  - Erosion reduction
    - Required area
      - Evidence base for use

- Wave attenuation
  - 10s meters
  - Reduces wave component of water levels
  - Surge attenuation
    - 100-1000s+ meters
    - Reduces surge component of water levels
  - Flood storage
    - 1000s+ cubic meters
    *note change in units

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  - 1000s+ cubic meters
  *note change in units
Erosion reduction

Strategies to cope with SLR can be adapted to the Great Lakes as a way to cope with fluctuating lake levels

from Leonardi et al, 2018

from Erie Conservation District

from MI Natural Shorelines Partnership

US Army Corps of Engineers ∙ Engineer Research and Development Center
Surge attenuation

**Relevant variables**
- Wind direction and duration
- Storm speed and direction
- Landscape position
- Bathymetry
- Wetland morphology
- Vegetation characteristics

**Reported attenuation**
- 1 m/1.4 km to 1 m/25 km
- Most effective for fast-moving storms with smaller storm surges
- May locally increase water levels

Image from Smolders et al., 2015

Proportion of total surge volume passing over marsh

Equation:
\[ \frac{dHWL}{dx} = -36.2 \cdot \alpha_v + 8.0 \]
\[ R^2 = 0.921 \]
\[ p < 0.001 \]
Wave Attenuation

- Evidence of wave height reduction available from field measurements, laboratory studies and numerical modelling
- Attenuation comes from the vegetation AND the topography
Field Studies

- Attenuation at least 2x greater over vegetation than mudflats (Moller et al. 1999, Cooper 2005, Yang et al. 2012)
- Attenuation greater with taller, rigid growth forms (Ysebaert et al. 2011)
- Seasonal patterns of wave attenuation correspond to growth cycles (Moller et al. 2006, Paul and Amos 2011)
- Most field studies generally conducted in low wave energy environments
- Variability in wave dissipation is large due to extensive variety of plants
  - on average, salt marshes reduced wave heights by 72% (Narayan et al. 2016, considering 69 field measurements)
- Field efforts serve as a body of evidence and foundation for laboratory efforts
Laboratory Studies

- laboratory offers a controlled environment to perform parametric analyses
  - identify **critical wave reduction factors** and isolate response as factors are manipulated
- vegetation modeled using **artificial, idealized** plant mimics most extensive approach
  - wooden dowels, foam, rope, flexible molded plastic

- **Spartina alterniflora** mimics
  - three stem densities (100, 200, 400 stems/m²)
  - hydrodynamic conditions with varying wave heights, wave periods, and water levels (submerged to emergent)
  - increase with stem density (15% bare vs 60% 400 stems)
  - decrease with deeper water (30% sub vs 64% emergent)
Wave Reduction Factors

- Stem density and height ↑, attenuation ↑
- Stem stiffness ↑, attenuation ↑
  - But stiffer vegetation may be more prone to damage/failure
  - Flexible vegetation may lay prone and protect soil during storms
- Marsh width ↑, attenuation ↑
  - Greatest reduction occurs over the first few meters
  - Additional wetland extents do not lead proportional increases in wave damping
- Water depth ↑, attenuation ↓
  - Emergent most effective
  - Decreases with larger ratios of water depth : vegetation height
- Incoming wave height and period ↑, attenuation ↓
  - Larger periods need longer distance to travel through vegetation for substantial dampening

Emergent, stiffer, denser, and taller vegetation dissipate wave energy more effectively than submerged, flexible, and short-stemmed vegetation.
Wave Modeling

- numerical modeling allows for scaling to local and regional landscape scales
- incorporated into STWAVE (Anderson and Smith 2015), SWAN (Suzuki et al. 2011), XBEACH
- common inputs include **stem density, stem height, stem diameter**, and a **drag coefficient**
  - drag coefficient is calibrated and accounts for unknown plant behavior and bio-mechanical properties
- Jamaica Bay, NY example
  - waves generated by southerly winds during a hypothetical hurricane
  - significant wave mitigation along northern shoreline due to vegetation and associated bathymetry modifications

![Wave Height Comparison](image_url)
Incorporating with Infrastructure

• wave attenuation services of vegetation may be incorporated into hybrid engineering solutions, creating operational and maintenance benefits
• common configuration is dike accompanied by a vegetated foreshore
• Rupp-Amstrong and Nicholls (2007)
  - considerable amounts of money spent to build up salt marshes in front of bare dikes and to sustain existing dike-fronting salt marshes in Germany
  - with 80-m-wide salt marshes, a 3-m-high seawall would be required (£400/m) whereas the seawall would have to be 12 m high (£5000/m) in their absence
• Vuik et al. 2018
  - method for comparison between nature-based flood defenses and traditionally engineered solutions
  - vegetated foreshores cause a reduction in failure probability for both wave overtopping and wave impacts
  - vegetation has the highest effect on failure probabilities at low protection levels
  - less important for more robust dikes because vegetation is not expected to survive the extreme wave conditions for which dike is designed

Fig. 7. Salt marshes along a Wadden Sea dike in the Netherlands (Fig. 6), with the Wadden Sea and the marshes on the right hand side of the dike. Photo: Beeldbank Rijkswaterstaat.
How do we implement wetland NNBF solutions?

- Conserve existing wetlands
- Restore degraded wetlands
- Expand the footprint of existing wetlands
- Build new wetlands

Data requirements
Modeling requirements
Regulatory involvement
Time required to see benefits
Cost
How do we design a wetland NNBF solution?

What are the objectives? Reducing erosion? Waves? Primary protection or hybrid? Focus on the aspects of the design we can control.

<table>
<thead>
<tr>
<th>Design parameter</th>
<th>Performance factors</th>
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<tbody>
<tr>
<td>Size and configuration (x,y)</td>
<td>Location along shore (river mouth, cove, etc.)</td>
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<tr>
<td></td>
<td>Total storage volume as a function of water level</td>
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<tr>
<td>Platform elevations (z)</td>
<td>Elevation relative to water level datum/water level range</td>
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<tr>
<td></td>
<td>Topography of wetland and transitions to other habitats</td>
</tr>
<tr>
<td></td>
<td>Range of elevations</td>
</tr>
<tr>
<td>Channel network</td>
<td>Drainage density, sinuosity, junction angles etc.</td>
</tr>
<tr>
<td></td>
<td>Channel width and depth</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Species (height, shape, density, flexibility, roots)</td>
</tr>
<tr>
<td></td>
<td>Distribution, zonation, and combination of plants</td>
</tr>
<tr>
<td>Sediment properties (when constructing)</td>
<td>Grain size, organic matter, bulk density, shear strength</td>
</tr>
<tr>
<td>Nearshore bathymetry</td>
<td>Depth, slope, sediment properties of adjacent subtidal mud/sand flats</td>
</tr>
<tr>
<td></td>
<td>Proximity to deep water</td>
</tr>
<tr>
<td>Proximity to traditional defenses</td>
<td>Distance to defense, configuration and geometry of defense</td>
</tr>
<tr>
<td>Upland transition</td>
<td>Upland slope, proximity to structures, adjacent vegetation communities</td>
</tr>
</tbody>
</table>
Northerly Island Ecosystem Restoration, Chicago, IL

U.S. Army Corps of Engineers and City of Chicago

Under

Section 506 Great Lakes Fishery & Ecosystem Restoration
Engineering:
- Hydrological Modeling – wave/storm intensity
- Geotechnical Assessment – substrate properties, use of hard features (concrete, boulders), design of slopes

Integrated Natural Features:
- Planting – species selection
- Erosion Control
- Wetland for Spawning Fish (nursery)

Integrated Recreation:
- Paved walking/biking trail
- Wildlife viewing
• Monitoring and Adaptive Management

• Storm Damages and Sustainable Solutions
Partnering with US Army Corps of Engineers

Programs Requiring Specific Authorization
• General Investigations (GI)
• Section 219 (Environmental Infrastructure)

Continuing Authority Programs
• Section 107 Navigation
• Section 111 Mitigation of Shore Damage Attributable to Navigation Works
• Section 1135 Project Modifications for Improvements to the Environment
• Section 204 Beneficial Use of Dredged Material
• Section 205 Flood Risk Management
• Section 206 Aquatic Ecosystem Restoration
• Section 208 Snagging and Clearing for Flood Risk Management
• Section 14 Emergency Streambank and Shore Protection
• Section 103 Small Hurricane and Storm Damage Reduction Projects (Beach Erosion)

Other Programs
• Planning Assistance to States (PAS)
• Great Lakes Fishery & Ecosystem Restoration (GLFER)
• Great Lakes Regional Sediment Management (GLRSM)
• Great Lakes Remedial Action Plans (GLRAP)
• Great Lakes Tributary Modeling Program (GLTMP)

Cat Island Dredged Material Disposal Facility and Ecosystem Restoration, Green Bay, WI
Collaboration opportunities with EWN®

Collaboration Across Government


USACE/NOAA-NMFS Collaboration Workshop Engineering With Nature, Gloucester, MA; October 5-6, 2016

Collaboration with Academia

- Texas A&M University
  - Partnering through the Coastal Science and Engineering Collaborative (CSEC)
  - Joint research on NNBF
  - EWN Seminar spring 2018
  - Developing graduate curriculum to support EWN

- University of Georgia
  - Institute for Resilient Infrastructure Systems (IRIS)
  - CRADA and Educational Partnering Agreement
  - Multiple levels of collaboration on EWN and NNBF
  - EWN curriculum development

Collaboration with the Private Sector

- Caterpillar Inc.
  - Restoring Natural Infrastructure Summit; November 4th, 2015; New York City
  - Natural Infrastructure Initiative – USACE Collaboration Work Streams
    1. NI Opportunity Evaluation Tool: Capitalizing on enterprise-level capability: CE Dredge DST
    2. Evaluation and Decision Making
    3. Field Application and Demonstration

- Western Dredging Association (WEDA)
  - Collaborative technical workshop on engineering and construction techniques for Engineering With Nature
International Guidelines on the Use of Natural and Nature-Based Features for Sustainable Coastal & Fluvial Systems

Purpose: Develop guidelines for using NNBF to provide engineering functions relevant to flood risk management while producing additional economic, environmental and social benefits.

- Publish NNBF technical guidelines by 2020:
  - Multi-author: government, academia, NGOs, engineering firms, construction companies, etc.
  - Addressing the full project life cycle
  - Guidelines in 4 Parts
    - Overarching
    - Coastal Applications
    - Fluvial Applications
    - Conclusions
QUESTIONS?

http://engineeringwithnature.org OR https://ewn.el.erdc.dren.mil/

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EWN AT SOO LOCKS
ONEHUNGA BAY FORESHORE RESTORATION
AUCKLAND, NEW ZEALAND
USACE PHILADELPHIA DISTRICT: EWN IN BACK BAY NEW JERSEY

Mordecai Island

Stone Harbor

Avalon
HUMBER ESTUARY; ALKBOROUGH, UK
(INCREASED FLOOD STORAGE CAPACITY)
FORT PIERCE CITY MARINA, FLORIDA
SOIL P SORPTION CAPACITY IN AGRICULTURAL TREATMENT WETLANDS

Soil phosphorus sorption capacity can be utilized to determine how much more phosphorus can be sequestered in a treatment wetland.

Franklin Research and Demonstration Farm, Lexington, IL.
Negative sorption capacity = soil sorption sites are full and phosphorus will not be retained. Water soluble phosphorus increases with negative sorption capacity.

Phosphorus decreases from treatment wetland 1, 2, 3, and the capacity to retain phosphorus increases from treatment wetland 1, 2, 3.