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Water Operations Technical Support (WOTS) and Dredging Operations Technical Support (DOTS)

Proceedings from the Basin Sediment Management for Unique Island Topography Workshop, Mayagüez, Puerto Rico

Rhonda Fields, Damarys Acevedo-Acevedo, Burton C. Suedel, E. Michelle Bourne, Pat Deliman, Carlos Ruiz, Jack Milazzo, Ismael Pagán-Trinidad, Luis Villanueva-Cubero, Dave Hampton, Billy Johnson, and Tim Dekker

October 2023



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Environmental Laboratory

Cover Photo:

Boquilla Nature Reserve at the La Boquilla Village and El Seco communities in Mayagüez, Puerto Rico. This site is where saltwater from Mayagüez beach mixes with freshwater from the Caño Boquilla. While residents in the surrounding communities continue to face major flooding events, they are not willing or are unable (due to social or economic challenges) to relocate (photo by Damarys Acevedo-Acevedo).

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Final report

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Abstract

This report summarizes the Basin Sediment Management for Unique Island Topography Workshop hosted in-person and virtually at the University of Puerto Rico Mayagüez (UPRM) Department of Civil Engineering and Surveying, Mayagüez, Puerto Rico on 11 March 2022. The workshop was attended by approximately 80 federal, state, local, and academic organizations participants. It focused on Engineering With Nature® (EWN®), green infrastructure (GI) and low impact development (LID) opportunities for unique tropical island topography and included seven presentations from subject matter experts, a discussion on limitations and problems with prior projects, and two concurrent breakout sessions.

Preworkshop activities included a field trip to multiple sites in the Añasco watershed conducted 09 March 2022, which served as a base case for the workshop. The field trip provided participants a unique perspective of the island's topography and post 2017 Hurricane María issues and impacts.

During the breakout sessions, participants identified new project opportunities for EWN®-GI and LID at two selected sites from the field trip. Each group developed alternatives for their chosen site and identified concepts that could turn into great opportunities for the surrounding communities and significantly benefit the state of practice in Puerto Rico's unique tropical island topography.

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Preface

The writing of this report was funded by the Water Operations Technical Support (WOTS) and Dredging Operations Technical Support (DOTS) programs, Drs. Pat Deliman and Burton Suedel, program managers, respectively.

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COL Christian Patterson was the commander of ERDC, and Dr. David W. Pittman was the director.

1 Introduction

1.1 Background

In September of 2017, two major hurricanes, Irma and María, made landfall in Puerto Rico, destroying many homes and businesses, losing over 90% of the power grid, wireless communication, access to potable water, and flooding in many areas throughout the island. Hurricane María, the largest hurricane to hit Puerto Rico since 1928, made landfall in the southeast coast with sustained winds just under 155 miles per hour (249 km/hr) and tracked over 75 miles (121 km) through the heart of the island, exiting in the northwest coast (Kwasinski et al. 2019). Since that time, many steps have been taken to restore the island, reduce the risks associated with the impacts of natural hazards, and improve resilience of buildings and infrastructure.

Puerto Rico suffers from numerous stresses. Of these, the implementation of Engineering With Nature® (EWN®) initiatives for green infrastructure and low-impact development (GI-LID) can address urban deforestation and poor access to green spaces, improper use of the land, vulnerable populations in high-risk areas, high-risk to natural hazards, sea-level rise, coastal and riverine erosion, landslides, soil instabilities, limited governmental resources, and obsolete, deteriorated, and aging infrastructure. Currently, Puerto Rico has approximately 331,322 structures and 200,000 homes within the floodplain area, with 488,844 people living at risk of floods[1]. Puerto Rico is overpopulated with hundreds of communities living in remote clusters prone to hazards and isolation due to floods and other natural challenges; 44 municipalities are located on the coast. This makes the implementation of these initiatives even more important for human and nature well-being.

Two programs within the US Army Corps of Engineers (USACE), the Water Operations Technical Support (WOTS) and Dredging Operations Technical Support (DOTS), support the flood risk management program for Puerto Rico. Integrating these two programs with EWN® concepts and

[1] Reimagine Puerto Rico's Recovers Process Through and Integrated Flood Risk Management Lens (Gonzalez, Juan, A. Reimagina Puerto Rico.) https://asfpm-library.s3-us-west-2.amazonaws.com/General/JAG_Presenation_PR_IFM_2019.pdf

practices provides resilient, sustainable, and ecologically friendly solutions to water and dredging problems. The WOTS Program was initiated in 1985 to support technology transfer efforts for environmental and water quality operational studies. It provides effective environmental and water management engineering technologies to address a wide range of water resource management problems at USACE's reservoir and waterway projects, and in the river systems affected by project operations nationwide.

The WOTS program provides technology to solve water management and related environmental problems resulting from the presence of nonindigenous aquatic species and tailwater fisheries at pump-back hydropower projects. The program also examines water management impacts of shoreline erosion control and reservoir sedimentation, and other project operations related to environmental and water management issues. Since its inception, the WOTS program has provided environmental and water management technological solutions to over 1,100 problems identified at projects from every USACE District. The program annually publishes and distributes user manuals, information bulletins, technical notes, and technical reports. In addition, the program annually conducts specialty workshops and trains personnel on the latest environmental and water management techniques.

The DOTS Program provides environmental and engineering technical support to the USACE operations and maintenance navigation and dredging missions. Technology transfer products and activities support diverse field needs that directly benefit navigation and dredging operations throughout the US.

The WOTS and DOTS program's personnel worked collaboratively with the University of Puerto Rico, Mayagüez Campus (UPRM), Department of Civil Engineering and Surveying, and the Federal Emergency Management Agency (FEMA) to host a workshop that was part of a three-day Puerto Rico River Basins Symposium from 09–11 March 2022. The WOTS and DOTS programs were feature considerations during the workshop, which sought new opportunities for implementing Engineering With Nature®–Green Infrastructure–Low Impact Development (EWN®-GI-LID) initiatives in Puerto Rico.

1.2 Purpose

The purpose of the workshop was to assemble subject matter experts (SMEs) from multiple disciplines to conceptualize research and development (R&D) geared towards identifying tropical island EWN®-GI-LID design questions that lead to demonstration projects and research strategies. These projects and research strategies evaluate outcomes for designing, constructing, and integrating EWN®-GI-LID types of features to assist in minimizing environmental damage from storm events.

EWN® shares concepts and constructs with the Ridge-to-Reefs initiative, which focuses on thriving, connected human and natural systems. Like Ridge-to-Reefs, EWN® works with local communities to develop nature-based solutions that create sustainable, resilient, healthy, and well managed river basins and coastal areas (IUCN 2022). This is particularly relevant in Puerto Rico; a land made up of ridges and reefs.

For the workshop, participants reviewed prior island best management practice designs and methods with a focus on projects using Natural and Nature-Based Feature (NNBF) construction methods consistent with EWN® principles. Alternative designs and construction methods were to be identified and discussed in context with integration of existing conventional construction techniques.

1.3 Objectives

By the close of the workshop, participants were able to do the following:

1. Identify technical design successes and lessons learned from prior tropical island design projects for basin sediment management.
2. Discuss opportunities and challenges of candidate island design techniques using EWN®-GI-LID technologies.
3. Identify those island EWN®-GI-LID design techniques that could be implemented for basin sediment management with unique short time of concentration limitations.
4. Identify design techniques that could be used for managing sediment removal in drinking water reservoirs to recover design capacity while promoting EWN®-GI-LID techniques.

2 Agenda and Workshop Structure

This one-day workshop followed a pre-symposium field trip to the Añasco River Watershed (09 March 2022) and a virtual and in-person Puerto Rico River Basin Symposium (From Mountain to Estuary, From Plan to Action, 10 March 2022). Participants attending the field trip and workshop are presented in Appendix A. Agendas for the field trip, symposium, and workshop are included in Appendix B.

2.1 Pre-symposium field trip

The pre-symposium field trip served as a baseline to the workshop, providing the attendees with a unique perspective of the island's topography. Four different sites located within the Añasco River Watershed were visited during the field trip. The agenda for this field trip is presented in Appendix B. The first site visited was the Ajíes Dam, which included the following three presenters:

- Luis A. Cruz-Arroyo (Nature Resources Conservation Service [NRCS] Caribbean Area Director)
- Yilia Baucage-Bou (NRCS Caribbean Area Engineer)
- Dr. Eric Harmsen (UPRM researcher)

In 1980 NRCS supported the Puerto Rico Department of Natural and Environmental Resources (DNER) in the construction of two Floodwater Retarding Structures within the Añasco River Watershed: The Dagüey and Ajíes Dams. Both earthen dams mitigate major flooding to the Añasco Valley Communities and industries downstream of the dam. The presenters discussed that the dams served its purpose during Hurricane María but suffered serious damage, which poses a flooding risk to the community and industries nearby due to overtopping through a structure like an earthen emergency spillway. A new project will be implemented to repair both structures and restore them to their pre-Hurricane Maria condition. The presenters discussed details related to the dams, the rehabilitation project, research, and watershed modeling conducted in this area.

The second site visited was the Ovejas Bridge at the Añasco River floodplain. Professor Ismael Pagán-Trinidad (Civil Engineering and Surveying Department and Coastal Resilience Center Director, UPRM) was the presenter. This bridge is particularly important for the community

due to its location in a highly agricultural area. This low-lying area along the Añasco River is ideal for agriculture, which currently consists primarily of plantain production. There exists a beneficial and detrimental symbiotic relationship between the river and the community it supports. Flooding and inundation of the area as well as river flows, benefit the fields by laying down nutrient-rich sediment. However, floodwaters also damage crops, dwellings, and other structures, and the fertilizers and pesticides used in agriculture have a negative impact when they reach the water system. High sediment loads also decrease the river conveyance capacity and pollute Mayagüez Bay at the river outlet, negatively impacting the bay's coral reefs and increasing seawater turbidity. Such sediment plumes at the bay disperse broadly for weeks. The bridge itself plays an important role in connecting communities to social, economic, and environmental resources. Damage from flood waters such as those experienced from hurricanes have the potential to exacerbate damages and impede recovery. Drought is also a concern in this area, as the lack of water limits agriculture and exposes infrastructure to shrinking and expanding soils and sedimentation, which could negatively impact the bridge infrastructure.

The Puerto Rico Aqueduct and Sewer Authority (PRASA) Water Intake was the third site visited. Presenters at this location included Engineer Glorymar Cortés-Arreizaga (Infrastructure Department, PRASA) and Dr. Walter F. Silva-Araya (Puerto Rico Water Resources and Environmental Research Institute [PRWRERI] Director, UPRM). The presenters discussed existing issues with the water intake and the communities that are served in this area. The components used for water treatment and the pump station were also discussed. A new project, which is currently under consideration for approval, will be implemented to improve the conditions of the pump station and water intake. Current research for modeling the meanders close to the water intake area was also discussed.

The last site visited was La Boquilla Village and El Seco Community, with Professor Ismael Pagán-Trinidad presenting. This site is within an area prone to major flooding and is surrounded by two different communities, known as La Boquilla Village and El Seco Community. The Mayagüez beach (saltwater) and Caño Boquilla (freshwater) both meet here, creating brackish water in the area. Red mangroves and a variety of fish were encountered at this location. Although the resilient communities in this area continue to face major flooding events, residents of these

communities are not willing or are not able to relocate. It is evident that these communities have lived there for long periods of time, but their location directly on the coast continues to subject them to periodic coastal and riverine flooding risks.

2.2 Welcome and Introductions

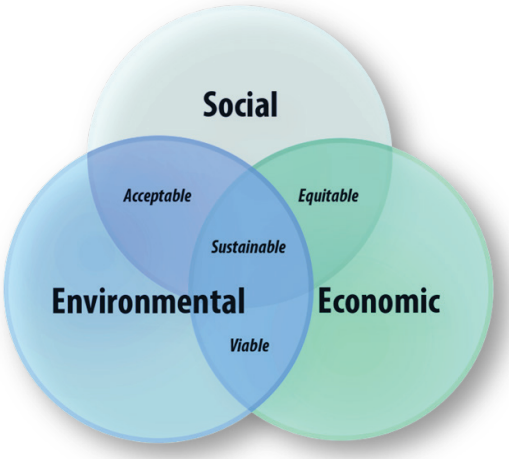
The workshop began with introductions and an overview of the purpose and objectives of the workshop, presented by Ismael Pagán-Trinidad (UPRM) and Carlos Ruiz (USACE). Each in-person attendee was asked to state their name and organization they represented, along with a brief description of their expected role in the workshop. Pat Deliman and Burton Suedel (both USACE) presented an overview of the workshop agenda, emphasizing and encouraging in-person workshop attendees to actively participate in the afternoon breakout sessions and the importance of receiving their feedback on GI-LID ideas for the Añasco River watershed. Please see Appendix A for a listing of both in-person and virtual workshop attendees. Appendix B presents the workshop agenda.

2.3 Setting the stage

After the facilitators' opening remarks and review of workshop agenda and objectives, Burton Suedel and Chris Haring from the USACE presented information that addressed island basin sediment transport. Dr. Suedel gave an overview of the USACE EWN® initiative and described how its principles and concepts could be used to design and implement GI-LID through dredging operations and other activities in Puerto Rico. Figure 1 shows the key elements required for EWN® projects. Dr. Haring presented information on water operations being used in other regions to accomplish GI-LID objectives. Both presenters focused on using a systems approach to implementing Nature Based Solutions (NBS) that can provide benefits across flood risk management, ecosystem restoration, and water operations objectives in island watershed sites. They included examples from other regions applicable to Puerto Rico that used NNBF, natural infrastructure, and natural materials to implement GI-LID in practice. They emphasized that there are multiple opportunities to implement GI-LID designs within the Añasco River watershed sites that were visited during the pre-symposium field trip. Please see Appendix C for their presentation slides.

Two SMEs with local knowledge of watershed challenges in Puerto Rico presented their experiences at the workshop. The first presenter was Yasiel A. Figueroa-Sánchez (Protectores de Cuencas, Watershed Protectors). The presentation focused on Project Management of Watersheds in Puerto Rico. Watershed Protectors is a nongovernment organization focused on ecological restoration, green infrastructure, and erosion and sedimentation control. They have collaborated with local, state, and federal agencies, municipalities, and academia. Watershed Protectors continually impact approximately seven watersheds in Puerto Rico, along with numerous potential restoration projects. They discussed the background, purpose, cycle, minimum criteria, and implementation challenges of a Watershed Management Plan. The Guánica Bay Watershed Management Plan and the Northeast Ecological Corridor Natural Reserve Integrated Watershed Management Plan were presented. At the end of the presentation, a project associated with erosion control research and erosion control at coffee farms was presented.

Figure 1. Key elements of EWN® projects.



2.4 Defining the system opportunities

Billy Johnson (LimnoTech) and Todd Steissberg (ERDC–virtual participant) provided a presentation on defining EWN® and LID system opportunities. They presented multiple examples of EWN® and LID strategies in riverine and upland regimes, coastal plane and wetland regimes, and coastal regimes. Multiple case studies were presented as examples from implemented projects. These included the natural flood

management scheme at Belford and techniques for slowing the flow and reducing flood risk at Pickering in the United Kingdom; the beneficial use of dredged material project at Pierce Marsh Texas, the Long Beach Island coastal storm damage reduction in New York, the Florida mangrove reef walls, and the SmartGate system at Tomago Wetlands in Australia.

Various funding opportunities available through FEMA were discussed by Nitza Ayala-Fontánez and Kathia Sánchez-Rios from the FEMA Hazard Mitigation Program. Various hazard mitigation techniques for riverine, coastal, and urban flooding, that could turn into project opportunities were discussed in this presentation. Examples of projects funded through the FEMA Hazard Mitigation Programs were presented. The Hazard Mitigation Programs include the Public Assistance Program and the Hazard Mitigation Assistance (HMA) Programs. The Public Assistance Program is disaster related and is used for mitigation of incident-caused damage. Four programs are part of the HMA Programs including the Hazard Mitigation Grant Program (HMGP), HMGP Post Fire, Building Resilient Infrastructure and Communities (BRIC), and Flood Mitigation Assistance (FMA) Program. Both the HMGP and HMGP Post Fire are disaster related and are used for multi-hazard statewide mitigation and mitigation after fire management assistance grant declarations, respectively. The BRIC and FMA Programs are nondisaster related and are used for multi-hazard project specific and flood mitigation for insured properties, respectively.

2.5 Prior experience with island EWN®-GI-LID construction

Dave Hampton and Tim Dekker (LimnoTech) discussed prior experience with island EWN®-GI-LID construction. They presented a three step processes consisting of reframing risks as opportunities, understanding the context, and actioning through the identification of projects involving people. For reframing risks as opportunities, a multicriteria analysis considering biophysical data (temperature, precipitation, vegetation cover, impervious area, salinity, sodicity, etc.), land use, political boundaries and jurisdictions, and demographics (populations, age, socio-economic and vulnerable populations) is recommended. There are three objectives for understanding the context including follow the water, use of typologies, and multi-scalar thinking. Multiple recommendations and examples were presented as part of actioning.

2.6 Limitations and problems with prior projects

Participants were asked to think about what challenges and limitations they have encountered during their experiences with both current and past GI-LID projects, and what potential solutions can overcome these challenges that could be applied as part of GI-LID in Puerto Rico. Participants were also asked to consider construction materials, alternative equipment, feature stability, material stability, operation and maintenance, property ownership, and social and economic impacts and benefits. They were then asked to bring these ideas with them for discussion during the afternoon breakout sessions.

2.7 Breakout session: Brainstorm new design measures: Challenges and opportunities

The objective of this breakout session was to identify specific project opportunities for incorporating EWN® principles and practices into GI-LID project development and operations by answering the following questions:

- How can EWN® principles and practices be integrated into both existing and new projects and operations?
- What do you consider to be the key aspects or elements to implement these projects?
- What are key next steps that should be taken to advance the project(s)?

Leaders divided participants into two breakout groups, based on affiliation and expertise. Group One was led by Burton Suedel (designated note-taker, Rhonda Fields, USACE SWF) and Group Two was led by Pat Deliman (designated note-taker, Dave Hampton, LimnoTech). As the group brainstormed ideas, Rhonda Fields (landscape architect) and Dave Hampton (architect, resiliency, and climate adaptation planner) sketched the group ideas to assist in visualizing how the GI-LID solutions would look if they became a reality.

3 Report Out

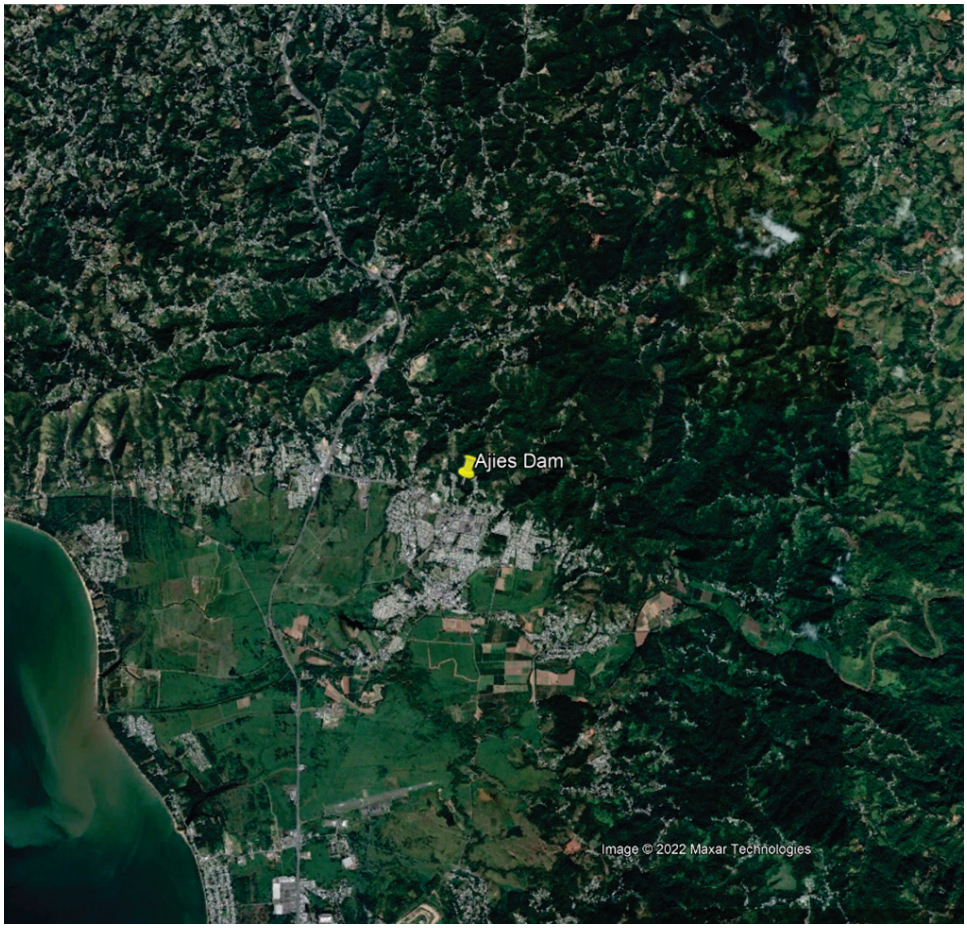
3.1 Group one

Group One started by answering the question "What is the highest GI-LID priority/opportunity within the Añasco River watershed of the field sites visited on 9 March 2022?" Their answer was the Ajíes Dam.

As background, the Ajíes Dam was built in 1984 as an earthen Floodwater Retarding Structure (FRS) within the Añasco River watershed to reduce flood risk to downstream communities. The dam performed its intended purpose by preventing major flooding to downstream communities in the watershed during Hurricane María in 2017. However, the dam suffered damage during the hurricane and hence needs repair to return the structure to meet current NRCS safety criteria and performance standards (http://www.pr.nrcs.usad.gov). The repair will also extend the life span of the dam beyond its initial 50 years. The scheduled repair offers a unique opportunity to advance the design of the repair to include various GI-LID features to greatly enhance the benefits associated with the repaired structure.

The overarching concept promoted by the group was to develop a Living Laboratory for the dam project that enhances the flood risk management capability of the structure while also promoting other unrealized environmental, social, and economic benefits of the infrastructure. The Living Laboratory would serve as a test bed for other similar dams and infrastructure across multiple Puerto Rico watersheds. As can be seen in Figure 2, the dam lies at the base of steep terrain and protects the community, industries, and croplands below. North of the dam exists wide areas of natural vegetation and interesting terrain, which provides multiple opportunities to create human interactions with nature.

Figure 2. Ajíes Dam location map. (Source: Google Maps 2022).



This natural area, thick with vegetation provides multiple opportunities for social and environmental interactions. The discussion was as follows:

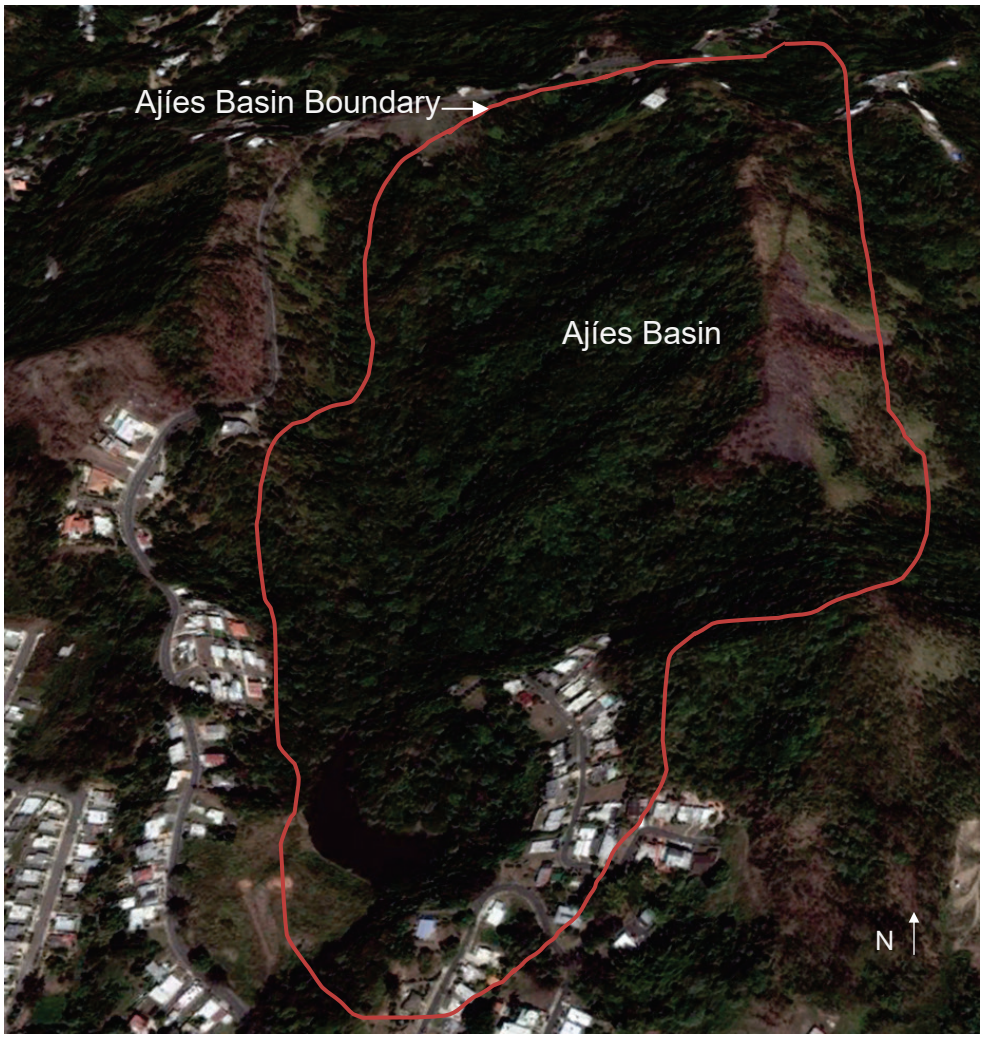
3.1.1 Living laboratory concept

The living laboratory concept operates in a real-life context with a user-centric, iterative, and open-innovation ecosystem approach. After experiencing the Ajíes Dam on the 09 March 2022 field trip, the team felt it was the ideal approach for addressing challenges and opportunities associated with the dam and the planned repair work expected to commence in late 2022.

The living laboratory approach for the Ajíes dam primarily focused on building the community, enhancing the ecological services associated with the infrastructure via GI-LID, improving the flood control benefits of the structure itself, and demonstrating processes and innovations broadly applicable to other similar areas. Figure 3 illustrates the sub-watershed

area considered for creating the living laboratory. This natural area, thick with vegetation provides multiple opportunities for social and environmental interactions.

Figure 3. Ajíes Dam sub-watershed catchment area. (Source: Google Maps 2017).



To implement this approach in practice, ideas were developed to seek opportunities for the ponded water behind the dam to serve as a surface water supply. In keeping with GI principles and ecological services, native herbaceous plants would be installed as soil engineers to trap soils on the dam and surrounding areas, which will reduce erosion and extend the life of the structure. Native plantings would be most beneficial on the dam itself and along its southwest side as shown in the foreground of Figure 4. Through these actions, the project could serve as a demonstration for managing soil, water quality, and conservation, which greatly increase the ecosystem services associated with the project.

Figure 4. Ajíes Dam impoundment. Waterbirds, waterfowl, and turtles were observed, and multiple songbirds were heard during the site visit (Photo: Burton Suedel).



3.1.2 Environment

Building a healthy living laboratory relies on the integration of people and natural resources. For this project, opportunities to create wildlife and biodiversity on the land and water, as well as developing an urban forest that creates GI-LID features promoting public access, is essential. This would be accomplished through developing a parkland environment and promoting eco-tourism and access to primitive campsites along a hiking trail.

Monitoring is an essential element of area management that will ensure the area remains viable and adaptive as appropriate to function as a living laboratory. As the impounded water is hydrologically connected to the nearest upstream impoundment, considerations should be given to managing the environmental flows of the basin to maintain higher water levels, which at present provides limited habitat for fish due to low water levels during dry periods. If the dam will be a multipurpose dam, then an operation plan to keep the water levels high during nonflood time periods and evacuate water to increase flood storage during large storm events will need to be developed. This will aid in creating a viable surface water supply in case of emergencies and will support larger fish, which will increase biodiversity and recreational use of the area. This information will help inform whether stocking with native fish would be a viable option

to improve biodiversity. There is an immediate need for research and development (R&D) to conduct biological surveys of existing species utilizing the habitat and to better understand ground water behavior.

During the site visit, multiple birds were heard, along with sightings of waterfowl, colonial waterbirds, turtles, and pollinators such as butterflies and bees. It is essential to support biodiversity in the area through planting native pollinator plants, shrubs, and trees, as well as surveying existing trees to remove those with low habitat value. Removing less ecologically valuable trees will open the canopy for other plants to thrive, and the use of downed trees could be used as habitat, trail markers, and erosion control. Additionally, planting native aquatic vegetation provides shelter for fish and herptiles, food for waterfowl, improves water quality, and reduces erosion as water levels fluctuate.

3.1.3 Education

One key component of a living laboratory is education and social interaction. Education opportunities abound at the Ajíes Dam site. R&D opportunities exist for everyone from kindergarteners through 12th grade and at universities to support science, technology, engineering, and mathematics, as well as build social networks and strong local communities. The living laboratory would naturally involve volunteers that support educational sessions, plant desired native species (Figure 5), and collaborate with local businesses to provide plants and other materials, as well as conduct open markets and other special events. The living laboratory would also provide opportunities for citizen scientists to get involved in monitoring various aspects of the project.

Figure 5. Flowers (both *top* and *bottom photos*) exist on the current unmanaged Ajíes Dam and surrounding area. Such flowers offer food for pollinating species such as bees and butterflies also observed during the visit. Native plants species could be planted on-site to increase the biodiversity of the area. The roots of these plants could also serve as soil engineers for purposefully stabilizing the dam (Photos: Burton Suedel).



3.1.4 Social/recreation

To create an environment that entices the local community to explore the area, a trail system should be constructed around the lake and into the surrounding sub-watershed. This would be supported through interpretive signage for public use, and the constructed trail should be suitable for walking, running, and cycling. Primitive campsites could be constructed for overnight stays in support of educational and recreational activities.

To ensure safety and reduce risks to the living laboratory, strategies should be explored to create a buffer zone around the lake, which might include adjacent owner buyout. Consideration should be given to support the predominant industry of the community, which is agriculture. Engaging the community in the planning, design, management, and use of the area will foster community ownership for the completed project. This would

include developing a series of dos and don'ts, related to behavior, activities, and physical construction related to the area. The community and SMEs could work together in exploring other ways that would link the broader lake purpose to the surrounding community's well-being.

Maintenance of the grounds will require special consideration, as the area is intended to be primarily natural. One suggestion from the group is the use of goats to sustainably maintain vegetation of the dam project at the desired height. This would require an experienced goat herder and temporary fencing strategically placed to keep goat droppings away from the water; such practices are used in the western US to reduce fuel for fires in forested areas because the goat-enriched soil holds more moisture. This approach would ameliorate the concerns about fouling the water as was the concern when horses previously began grazing on the project footprint. Currently the area is maintained by periodic mowing and bushhogging, which would be problematic in maintaining a natural setting (Figure 6). The associated noise would also disturb wildlife.

Figure 6. Ajíes Dam and related flood control structure. The vegetation on the dam and surrounding area consists of volunteer species periodically maintained by mowing and bush-hogging (Photo: Burton Suedel).



While several ideas were captured by Group One during the workshop, there are a multitude of opportunities in which to develop the living laboratory and maintain and enhance the primary flood risk management

mission of the dam. These should be collaboratively explored through a variety of stakeholders such as the local communities, schools, universities, law enforcement, public health, fire protection, businesses, and local, state, and federal agencies. Working together, the Ajíes Dam living laboratory (Figures 7, 8, 9, and 10) will serve the community and the environment for decades to come.

Figure 7. Ajíes Dam Living Laboratory at Ajíes conceptual map (Map design by Rhonda Fields).

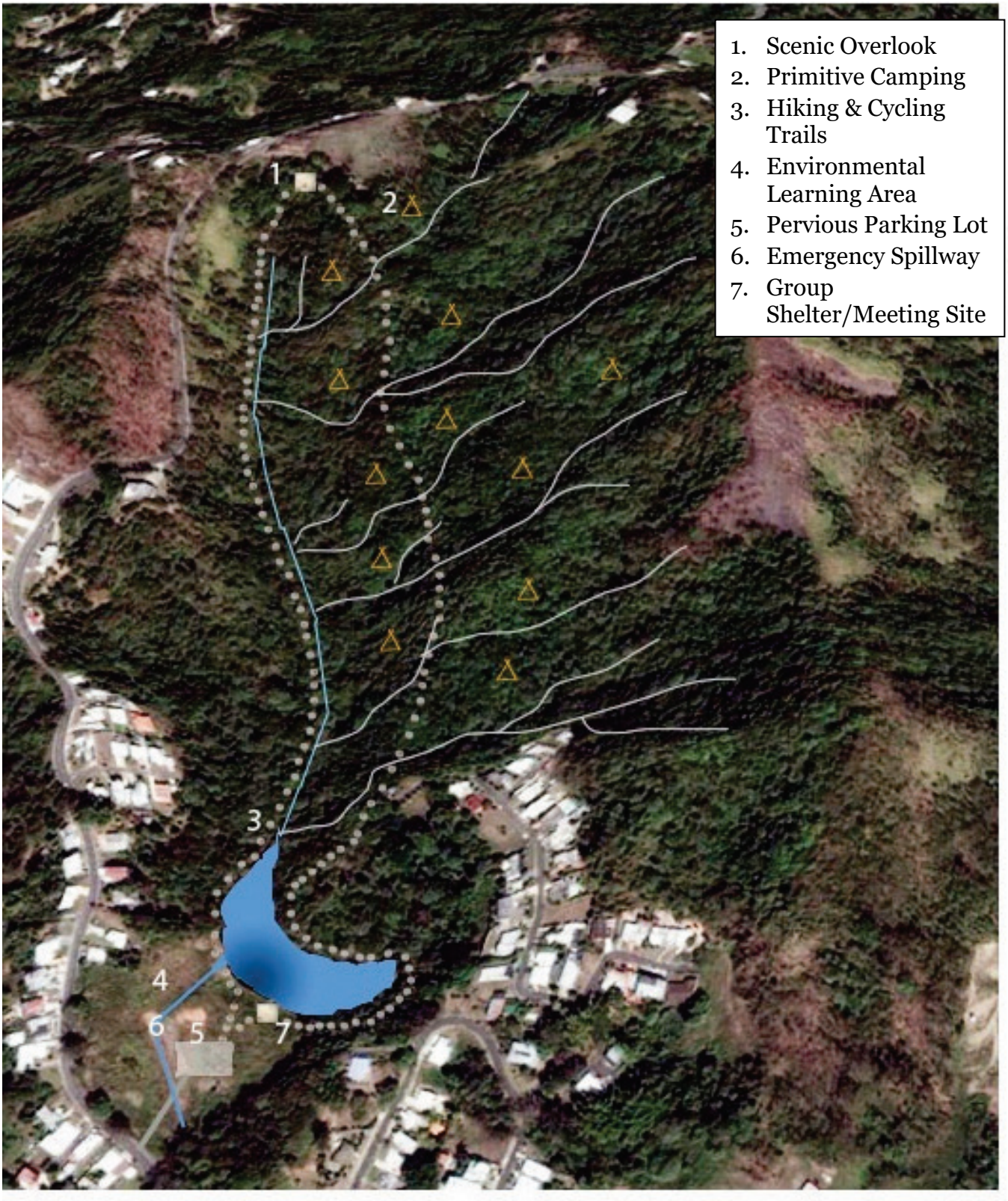


Figure 8. Examples of the environmental area (*top left*, Photo by Rhonda Fields), Pervious Paving (*bottom left*, TRUEGRID PAVERS at https://www.truegridpaver.com/complete-guide-permeable-paving-systems%EF%BB%BF/) and Group Shelter/Meeting Site (*right*, Westcave Outdoor Discovery Center at https://westcave.org/visit-our-preserve/warren-skaaren-environmental-learning-center).



Figure 9. Living laboratory section illustrative. Rendering: Jack Milazzo.

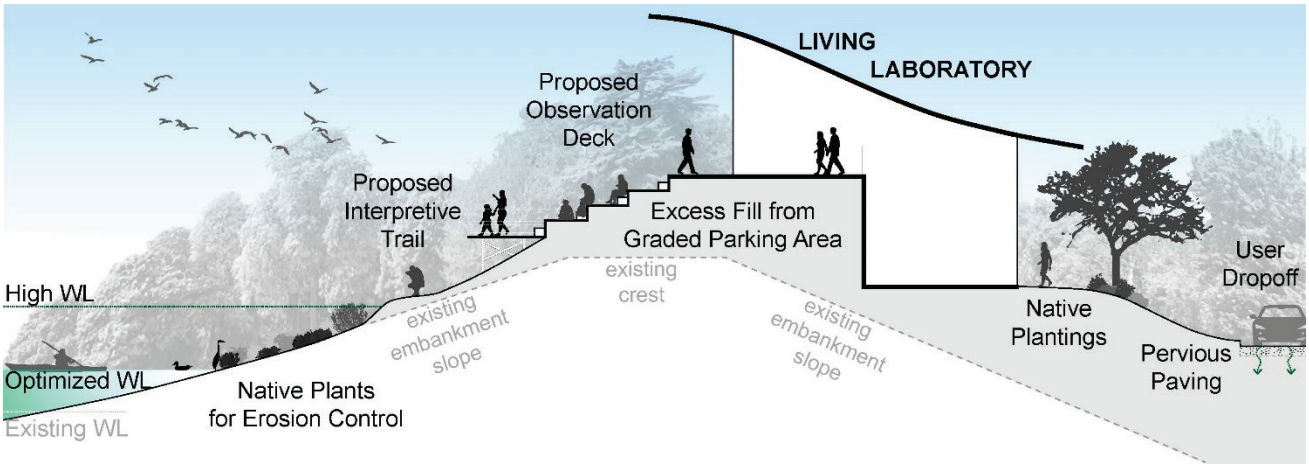


Figure 10. Living laboratory environmental learning area. Rendering: Jack Milazzo.



Figure 11. Living laboratory maintenance considerations. Rendering: Jack Milazzo.



3.2 Group Two

The Group Two discussion centered on opportunities that could have beneficial impacts across the entire watershed. Two areas emerged from the discussion that are present – and common – in watersheds: infrastructure resilience and policy opportunities.

Group Two chose the bridge over the lower Añasco River at Boquilla Village, Mayagüez, which is shown in Figure 12. This river is a major water source used by the Puerto Rico Aqueduct and Sewer Authority (PRASA) to supply drinking water for the region. PRASA is the government-owned corporation water company responsible for water quality, management, and supply in Puerto Rico. The bridge is a major crossing for the community, and its failure would have a negative impact on the social and economic health of the region, not to mention the environmental impacts downstream from the destruction of the bridge. This was the case when the Río Grande bridge in Arecibo, Puerto Rico failed during Hurricane María. Employing EWN® principles would offer an effective, economical solution to this engineering problem.

3.2.1 Infrastructure resilience: the 'River Lance'

First, the group identified general challenges, including flood control, soil management, debris impact, and the maintenance of plants. Opportunities included bank stabilization, buffer zones, sediment control, adaptive management, and debris reuse.

The presence of bamboo embodied both a challenge and an opportunity, being seen both as a disadvantage and advantage. The disadvantage being bamboo is an invasive species often growing thickly along stream and riverbanks (Figure 13) which may choke waterways as debris following storms or floods, creating a nuisance and hazard at bridges and other infrastructure. And, the advantage of bamboo, as a locally available source of material for building check dams (such as Figure 14) for erosion control and peak flow attenuation along the watershed. Figure 13 shows clusters of bamboo located at the PRASA intake located in the Añasco River.

Figure 12. Bridge over the Lower Añasco River at Boquilla Village, Mayagüez. Image: Dave Hampton.



Figure 13. Clusters of bamboo (*at left behind the group of people*) grows tall and thickly along the Añasco River, Mayagüez. Photo: Dave Hampton.



Figure 14. Example of a bamboo check dam, Belford Natural Flood Management Scheme, England, UK. Image: Nicholas Barber, Newcastle University.



Next, bridges such as the bridge over the lower Añasco River at Boquilla Village, Mayagüez were identified as common occurrences within the watershed (Figure 12), and therefore both an infrastructural and hydrological / ecological condition typology worthy of consideration for an intervention which could be repeated in various locations, adjusting for micro-local conditions.

A play on literature's windmill-charging character Don Quixote (Figure 15) was suggested: the 'River Lance' consists of a vertical pole-like element or set of elements diagonally placed in the river some distance upstream from a bridge to intercept debris before striking the bridge or creating a debris jam (Figures 16 and 17).

Figure 15. 'Don Quixote' by Pablo Picasso, 1955. Image: https://www.pablopicasso.net/don-quixote/.



Figure 16. The 'river lance', longitudinal section. Image: Dave Hampton.

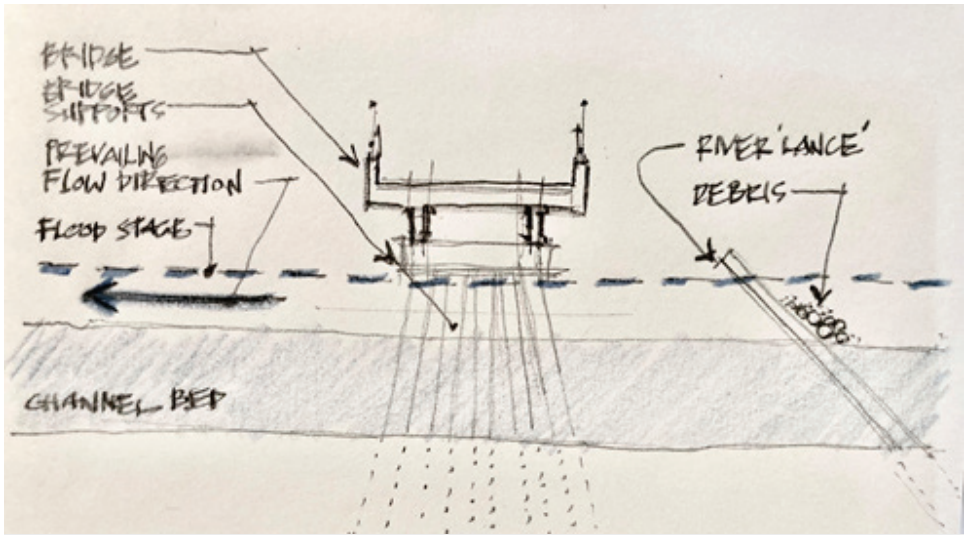
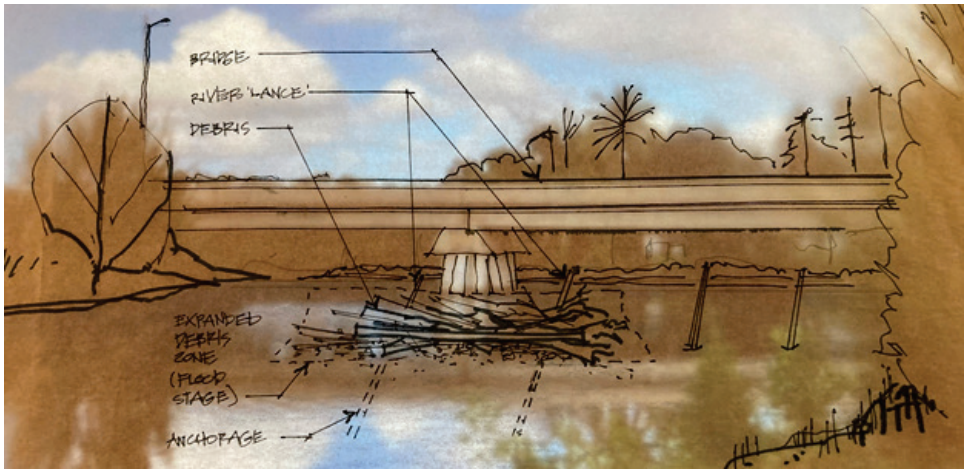


Figure 17. The 'river lance', perspective facing downstream. Image: Dave Hampton.



3.2.2 Advantages

Unlike its idealistic and impractically questing analogue, the river lance would be realistic, practical, and efficient. Single elements able to be economically placed, adjusted, and replaced would be relatively cost effective compared to traditional infrastructure. Replicability of component design and fabrication combined with flexibility of placement offer chances to retrofit existing conditions and tailor to new installment. Other advantages include structural independence as the system would be separate from bridges and would transfer no additional load or stress to the bridge structure, foundations, or abutments. The river lance would likely have mostly positive impacts by extending the bridge life span, and

by limiting degradation from debris. Adaptive management opportunities for this intervention are particularly noteworthy.

Again, the initial placement of lances would be determined by analyzing optimal location(s) based on factors including (but not limited to) bridge span, location in river, bathymetry, streambed composition, water velocity, and depth. Short-term temporal impacts, such as changes during extreme weather events (i.e., additional rainfall or flooding from hurricanes) and long-term impacts from climate change (i.e., sea level rise and drought) should also be considered. Therefore, a relatively small component or set of components nimble enough to allow for adjustments to changing local microclimatic and broader climatic conditions (rarely a hallmark of traditional gray infrastructure), which can also amplify the effectiveness of existing infrastructure, demonstrate the deep integration of adaptation as a core principle.

Workshops focused on implementation of low cost EWN® features using locally available materials will be offered to the community. The main goal of these will be to educate the community on how to design and construct NNBF and understanding the multiple benefits associated with them. It is important for the community to be engaged and understand these are not meant to be permanent features and will need to be maintained with time. This, in turn, will promote the communities' involvement (and buy-in) with maintaining the integrity of the structures.

3.2.3 Disadvantages

As with all engineering solutions, there are a few disadvantages to implementing this technique. First, there is the potential for backwater effects and thus upstream flooding that currently may not occur, though this may be of little impact overall. Second, this technique requires a rigorous maintenance program to clean out debris captured by the river lances and ensure the system functions as intended. Included in the maintenance function is monitoring the sediment from upstream of the features, which may require dredging. This maintenance would also be required if the technique were not implemented, but it would be the bridge itself that would collect some of this debris.

It is important to consider the pre- and post-construction hydrodynamics of the river with and without the debris control structure. There may be

potential for some flow acceleration with additional potential of local bank erosion and scouring.

3.2.4 Additional questions

There are several questions that will need to be answered in preparation for designing and implementing the river lance technique for EWN®. Design and construction materials and methods, such as materials, engineering and design specifications, and construction sequencing, need to be carefully considered. It will also be important to determine ownership and jurisdiction to insure proper coordination in the design, implementation, and maintenance of the lances. Included in this are developing standards, regulations, and processes, that is, what codes or processes exist or need to be established for the design and placement of the river lances. Design standards (i.e., codes, regulations, and permitting) for design and placement will need to be followed or developed. It will also be critical to determine who has ongoing operational and maintenance responsibilities.

A large consideration is the handling of debris. This will include determining who will remove debris, how often, and where the debris will be stored or used. To continue the EWN® principles, sustainable ways for removal, reuse, and disposal of the material for nonhazardous material such as logs and branches need to be developed. Additionally, processes and programs need to be developed for mitigation of inorganic and hazardous materials.

3.2.5 Removing barriers to implementation: Policy opportunities

Group Two also identified opportunities for impact across the entire watershed and in response to overarching policy challenges, including policy enforcement, governance, and the prevalence of risk assessments, hazard mitigation plans (Figure 18), and territorial plans. Opportunities centered on the *institutional capacity,* such as that present at UPRM, to provide SMEs and technical expertise to fellow Puerto Ricans. This may include advising clients ranging from municipalities to nongovernmental organization (NGOs) and civil societies to private sector actors in matters of project implementation due diligence by providing SMEs and technical experts. These SMEs and technical experts will evaluate the assessments and plans mentioned above and collaboratively create roadmaps for implementation in coordination with stakeholders. Other tasks may

include advising on policy changes or assisting with policy enforcement such as inspections or providing training for homeowners on hurricane- and earthquake-safe home design and construction. The university system has 11 campuses conveniently located to act as hubs, never prohibitively far from the clients they would serve.

Figure 18. Puerto Rico State Natural Hazard Mitigation Plan 2021 (Puerto Rico NMEAD 2021).



Additionally, effective SME expertise was seen by Group Two as being able to tailor solutions to the local context, such as the proper selection of plants for EWN®-NBS. Geological, hydrometeorological, and other knowledge of local conditions essential for the successful implementation of projects were also seen as an advantage to this approach. Other opportunities included the nature of jobs in installing, maintaining, and monitoring the performance of EWN®-NBS-LID, which would be primarily local and difficult to outsource or export.

Additional challenges for removing barriers were discussed, but for which no interventions were specifically identified, including political favoritism and how to mitigate its effects. Continuity of hazard mitigation plans and territorial plans are common, but follow-through on implementation is rare. There are also issues with the different timing, sequencing, or phasing of projects in municipal, territorial, and federal jurisdictions, as well as the limitations of election cycles. Election cycle problems stem

from the strategic and territorial plan horizons often exceeding the terms of elected officials and necessitate a reset or restart in familiarity with said plans, often requiring resubmittal of plans submitted under prior administrations.

3.2.6 Further research

The group identified generalized factors along the watershed which may affect the location, siting, and design of any EWN®-GI-LID interventions, and the "river lance." These include events that may affect the effectiveness and maintenance of the river lances. To ensure the system is engineered to function as designed, changes in climate and weather, rainfall and temperature intensity, and extreme events such as droughts and wildfires need to be examined and modeled. Debris type, including small or lighter organics (bamboo, branches etc.) versus heavier, denser organics (i.e., logs, trees, dead livestock), and inorganics (i.e., vehicles, appliances) will need to be examined to determine the frequency and impact of this technique, especially during extreme events when debris loads are highest. Efficient ways to remove the debris collected by the river lance will need to be researched. Other factors to consider are the change in river or stream meander, flood stage variability, bathymetry, stream channel diversity, multiple cascading events (e.g., storm surge and extreme precipitation), and local geography, slope, and microclimate, such as local rainfall variations. For example, El Yunque Rainforest receives an average of 120 in. (305 cm) of annual rainfall, while Ponce on the drier southern side of the island is usually protected by the central cordillera from hurricanes receives an average of 32.9 in. (84 cm) per year.

Other research opportunities identified include hydrological modeling, hydraulics and hydrology (H&H) studies, sub-basin studies, groundwater quality, and ground-truthing in the field of models and studies. These studies would be done to ensure techniques are implementable over other projects in other areas and to improve the technique over time.

4 Summary, Review, and Next Steps

4.1 Summary and review

The objective of this workshop was to bring together SMEs and members of the community to explore EWN®-GI-LID strategies, and NBS for Puerto Rico's natural water infrastructure needs. The workshop breakout sessions revealed unique ideas and concepts discussed within the two groups.

Group One proposed the development of a living laboratory concept for the Ajíes Dam project. The concept, if implemented, would enhance the existing flood risk management capability of the project while creating additional environmental, social, and economic benefits of the infrastructure. In a report on 30 September 2019 from the USDA Forest Service Institute of Tropical Forestry, it is stated that 340,461 acres (1,378 km^2) of land, or 16% of the Island, are considered Natural Protected Areas (NPA's) (Castro-Prieto et al. 2019). With the diverse beauty and grandeur of Puerto Rico's natural environment, much of which is currently undeveloped, the living laboratory can serve as a prototype for developing communities along Puerto Rico's many waterways. The living laboratory would serve as a test bed that could be applied at many other flood control infrastructure projects across Puerto Rico. This area is community based and offers opportunities for education, economic growth, and the study of the environment for people of all ages. The Ajíes Dam Living Laboratory has the potential to serve the community and the environment for decades to come.

Group Two discussed opportunities that could positively impact the entire watershed, focusing on infrastructure resilience and policy opportunities. One infrastructure opportunity discussed was using river bridges as an enhanced conduit for GI-LID, with the bridge over the lower Añasco River at Boquilla Village, Mayagüez as a key example. Bridges like this one serve as a major crossing for the community, and its failure would not only have negative social and economic health impacts, but also environmental impacts downstream if the bridge is destroyed during a storm. A river lance type structure was proposed, where a vertical pole-like element or set of elements diagonally placed in the river upstream from the bridge would intercept debris, preventing them from striking the bridge or creating a debris jam. The group also discussed opportunities to overcome policy challenges, including policy enforcement, governance, and the prevalence of risk assessments, hazard mitigation plans, and territorial

plans. Additionally, the group discussed opportunities for further research focused on the engineering and scientific data and information needed to design, implement, and maintain a successful project.

According to the National Bridge Inventory (ARTBA 2017), Puerto Rico has an estimated 2,334 bridges in the Commonwealth, with 282 (12%) of them classified as structurally deficient. Designing and constructing GI-LID to preserve these bridges will continue to rise in importance as a means of protecting the built and natural infrastructure into the future. The river lance concept developed during the workshop offers a cost-effective and easily implementable means of protecting these important pieces of infrastructure.

These ideas can be further developed and implemented across various locations and scales, bringing nature-based infrastructure solutions to Puerto Rico for the improvement of the environment, the economy, and the communities.

Bridges et al. (2018) states "We rely on natural process and landscapes to sustain human life and well-being. Our energy, water infrastructure, and agricultural systems use these processes and landscapes to satisfy our most basic human needs." To be effective, a systems approach must be used in planning, designing, implementing, and operating these strategies. Through collaborative work with communities and other stakeholders, EWN® concepts and principles can bring communities together, protect vital infrastructure, and protect the natural beauty and functionality of Puerto Rico's ecosystems.

4.2 Next steps

The next steps are follow-up meetings and workshops to continue refining the design details of the two proposed ideas presented. Participants tasked with the further development will include the project team and others with interest in the geographic area.

Anticipated workshop products are

1. Workshop proceedings report (this document) to be published with the support of the US Army Corps of Engineers Water Operations

Technical Support (WOTS), Dredging Operations Technical Support (DOTS), and EWN® Programs

2. Follow-on meetings with the USACE Jacksonville District, UPRM faculty and staff, and ERDC researchers to develop plans to identify funding sources and to implement the GI-LID designs presented in this report

EWN® is a continually renewing process, and each new project brings opportunities for future project development across different scales and lessons learned. It is important, then, to ensure the proper documentation of each step in the process, which this report serves as the first step. The authors envision after further analysis and design, optimum flood risk reduction alternatives in the Añasco River basin will likely consist of a set of hybrid solutions, which may include a series of conventional hard and natural infrastructure solutions working harmoniously. Future progress on these projects will require similar documentation, which will be housed within ERDC and distributed widely. USACE/ERDC would like to take this opportunity to thank all participants in this effort to create a more resilience, livable Puerto Rico.

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Appendix A: Participant List

There were 41 participants in the pre-symposium field trip and 103 in the workshop, both in person and virtually. Information associated with those participants is included below.

Name	Sector	Institution
Idania Rodríguez Santiago		
Adianez Santana Pruna	Student	Interamerican University of Puerto Rico: San Germán Campus
Alberto Camacho Meléndez		
Alberto Mercado	Professional	The Nature Conservancy
Alex Volcy-Sánchez	Government	PR Housing Department
Alexandra López Juarbe	Student	Universidad Ana G. Mendez
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Amarilys Rosa Torres	Government	FEMA
Ana Josefina Navarro Rodríguez	Faculty	UPR-Sea Grant
Andres Suarez Elicier	Government	Federal Government
Angela Isabel Perez	Professional	Private
Ann Ventura		
Annette María Reyes	Professional	Business Insights
Antonio González-Walker		
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Aurielee Diaz Conde		
Axel Omar Centeno Torres	Student	College
Brenda Torres Barreto	_	_
Billy Johnson	Professional	LimnoTech
Burton Craig Suedel	Government	USACE ERDC
Carla Mari Montalvo Martínez	Student	Pontifical Catholic University of Puerto Rico
Carlos Gabriel Velázquez Sierra	Student	Yale University
Carlos J. Díaz Reyes	Student	Saint Louis University (SLU)
Carlos R Robert-Colón	Government	FEMA
Carlos Ruiz	Government	USACE ERDC

Name	Sector	Institution
Carmen J. Vega-Lugo		
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Christian Carlos Padilla Ortiz	Student	UPRM
Christian Torres	Professional	Coccoloba AgroEnvironmental
Christopher E. Orozco González	Student	Ana G Mendez University
Conrado Manuel Calzada Cordero	Faculty	Pontificia Universidad Católica de Puerto Rico
Cristina Ramírez		
Cristina Von Essen	Professional	CAAPPR
Cynthia A. Manfred	Community	Organized community group
Daleen Marie Torres Burgos	Student	UPRM
Damarys Acevedo	Government	US Army Engineer Research and Development Center
Dania Esther Serrano Castro	Government	Departamento de la Vivienda
Daniel Bair	Faculty	University of Puerto Rico, Mayagüez
Dave Gray Hampton, Jr.	Professional	LimnoTech
David J. Rodríguez Castro		
Deborah Diaz		
Deborah Rivera		
Dilcia Margarita Torres Alvarado	Community	Colectivo El Ancón de Loíza
DRIVERA		
Eber Candelario Olivieri	Government	NMEAD
Edgar Raúl Montañéz-Pérez	Professional	Colegio de Arquitectos y Arquitectos Paisajistas de PR
Edgardo González	Professional	Centro para la Conservación del Paisaje
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Elba G. Almedina Melendez	Government	Municipality of Cayey
Elvin Rodán	Government	Municipality of Mayagüez
Emma M. Quero Torres	Professional	Estudios Técnicos, Inc.
Enrique Rodríguez	Student	RUM
Eric William Harmsen	Faculty	UPRM

Name	Sector	Institution
Erin Bennett	Academia	Trent University
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Fernando Figueroa Bonaparte	Professional	Freelancer
Fernando Pantoja Agreda	Faculty	University of Puerto Rico
Francisco Arroyo Rojas	Professional	FARchitecture
Franco A. Catalá Míguez		
Gabriel López De la Rosa	Government	Municipio de Mayagüez
Gladys Jaime Fernández	Professional	Consultora independiente
Gloria Brana Mulero	Professional	Private Industry
Glorymar Cortés Arreizaga	Private	AAA
Gradissa Fernandez		
Gury Truck Services		
Hector Gonzalez		
Héctor R. Rivera Mercado	Professional	Private Industry
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Jeff Smythe		
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José Elizalde		

Name	Sector	Institution
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Jose Maldonado		
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Jose Santiago	Government	US Army Corps of Engineers
Jose Tirado		
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Juan A. Santiago Rivera	Government	FEMA
Juan David Murcia		
Juan De Dios		
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Kathia Sánchez Rios	Government	FEMA
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Linna Irizarry-Mayoral		
Luis Alberto Cruz Aroyo	Government	USDA-NRCS
Luis Angel Rivera	Government	Municipio de Trujillo Alto
Luis Antonio Cuba Gerena	Student	University of Puerto Rico Mayagüez Campus
Luis Jorge Rivera Herrera	Government	Federal agency
Luis Lebron Ginorio	Professional	Private
Luis Villanueva Cubero	Government	FEMA
Luisa Feliciano Cruz	Student	UPRM
Luraida Rivera		
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Maria de Lourdes Olmeda Marrero	Government	Departamento de Recursos Naturales y Ambientales
María N. Colón Mulero		
Maria Vega-Rodriguez	Government	Puerto Rico Department of Environmental & Natural Resources
Maribelis Santiago	Government	USDA Forest Service IITF
Maricela Perryman	Professional	San Juan Bay Estuary Program
Mariela Collazo		
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Mario Rodríguez	Government	USDA
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Miguel Antonio García Bermudez	Government	Fish and Wildlife Service
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Omar Gutiérrez del Arroyo	Government	Instituto Internacional de Dasonomía Tropical
Omayra Avilés Santiago	Professional	Departamento de la Vivienda
Oscar Hernán Martinez Pinilla	Professional	Private Industry

Name	Sector	Institution
Oscar R. Cordero Perez	Student	University of Puerto Rico - Mayagüez
Oscar Rafael Cordero Pérez		
Pamela Bonilla		
Patrick Deliman	Government	USACE ERDC
Pedro Israel Matos Llavona	Student	University of Massachusetts Amherst
Pedro Janer		
PJ Santa	Professional	Private industry
Rafael Diaz		
Rafael Olivencia Llavona	Professional	Rafael Olivencia and Associates
Raúl E. Zapata López	Faculty	University of Puerto Rico
Raul Santini Rivera		
Rebeca De Jesus Crespo	Faculty	Louisiana State University
Reyes E Rodríguez		
Rhonda Fields	Government	USACE Ft. Worth District
Ricardo A. Berrios-Perez		
Ricardo Javier Colón Merced	Government	USDA-NRCS
Ricardo Ramos		
Richelle Vázquez		
Robert Jonathan Hobbins	Faculty	Georgia State University
Rodolfo Ariel Serrano Rodríguez	Professional	Private Industry
Roxanne Marie Almodovar Perez	Community	--
Rubén Rolando Solla Rosario	Community	BARRIO
Sacha Ivette Caraballo Vega	Government	FEMA
Sally González	Faculty	UPRM-CCA-SEA
Samuel Garcia	Government	Department of Natural and Environmental Resources
Sandra E. Rosas Vélez	Government	Municipality of Hormigueros
Sandra Marlín Velázquez Rivera	Government	HUD
Sixto A. Machado		
Sofia Burgos Caraballo	Community	NA
Sofía Olivero Lora	Government	USEPA
Suhey Ortiz Rosa	Student	UPRM
Tamara Orozco	Professional	CIPM

Name	Sector	Institution
Teresa H. Pérez Rivera	Professional	Industry
Teresita M. Del Valle Beltrán	Professional	tmdv
Thayria Warner Peña		
Thomas Douthat	Faculty	LSU
Timothy Dekker	Professional	LimnoTech
Trisha Muñoz Erickson		
Walter F. Silva Araya	Faculty	PRWRERI
Walter Soler Figueroa	Professional	Ambienta Inc.
Wilberto González Muñoz	Community	FEMA
William J Hernandez	Faculty	UPR Mayagüez
Yasiel Angel Figueroa Sánchez	Professional	Protectores de Cuencas
Yesenia Franqui	Student	UPRM
Yesenia Marie Rivera López	Student	University of Puerto Rico - Mayagüez Campus
Yilia Baucage-Bou	Government	NRCS-USDA
Yohaira Maritza Ayala Torres	Government	DRNA
Yulianna de la Cruz Montañez	Professional	PEBSJ
Zilkia M. Hernández López	Professional	IAPPR

Appendix B: Agendas

PR 2022 River Basin Symposium: Pre-Symposium Field Trip
Agenda: Wednesday, March 9, 2022

Activity: Pre-Symposium Field Trip
Date: Wednesday, March 9, 2022
Time: 8:30 am – 4:00 pm
Location: Añasco River Watershed
Limit: 30 people
Stops:

1. Starting Point (18.215097, -67.139374): University of Puerto Rico, Civil Engineering and Surveying Dept (Parking Lot)
2. Presenter # 1: Prof. Ismael Pagán-Trinidad, CRC (Brief 5 min introduction)
3. Presenter # 2: Dr. Patrick N. Deliman, USACE (Brief 5 min introduction)

[25 min. de UPR-Mayagüez to Ajíes Dam]

1. Ajíes Dam (18.298161°, -67.137101°):
2. Presenter #1: Mr. Luis A. Cruz-Arroyo, NRCS
3. Presenter # 2: Mr. Mario Rodríguez, NRCS
4. Presenter # 3: Dr. Eric Harmsen, UPRM (Description of the Añasco River Watershed and his research)

[10 min. from Ajíes Dam to Ovejas Bridge]

1. Ovejas Bridge (18.272885, -67.126913):
2. Presenter: Prof. Ismael Pagán-Trinidad, CRC

[5 min. from Ovejas Bridge to PRASA Water Intake]

1. PR Aqueduct & Sewer Authority Water Intake (18.264000°, -67.133800°):
2. Presenter # 1: Ing. Joel Lugo-Rosa, PRASA Infrastructure director
3. Presenter # 2: Dr. Walter Silva, PRWRERI

[20 min. from PRASA Water Intake to La Boquilla Nature Reserve]

1. Boquilla Village and Nature Reserve (18.251226°, -67.176495°):
2. Presenter: Prof. Ismael Pagán-Trinidad, CRC

[5 min. from La Boquilla Nature Reserve to UPR-Mayagüez]

Basin Sediment Management for Unique Island

Topography Engineering With Nature® (EWN®)

Green Infrastructure – Low Impact Development

(GI-LID)

University of Puerto Rico Mayagüez (UPRM)

Department of Civil Engineering

Date: Friday, 11 March 2022. 9:00am – 4:30pm **(AST)**

Purpose: The purpose of the workshop is to assemble subject matter experts to conceptualize research and development geared towards identifying tropical island EWN®-GI-LID design questions that will lead to demonstration projects and research strategies to evaluate outcomes for designing, constructing, andintegrating these types of features to assist in minimizing environmental damage from storm events.

We will review prior island best management practice designs and methods with a focus on projects using Natural and Nature-Based Feature (NNBF) construction methods consistent with EWN® principles. Alternative designs and construction methods will be identified and discussed in context with integration with existing conventional construction techniques. The results of the workshop will be documented in a Proceedings Report that will be published with the support of the US Army Corps of Engineers Water Operations Technical Support (WOTS), Dredging Operations Technical Support (DOTS),and EWN® Programs.

Objectives:

By the close of the workshop, participants will:

- Identify technical design successes and lessons learned from prior tropical island design projectsfor basin sediment management.
- Discuss opportunities and challenges of candidate island design techniques using EWN®-GI-LIDtechnologies.
- Identify those island EWN®-GI-LID design techniques that could be implemented for basinsediment management with unique short time of concentration limitations.

- Identify design techniques that could be used for managing sediment removal in drinking waterreservoirs to recover design capacity while promoting EWN®-GI-LID techniques.

Participants:

UPRM – University of Puerto Rico Mayagüez, FEMA – Federal Emergency Management Agency, NRCS – Natural Resources Conservation Service, USACE – US Army Corps of Engineers

TIME	CONTENT/ACTIVITIES	MATERIALS
8:30 – 8:50	**Facilitator login and setup** • Assign cohosts • Upload any shared documents • Assign participant privileges • Record	All PPT slides or other documents to be shared
8:50 – 9:00	**Participant login and setup**	
9:00 – 9:30	**Welcome and Introduction** 1. **Meeting opening:** Ismael Pagan & Carlos Ruiz a. Welcome participants, review workshoppurpose and objectives. 2. **Review Agenda:** Pat Deliman & Burton Suedel 3. **Review How to Engage:** Pat Deliman & Burton Suedel a. Facilitate participant Introductions b. Ask people to share their name,organization, and role	Opening slide: Welcome/Workshop Title Slide: Purpose, Objectives Slide: Agenda Slide: How to engage Slide: Relevant experience
9:30 – 10:30	**Setting the Stage: Defining Island Basin SedimentTransport** • **Water Operations EWN®-GI-LID:** Chris Haring • **Dredge Operations EWN®-GI-LID:** BurtonSuedel **Local Speakers** • Yasiel A. Figueroa-Sánchez, Protectores deCuencas (Watershed Protectors) • Brenda Torres, San Juan Bay Estuary Program	20 min for each speaker
10:30 – 11:00	**Defining the System Opportunities** 1. Billy Johnson & Todd Steissberg, USACE **Identifying Funding Opportunities: Example of Potential Mitigation Projects through FEMA** 2. Nitza Ayala-Fontánez & Kathia Sánchez-Rios,FEMA Hazard Mitigation	
11:00 – 11:15	**BREAK**	
11:15 – 11:45	**Prior Experience with Island EWN®-GI-LID Construction**	25 min for speaker + 5 min for Q&A

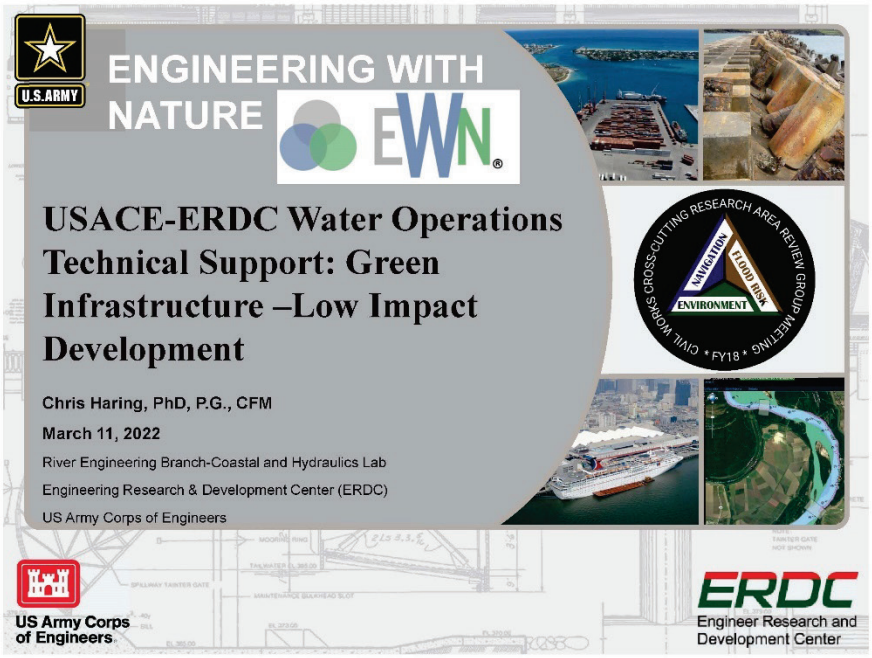
TIME	CONTENT/ACTIVITIES	MATERIALS
	• Tim Decker & Dave Hampton, LimnoTech	
11:45 – 12:15	**Limitations/Problems with prior projects** **<u>Discuss</u>** Participants take 5 minutes to jot down their notes/ideas on each of the aspects below. What limitations or challenges have occurred with prior	
	projects, and what are solutions that can overcome these challenges? ○ **Construction material** ○ **Alternative equipment** ○ **Feature stability** ○ **Material stability** ○ **Operation and Maintenance** ○ **Property ownership** ○ **Social and economic impacts** **Facilitator will guide discussion on each subtopic. This discussion designed to prepare for the breakout session after lunch.**	
12:15 – 1:00	**LUNCH**	
1:00 – 2:00	**Breakout Session: Brainstorm new design measures: Challenges and Opportunities** **Purpose: The objective of this breakout session is to identify specific project opportunities for incorporating EWN® principles and practice into GI-LID project development and operations. How can EWN® principles and practices be integrated into both existing and new projects and operations? What do you consider to be the key aspects or elements to implement these projects? What are key next steps that should be taken to advance the project(s)?** **Leaders will divide participants into two breakout groups. Group 1 – Pat Deliman (to designate note-taker) and Group 2 – Burton Suedel (to designate note-taker) will each lead a breakout. As the group is brainstorming ideas Rhonda Fields, TBD (landscape architects) will sketch out the breakout group ideas to help visualize.** • **Group 1 – Water Operation Activities** • **Group 2 – Dredging Operation Activities**	

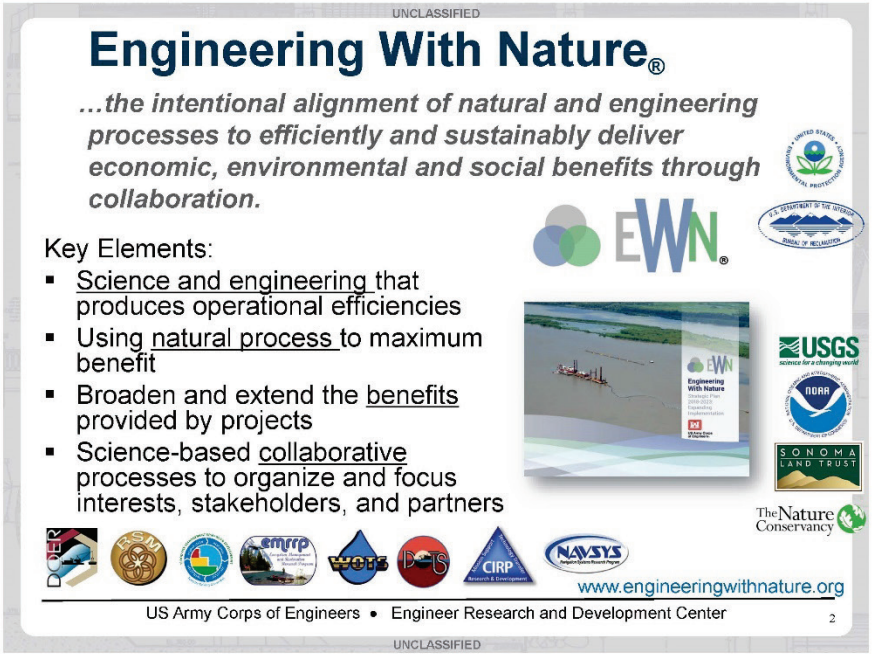
TIME	CONTENT/ACTIVITIES	MATERIALS
2:00 – 2:15	**BREAK**	
2:15 – 3:00	**Report out** **Share** **Group 1 (Pat Deliman) will share for 20 minutes** **Group 2 (Burton Suedel) will share for 20 minutes**	
	5-minute Energizer **TBD based on energy (or lack of) levels of the group**	
3:15 – 4:15	**Brainstorm new research and development opportunities and projects for EWN®-GI-LID related to island basin sediment management** **Discuss** • **Conventional Current State of the Art** • **Hybrid Construction with NNBF** • **Innovative Future Concepts**	
4:15 – 4:30	**Summary and Review, Next Steps** **Activity: Review objectives – did we get there? Participants will use annotation features to rank how well objectives were met** **Activity: I like, I wish exercise – participants provide feedback in the chat. What did they like about the workshop? What worked well? Conversely, what could have been improved? What do they wish had happened?** **Deliman/Suedel share next steps – what will be done with the information generated?** **A proceedings report will be generated to publish the participants, presentations, discussions, and results of the workshop as an USACE ERDC Technical Report jointly published with the UPR, etc.**	
4:30	**Adjourn**	

Appendix C: Presentations

Appendix C.1: "Engineering With Nature® - USACE-ERDC Water Operations Technical Support: Green Infrastructure-Low Impact Development"

By: Chris Haring, PhD, USACE ERDC





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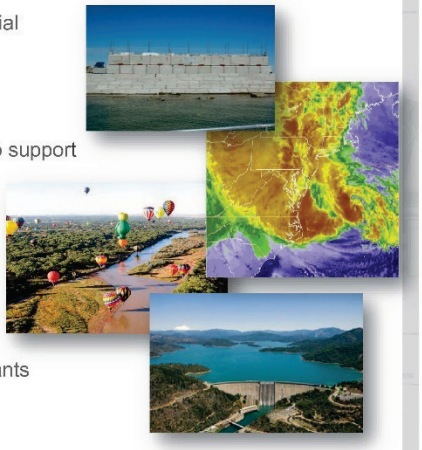
EWN® ACROSS USACE MISSION SPACE

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



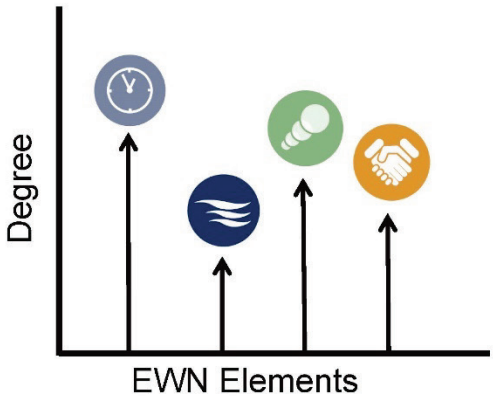
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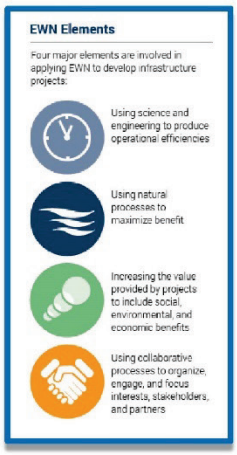
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Engineering With Nature®

Elements



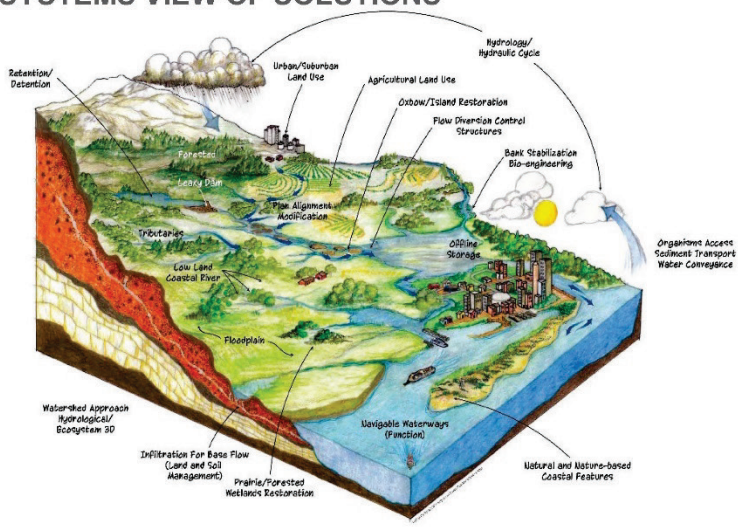


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A SYSTEMS VIEW OF SOLUTIONS



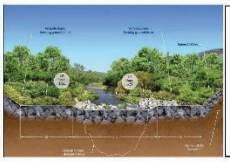
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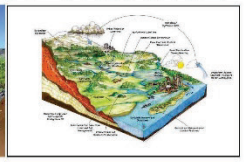
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NNBF ENGINEERING PERFORMANCE







Levee Setbacks

Benefits/Processes

-decreased flood levels and velocities
-reduced frequency of maintenance and repair on levee
-reduced navigational maintenance
-reduction in erosion/scour and O&M costs
-increased recreational, cultural, and educational opportunities

Performance Factors

-amount of new floodplain affects hydrologic loading
-alignment options for improved hazard mitigation
-ecological goals of project with increased floodplain connection
-collaboration with stakeholders and other Federal agencies

Naturalization of Channel Design

Benefits/Processes

-reduced frequency of maintenance on levee and restoration projects
-naturalization of flow regimes and floodplain reconnection
-ecological benefits to floodplain habitat
-reduction in erosion/scour and O&M costs
-increased recreational, cultural, and educational opportunities

Performance Factors

-type of practice determines hydrologic loading
-practice determines options for improved hazard mitigation, erosion control, and streambed and bank stability
-collaboration with stakeholders and other Federal agencies
-sediment management options

Watershed Treatments

Benefits/Processes

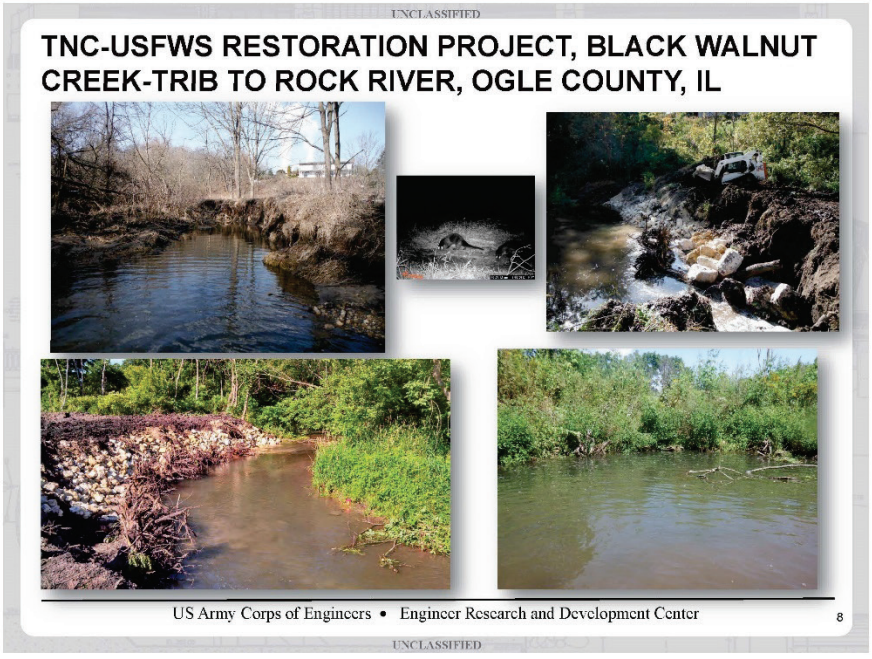
-naturalization of hydrologic watershed regimes
-reduced navigational maintenance
-reduction in O&M costs
-increased recreational, cultural, and educational opportunities
-reduced frequency of maintenance and repair on levee and restoration projects

Performance Factors

-watershed management options determine effects on hydrologic loading
-practice options for improved hazard mitigation, upland erosion control, and groundwater recharge
-sediment management options
-collaboration with stakeholders and other Federal agencies

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ENGINEERING WITH NATURAL MATERIALS
National Large Wood Manual
Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure
January 2016
A Design Manual:
Engineering With Nature Using Native Plant Communities
www.engineeringwithnature.org
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TNC-USFWS RESTORATION PROJECT, BLACK WALNUT CREEK-TRIB TO ROCK RIVER, OGLE COUNTY, IL
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MISSOURI RIVER LEVEE SETBACK OMAHA DISTRICT



Producing Efficiencies

Setback reduces frequency of maintenance and repair of levees; reduced navigational maintenance; reduction in associated O&M and RR&R costs.

Using Natural Processes

Setback leverages decreased hydrologic loading, decreased flood velocities, and reduced erosion/scour.

Broadening Benefits

Improved ecosystem sustainability; improved hazard mitigation; increased recreational, cultural and educational opportunities.

Promoting Collaboration

NWO collaboration with USGS, USFWS, Idaho Dept. of Natural Resources, NGOs, and stakeholders.





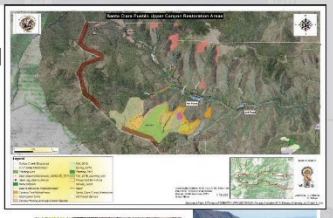
R&D: Opportunities to quantify ecological, engineering, and societal benefits; increase USACE's capacity to provide effective programs for NSA applications; and data/lessons learned will advance guidance and policy that supports future levee setback projects.

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USACE ALBUQUERQUE DISTRICT: SANTA CLARA PUEBLO WATERSHED EWN



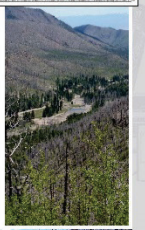
Producing Efficiencies

Working with natural processes using local materials to stabilize the watershed and stream channels; reduced time and cost of importing materials, ecological and aesthetics benefits.

Using Natural Processes

Uses local material in system vs. introducing riprap; placement of materials in situ with native vegetation to re-establish natural channel tendencies.





Broadening Benefits

New options to place existing materials; habitat created; restoration of channel and reduction of sediment delivered to channels and reservoirs.



Promoting Collaboration

Partnering with Santa Clara Pueblo, USGS, USFS, BIA, NMDOT, and NRCS

Structures



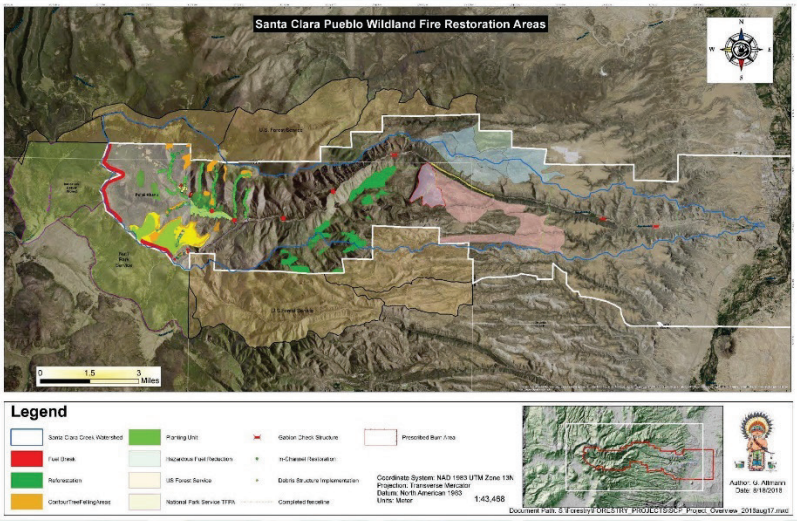
R&D: Implement, study and long-term performance of NNBF; Offers opportunities to determine appropriate performance metrics aligned with ecosystem and engineering services.

➡ Funded by DOTS REQUEST

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Albuquerque District-Santa Clara Canyon
Managing Wildfire Recovery



Santa Clara Canyon-Damage

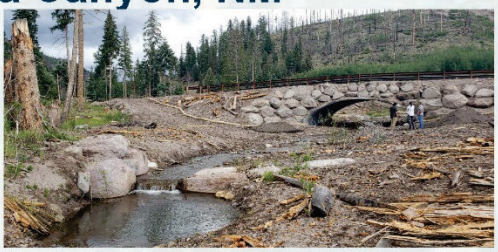


Santa Clara Canyon-Recovery



NNBF Applications
Santa Clara Canyon, NM

- Wetland & Erosion Control
- Bottomless Culvert





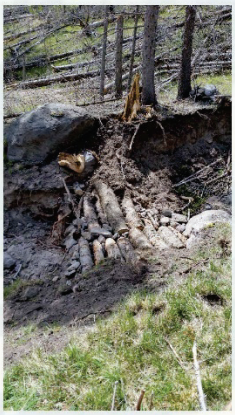
ERDC

tions for a safer, better world

NNBF Applications
Santa Clara Canyon, NM

- ❑ Wood structures
- ❑ Rock onsite
- ❑ Combination





BUILDING STRONG®

ERDC

Innovative solutions for a safer, better world

NNBF Applications
Santa Clara Canyon, NM

- ❑ Wood structures
- ❑ Rock onsite
- ❑ Combination







BUILDING STRONG®

NNBF Applications
Watershed Assessment Tool

- ❑ Wood structures
- ❑ Rock onsite
- ❑ Combination







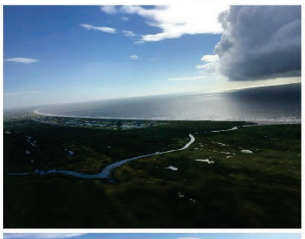
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BUILDING PROGRESS

Engineering With Nature

- Expand the "vision" to diversify project benefits
- Increase collaboration and cross-sector partnerships
- Commit to innovation
- Pursue realistic and affordable projects
- Document the value created
- Coordinate communication across partnering organizations for maximum impact





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INTERNATIONAL GUIDELINES ON THE USE OF NATURAL AND NATURE-BASED FEATURES FOR SUSTAINABLE COASTAL AND 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 2021:
  - 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

THE WORLD BANK

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WHAT IS FLUVIALGEOMORPH?

FluvialGeomorph (FG): is a rapid watershed assessment toolkit developed by the Corps of Engineers to assess stream channel stability.

uses existing high-resolution terrain data-Light Imaging Detection and Ranging (LiDAR) or other available data sets to measure and compare channel morphology.

channel morphology is then mapped and compared against representative stable channel dimensions (empirical relationships) to identify locations within the watershed where channel instability exists.

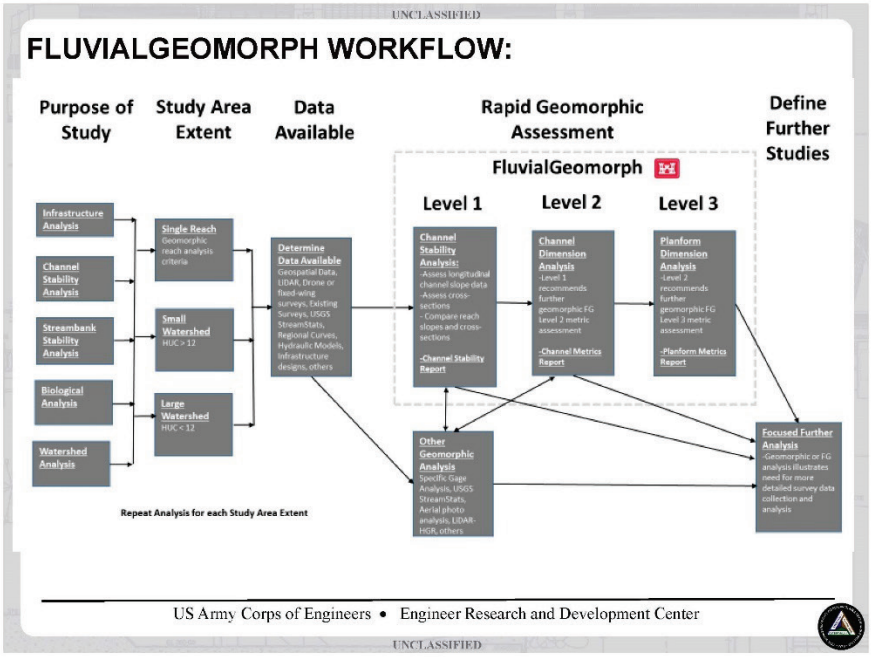
Assessments are completed on a single data set or multiple years depending on the availability of data.

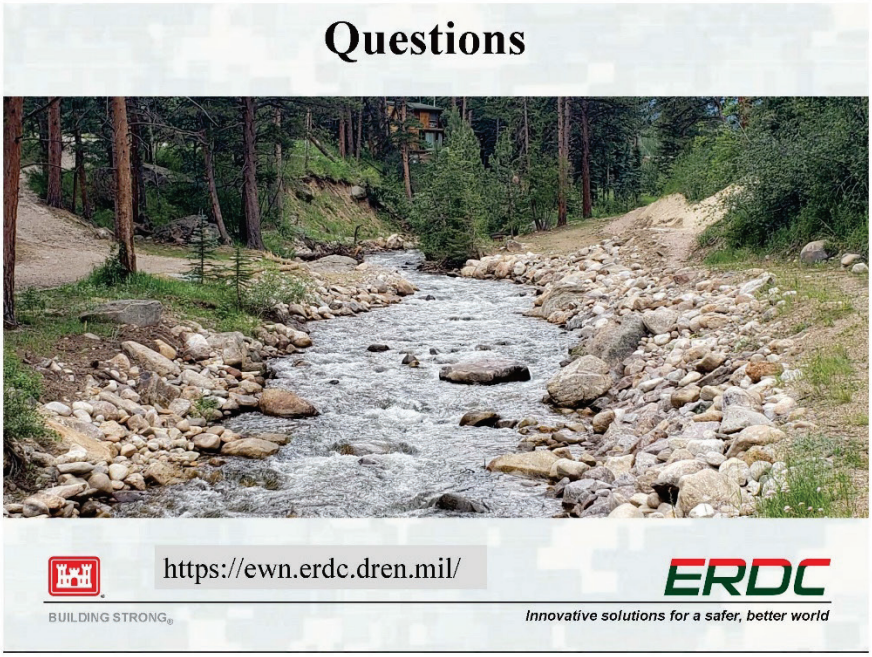
Geomorphic mapping and the associated metrics provide a basis to identify and assess priority locations within the watershed for further data collection and study or concentrated restoration.



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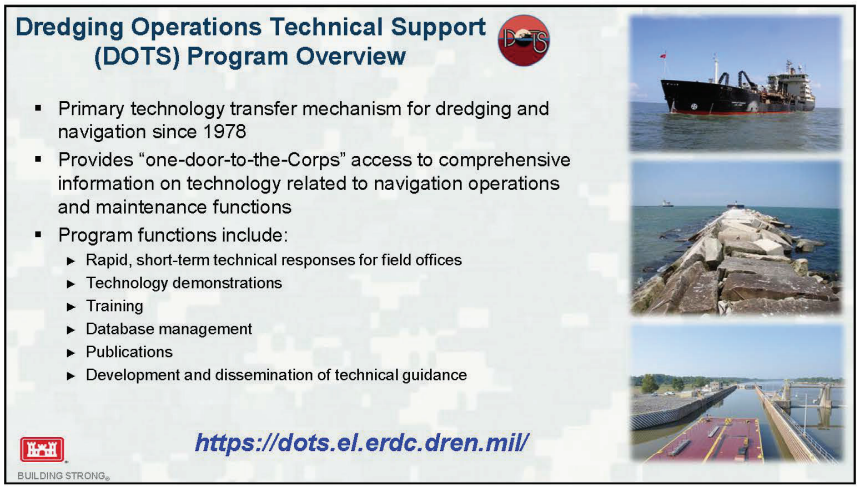

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FLUVIALGEOMORPH WORKFLOW:
Purpose of Study
Study Area Extent
Data Available
Rapid Geomorphic Assessment
Define Further Studies
FluvialGeomorph
Level 1
Level 2
Level 3
Infrastructure Analysis
Channel Stability Analysis
Streambank Stability Analysis
Biological Analysis
Watershed Analysis
Single Reach
Geomorphic reach analysis criteria
Small Watershed
HUC > 12
Large Watershed
HUC < 12
Determine Data Available
Geospatial Data, LIDAR, Drone or fixed-wing surveys, Existing Surveys, USGS StreamStats, Regional Curves, Hydraulic Models, Infrastructure designs, others
Channel Stability Analysis:
-Assess longitudinal channel slope data
-Assess cross-sections
- Compare reach slopes and cross-sections
-Channel Stability Report
Channel Dimension Analysis
-Level 1 recommends further geomorphic FG Level 2 metric assessment
-Channel Metrics Report
Planform Dimension Analysis
-Level 2 recommends further geomorphic FG Level 3 metric assessment
-Planform Metrics Report
Other Geomorphic Analysis
Specific Gage Analysis, USGS StreamStats, Aerial photo analysis, LIDAR-HGR, others
Focused Further Analysis
-Geomorphic or FG analysis illustrates need for more detailed survey data collection and analysis
Repeat Analysis for each Study Area Extent
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Questions
https://ewn.erdc.dren.mil/
BUILDING STRONG®
ERDC
Innovative solutions for a safer, better world

Appendix C.2: "Engineering With Nature® and Green Infrastructure-Low Impact Development: Dredging Operations"

By: Burton Suedel, PhD, USACE ERDC





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



www.engineeringwithnature.org

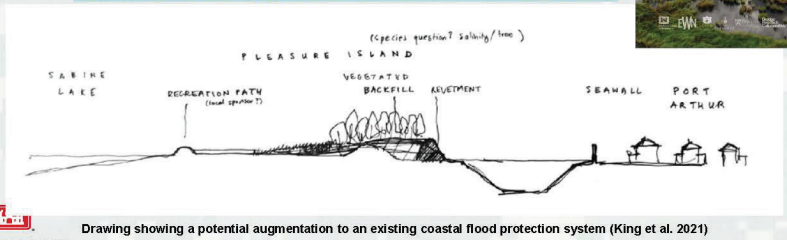
3

Leveraging EWN + Landscape Architecture to Promote GI-LID

- Collaborations amongst science, engineering, and landscape architects jointly contribute to EWN implementation through best management practices and scientific research
- CSRM projects are being implemented that incorporate EWN+LA practices to achieve additional environmental and social benefits maintaining intended engineering project functions

EWN website designs page: https://ewn.el.erdc.dren.mil/designs.html



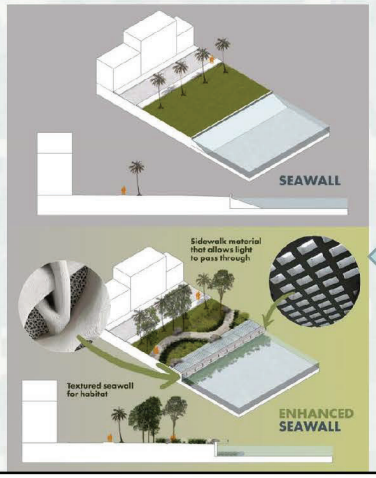


Drawing showing a potential augmentation to an existing coastal flood protection system (King et al. 2021)

Detailed Renderings Aid GI-LID Decision-making

Common coastal infrastructure types that can be enhanced for biodiversity:

- Thin layer placement
- Living shoreline
- Seawall
- Revetment
- Bulkhead
- Detached breakwater and jetty
- Sill
- Tidal control structure
- Groin



Renderings of a conventional seawall design (top) and an enhanced seawall design (bottom) that includes various NNBF for improving habitat quality of the structure, thereby promoting biodiversity and other benefits.

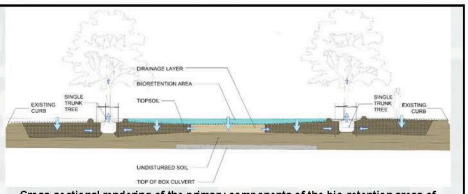
From Suedel et al. (In Review)

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EWN GI-LID R&D

Southeast Louisiana Urban Flood Control Project (SELA) Project

- Responding to extensive flood damage in SE Louisiana in 1989 & 1995
- Providing flood risk reduction up to a level associated with a 10-year rainfall event
- Strengthening the City's neutral grounds as greenway connectors
- Reinforcing sustainable and resilient image through visual design
- Expanding New Orleans' urban forest
- Enhancing environmental value of urban green spaces
- Reducing burden on the storm drainage system
- Slowing land subsidence through groundwater recharge and infiltration
- Improving water quality



Cross-sectional rendering of the primary components of the bio-retention areas of the SELA project. Arrows mark surface and near surface water flow designed to reduce flood risk (Bourne et al. In Review).



Ground-level view of the bioretention component of the neutral ground. Bermuda grass was planted, consistent with Parks and Parkways maintenance standards, to foster biofiltration.

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6

EWN GI-LID Best Practice

Fowl River Private Living Shorelines (AL)

- Living shorelines constructed by TNC for private landowners with river-adjacent property
- Replaced failing bulkheads experiencing erosion caused from boat wakes
- Stabilized existing bulkhead using tiered gabion baskets filled with dredged sediment, then planted with native marsh grass
- 40 ft of natural shoreline and an existing marsh island were protected by two gabion-basket breakwaters utilizing sediment dredged from nearby canal
- Protected 200 ft of shoreline and enhanced 720 ft^2 of marsh
- Design leaves failing bulkhead in place and stabilizes the structure, saving cost of removal





In: EWN Atlas Volume 1 (pages 232-235)

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7

EWN GI-LID Best Practice

Mangroves & Recreation Infrastructure

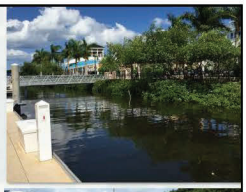
Nature-based Solutions

- Ecological Functions
- Amenities / recreational values
- Cost reduction (e.g., vs. seawall)
- Adaptability to sea level rise

Potential Environmental Design Features

- Living shorelines
- Mangrove islands
- Boardwalks & kayak trails

Mangrove Shoreline (Harborside, Jupiter, FL)



Mangrove Shoreline (Admiral's Cove, Jupiter, FL)



Mangrove Marina Edge (Jupiter Yacht Club, FL)



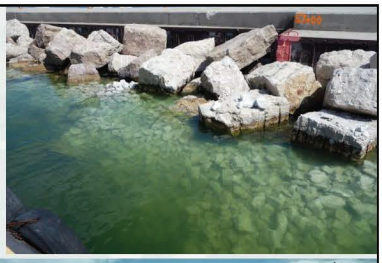
Courtesy: Esteban Biondi (ATM)

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EWN GI-LID R&D

Milwaukee Harbor Green Breakwater

- Modify design of rubble mound breakwater during maintenance
- Extend beyond indirect and unplanned habitat creation
- Provide features creating habitat opportunities for fish and other aquatic life
- Examine creation of habitat surfaces using rubble mound
  - Stone size
  - Gentler sloping shelf
- Create habitat for fish such as walleye and lake trout
- Approach widely applicable





In: EWN Atlas Volume 1 (pages 220-223) (top)

Rendering of living jetty (bottom)

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EWN in New Jersey Back Bays

- Federal navigation channel and coastal marsh habitat damaged by Hurricane Sandy
- Restore the New Jersey Intracoastal Waterway and local marshes
- Improve coastal navigation in New Jersey
- Stone Harbor Black Skimmer habitat restored via thin-layer placement with dredged sediment from adjacent navigation channel





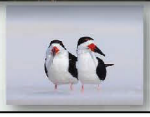
Mordecai Island



Avalon



Stone Harbor



Black Skimmer (*Rynchops niger*)

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Barrier Island: Deer Island, Biloxi, MS

- Biloxi Harbor Navigation Project – 3.65 m (12 ft) deep navigation channel
- Sediment beneficial use to restore marsh, create terrestrial and aquatic habitat, provide a more resilient shoreline for future storm events, create long term disposal capacity
- Hurricanes over time destroyed forests, significantly eroded shoreline, and left elevations too low to support marsh vegetation
- Filled breach in west end of the island
- 1.5 mcm dredged material to restore southern shoreline using 4 km long wave barrier
- Strategic vegetation plantings (625,000+ plants)
- Construction of a 0.76 mcm lagoon for BU dredged material from navigation channels
- Providing significant environmental, coastal storm, and recreational benefits





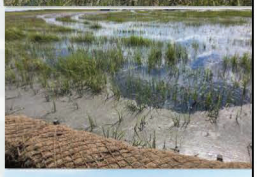
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Coastal Wetland: Jekyll Island, GA

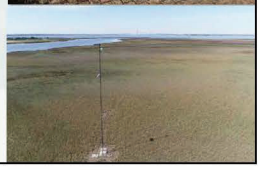
- Two objectives:
  - Elevation enhances marsh resiliency to marsh subsidence and sea level rise
  - Added dredged material promotes new growth of marsh grasses.
- ~5,000 cy non-beach quality was dredged from Jekyll Creek
- Placed in an adjacent 5 ac salt marsh using a thin-layer placement technique to increase marsh elevation
- First TLP project in GA
- Increases resiliency of communities upland of the site



First day of sediment placement (Photo: Georgia Department of Natural Resources' Coastal Resources Division)



Dredged sediment spreading across the containment Area (Photo: Clay McCoy, USACE Jacksonville District)



Site monitoring camera installed prior to material placement (Photo: Georgia Department of Natural Resources Coastal Resources Division)

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Horseshoe Bend River Island Producing Multiple Benefits



500,000 cy 10-21
Jan 2020

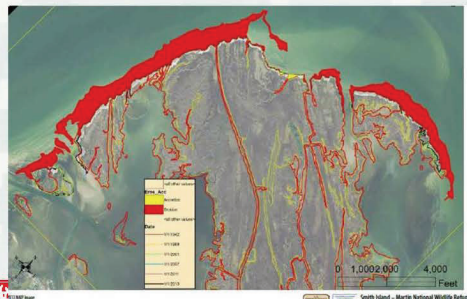


- Problem: capacity of bankline disposal areas exhausted
- Solution: mid-river mounding of dredged material
- Island formation reduced dredging requirements
- Natural channel formed east of the island due to self-scouring
- US Coast Guard realigned channel
  - channel length reduced
  - sharp bends eliminated
  - improved navigation safety
- Reduction in long-term dredging requirements
- Resultant carbon savings and reduced air pollution

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Swan Island, Chesapeake Bay

- Erosion 2-3 meters per year for Swan Island & Martin National Wildlife Refuge since 1942
- Island fragmented, low marsh at sub-optimal elevations
- Natural wave break for Town of Ewell.





Swan Island Restoration Sediment Beneficial Use

- Economic benefits from proximity to Federal navigation channel
- Social benefits to Smith Island communities
- USACE Baltimore District beneficially placed dredged sediment from Federal navigation channels (completed April 2019)
- ~ 60,000 CY, 65% silt, 35% fine grained sand







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Take Home Points

- **Environmental and developmental pressures increasingly threaten coastal communities, yet hardened shorelines are leading to environmental degradation and biodiversity loss.**
- **Such pressures necessitate the development of GI-LID to provide protection in ways that balance economic, environmental, and social benefits through collaboration.**
- **Engineering practice can be advanced through structured decision-making that integrate multiple disciplines for enhancing coastal resiliency.**
- **Challenges >>> Opportunities**





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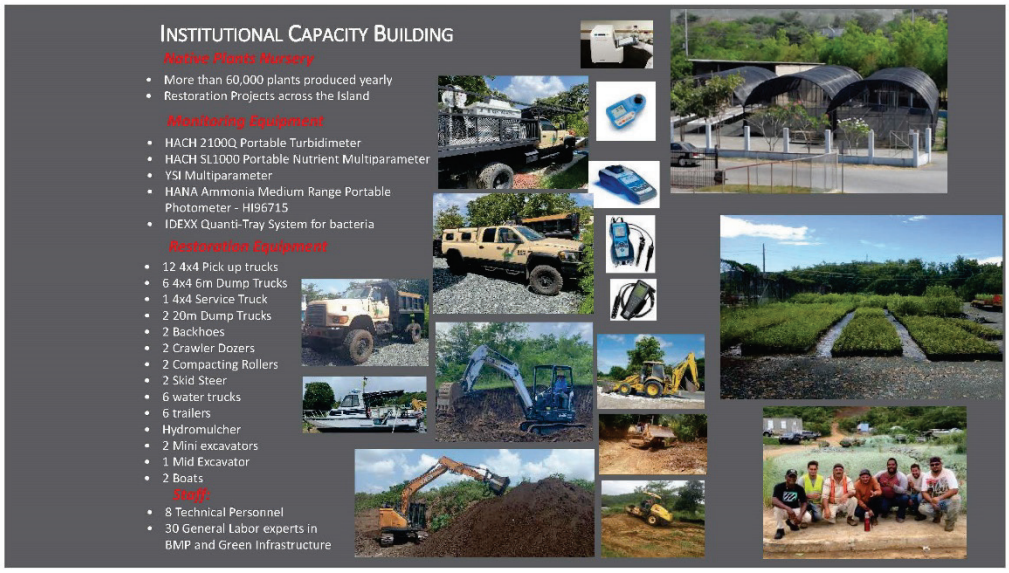


Appendix C.3: “Gerencia y Manejo de Cuencas Hidrográficas en Puerto Rico”

By: Yasiel Figueroa-Sánchez, Protectores de Cuencas

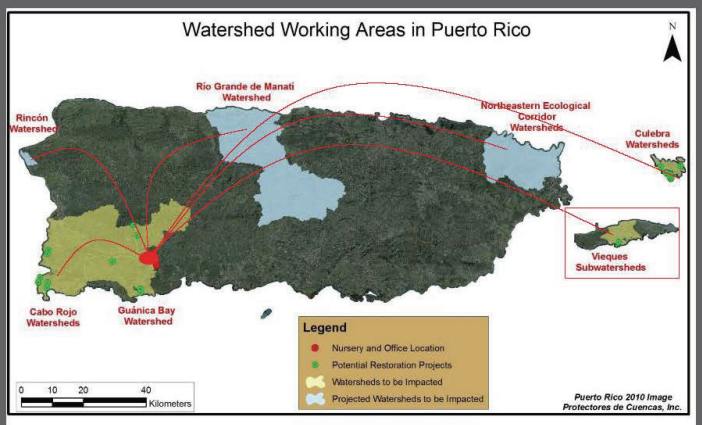





INSTITUTIONAL CAPACITY BUILDING
Native Plants Nursery
More than 60,000 plants produced yearly
Restoration Projects across the Island
Monitoring Equipment
HACH 2100Q Portable Turbidimeter
HACH SL1000 Portable Nutrient Multiparameter
YSI Multiparameter
HANA Ammonia Medium Range Portable Photometer - HI96715
IDEXX Quanti-Tray System for bacteria
Restoration Equipment
12 4x4 Pick up trucks
6 4x4 6m Dump Trucks
1 4x4 Service Truck
2 20m Dump Trucks
2 Backhoes
2 Crawler Dozers
2 Compacting Rollers
2 Skid Steer
6 water trucks
6 trailers
Hydromulcher
2 Mini excavators
1 Mid Excavator
2 Boats
Staff:
8 Technical Personnel
30 General Labor experts in BMP and Green Infrastructure


Colaboradores
Yauco
Guánica
Guayanilla
Lajas
NRCS
GlobalGiving
hispanicfederation
ENGINEERING-COOP
NASA
The University of Texas at Austin
Teresa Lozano Long Institute of Latin American Studies
FUNDACIÓN COMUNITARIA DE PUERTO RICO
USDA

Áreas de Trabajo de PDC

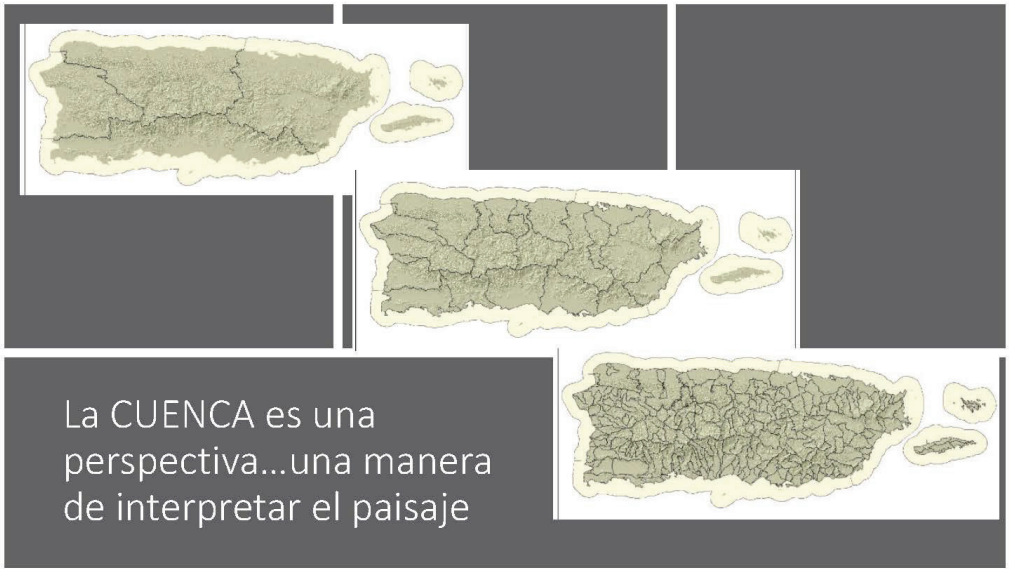


Preguntas Guías

1. ¿Cómo se establece un plan de manejo y cómo se puede incorporar medidas de mitigación?

2. ¿Cuáles son los retos de la implementación de un plan de manejo y a quién le toca resolverlos?

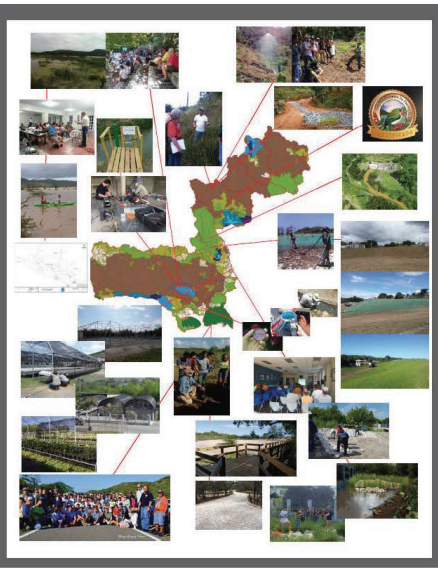
3. Estructuras de gobernanza. ¿Cómo se desarrollan? ¿Ejemplos en PR? ¿Lecciones aprendidas? Sugerencias o plataforma de gobernanza sugerida.



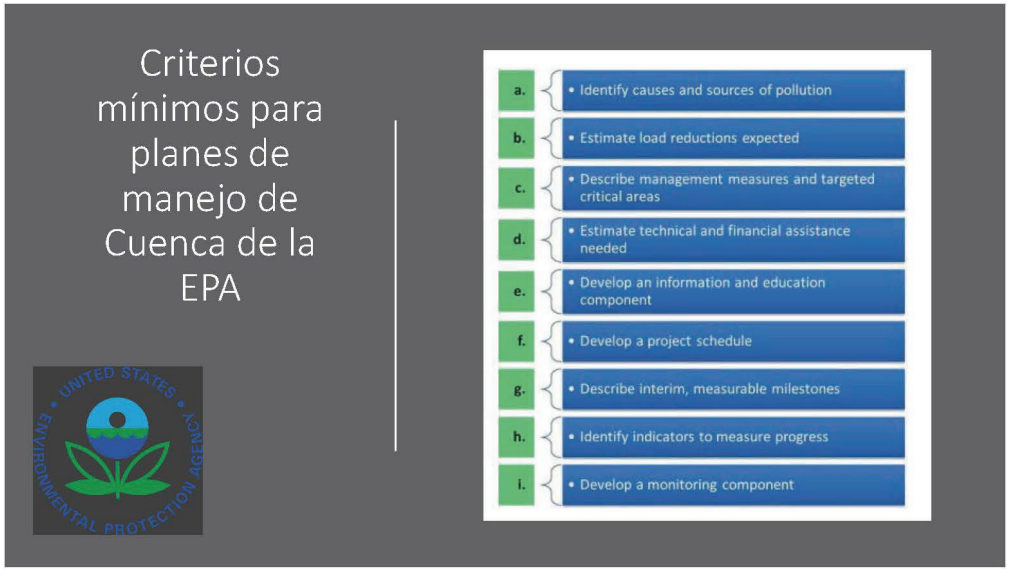
La CUENCA es una perspectiva…una manera de interpretar el paisaje

¿Plan de Manejo de Cuenca?

- El Plan debe ser una Guía flexible y adaptativa que exponga las necesidades principales de la cuenca y como atenderlas.
- Nace de problema o interés común identificado por residentes locales, academia y/o gobierno.
- Recoge los problemas ambientales asociados a los usos y recomienda soluciones para resolverlos.
- Debe ser elaborado en conjunto con las personas que viven en la cuenca.
- Es un esfuerzo multisectorial.




Ciclo del Plan de Manejo
Definir limites geográficos
Integración de partes interesadas
Conocer Cuenca
Identificar y priorizar problemas
Proponer proyectos
Implementar
Medir efectividad
Adaptar


Criterios mínimos para planes de manejo de Cuenca de la EPA
a. Identify causes and sources of pollution
b. Estimate load reductions expected
c. Describe management measures and targeted critical areas
d. Estimate technical and financial assistance needed
e. Develop an information and education component
f. Develop a project schedule
g. Describe interim, measurable milestones
h. Identify indicators to measure progress
i. Develop a monitoring component

Problemas principales de plan de manejo para la Bahía de Guánica

A number of critical issues were identified in the GB/RL watershed related to the impact of land based sources of pollutants on the near shore coral reefs in the areas surrounding the Guanica Bay. These include:

1. Upland erosion in the coffee growing regions;
2. Reservoir sedimentation and transport;
3. In-stream channel erosion;
4. Loss of Historic Guánica Lagoon;
5. Legacy contaminants;
6. Sewage treatment.

Table 5. Implementation Recommendations for Guánica Bay/ Rio Loco watershed

Recommendation	Rationale	Cost	Partners	Location
#1Rio Loco streambank riparian plantings and removal of historical irrigation infrastructure (likely have a willing farmer and existing USDA programs for funding)	Farmers are losing land and excess nutrient rich sediment and topsoil is being exported to the Guánica Bay and reefs	$50k-100k depending on length	USDA, NOAA, DRNA	Demo area that was visited on farm tour just downstream of Yauco before Rio Loco crosses under Rt. 116
#2 Demonstration project where sewage effluent is treated in a series of treatment wetlands or living machine to reduce nitrogen export (2nd most important recommendation after Restoration of the Guánica Lagoon)	Nutrients particularly nitrogen are not significantly removed in a primary or secondary treatment system a treatment wetland would result in increased denitrification of sewage effluent	$50-100k	UPR, PRASA, NOAA	Guánica STP, Cana Gorda STP
#3 Hydroseeding of areas with bare soil associated with roads or clearing of home sites in high elevation erodible soil areas	Sediment loss of highly erodible clay is filling reservoirs and remaining in suspension and reaching Guánica Bay	$20-30k	USFWS, USDA, Ag Consultants	High elevation areas in Loco and Lucchetti

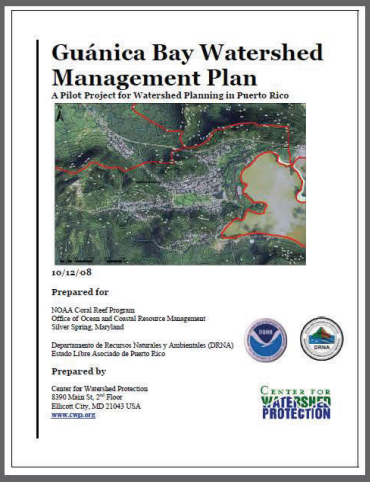




Figure 64. Soil stabilization recommended projects in the NEC.

Table 16. Soil stabilization Practices proposed projects list description.

ID	Sub Watershed	Observations	Est. Unstable Soil Area (acres)	Est. Distance from a stream (meters)	GPS Coordinates	Type	Ownership	Existing Land Use	Slopes Type
SS-1	MP	Active construction site since year 2013 or earlier for urbanization expansion. Appears to be inactive at the moment	40	230	18.373525° -65.743184°	Land Clarence	Private	Urban	Low
SS-2	RJM	Dirt parking area very close to shore.	3	130	18.364917° -65.692980°	Dirt Parking	Private	Urban	Low
SS-3	RP	Land clearing for housing development since year 2004 or earlier.	10	60	18.335131° -65.703936°	Land Clearance	Private	Low Density Urban	High
SS-4	RP	Active farmland	6	560	18.343473° -65.719539°	Land Clearance	Private	Agriculture	Moderate
SS-5	BF	Land clearing for tourism development since year 2004 or earlier.	30	60	18.344919° -65.641706°	Land Clearance	Private	High Density Urban	High to Moderate
SS-6	BF	Land clearing for tourism development since year 2004 or earlier.	2	20	18.346237° -65.638976°	Land Clearance	Private	Low Density Urban	High to Moderate
SS-7	BF	Land clearing for construction of urbanization. Abandoned lot remnant with severe erosion rates.	2	375	18.345016° -65.651108°	Land Clearance	Public	High Density Urban	High to Moderate
SS-8	BF	Land clearing for tourism complex development. Active construction site.	100	1	18.302392° -65.627740°	Land Clearance	Private	Low Density Urban	High to Moderate
DRS-1	RP	Dirt access road in sever erosion conditions that drains to adjacent water bodies that	5	1	18.358593° -65.698015°	Dirt Road	Public	Conservation	Low

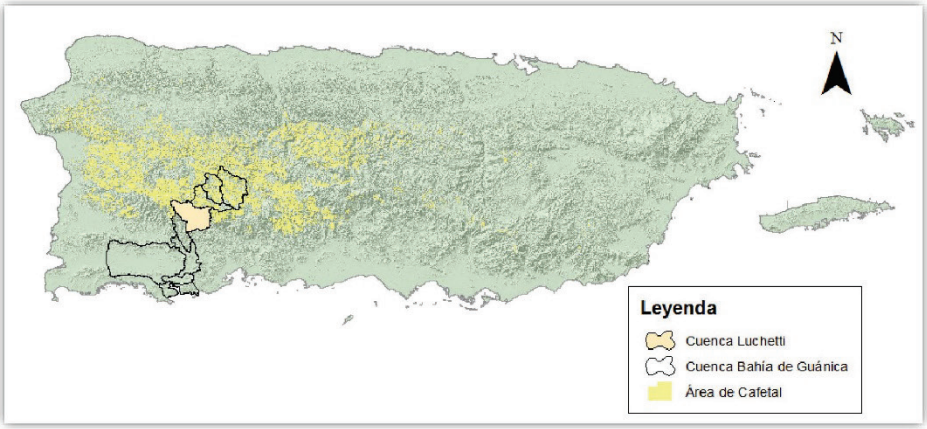


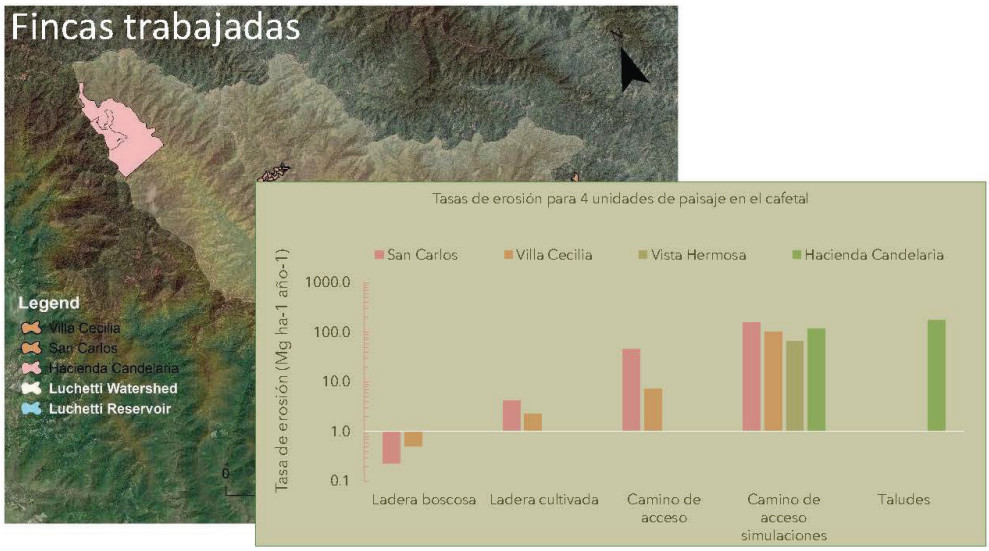
Ejemplo del Plan de Manejo Integrado de Cuencas del Corredor Ecológico del Noreste

¿Cuáles son los retos de la implementación de un plan de manejo y a quién le toca resolverlos?

- Retos filosóficos
- Retos económicos
- Retos políticos
- Retos logísticos

Implementaciones en caminos de tierra en cafetales




Fincas trabajadas
Legend
Villa Cecilia
San Carlos
Hacienda Candelaria
Luchetti Watershed
Luchetti Reservoir
Tasas de erosión para 4 unidades de paisaje en el cafetal
San Carlos
Villa Cecilia
Vista Hermosa
Hacienda Candelaria
Tasa de erosión (Mg ha-1 año-1)
1000.0
100.0
10.0
1.0
0.1
Ladera boscosa
Ladera cultivada
Camino de acceso
Camino de acceso simulaciones
Taludes


Estabilización de caminos de tierra en fincas de café
(c)
(d)

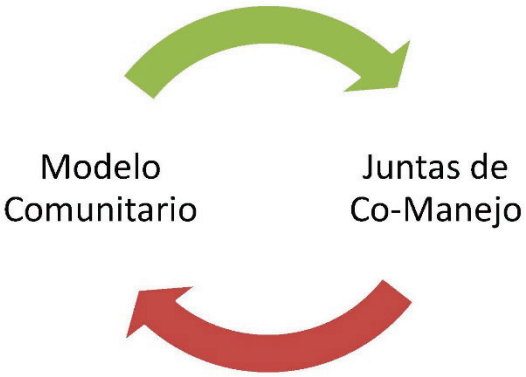


Estructuras de gobernanza.

¿Cómo se desarrollan?
¿Ejemplos en PR?

¿Lecciones aprendidas?

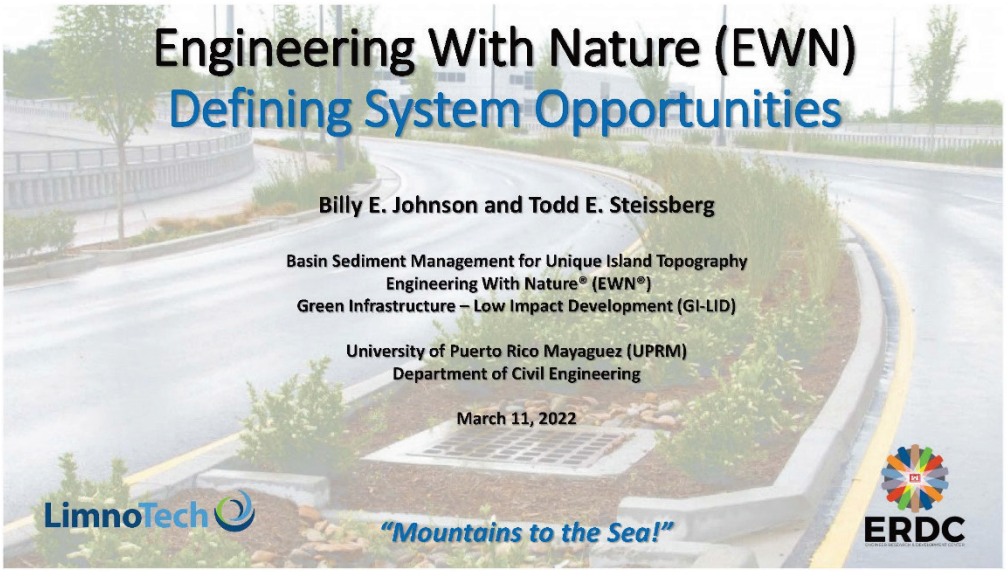
Sugerencias o plataforma de gobernanza sugerida.

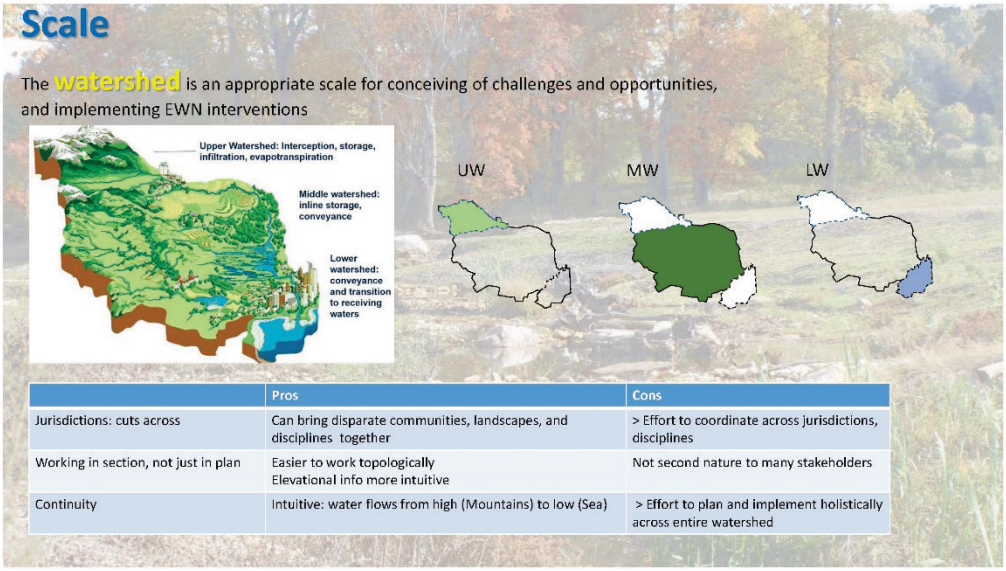



Gracias

Appendix C.4: "Engineering With Nature®: Defining System Opportunities"

By: Billy Johnson & Todd Steissberg, USACE ERDC







Low Impact Development

Low-impact development (LID) is a term used in Canada and the United States to describe a land planning and engineering design approach to manage stormwater runoff as part of green infrastructure.

LID emphasizes conservation and use of on-site natural features to protect water quality.

This approach implements engineered small-scale hydrologic controls to replicate the pre-development hydrologic regime of watersheds through infiltrating, filtering, storing, evaporating, and detaining runoff close to its source.

Green infrastructure investments are one approach that often yields multiple benefits and builds city resilience.



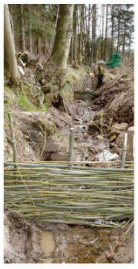
Upland Areas



Compost filter socks are a three-dimensional tubular sediment control and storm water runoff filtration device typically used for perimeter control of sediment and soluble pollutants (such as phosphorus and petroleum hydrocarbons).

Compost filter socks trap sediment and soluble pollutants by filtering runoff water as it passes through the matrix of the compost filter socks and by allowing water to temporarily pond behind the compost filter socks, allowing deposition of suspended solids.

Compost filter socks are also used to reduce runoff flow velocities on sloped surfaces.



Low Cost Check Dam using Local Materials



Slowing the Flow at Pickering - Pickering, North Yorkshire, England, United Kingdom

An integrated application of a range of land management interventions and measures was investigated to help reduce flood risk at the catchment scale. A set of seven measures were planned—including constructing low-level berms in the Pickering Beck catchment to increase flood storage capacity within the floodplain; planting 50 hectares of riparian woodland in the Pickering Beck catchment and 30 hectares of floodplain woodland in the neighboring catchment of the River Seven at appropriate sites to delay and reduce flood flows; constructing 100 large woody debris dams in the Pickering Beck catchment and a further 50 in the River Seven catchment to increase floodplain storage and delay flood flows; and planting 5 hectares of farm woodland on sensitive soils to increase soil infiltration and reduce rapid surface runoff, erosion, and sediment delivery to watercourses.

The project gained a very strong national profile and is well cited as a case study demonstrating the value of working with natural processes. Of special note has been the project's role in helping guide and integrate the implementation of government policy on flood-risk and land-use management. In particular, the project's success has underpinned key regional and national initiatives on Woodlands for Water, including the use of opportunity mapping to identify priority locations for planting to reduce flood risk, and the introduction of a Woodland for Water grant payment per hectare under the previous English Woodland Grant Scheme.









Bendway Weirs

Advantages of Bendway Weirs in the realm of streambank stabilization are:

- flow can be redirected
- flow within the weir field is considered controlled
- weirs work best under high-flow, high-energy conditions
- costs are competitive or lower than traditional methods
- weirs blend well with other bank protection methods and have been retrofitted into existing under-performing projects to improve hydraulic performance of those projects









Belford Natural Flood Management Scheme - Belford, Northumberland, England, United Kingdom

The approach presented in the proactive study was to install passive intervention on farms to control large volumes of runoff.

The features are multipurpose and address water quality, trapping sediment, creating new habitats, and storing and attenuating flood flow.



Pierce Marsh - Hitchcock, Texas, United States

Silts and soft clays, also known as fines, are the most common material excavated in maintenance dredging in this reach of the Gulf Intracoastal Waterway.

The material is ideal for beneficial-use projects that restore eroded habitat.

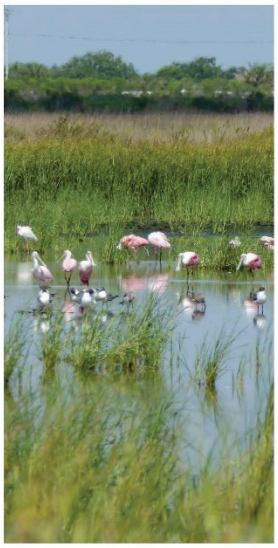
Therefore, the Pierce Marsh project took advantage of this plentiful resource to elevate the marsh and restore habitat for colonial nesting birds and native vegetation.

By using engineered perimeter berms and grade control markers, the team contained the dredged sediment in target areas while avoiding previously restored sections of the marsh.

Now the coastal marsh can provide its own natural engineering benefits, such as protection against storm surge.







Tomago Wetlands - Tomago, New South Wales, Australia

Examining hydroperiods of salt marsh and mangrove systems across the estuary determined the optimal operational design to promote ecosystem recovery.

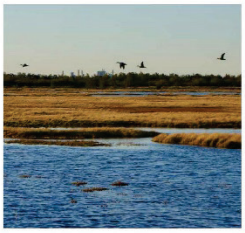
The project team incorporated these variables into a detailed ecohydrodynamic model to provide on-the-ground site management options.

To maximize salt marsh growth while also ensuring that adjoining landholders were not negatively affected, the team implemented an innovative SmartGate system at Tomago.

The gates permit adaptive tidal inundation control across the large intertidal flats, protecting both the restored areas and the adjoining commercial properties from river-based floods.









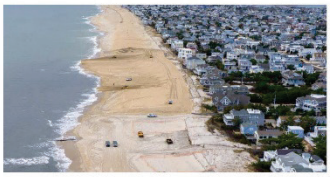


Long Beach Island Coastal Storm Damage Reduction – Long Island, NY

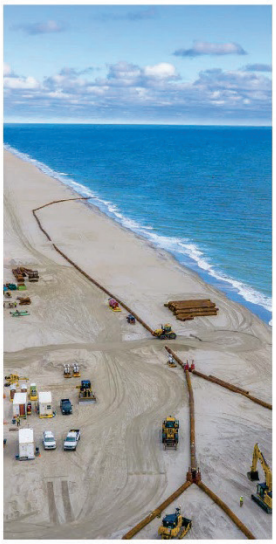
This project consisted of creating a berm and dune extending along the oceanside of the island; these nature-based features were designed to minimize flooding and coastal storm damage for the island's communities. The features were built with sand obtained from an offshore borrow source. Incorporated into the Natural and Nature-Based Features project plans were periodic sand nourishments every 7 years for 50 years.

This project has tremendous social and economic value, as it was designed to mitigate erosion, flooding, and property damage that can result from storms, hurricanes, and other extreme weather events. The revitalized beach will also improve recreational opportunities for the island's inhabitants and visitors. The plantings will provide habitat for wildlife—an environmental benefit.

This project was a joint effort between the USACE and the project sponsor and cost-sharing non-federal partner, NJDEP. In 2014 USACE awarded a contract to the Great Lakes Dredge and Dock Company to complete initial construction of the project.







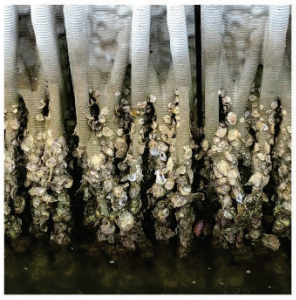
Mangrove Reef Walls – Englewood and Fort Pierce, FL

Mangrove Reef Wall panels ensure an ecologically responsive and viable approach to shoreline enhancement. The custom high-strength concrete is balanced with oyster flour, silica fume, and macrofiber reinforcement to attract oysters, resist saltwater deterioration, remove spalling risk, and double the material's lifespan. Further, the design uses existing seawall production methods, creating a high-impact investment when replicating many panels.

Mangrove Reef Walls create a scaffold for nature, enhancing ecosystems alongside human development. The walls' ability to dissipate wave energy in the same way that mangroves do improves water clarity by reducing suspended sediment and increases the walls' longevity by preventing sediment erosion. The small eddies produced by the uneven surface of the walls help attract drifting colonizers, diversifying the ecosystem and attracting grazing species, which in turn attract larger predators.

The filtration capacity of tidal ecosystems directly affects water quality.

Increasing filter-feeder populations may also mitigate harmful algal blooms (red tides), one of the most serious environmental and economic threats to Florida communities.

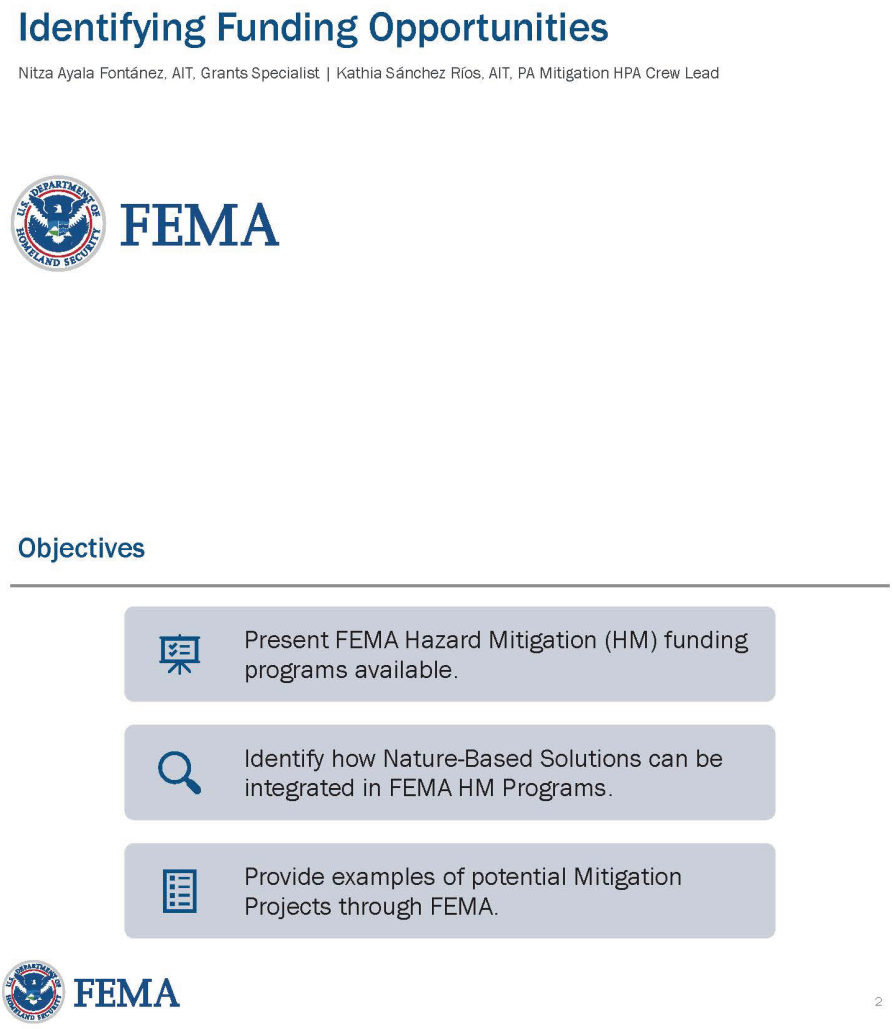






Appendix C.5: "Identifying Funding Opportunities"

By: Nitza Ayala-Fontánez and Kathia Sánchez-Ríos, FEMA



FEMA's Hazard Mitigation Definition

"Any cost-effective sustained action taken to reduce or eliminate long-term risk to people and property from natural hazards and their effects."

FEMA – Hazard Mitigation Programs

Stafford Act Section 406	Stafford Act Section 404		Stafford Act Section 203	National Flood Insurance Act of 1968 NFIA
PA Program	Hazard Mitigation Assistance (HMA) Programs			
Disaster-related program	Disaster-related program		Non-disaster-related programs	
 Public Assistance Program and Policy Guide	HMGP Hazard Mitigation Grant Program	HMGP Post Fire Hazard Mitigation Grant Program Post Fire	BRIC Building Resilient Infrastructure and Communities	FMA Flood Mitigation Assistance Program
Mitigation of incident-caused damage	Multi-hazard; statewide mitigation	Mitigation after Fire Management Assistance Grant declaration	Multi-hazard; project-specific	Flood mitigation for insured properties

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4

Public Assistance (PA) Mitigation

Implements mitigation measures to reduce the potential of future, similar damages during facility repair.

- Funding is available when authorized through a Presidential major disaster declaration. (For example, Hurricane Maria in 2017.)
- Eligibility criteria is established by the Public Assistance Program and Policy Guide (PAPPG).
- Mitigation projects must be reasonable, feasible, cost effective and compliance with EHP laws, regulations, and EOs.
- FEMA provides assistance for facilities that were damaged during a declared incident.
- The mitigation cannot negatively impact the facility's operation or surrounding areas or create susceptibility to damage from another hazard.

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5

Hazard Mitigation Grant Program (HMGP)

Implements mitigation measures to reduce risk of loss of life and property from future natural disasters during reconstruction process following a disaster.

- Funding is available when authorized through a Presidential major disaster declaration. (For example, Hurricane Maria in 2017.)
- All Applicants and Subapplicants must have a FEMA-approved mitigation plan, in accordance with 44 CFR Part 201.
- The Governor's Authorized Representative (GAR) or equivalent serves as the grant administrator for all assistance provided.
- Mitigation projects funded by HMA must be cost-effective and feasible at mitigating the risks of the hazard(s) for which the project was designed.
- FEMA cannot provide assistance for activities funded or under the authority of another federal agency or program.

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6

Summary of PA Mitigation and Hazard Mitigation Grant Program

PA Mitigation

- FEMA administers the program (PA)
- Funding is not competitive
- FEMA can prepare applications
- Only damaged facilities are eligible
- Only declared areas participate in the program
- Mitigation work completed before FEMA funding approval is eligible

Hazard Mitigation Grant Program

- State administers the program
- Funding is competitive and limited
- Only applicants prepare applications
- Undamaged facilities are eligible
- Entire state participates in the program
- Work started before approval is not eligible

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7

FEMA – Hazard Mitigation Assistance Programs

PA Mitigation (406)
Use funds to provide protection against future events to elements of a facility that were damaged during a disaster.

HMGP (404)
Use funds to provide protection against future events to elements of a facility regardless if the elements were damaged or not during a disaster.

Leveraging 404 and 406 is appropriate when:

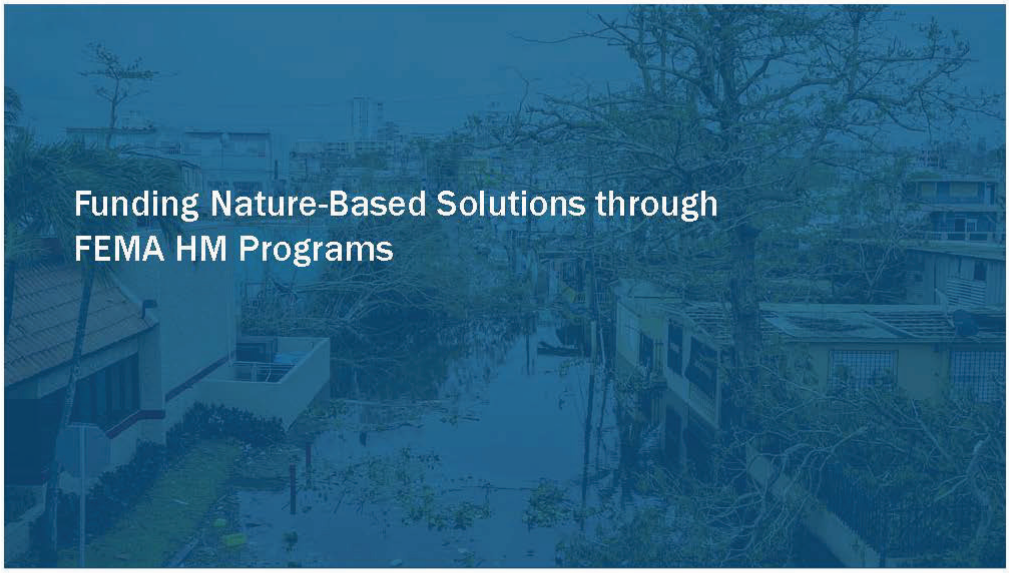
- Mitigation is needed to provide protection to both damaged and undamaged eligible sites.
- A comprehensive, more complex solution is needed / desired. For example, including watershed wide solutions to address flooding.

Benefits of leveraging 404 and 406:

- Allows a comprehensive project scope
- Extends the use of limited Section 404 funds.
- Combines project benefits in one BCA.

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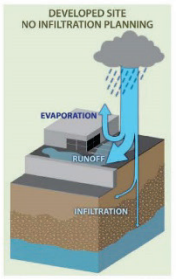
8



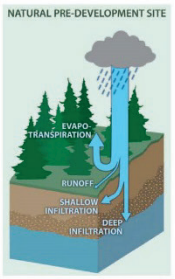
FEMA's Nature-Based Solutions Definition

"Sustainable planning, design, environmental management, and engineering practices that weave natural features or processes into the built environment to build more resilient communities."

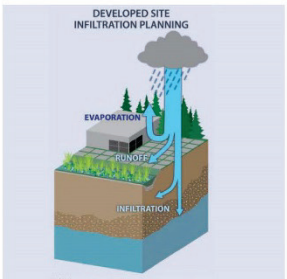
Nature-Based Solution Intent Example



- In urban areas, about 55% remains as runoff.
- Weakens faster; expensive to build, maintain, and repair



- In forested areas, about 50% of rainfall is infiltrated
- Only 10% flows along the surface as runoff.



- NBS emulate natural systems and increase infrastructure resilience.
- Investment up front, reduces maintenance over time, does not fail as catastrophically

FEMA

Source for images: Stormwater: The Journal for Surface Water and Erosion Control Professionals, Issue Winter 2022. Article: Infiltration System SOPs: How Deep Does Your Water Go?, John Knutson (Page 14)

Steps for identifying a Nature-Based Solution as HM Strategy

FEMA – HM Assistance Programs	Mitigation Techniques	Quantifying Benefits	Approach & Strategy
• Is the need for a mitigation project driven by post disaster recovery or pre-disaster preparation?	• Is the primary hazard affecting the site's coastal flooding, riverine, urban flooding, landslide, drought?	• How to best quantify the benefits of NBS using FEMA's Benefit Cost Analysis (BCA) tool?	• How to maximize possible mitigation benefits and/or improve project impact?

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12

Promoting NBS through FEMA programs



Small Scale



Large Scale

Nature-based solutions often work best when applied at larger scales across whole landscapes, ecosystems, or communities.

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Sources for images: The Nature Conservancy, Promoting Nature-Based Hazard Mitigation Through FEMA Mitigation Grants, 2021 (page 32) / Green Terramesh system is successfully certified | Maccaferri UK & Ireland /

13

Mitigation Techniques



Riverine Flood

- Stormwater Park
- Stream/River Restoration
- Horizontal Setback Levee
- Streambank Stabilization



Coastal Flood

- Coral Reef Restoration
- Coastal Wetland Restoration
- Tidal Circulation
- Beach Parks



Urban Flood

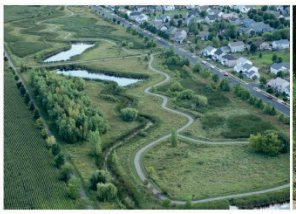
- Rain Garden
- Rainwater Harvesting
- Vegetated Swales
- Permeable Pavers

FEMA

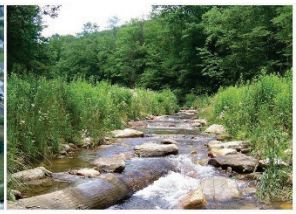
Sources for images: Figure_6_Restoration_of_the_Headwaters_of_the_Big_Darby_River_in_Ohio_(7590258538).jpg (752×528) (wikimedia.org) / Reef ball burials: the new trend for becoming 'coral' when you die | Marine life | The Guardian/

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Mitigation Techniques – Riverine Flood Watershed Scale



Stormwater Parks



Stream Restoration



Streambank Stabilization

FEMA

Sources for images: Prairie Waterway Stormwater Park – Balmori Associates / Wildlands Engineering | Linville River Restoration Project / FEMA Job Aid, Bioengineered Streambank Stabilization (Page 5), 2017

15

Mitigation Techniques – Streambank and Slope Stabilization



Vegetation (Live Stakes)



Vegetated Rip Rap



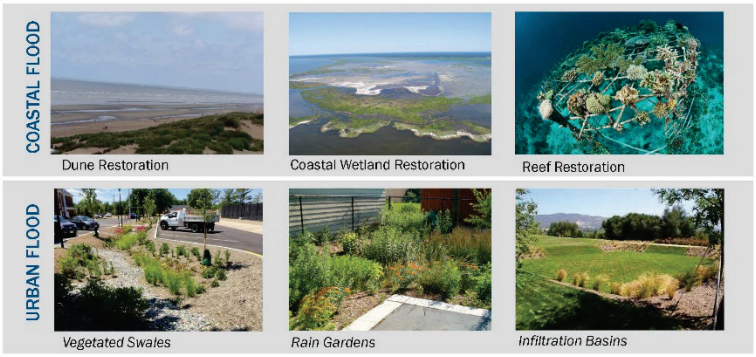
Green Gabions

FEMA

Sources for images: FEMA Job Aid, Bioengineered Streambank Stabilization (Page 5), 2017 / Revetments - Warner Park Beach (weebly.com) / Green Terramesh system is successfully certified | Maccaferri UK & Ireland

16

Mitigation Techniques

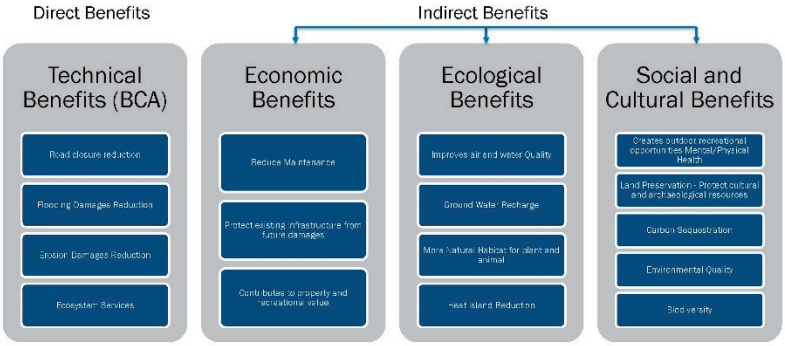


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Sources for images: https://commons.wikimedia.org/wiki/File:Beach-dunes.jpg 14 August 2005, 22:00 / https://upload.wikimedia.org/wikipedia/commons/0/00/Goose_Point_Marsh_Creation.jpg / Healthy hard corals growing on a Biorock reef restoration structure, Gili Trawangan, Lombok, Indonesia. | MATTHEW OLDFIELD PHOTOGRAPHY (photoshelter.com) / FEMA: Building Community Resilience with Nature-Based Solutions: A Guide for Local Officials (page 5) / File:7sigma RainGarden 66.JPG - Wikimedia Commons / Infiltration basin | A completed sports field serves to capt... | Flickr

17

Quantifying Benefits



FEMA

18







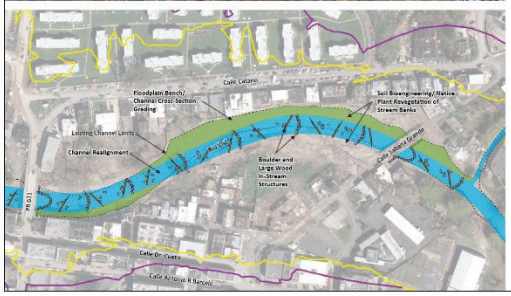
Slope Stabilization Project

- Applicants are proposing to install gray infrastructure, such as gabion walls.
- **Proposed Scope of Work:** install living system with vegetation to reinforce soil and create resistance through root development.
- **Benefits:** reduce long-term maintenance and stabilization results

Sources for images: Taken by HM Specialist - Kathia Sanchez @ Mennonite General Hospital / Groynes and Gabions - Coastal and Environmental, Marine and Water Resource Engineering - Ocean Caraibes

Potential Mitigation Projects through FEMA HM 20

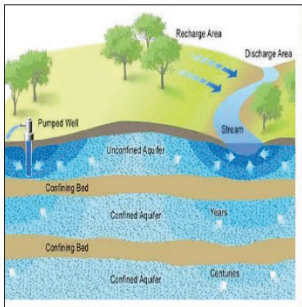




Watershed Management Project

- **Proposed Scope of Work:** Realign channel in several section, grading, built instream structure (add wood debris, gravel, etc.) and stabilize stream bank (add native plants). Potential Land Acquisition.
- **Benefits:** Reduces erosion, sediments and flooding.

Sources for images: RiparianEngineering.com / Figure 8. Concept for Stream Restoration in Rio Vivi Reach 1 - Downtoen Utuado, PR (page 12)





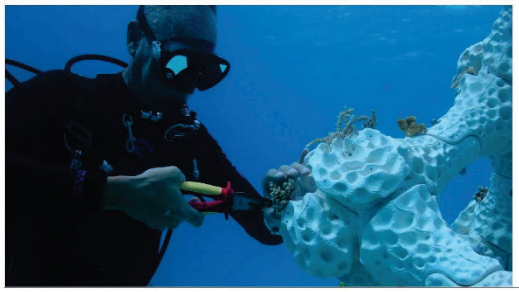


Aquifer Storage Recovery

- **Proposed Scope of Work:** harvest rainwater overflow from Patillas Reservoir into Salinas through a canal.
- **Benefits:** reduce drought and flood risks, improve water recharge, increase flora and fauna, protect freshwater supply from saltwater intrusion, among others.

Sources for images: Aquifers - Water Education Foundation / Aquifer Storage and Recovery: A Strategy for Long-Term Water Security in Puerto Rico | U.S. Climate Resilience Toolkit





Coral Reef Restoration

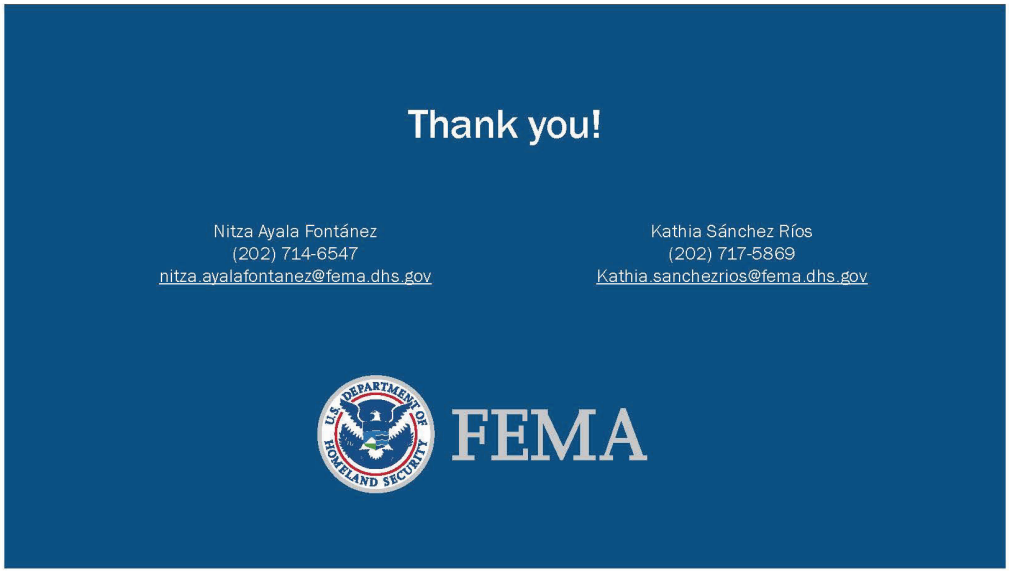
- **Proposed Scope of Work:** integrate different types of coral and distribution of artificial reef module/system.
- **Benefits:** improve durability and strengthen structure, attenuate energy of incoming waves, reduce shoreline erosion and attenuate surge water levels.

Sources for images: DNER shared this information with Public Assistance Staff / Maldives, artificial barrier reef | Abitare

Available Resources

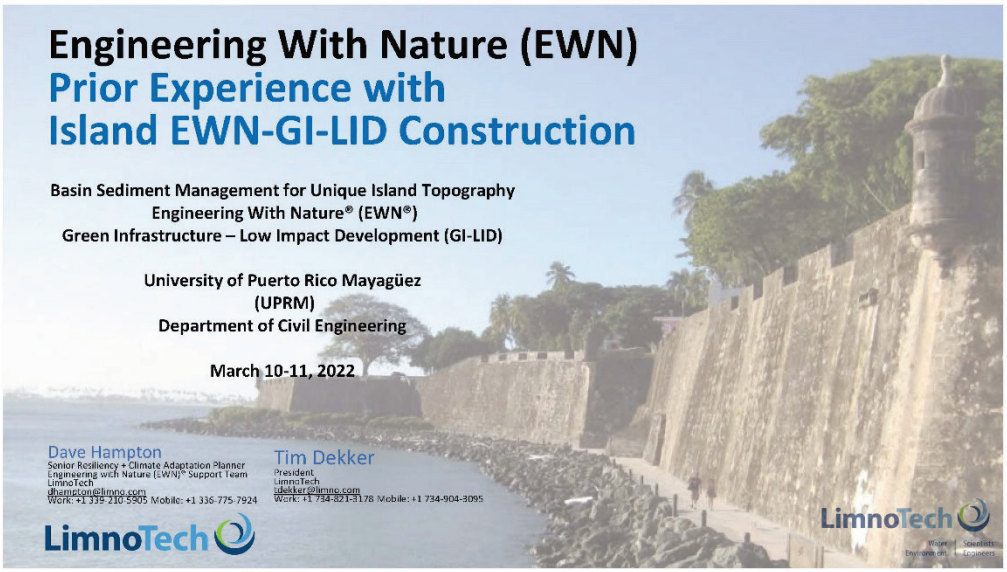
- Hazard Mitigation Assistance Grants | FEMA.gov
- Promoting Nature-Based Hazard Mitigation through FEMA Mitigation Grants
- Natural and Nature-Based Features International Guidelines
- Building Community Resilience with Nature-Based Solutions: A Guide for Local Communities
- Innovative Drought and Flood Mitigation Projects
- FEMA Fact Sheet – Bioengineered Streambank Stabilization
- FEMA Fact Sheet – Aquifer Storage and Recovery
- FEMA Fact Sheet – Flood Diversion and Storage
- FEMA Fact Sheet – Floodplain and Stream Restoration
- FEMA Fact Sheet – Green Infrastructure Methods

FEMA


Thank you!
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Kathia Sánchez Ríos
(202) 717-5869
Kathia.sanchezrios@fema.dhs.gov
FEMA

Appendix C.6: "Engineering With Nature®: Prior Experience with Island EWN®-GI-LID Construction"

By Dave Hampton and Tim Dekker, LimnoTech





1. From risks to opportunities



Boquilla Village and Nature Reserve, Mayagüez. Photo: Dave Hampton

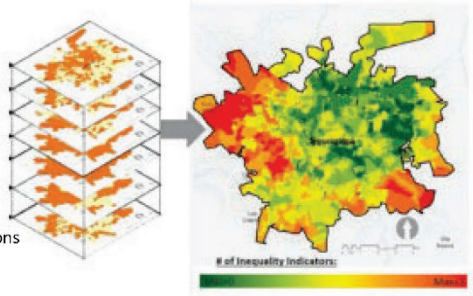
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Understand the context

(Re)frame risks as opportunities

Multi-criteria analysis

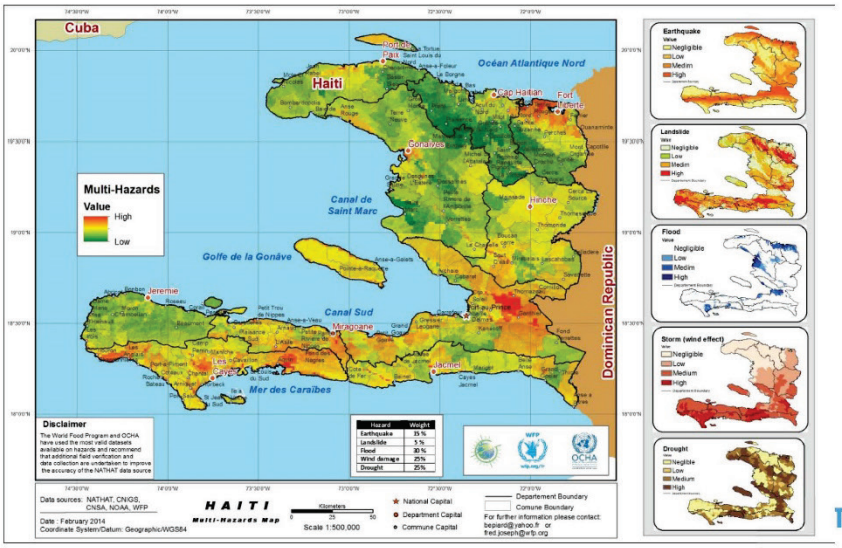
- Bio-physical data
  - Temperature
  - Precipitation
  - Vegetation cover
  - Impervious area
  - Salinity, sodicity
  - Etc.
- Land use
- Political boundaries / jurisdictions
- Demographics
  - Populations
  - Age
  - Socio-economic
  - Vulnerable populations



Multi-criteria sensitivity map

Source: GeoAdaptive LLC. http://geoadaptive.com/

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Source: https://reliefweb.int/sites/reliefweb.int/files/resources/Multi%20Hazards%20Map.pdf

Human settlement



Source: Graduate City and Regional Planning | Weitzman School (upenn.edu)

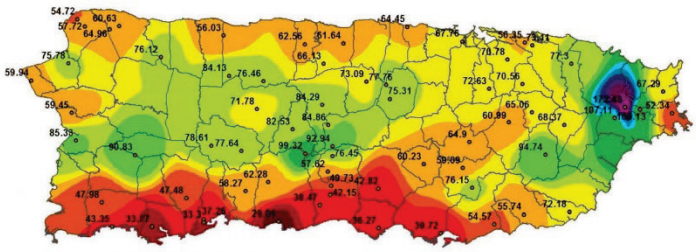
Geology



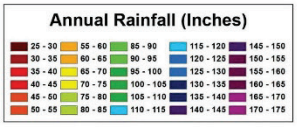
Source: Graduate City and Regional Planning | Weitzman School (upenn.edu)

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Precipitation



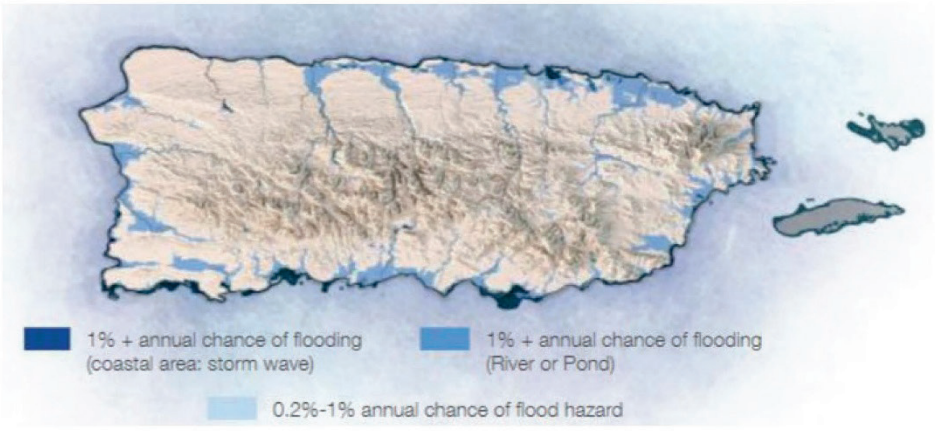
Mean annual rainfall 1981-2010



Source: https://statesummaries.ncics.org/chapter/pr/

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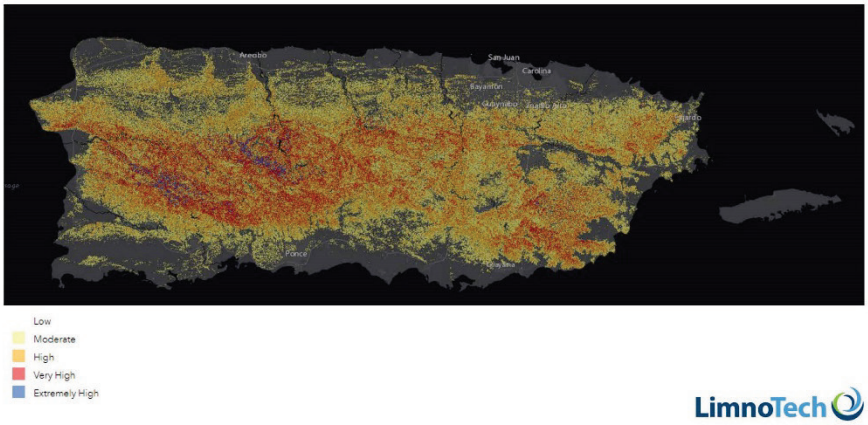
Flood risk



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Environment | Engineers

Source: Graduate City and Regional Planning | Weitzman School (upenn.edu)

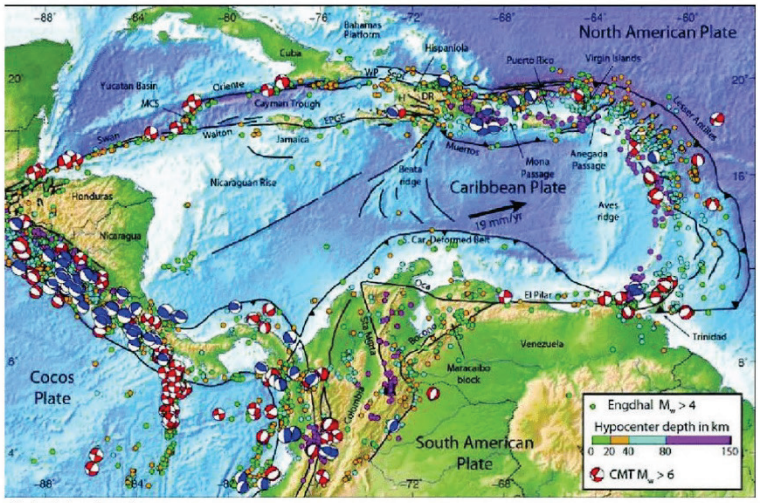
Landslide susceptibility



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Environment | Engineers

Source: https://www.arcgis.com/apps/webappviewer/index.html?id=10506ecc7f15491daee17647f19248ee

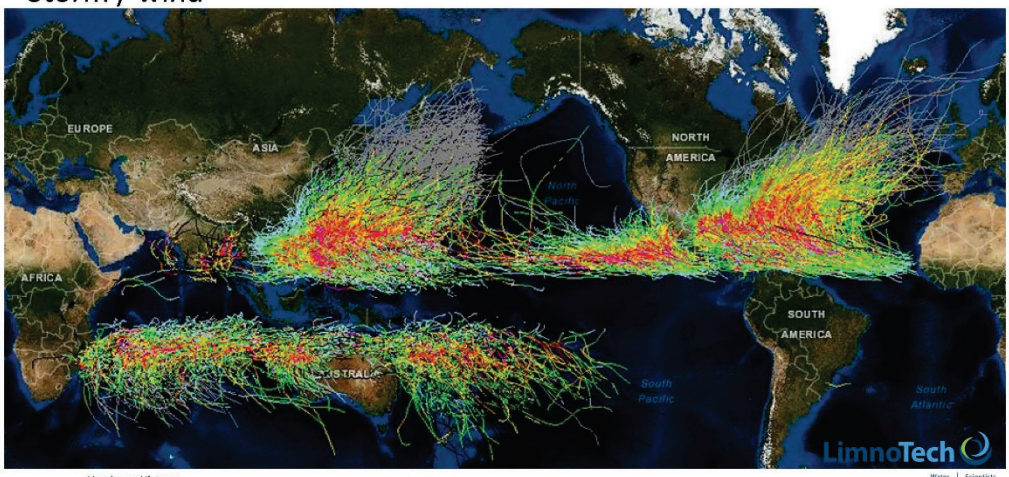
Seismic



A seismically active region: Seismo-tectonic setting of the Caribbean region. Black lines show the major active plate boundary faults. Colored circles are precisely relocated seismicity color-coded as a function of depth. Earthquake focal mechanism are from the Global CMT Catalog, thrust focal mechanisms are shown in blue, others in red. H Haiti, DR Dominican Republic, MCS mid-Cayman spreading center, WP Windward Passage, EPGF Enriquillo Plaintain Garden Fault. Source publication

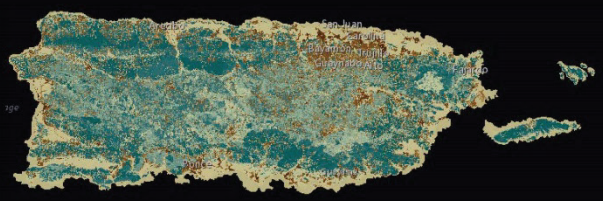
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Storm / wind



Hurricane History
View more than 150 years of hurricane tracking data in your region. Shown here: Category 4 and 5 hurricane tracks from 1851-2016 in the East Atlantic ocean basin.
https://oceanservice.noaa.gov/news/historical-hurricanes/

Community exposure



Community Exposure Index
Product of Asset and Threat indices which suggests areas on the landscape where community assets are potentially exposed to flood-related threats

Low — High

6 key questions

1. Who determines hazard, vulnerability, and risk?
2. What are its implicit biases?
3. Who/how determines priorities?
4. Are biophysical hazards enough?
5. Consider multi-hazards (not just flooding)
6. What about *socio-economic* vulnerabilities?

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Source: NFWF Coastal Resilience Evaluation and Siting Tool (CREST)
https://resilientcoasts.org/#AnalyzeProjectSites

Community exposure



Condado neighborhood, San Juan. Photo: Dave Hampton



La Perla neighborhood, San Juan. Photo: Dave Hampton

Who and what is (most) at risk?
For what?
When?
Where?

How might you reduce exposure?

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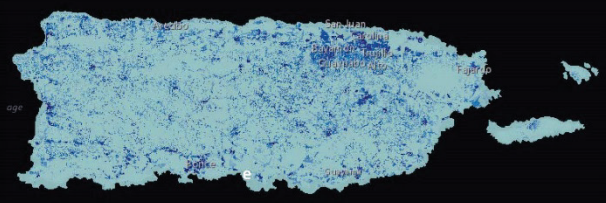
Obrero neighborhood along Caño Martín Peña, Mayaguez. Photo: Dave Hampton



Boquilla Village, Mayagüez. Photo: Dave Hampton

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Community assets / adaptive capacity

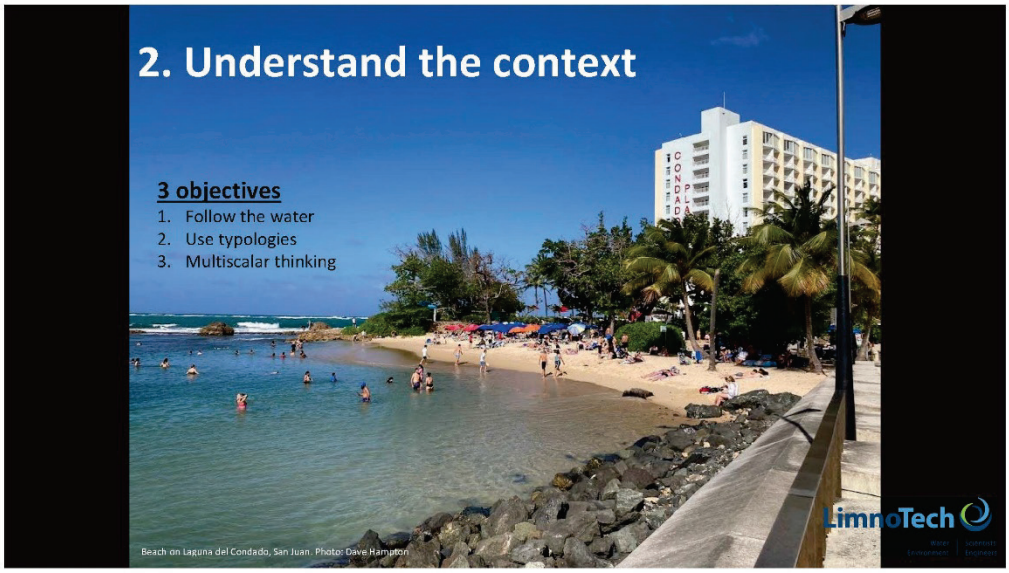


Community Asset Index
Index of community assets critical to the recovery of an area and human population. High values suggest areas with a higher, cumulative prevalence of community assets on the landscape.

Low — High

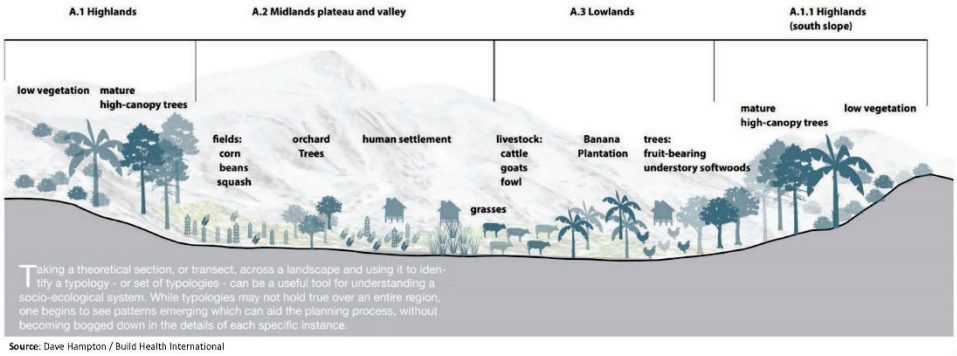
Source: NFWF Coastal Resilience Evaluation and Siting Tool (CREST)
https://resilientcoasts.org/#AnalyzeProjectSites

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Typologies

Not every single location can be addressed. So…
Think typologically



Source: Dave Hampton / Build Health International

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A. SOCIO-ENVIRONMENTAL SYSTEMS
1. AGRICULTURE & FOOD SECURITY | HIGHLANDS




Fig. II.A.1.1. Path to Bernadel with understory trees and interspersed agriculture (corn, squash) beyond.
Fig. II.A.1.2. Ravine with high canopy trees (coconut palm, mango) and understory species.

Food insecurity in Haiti is high: 50% of the population is undernourished according to the UN World Food Program's, comparing with North Korea and sub-Saharan African nations such as Namibia and Malawi.
Workshop and Assessment Report results acknowledged the importance of food security, with drought listed as a top environmental challenge by 21% of interviewees. Other reflections included loss of certain plants such as citrus, coffee, and cotton.

During the transect walks, a variety of highland conditions were observed.
In a high ravine above (north of) Gaspard II on southeastern slopes, a mix of moderate high canopy trees (coconut palm, mango), understory (coffee) with interspersing of crops (corn, beans, squash) was present, with minimal erosion mostly confined to pedestrian and pack animal paths.Anecdotal evidence suggests that reforestation programs were encouraged by - and funded by - the Government of Haiti in the 1980's, attributing subsequent deforestation to charcoal production, citrus epidemics.

In the drier, mostly south-facing hillsides between Vibert and Mirye (Figs. II.A.1.5-10), fewer high canopy trees were present, with more erosion visible especially where terracing does not occur. Of the few examples of terraced farming observed (Figs. II.A.1.10-12), generally accepted practice of building ridge-and-channel across existing slopes to intercept runoff water and reduce soil erosion is not followed, rather, terraces are generally cut into the existing topography, contributing to destabilization of soil and exacerbating erosion. This was acknowledged by the Community & Natural Resources sector/cluster: "Kanal de kontou", or building of canals along contours.

Crop diversity generally appeared low, but traditional for the area, with an overwhelming reliance on corn, beans, and squash. Some innovation was present, such as pineapple (Fig. II.A.1.11).

Construction of buildings in or immediately adjoining highland ravines is minimal, observed only near Vibert (private homes), but should continue to be monitored, especially as a Community & Natural Resources action plan item is the admishment "don't build in inappropriate places."

© 2017 Dave Hampton

Source: Dave Hampton / Build Health International

"Used to be trees so thick you couldn't walk".
"People need to become educated, because how can they cut a fruit tree to make charcoal?"
– Dominique Guirand, Sainthon resident




Fig. II.A.1.3. Ravine with path, crops at left (corn, beans, squash), coffee at right, and high canopy trees (mango).
Fig. II.A.1.4. Coffee trees present in understory.

LINKS TO OTHER THEMES
Agriculture in midlands / plateau and valley, Agriculture in lowlands, Erosion, Economy & Livelihoods

Fig. A.1.5. Highland field between Bernadel and Gaspard II.
Fig. A.1.6. Field on sloped topography near Vibert.




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A. SOCIO-ENVIRONMENTAL SYSTEMS
3. AGRICULTURE & FOOD SECURITY | LOWLANDS




Fig. II.A.3.1. Streamside subsistence agriculture between Kalya and Balangen: corn, plantain.
Fig. II.A.3.2. Tobacco crop adjoining Ravine Dubois, upstream from Dipé.

Lowlands normally include streams and water bodies, thus tend to be wetter environments with alluvial soils, but with some deposition of geological material from higher elevations (rounded stones). Some high-canopy trees - softwoods such as royal palm and hardwoods such as mango - are present in lowlands.
During field walks, crop diversity generally appeared low, but traditional for the area, with an overwhelming reliance on corn, beans, and squash. Some rarer crops were present, such as tobacco (Fig. A.3.2).

A brief conversation with coffinmaker Pierre - a coffinmaker, handyman, and subsistence farmer - revealed that his approximately 0.5 acre (0.2 hectare) plot of lowland crops of corn, beans, squash (Figs. A.3.3-4) within 50 meters of a stream floods periodically, but only during hurricanes are crops typically lost.
Another passing farmer noted that his goats are often left to graze unattended during the day along the stream, which return to him at end of the day; the practice appears to be common.

Construction of buildings in or immediately adjoining lowland ravines is minimal, observed only near Vibert (private homes), but should continue to be monitored.

Charcoal production was evident (see p. 90 for additional discussion on economy and livelihoods).

LINKS TO OTHER THEMES
Agriculture in highlands, Agriculture in midlands / plateau and valley, Erosion, Flooding, Economy & Livelihoods

© 2017 Dave Hampton

Source: Dave Hampton / Build Health International

"My fields flood periodically, but I only lose crops during a hurricane."
– Pierre, subsistence farmer, coffinmaker




Figs. II.A.3.3. Streamside subsistence agriculture between Balangen and Ka Lendi: corn, beans, squash.
Figs. II.A.3.4. Same as above.

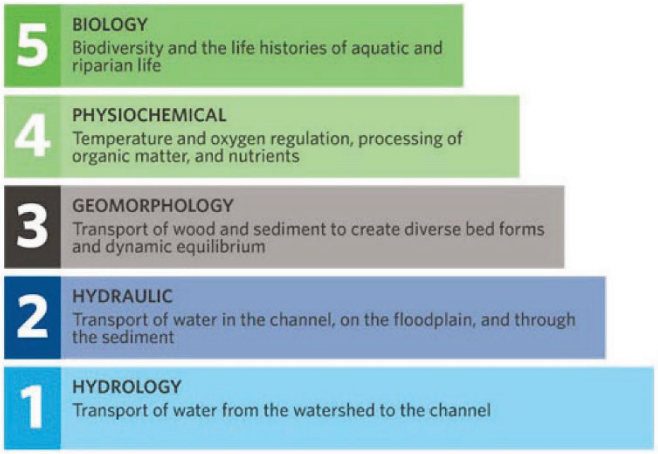
FUTURE SCENARIO
Increasing swings in temperature extremes will increase the likelihood of summer storms and amount of rainfall, and with species migration from low to higher elevations. More surfacewater will move quickly through the landscape with highlands left drier, threatening cooler weather and moisture-loving crops.
Low-lying areas will experience increased water volumes and flow, impacting road-stream/river crossings.

RECOMMENDATIONS
Community health - expand concept of healthcare to preventative practices, incl. nutrition, access, & food security.
Document other lowlands areas in Fond des Blancs.
Preserve subsistence agriculture and especially mature high-canopy trees and fruit-bearing species.
Divert polluted surfacewater flows from/into waterbodies.
Workshop / Focus Group: Agricultural best practices (crop diversity, interplanting, crop rotation/tilling, terracing, etc.)

SUGGESTED LITERATURE
Watson, C. (2017). Land restoration in Ethiopia: 'This place was abandoned... This is incredible to me', The Guardian, 21 June 2017

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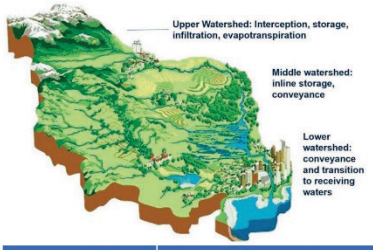


Source: LimnoTech

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Scale

The watershed is an appropriate scale for conceiving of challenges and opportunities, and implementing EWN interventions





	Advantages	Challenges
Jurisdictions: cuts across	Can bring disparate communities, biomes, and disciplines together	> Effort to coordinate
Working in section, not just in plan	Easier to work typologically Elevational info more intuitive	Not second nature to many stakeholders
Continuity	Intuitive: water flows from high (Mountains) to low (Sea)	> Effort to plan and implement holistically across entire watershed
Breadth	Knits whole landscape together	> Effort to coordinate across jurisdictions, disciplines

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3. Actioning: Identifying projects, involving people



Climate Ready Dorchester, Massachusetts. Source: https://www.scapestudio.com/projects/climate-ready-dorchester/



1. "Pwoblèm lan souvan gen solisyon an"
   "The problem often contains the solution"

© 2018 Dave Hampton





2. Solisyon lokal yo pwisan
   Local solutions are powerful

© 2018 Dave Hampton

Pivot quickly from problems to opportunities

From a workshop in Fond-des-Blancs, Haiti

Avoid overreliance on outside experts and ideas.

Empower local actors, culturally-relevant approaches

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3. Entè sektè-gwoup
Interdisciplinarity

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Hold workshops.
Group sectors/disciplines by local expertise and interest.
Allow for cross-pollination

From a workshop in Fond-des-Blancs, Haiti



risk ↔ opòtinite yo
risk ↔ opportunity

vilnerabilite → pwisans, kapasitè
vulnerability → strength, capacity

4. Dualitès
Dualities

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'Risk-opportunity' reflects dual nature

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5 risk-opòtinite yo — **risk-opportunities**

ekstrèm chalè + sechrès	extreme heat + drought
gwo van	high wind
inondasyon	flooding
dlo aksé	water access
sekirite alimantè	food security

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Multi-hazards/risks

Pick two inter-related risks
('hazard-perspective')

From a workshop in Fond-des-Blancs, Haiti

Ki sa ki yon **risk-opòtinite?**

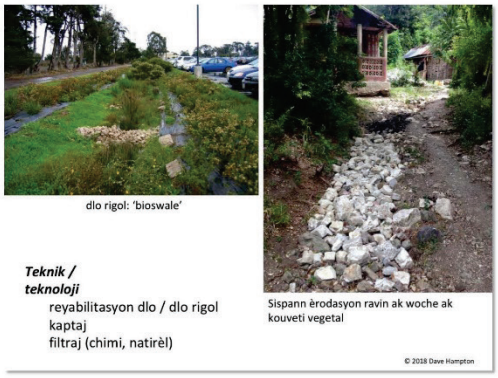


risk-opòtinite yo → aspirasyòn / aksyon → teknik / teknoloji → pwojèt katalitik

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...and re-frame as opportunities according to aspirations/actions previously identified by community

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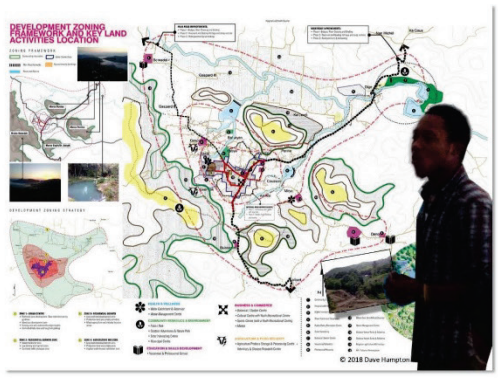


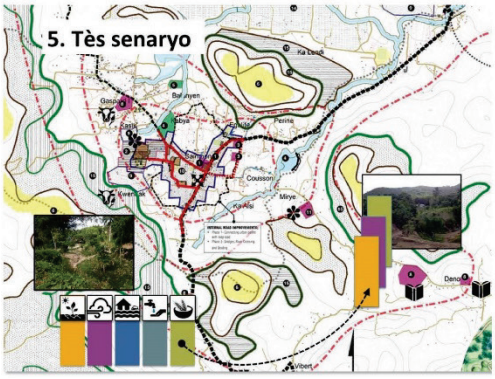
Try to draw from both 'accepted practice' and local technologies

Scale: toggle between household, community, and landscape.

From a workshop in Fond-des-Blancs, Haiti

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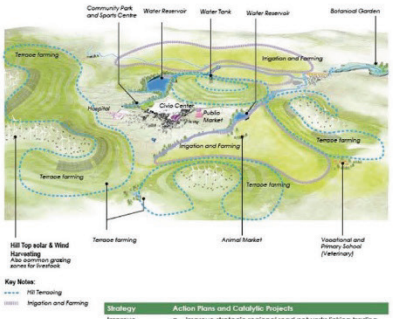




Ideate and test scenarios against actual sites.
Visit field to determine feasibility.
Repeat.

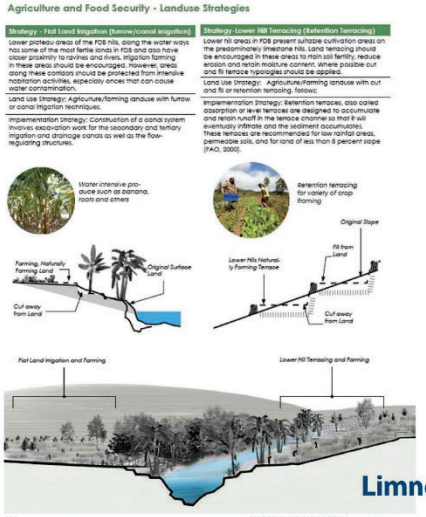
From a workshop in Fond-des-Blancs, Haiti

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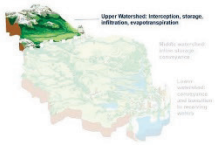
Strategy	Action Plans and Catalytic Projects
Improve Agriculture related Infrastructure	▫ Improve strategic regional road networks linking trading nodes within the region. Explore regional municipal partnerships to develop 'Regional Corridor Initiatives' to enable infrastructure investments. ▫ Invest in water harvesting and irrigation infrastructures to improve agriculture yields. ▫ Develop micro grid electricity
Education and Skills Development	▫ Develop veterinary and vocational training institution to support agriculture in the region. ▫ Support skills development in agribusiness
Smart Landuse and Innovation	▫ Protect agriculture landuse from over development through landuse regulation ▫ Maximize farming landuse through innovative farming practices such as; irrigation farming, terracing, crop rotation (Spotlight) ▫ Soil management practices and soil conservation techniques.

Image source: Build Health International



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Upper Watershed



Strategy	Applicability to Puerto Rico	Applicability reason	Locations	Potential Federal funding source(s)
Impervious surface reduction	Very High	Impervious surfaces common in developed areas Easily scalable to sites large and small	Multiple Towns, hills, sloped areas, headwaters	HUD CDGB DR
Agricultural conservation, forestry	Moderate		Mountains, hills, sloped areas	USDA NRCS: USDA National Urban & Community Forestry
Planning	Very High	Development of conservation plans	Anywhere	USACE Planning Assistance to States; EPA Building Blocks Program
Multi-layered gray-green	Very High	Works with existing infrastructure; Adaptation over time may be feasible	Multiple Towns, hills, sloped areas, headwaters	USFWS Coastal Program; NFWF National Coastal Resilience Fund Resilient Communities Program; FEMA BRIC and Flood Mitigation Assistance; DOT BUILD Grant Program; FHWA Congestion Mitigation & Air Quality



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Roadway buttressing in ravine, Dominica, 2018. Photo: Dave Hampton

- Interrupt the natural hydrology

- Work with existing topography.
- Consider restoring if significantly altered



- Expect flows to remain static

- Design infrastructure which can adapt to change.
- Adjust when infrastructure becomes obsolete



Obsolete river embankment buttressing, Roseau River, Dominica, 2018. Photo: Dave Hampton

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Boardman River Dam Removals, Traverse City, Michigan, US
Top to bottom: Sabin Dam and pond prior to removal; during drawdown; and in the last stages of drawdown, following demolition of powerhouse. Photos: Brett Fessell, GTB Natural Resources



Erosion in upslope ravine, Fond-des-Blancs, Haiti.



Trash and raw sewage in canals at base of mountains, which overflow during heavy rains, causing flooding, Port-au-Prince, Haiti.



- Let upslope areas erode
- Interrupt natural hydrology
- Wait to manage water and waste at "end of the pipe"

- Start upstream
- Use checkdams to address debris flows
  - Engineered systems
  - Gabions
  - Concrete
  - Natural / living materials (logjams, tree branch cuttings)
- Use upstream / watershed management best practices

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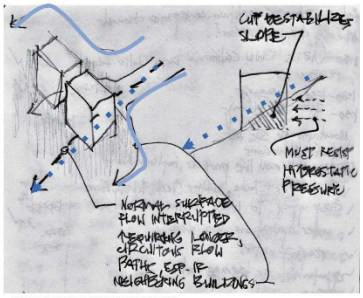
Steel cable debris net, Camarillo, CA, USA.
https://mountainscholar.org/bitstream/handle/11124/173_17/06-10_Kane.pdf?sequence=1



Stone-filled wire gabion baskets. https://www.indiamart.com/proddetail/check-dam-welded-gabion-19916112291.html



Farmers build check dams using living tree branch cuttings, Himalayas. (Thomson Reuters Foundation)
https://www.farmit.com/mitigation_measures/1029/



Surface flows impeded by buildings


Increased chance of landslide risk.

- Cut into slopes to build
- Impede surface water flows
- Make buildings need to resist hydrostatic pressure
- Increase risk of landslide vulnerability

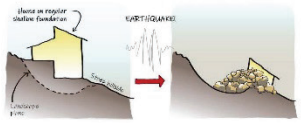
- Consider construction which doesn't impede surface water flow
  - Buildings elevated on pilings, columns, or piers
  - Provide technical assistance and education for homeowners and builders

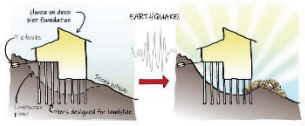
HOWEVER **must**
- Be engineered.
- Be seismic, landslide, and hurricane resistant
- Ensure built correctly (permit, inspections)

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Precast concrete system example by Preconco (manufactured in Barbados) in post-Hurricane Maria recovery, Dominica, 2018.





https://www.zfa.com/solutions/designing-to-withstand-a-landslide/
ZFA STRUCTURAL ENGINEERS



Home, Dominica. Photo: Dave Hampton





Post-Hurricane Maria recovery home, Dominica. Photo: Dave Hampton



Post-Hurricane Maria recovery home, Dominica. Photo: Dave Hampton



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Peninsula de Cantera Community Center. Photo: Dave Hampton



Peninsula de Cantera Community Center. Photo: Dave Hampton



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Post-Hurricane Maria recovery home, Dominica. Photo: Dave Hampton

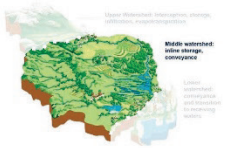


Home in Boquilla Village, Mayagüez. Photo: Dave Hampton



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Middle Watershed



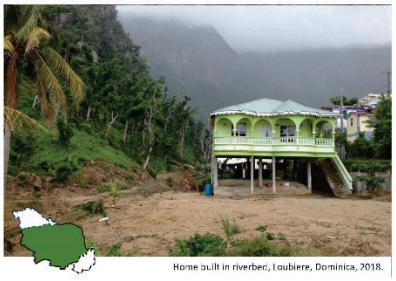
Strategy	Applicability to Puerto Rico	Applicability reason	Locations	Potential Federal funding source(s)
Impervious surface reduction	Very High	Impervious surfaces common in developed areas Easily scalable to cities large and small	Urbanized areas Industrial and commercial sites	HUD CDGB-DR
Planning	Very High	Development of conservation plans	Anywhere	USACE Planning Assistance to States; EPA Building Blocks Program
Low impact Development, sustainable development	High		Coastal cities	HUD CDBG-DR; HUD Sustainable Communities Regional Planning; EPA Brownfields Grant / Superfund Redevelopment Programs
Conservation, restoration, forestry	High		Coasts, rivers, forests	NFWF National Coastal Resilience Fund Emergency Coastal Resilience Fund; EPA Five Star & Urban Waters Restoration; EPA Environmental Justice Small Grants; USDA National Urban & Community Forestry
Multi-layered gray-green	Very high	Works with existing infrastructure; Adaptation over time may be feasible	Coastal cities, coasts, beaches, military installations	USFWS Coastal Program; NFWF National Coastal Resilience Fund Resilient Communities Program; FEMA BRIC and Flood Mitigation Assistance; DOT BUILD Grant Program; FHWA Congestion Mitigation & Air Quality; USACE REPI



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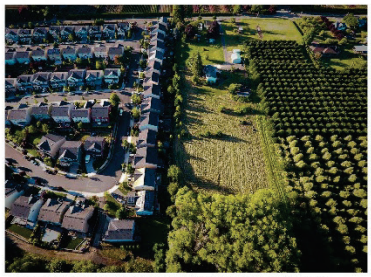
Portion of Bath Estates built in floodplain of Roseau River, Dominica, 2018.



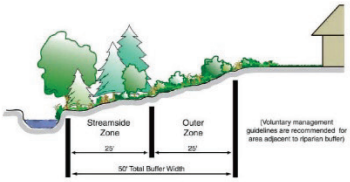
Home built in riverbed, Loubiere, Dominica, 2018.

- Build in
  - River beds
  - flood plains

- Consider development boundaries
- Maintain riparian buffer zones
- Reduce impervious areas



Urban growth boundary between metropolitan Portland, OR, US (left) and adjacent rural acreage (right). https://modernfarmer.com/2016/09/portland-urban-growth-boundary/



Two-zone riparian buffer example limiting the extent of development. http://superiorwatersheds.org/images/riparianbufferreportnew.pdf

Micro-catchment & infiltration

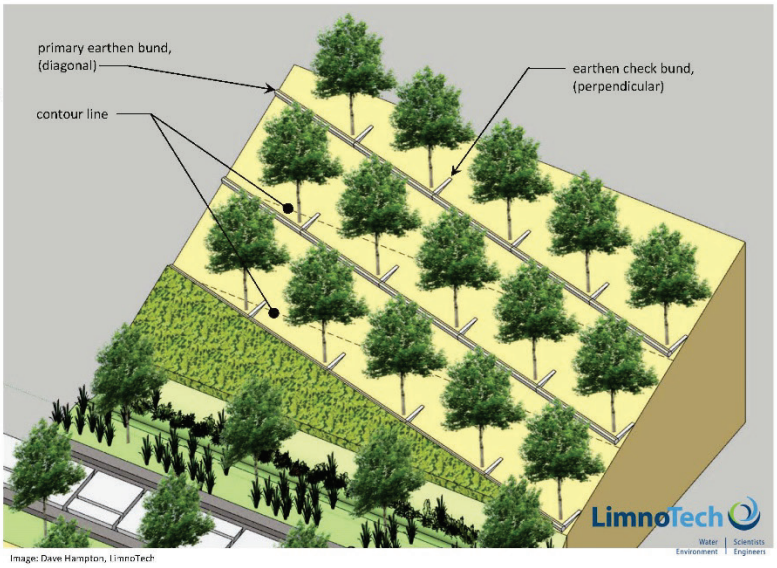


Image: Dave Hampton, LimnoTech

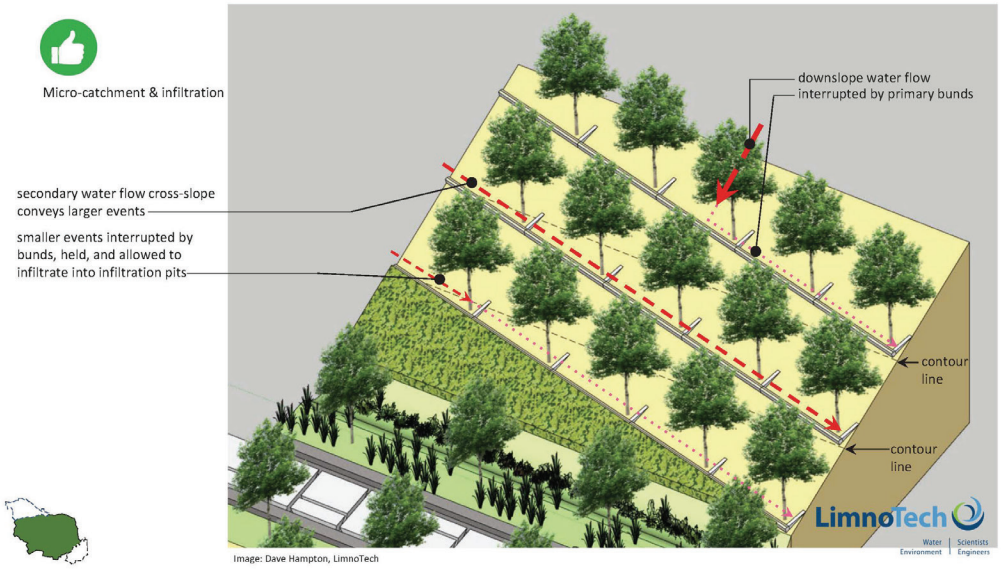


Image: Dave Hampton, LimnoTech

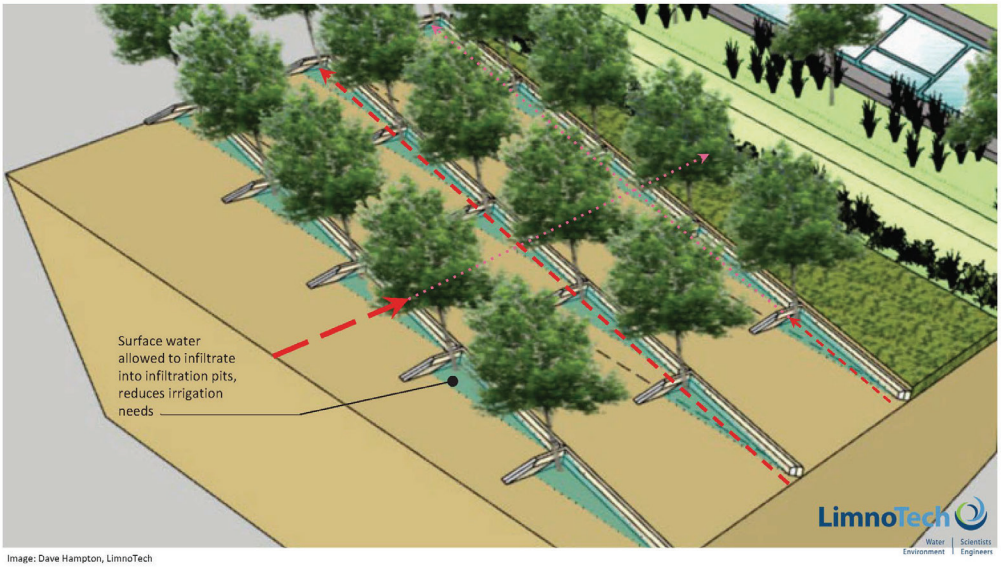


Image: Dave Hampton, LimnoTech

Streambank stabilization





Puyallup River Revetment, Orting, Washington, US

The leaky engineered wood barrier is designed to allow water to pass underneath during low flow (above) and above, around and through (below). (Photos by WCRT)

Debris on top of the log jam ballast the material beneath. The team will overlay additional large wood and slash material to visually blend them into the natural landscape. (Photo by Pierce County Staff)



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Streambank stabilization





Puyallup River Revetment, Orting, Washington, US

Aerial view of the floodplain reconnection area. Orville road runs by the conifers on the middle left. (Photo by Pierce County Staff)

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Lower Watershed



Strategy	Applicability to Puerto Rico	Applicability reason	Locations	Potential Federal funding source(s)
Dredge material beneficial use	High	Range of coastal environments, from high energy wave to protected bay / estuaries	Coasts, estuaries, bays, military installations	USACE REPI
Multi-layered gray-green	Very High	Works with existing infrastructure; Adaptation over time may be feasible	Coastal cities, coasts, beaches	USFWS Coastal Program; NFWF National Coastal Resilience Fund Resilient Communities Program; FEMA BRIC and Flood Mitigation Assistance; DOT BUILD Grant Program; FHWA Congestion Mitigation & Air Quality; USACE REPI
Living shorelines / breakwaters	High	Range of coastal environments, from high energy wave to protected bay / estuaries	Coastal cities, coasts, beaches	USFWS Coastal Program; NFWF National Coastal Resilience Fund Resilient Communities Program; NFWF Coral Reefs Program; FEMA BRIC and Flood Mitigation Assistance
Coastal conservation, restoration, and forestry	High		Coasts, rivers, forests	NFWF National Coastal Resilience Fund Emergency Coastal Resilience Fund; EPA Five Star & Urban Waters Restoration; EPA Environmental Justice Small Grants; USDA National Urban & Community Forestry
Land acquisition / property buyouts	High		Coastal cities / communities	FEMA HMGP
Low impact Development, sustainable development	High		Coastal cities	HUD CDBG-DR; HUD Sustainable Communities Regional Planning; EPA Brownfields Grant / Superfund Redevelopment Programs
Impervious surface reduction	High			HUD CDBG-DR; FEMA BRIC and Flood Mitigation Assistance
Planning	Very High	Development of conservation plans	Anywhere	USACE Planning Assistance to States; EPA Beaches Blocks Program
Livelihoods	Moderate	Aquaculture, fisheries, aquatic habitats	Coasts, rivers	NOAA Community-Based Restoration Program



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River-borne debris near Petite Soufriere, Dominica, 2018. Photo: Dave Hampton



Bridge damaged by stormwater-borne ravine debris. May 2018, Roseau, Dominica. Photo: Dave Hampton



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Bridge damaged by stormwater-borne ravine debris. May 2018, Roseau, Dominica. Photo: Dave Hampton



Sediment which choked streams and rivers after Hurricane Maria (2018) deposited along coast of Dominica. Photo: Dave Hampton



Debris flow through neighborhood along river, post-Hurricane Maria, Dominica, 2018. Photo: Dave Hampton.



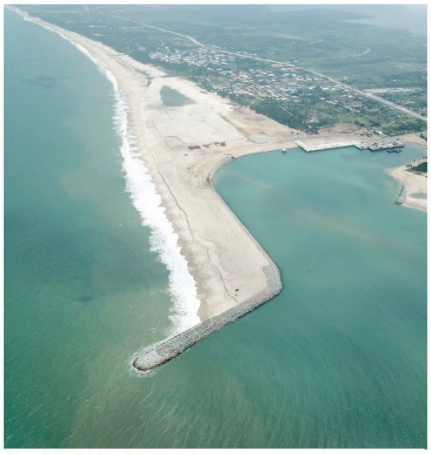
- Ignore debris and fill... until it becomes a liability.
- Move it and forget it.
- Leave coastal development to chance.



- Manage debris upstream (see Upper Watershed)



- Use debris and dredge material creatively
- Plan in advance for how newly created land will be used.



Dangote Sandbar Breakwater, Lekki, Lagos State, Nigeria
Completed breakwater and marine terminal entrance using a combination of dredged material, engineered fill, and traditional rock.

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Seawall along beach, Marshall Islands, 2021. Photo: Dustin Langdrik.



Trash and raw sewage in canals at base of mountains, which overflow during heavy rains, causing flooding. Port-au-Prince, Haiti.



- Rely only on "Maginot Line": one layer of traditional gray, hard infrastructure
- Wait to manage water and waste at "end of the pipe"
- Impermeable barriers

- Use hybrid gray-green or multiple layers of infrastructure
- Manage water upstream
- Permeable: allows water exchange, aquatic species movement, substrate for organisms
- Use breakwaters to break up wave energy offshore and maintain beach access



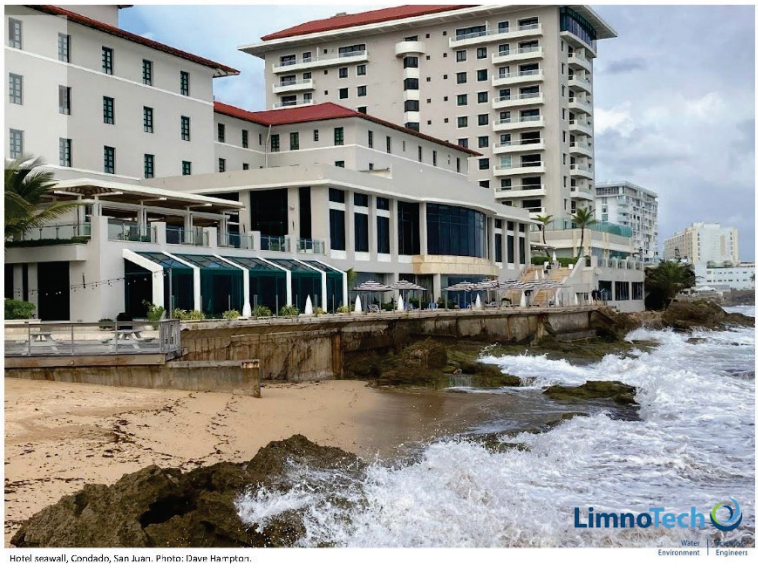
Horizontal levee design that achieves storm and flood risk reduction while increasing habitat value. Source: https://cwn.erdc.dren.mil/?page_id=81



Multi-layered approach with living breakwaters. Source: https://www.scapestudio.com/projects/living-breakwaters-design-implementation

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Single-layer, hard infrastructure
- vulnerable
- false sense of security
- allows for no movement of species



Hotel seawall, Condado, San Juan. Photo: Dave Hampton.

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Multi-layered approach: stepped double-seawall with seaward edge well-integrated with reef, following coastal topography. Pedestrian walkway spans seaward and landward edges with chamber below to allow high tide to drain back oceanward. Barbados,



Goldbug Living Shoreline, Sullivan's Island, South Carolina, US
The reef structure reduces wave energy from boat wakes and promotes sediment accretion on the landward side of the reef. The presence of soft, watery mud might have made for a difficult and expensive installation, but the team used pallets as a base layer and wrapped them in geotextile fabric to "float" in the mud. These pallets, combined with Oyster Castles and dried, bagged oyster shells, will stay within the water column and remain available for future spat to set.Ie. Nearly 200 volunteers helped install the shoreline which uses.
Photo: South Carolina The Nature Conservancy (SCTNC)

Brunswick Town / Fort Anderson, Cape Fear River, North Caroline, United State
The new structure has stabilized the shoreline and allows for sediment accretion. Photo: Christopher Dustin, Scenic Consulting Group LLC.

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Breakwater, Condado, San Juan. Photo: Dave Hampton.



Abbreviations

BRIC	Building Resilient Infrastructure and Communities
DNER	Department of Natural and Environmental Resources
DOTS	Dredging Operations Technical Support
ERDC	Engineer Research and Development Center
ERDC-EL	Engineer Research and Development Center Environmental Lab
EWN®	Engineering With Nature®
FEMA	Federal Emergency Management Agency
FMA	Flood Mitigation Assistance
FRS	Floodwater Retarding Structure
GI	Green Infrastructure
H&H	Hydraulics and Hydrology
HMA	Hazard Mitigation Assistance
HMGP	Hazard Mitigation Grant Program
LA	Landscape Architecture
LID	Low Impact Development
NBS	Nature Based Solutions
NNBF	Natural and Nature Based Features
NGO	Non-Governmental Organization
NPA	Natural Protected Areas
NRCS	Nature Resources Conservation Service
PR	Puerto Rico

PRASA	Puerto Rico Aqueduct and Sewer Author
PRWRERI	PR Water Resources and Environmental Research Institute
R&D	Research & Development
SME	Subject Matter Expert
SWF	Southwestern Division
UPRM	University of Puerto Rico Mayagüez
USACE	United States Army Corps of Engineers
WOTS	Water Operations Technical Support

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14. ABSTRACT

This report summarizes the Basin Sediment Management for Unique Island Topography Workshop hosted in-person and virtually at the University of Puerto Rico Mayagüez (UPRM) Department of Civil Engineering and Surveying, Mayagüez, Puerto Rico on 11 March 2022. The workshop was attended by approximately 80 federal, state, local, and academic organizations participants. It focused on Engineering With Nature® (EWN®), green infrastructure (GI) and low impact development (LID) opportunities for unique tropical island topography and included seven presentations from subject matter experts, a discussion on limitations and problems with prior projects, and two concurrent breakout sessions.

Preworkshop activities included a field trip to multiple sites in the Añasco watershed conducted 09 March 2022, which served as a base case for the workshop. The field trip provided participants a unique perspective of the island's topography and post 2017 Hurricane María issues and impacts.

During the breakout sessions, participants identified new project opportunities for EWN®-GI and LID at two selected sites from the field trip. Each group developed alternatives for their chosen site and identified concepts that could turn into great opportunities for the surrounding communities and significantly benefit the state of practice in Puerto Rico's unique tropical island topography.

15. SUBJECT TERMS

Tropics—Islands; Dredging; Environmental engineering; Añasco Bay (P.R.); Sedimentation and deposition; Environmental management; Puerto Rico

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