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Special Series

Integrating Engineering With Nature® strategies and landscape architecture techniques into the Sabine-to-Galveston Coastal Storm Risk Management Project

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EDITOR'S NOTE:

This article is part of the special series "Incorporating Nature-based Solutions to the Built Environment." The series documents the way in which the United Nations Sustainable Development Goal (SDG) targets can be addressed when nature-based solutions (NBS) are incorporated into the built environment. This series presents cutting-edge environmental research and policy solutions that promote sustainability from the perspective of how the science community contributes to SDG implementation through new technologies, assessment and monitoring methods, management best practices, and scientific research.

Abstract

Damaging storm events frequently impact the Texas coast. In response, the US Army Corps of Engineers Galveston District (SWG) has undertaken the Sabine-to-Galveston (S2G) Coastal Storm Risk Management (CSRM) Project. This approximately $3.9B project includes numerous measures across several counties of the upper Texas coast, including levees, floodwalls, and pump stations. In June 2019, SWG leadership enlisted a team including the paper authors to integrate Engineering With Nature (EWN) strategies into this infrastructure project. EWN strategies intentionally align natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaboration. The first step in this process was to develop potentially relevant EWN strategies. A collaborative workshop included visits to project sites and working sessions where the project team reviewed challenges associated with each site, generated an array of EWN strategies, and began to test design concepts based on those strategies through collaborative drawing sessions. Afterward, prioritized ideas were refined and evaluated in terms of property acquisition, estimated cost, logistics, stakeholder and sponsor interest, constructability, aesthetics, recreational opportunities, and ecological benefit. Design concepts considered feasible for integration into the broader S2G project included horizontal levees, inland floodwater storage areas that double as wildlife habitat, and strategic placement of sediment berms to reduce storm impacts and provide marsh substrate. All these concepts should achieve intended CSRM outcomes while enhancing environmental and social benefits. This assimilation of EWN strategies and landscape architecture techniques into a large CSRM study illustrates a method for expanding overall project value and producing infrastructure that benefits coastal communities. *Integr Environ Assess Manag* 2021;00:1–11. © 2021 SETAC

KEYWORDS: Coastal Storm Risk Management, Engineering With Nature, Infrastructure, Landscape architecture, Natural and Nature-Based Features

INTRODUCTION

The Gulf Coast of Texas, USA, from the Rio Grande north to Sabine Lake, frequently experiences major storm events, which pose a significant risk to communities along that coast. The US Army Corps of Engineers (USACE) Galveston District (SWG) is, in coordination with state and local partners, tasked with planning and building protective infrastructures to mitigate this risk. In 2019, SWG invited the

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Engineering With Nature (EWN) initiative to assist SWG in incorporating "Natural and Nature-Based Features" (NNBF) into protective measures being devised for three of these communities as a part of SWG's Sabine-to-Galveston project (S2G). Engineering With Nature was able to bring the established project processes of its EWN + landscape architecture design research initiative (EWN + LA) to bear on this collaborative effort. These processes were expanded and adapted to fit the needs of the S2G project. Together, the Project Development Team (PDT) formed for this work was able to produce a set of recommendations for incorporating NNBF as core components of S2G; if implemented, these NNBF will represent a substantial advancement toward a new generation of coastal protective infrastructure that links social, economic, and ecological value. This paper reports on the process for developing these recommendations, the proposed NNBF, and lessons learned for future collaborative processes between engineers, scientists, landscape architects, and decision makers charged with protecting coastal communities.

The Texas Coast, storm events, and infrastructure design

It is difficult to speak of damaging coastal weather in the Gulf of Mexico without starting in 1900 in the city of Galveston, Texas. The Galveston Hurricane of that year still holds the record as the deadliest natural disaster in US history, taking over 8000 lives and inundating the city with a 15-foot wall of water (Roth, 2010; NOAA National Hurricane Center). Texas receives more hurricane strikes than any other US state besides Florida, as Texas has experienced 65 direct hits since 1851, inclusive of 2020's Hanna. A 2010 report from the National Weather Service stated that a hurricane would, on average, hit any given 50-mile stretch of Texas coast about once every 6 years (Roth, 2010). And while there has been little evidence of an increase in the number of storms per year in the past 100+ years of data (Vecchi & Knutson, n.d.), higher sea levels and increased coastal development do mean that these storms are more destructive, as they reach farther inland. Living on the Texas shore means living with coastal storms, now more than ever.

These climate and weather conditions overlay and interact with a diverse set of coastal processes and ecosystems. Recent hurricanes like Rita in 2005 and Ike in 2008 have been shown to have had considerable effects on the larger coastal ecosystems, scouring some areas of sand entirely, while burying other areas in feet of sediment. The storm surges of saltwater have also reached inland and destroyed salt-sensitive fresh and brackish coastal habitats. 2017's Hurricane Harvey was considered by some to be the worst storm to impact Orange, Texas—one of the focal cities for the collaborative work discussed in this article—in the city's history, flooding thousands of homes, in addition to the devastating impacts it had on the Houston metropolitan area. Harvey is representative of another distinct danger that hurricanes pose, which is that, even when they do not cause severe storm surge, they can produce heavy enough rainfalls to overwhelm both natural drainages and constructed stormwater management systems, producing severe inland flooding in low-lying coastal areas.

Moreover, the dangers posed by coastal storms also produce the need to protect the lives of the over 7 million residents of Texas who live along the Gulf Coast, their property, and the infrastructure they depend on. Texas has the largest waterborne commerce industry in the country, centered in Gulf Coast ports like those in Galveston Bay, on Sabine Lake, and Corpus Christi. The Texas coast is also home to the backbone of the nation's petroleum industry.

After the great hurricane of 1900, the city of Galveston, then Texas' most important port, began the construction of its now well-known seawall to protect the city. However, this fixed piece of infrastructure, while providing necessary protection, also serves as a cautionary story regarding the negative effects of such features. The erosion of the beaches that laid in front of the seawall has been extreme (Dean, 1999). Negative effects of hard infrastructural interventions in dynamic coastal environments such as this provide perspective on contemporary infrastructure planning and demonstrate the need for more incorporative, adaptable forms of infrastructure—forms that work with nature rather than against it. The desire to see such living, dynamic infrastructure deployed widely motivates both the EWN program and many landscape architects working along the coasts of the United States.

The most comprehensive collection of EWN projects and strategies can be found in the two EWN Atlas books (Bridges et al., 2018, 2021). A recent pair of coastal design competitions (Rebuild by Design, New York City region, 2013; Resilient by Design, San Francisco Bay Area, 2017) also demonstrated the role that landscape architects could have in responding to the dynamic conditions of coasts.

The focus of this paper is to describe the working process utilized by the EWN + LA team to iteratively develop NNBF for incorporation into the larger S2G project. At its core, this process is meant to facilitate collaboration, and so the work documented in this paper is the result of the multidisciplinary efforts of the engineers, scientists, and landscape architects who formed the PDT. This work, which took place in 2019, both demonstrates the effectiveness of the process in developing site-specific NNBF alternatives and makes clear additional tasks whose execution would further the adoption of NNBF within coastal protection planning.

THE S2G CSRM PROJECT

The Galveston District of the USACE (SWG) is charged with planning Coastal Storm Risk Management (CSRM) measures for the Texas Coast in coordination with state and local entities. In 2017, SWG issued a Final Integrated Feasibility Report for the S2G study (USACE SWG, 2017). S2G is a very large-scale example of the kind of contemporary infrastructure planning project that can benefit from the incorporation of NNBF, as it encompasses a 120-mile stretch

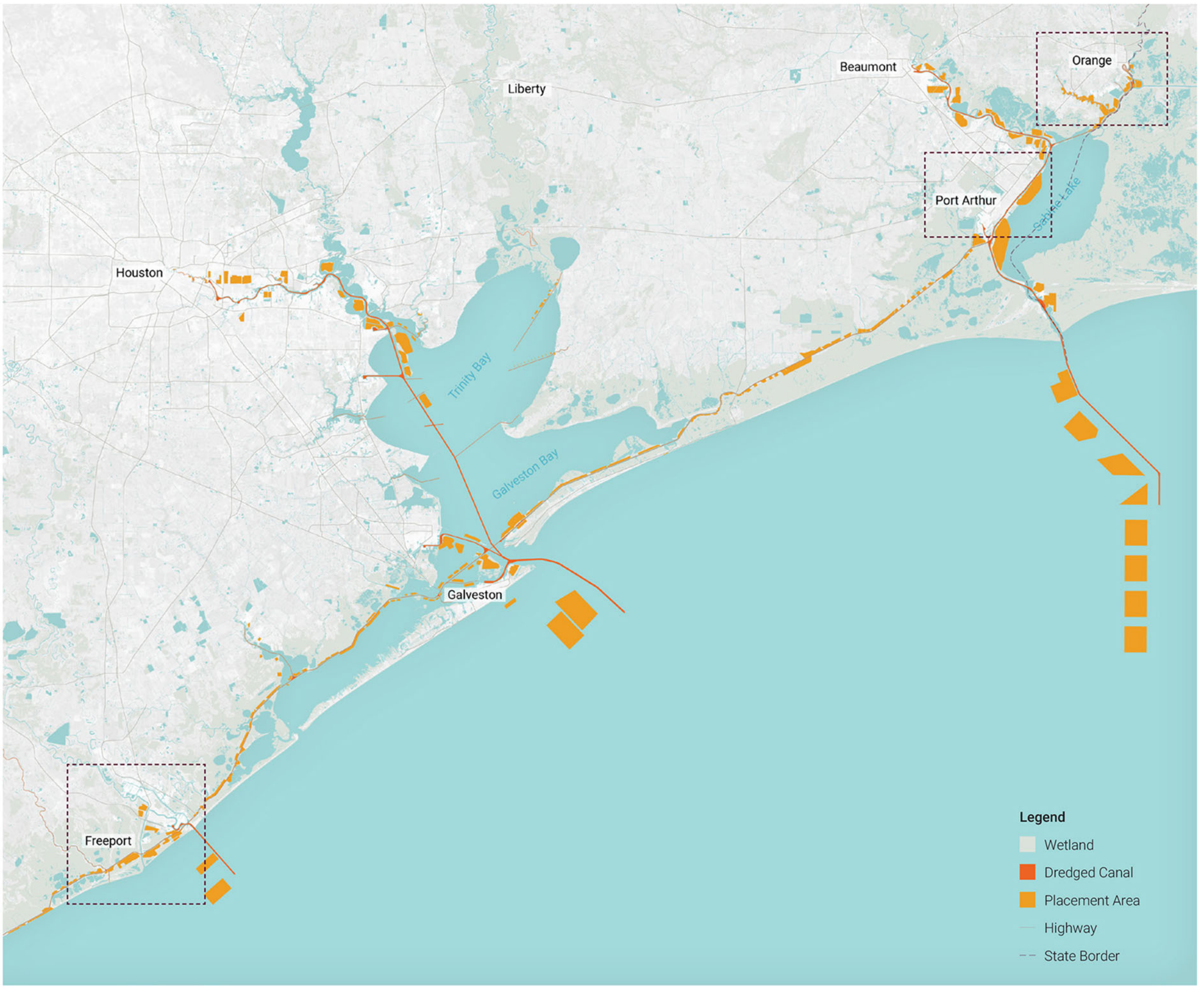

FIGURE 1 Overview map showing the project areas in Orange, Port Arthur, and Freeport, Texas

of the north Texas coast within the counties of Orange, Jefferson, Chambers, Harris, Galveston, and Brazoria. Shortly after the project began, S2G's scope was narrowed to focus on the Sabine region (Orange and Jefferson counties, including the cities of Port Arthur and Orange) and the Brazoria/Freeport region (Figure 1), due to the need to comply with federal rules governing the funding of USACE planning studies. S2G looked at both CSRM measures and Ecological Restoration (ER) opportunities and was guided by the following objectives:

- Objective 1: To reduce economic damages to business, residents, and infrastructure for the Sabine and Brazoria regions for the 50-year period of analysis;
- Objective 2: To reduce risk to human life from storm surge impacts for the Sabine and Brazoria regions for the 50-year period of analysis;
- Objective 3: To maintain and/or restore coastal habitat that contributes to storm surge attenuation where feasible for the 50-year period of analysis;
- Objective 4: To enhance energy security and reduce economic impacts of petrochemical supply-related interruption for the Sabine and Brazoria regions for the 50-year period of analysis;
- Objective 5: To reduce risk to critical infrastructure (e.g., medical centers, ship channels, schools, transportation) for the Sabine and Brazoria regions for the 50-year period of analysis; and
- Objective 6: To identify opportunities to enhance the functionality of existing hurricane protection systems including evaluation of impacts due to sea-level rise for the 50-year period of analysis (USACE SWG, 2017).

SWG prepared a set of alternatives that included various combinations of structural and nonstructural measures, as well as no-action components. These alternatives "were screened using three quantitative criteria (economic benefits, environmental benefits, and implementation costs) and one qualitative criterion (environmental impacts)" to determine which alternative would be most cost-effective at meeting the six objectives (USACE SWG, 2017). The initial set of 25 alternatives was whittled down to a final array of "separable elements," from which three major elements were selected for the Recommended Plan: a new levee system in Orange–Jefferson Counties, improvements to existing structural systems in Port Arthur and its vicinity, and a variety of structural measures in Freeport and its vicinity (USACE SWG, 2017). The work documented in this paper built on and was intended to be integrated with these elements of the Recommended Plan. The S2G project will also complement other CSRM projects like the Texas General Land Office effort at McFaddin National Wildlife Refuge that is applying NNBF concepts to also help protect freshwater marsh habitat in the area (https://txglo.medium.com/a-texas-sized-makeover-mcfaddin-beach-2c3da8e48c92).

The EWN + LA design research initiative

Since 2018, EWN + LA has been working with USACE Districts around the United States to assist those districts in incorporating NNBF into their ongoing water resources infrastructure projects (King et al., forthcoming). Through 2020, the EWN + LA initiative has completed six reports for five districts, dealing with a broad range of types of infrastructure in diverse geographic circumstances, from jetties in the Chesapeake Bay and dredged material placement areas on the Caloosahatchee River in Florida to large-scale CSRM efforts in New Jersey and Texas (https://ewn.el.erdc.dren.mil/designs.html). Engineering With Nature + LA focuses, in particular, on how the methods and expertise of landscape architects can support the EWN initiative in providing project-specific recommendations for NNBF to USACE districts. The discourse on landscape infrastructure in the discipline of landscape architecture has been expanding in the last two decades (Mossop, 2006; Orff and SCAPE Landscape Architecture, 2016), including an engagement with dredging activities and sediment systems, which are often crucial for building and maintaining NNBF (Burkholder, 2016; Hametz & Davis, 2019; Milligan & Holmes, 2017). A good example of the use of landscape architecture methods to integrate natural systems and infrastructure can be seen in the Living Breakwaters project, developed by a team led by SCAPE Landscape Architecture for the aforementioned Rebuild by Design competition. Living Breakwaters demonstrated how landscape architecture works synthetically to incorporate social and ecological objectives into coastal infrastructures (SCAPE Studio, n.d.). The remainder of this article explores one example of the EWN + LA initiative's work, the collaboration between the EWN + LA team and SWG on S2G, which is representative of how EWN practices can benefit from the incorporation of landscape architectural expertise.

EWN + LA and S2G

In 2019, EWN was asked to assist SWG in identifying opportunities for incorporating NNBF into the three components of the S2G project identified in SWG's Recommended Plan: Orange and Jefferson Counties (typically referred to hereafter as Orange, as the work is primarily in Orange County), Port Arthur, and Freeport (Figure 1). Orange and Port Arthur both lie off Sabine Lake, a 90 000-acre estuarine bay of the Gulf of Mexico, which is fed by the Neches and Sabine Rivers. Port Arthur is already protected by a substantial system of levees and floodwalls, whereas Orange is relatively sparsely protected. Both Port Arthur and Orange are connected to the Gulf through Sabine Lake by the Sabine–Neches Waterway (SNWW), a dredged deep-draft navigation channel, which supports significant waterborne commerce, much of which is associated with the petrochemical industry. Freeport is a smaller community, which lies almost directly on the Gulf Coast, south of Galveston. It too is home to substantial petrochemical industry and navigation channels.

To enhance the CSRM systems protecting these communities, the Recommended Plan of the S2G Feasibility Report (USACE SWG, 2017) endorsed the creation of 15.6 miles of new levee and 10.7 miles of new floodwalls, along with new closure gate structures and pump stations, in Orange and Jefferson Counties; the raising of 5.5 miles of levee and improvement of 5.7 miles of floodwall in and around Port Arthur; and the raising of 13.1 miles of levee and improvement of 5.5 miles of floodwall for Freeport and vicinity. It is important to note that the development of the Recommended Plan preceded collaboration between the EWN + LA team and SWG. As such, the NNBF concepts described below were intended to augment and integrate with the Recommended Plan. Their development did not involve revisiting the full study area of the Sabine and Brazoria regions, but was focused by the study already completed for the Feasibility Report. The geographic scope of the EWN + LA work is, therefore, further narrowed to a subset of sites within the Sabine and Brazoria regions, identified through a collaborative workshop, as described below.

In keeping with the "triple-win" objectives of the EWN initiative, the NNBF concepts were designed to prioritize the holistic combination of engineering performance relative to project criteria (in this case, managing flood and storm risk), ecological integration, and the creation of social value through recreational opportunities and aesthetic improvement. Constructability and feasibility were conceptual considerations, as well, but the design concepts described below did not undergo engineering review or modeling as a part of the EWN + LA process. Rather, they were developed through a collaborative workshop and subsequent iterative design revision. The account of the EWN + LA project process that follows focuses primarily on these activities.

EWN + LA project process

The PDT's first stage of work was a week-long workshop, hosted by SWG, which took place from June, 24 to June 29, 2019. The workshop had approximately 15 participants, including personnel from SWG, personnel from EWN, engineering faculty from Texas A&M University, and landscape architects working on the EWN + LA initiative. The social and intensive nature of the workshop was crucial to facilitating rapid multidisciplinary collaboration between personnel who did not have significant prior experience collaborating with one another. During the workshop, the PDT and the other participants worked to identify issues and opportunities associated with each of the three main project components, as well as general NNBF strategies that might respond to those issues and opportunities. This process of identification began with 2 days of on-site inspection, discussion, and investigation in Orange and Port Arthur, led by personnel from SWG. This was followed by 3 days of work hosted at Texas A&M University's Galveston campus.

With issues and opportunities identified, the participants split into a series of teams that worked to refine the general strategies into specific features and approaches. The teams were organized around both expertise and interest, with each team composed of a cross-section of the organizations and disciplines present. Each team sought to have at least one member with landscape architecture, drawing and design expertise, at least one member from EWN, and several members from SWG (Table S1). For each study region—Orange County, Port Arthur, and Freeport—between two and four teams were formed, subdividing the study regions into smaller geographic focus areas. SWG participants tended to join groups based on their direct knowledge and role in particular study regions. These groups were dynamic and fluid, re-arranging each time the workshop focused on a new study area.

The teams developed initial design concepts through simultaneous discussion and drawing, using plans of existing conditions and satellite imagery viewed on laptops as base information for drawing in both plan and section. This development provided not only the opportunity to sketch out ideas, but also to test those ideas, both in terms of their feasibility given existing conditions (such as channel dimensions, water body depths, landmass elevations, or plant communities) and in terms of review and discussion by the expert participants in each team. For example, after a site visit to Pleasure Island in Port Arthur, the team began sketching configurations of constructed marsh that could effectively address storm surge across the local marina, the thinnest and least protected area of the island. Participating EWN engineers with expertise in sediment transport suggested the possibility of deploying highly stable clay-based submerged breakwaters, made of dredged sediment that had been field-proven elsewhere in the SWG. They also provided feedback on the elevation and orientation of the berms to maximize protection while still permitting recreational navigation from the marina. Each team also presented its individual work to the larger group for comment and review. This process facilitated the collection of input from each member of the workshop group and permitted a broad array of disciplinary (and organizational) perspectives to be rapidly synthesized into a collective output.

This work was summarized by the EWN + LA team on the final day of the workshop, and the PDT collectively reviewed the summary to select high-priority features and approaches for further development and inclusion in the EWN + LA team's final report.

On the basis of this prioritization, the EWN + LA team continued to refine the design concepts and produced a series of draft concept drawings, which were presented to the full PDT via webinar in July. After this webinar, the PDT returned to a final round of refinements of the design concepts. Several core tasks were involved in making these refinements. The EWN + LA team iteratively advanced design concept drawings (plans, sections, perspectives) and models (digital models) to study feature layout, relationship with existing conditions, and socioecological linkages (recreational opportunities, ecological benefits, and aesthetic impacts). They also evaluated suitable sites for the proposed features, particularly in Orange County, on the basis of existing infrastructure, infrastructure proposed in the feasibility report's (USACE SWG, 2017) recommended plan, existing land use, existing land cover, and existing property ownership. Finally, they considered the constructability of proposed alternatives, particularly for the horizontal levee components of the proposed Orange Hurricane Flood Protection System (HFPS).

Study observations and proposed NNBF

Although the three areas of study were linked by the common concern of storm risk management, the PDT found that distinct NNBF approaches were required for each area, due to the combination of unique geographical qualities and differences in the infrastructure systems being proposed in USACE SWG (2017). Thus, here we describe the EWN + LA team's proposed NNBF for each area in turn, beginning, in each case, with the issues and opportunities that these proposals responded to.

Orange. In Orange, the primary focus of the study was the levee system recommended in USACE SWG (2017) and associated issues of flood risk reduction (Holmes et al., 2019). The EWN + LA team and the workshop participants identified five key issues and opportunities for Orange.

First, due to its low-lying elevation and flat topography, the portions of Orange County that lie behind the proposed CSRM system is at risk for both coastal flooding (storm surge arriving at the front of the CSRM across Sabine Lake) and inland flooding (flooding behind the CSRM system resulting from upland rainfall). Flood risk management in areas that may have compound flooding potential requires a bidirectional approach.

Second, the proposed CSRM includes significant new levees. Constructing these levees will require locating and excavating suitable fill material from upland sources. The sites of these excavations could potentially become basins for detaining and retaining inland floodwaters, if they are designed properly.

Third, as the CSRM for Orange is proposed rather than existing, it represents a significant opportunity to integrate NNBF directly into the design of features, rather than augmenting or supplementing existing features.

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Fourth, the construction of significant NNBF will require large quantities of sediment. Actively maintained navigation channels on the Neches River, on the Sabine River, and in Sabine Lake are potentially major sources of sediment that could link operational demands (the need to place dredged material in a suitable location) with proposed NNBF, through the beneficial use of dredged material. It is also possible that NNBF could obtain some or all of the needed sediment by strategically utilizing and/or altering the flow of sediment within natural systems, as in projects currently in development in Louisiana and California (Allison et al., 2014; Public Sediment, 2018). However, scientific understanding of sediment dynamics in the Sabine Lake region is not currently adequate to support the development of NNBF alternatives that rely on natural sediment supply.

Fifth, the proposed CSRM faces large areas of marsh, particularly in the Lower Neches Wildlife Management Area. This marsh potentially has significant CSRM value in addition to its value as an ecological and social resource. However, the marsh is significantly degraded and in many places has subsided and/or eroded into open water. The Hickory Cove Marsh Restoration and Living Shoreline Project is one ongoing initiative that is seeking to address this degradation.

The NNBF proposed in response centered on two primary measures (Figure 2). The first introduced an additional type of protective infrastructure, the horizontal levee, in addition to the floodwalls and traditional levees already recommended for the Orange HFPS (USACE SWG, 2017). Four separate segments were identified where sufficient space appeared to be available on the outboard side of the HFPS to accommodate the gentle slope of a horizontal levee. In this type of NNBF, a standard levee core, whose flanks are typically sloped around 3:1, is augmented with a long, shallow slope, typically 30:1 or less. Relative to a traditional levee, a horizontal levee has the potential to improve risk reduction performance, provide new habitat, and enhance levee aesthetics. For instance, where it extends into a water body, this long slope can be planted to provide an extended interface between land and water. A horizontal levee in San Lorenzo, California, was constructed at the edge of the San Francisco Bay with a 30:1 ecotone slope. That horizontal levee was designed with 12 experimental beds with different substrates and vegetation mixes to adapt alongside sea-level rise and support a 10-acre water filtration field adjacent to the Oro Loma wastewater treatment and purification plant in San Lorenzo (Cecchetti et al., 2020).

After exploring a series of alternatives for the construction of a horizontal levee as part of the Orange HFPS, the EWN + LA team recommended using a construction method designated as a "dredge ecotone slope" (Figure 3), where very gently sloped ridges (100:1) would be constructed through the sequenced pumping of unconfined

FIGURE 2 Potential locations of natural and nature-based features in relation to the proposed Orange, Texas, Hurricane Flood Protection System

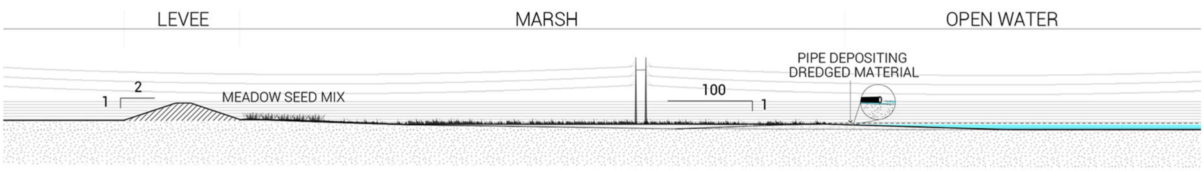

FIGURE 3 Diagrammatic section of a "dredge ecotone slope"

slurries containing clean dredged material. Three of the four segments recommended for construction in this fashion would extend into the degraded marshes noted above (Figure 4), both contributing to storm risk management, through the established protective value of vegetated wetlands (Moller et al., 2014; Vuik et al., 2016; Wamsley et al., 2010), and utilizing dredged material to rebuild ecosystem function and capacity (Bray, 2008; USACE/USEPA, 2004).

The second major NNBF proposed for Orange was a system of inland floodwater retention basins. These basins would take advantage of the need to excavate significant amounts of fill material for levee construction. The pits made by this excavation would be designed to connect to the regional drainage system, providing storage capacity during rain events, which is particularly crucial in compound flooding situations. This would have the effect of reducing pressure on pump stations during flooding and, correspondingly, could lower pump station costs, which are the most expensive part of the CSRM. In addition to performing this CSRM function, the basins would also be designed as habitat and for recreational use (Figure 5), enhancing their value during the long periods when they are not in use for floodwater storage.

The EWN + LA team investigated a broad range of potential sites for these inland storage basins, considering criteria including existing site disturbance (land that has already been disturbed by human activity such as excavation or clearing was prioritized), evidence of vacancy or disuse (parcels that appeared to be abandoned or that had abandoned structures were prioritized), and linkages to existing drainages (whether constructed stormwater canals or natural waterways like Cow Bayou). The EWN + LA team recommended a network of three different types of basins: upland pits, drainage floodrooms, and urban basins (Figure 2). The upland pits were generally located inland and upland of Orange's two main natural drainages, Cow Bayou and Adams Bayou, on sites that typically already appeared to have been mined to some extent for sand or clay. These were proposed as the largest features and would offer opportunities for major recreational features like multipurpose trails, wetland boardwalks, fishing piers, and birding. Other sporting activities like duck hunting could be considered.

FIGURE 4 Aerial perspective view of potential horizontal levee implementation in Bridge City (Orange County), Texas

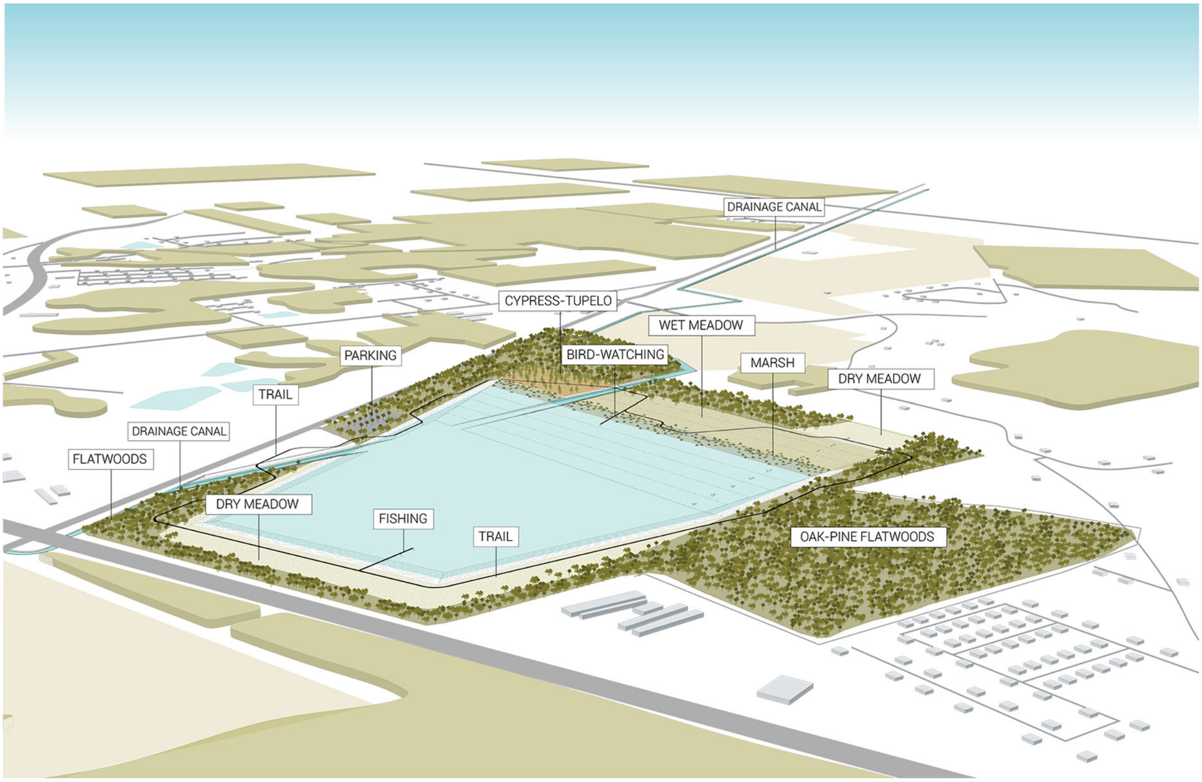

FIGURE 5 Aerial perspective view of potential upland basin natural and nature-based features in Orange County, Texas

They would likely include areas of open water. The drainage floodrooms were sited on or adjacent to natural drainages, and would be intended to function primarily by expanding the breadth and depth of natural floodplains. These would be heavily vegetated and intended to offer habitat connectivity to riparian and wetland species. The final category, urban basins, was generally smaller in size (though several larger basins are recommended in Bridge City). These would be excavated out of vacant properties within the urban fabric. They could be developed as small parks or for active recreational features like ballfields.

Port Arthur. For Port Arthur, the primary area of focus centered around Pleasure Island that lies immediately east of downtown Port Arthur, between the deep water of the dredged SNWW and the shallow breadth of Sabine Lake. Historically, Pleasure Island has protected and buffered Port Arthur from coastal storm impacts. Unfortunately, the island has suffered from significant degradation, including erosion on its channel side along the SNWW.

Three major NNBF were recommended for Pleasure Island to address this degradation: an "upland berm" on the northern portion of the island, a constructed marsh near the marina on the narrow central neck of the island, and shoreline repair along the SNWW on the western coast of the island (Holmes et al., 2019). As in Orange, the construction of significant NNBF for Port Arthur would require large quantities of sediment. The EWN + LA team noted that the actively maintained navigation channels of the SNWW are potentially major sources of sediment that could link operational demands (the need to place dredged material in a suitable location) with proposed NNBF.

The proposed "upland berm" would line the northwestern edge of the island. A traditional levee core would be constructed along this edge, and it could be backfilled with dredged material to produce a shallow slope, covering the existing grade and the low existing levee, then gradually flattening into the open water of the existing dredged material placement area. This landside slope would be vegetated with both perennial salt-tolerant vegetation and woody salt-tolerant vegetation for both habitat value and to increase the wave energy reduction value of the feature. On the channel side, the levee revetment would be constructed using a segmented ecoblock with demonstrated habitat value and shellfish recruitment potential (Ido & Shimrit, 2015; Strain et al., 2018).

The second Pleasure Island feature, a constructed marsh, would protect the thinnest (and most developed) portion of Pleasure Island, in front of the marina. A series of berms would be built using the highly plastic, immobile clay material that will be obtained during the SNWW channel deepening. The space between these berms would then be brought up to marsh elevation using looser dredged material. Dense, slow-growing *Spartina* sp. grass would be planted on the front edges of the berms to secure them, whereas faster growing but less resilient *Spartina* sp. would be planted in the gaps between berms. A navigation channel would be maintained between marsh segments for access to and from the marina.

Finally, for Port Arthur, the channel shoreline along the western edge of Pleasure Island is highly degraded in several locations. The shoreline would be repaired by constructing a segmented breakwater using ecoblock along these eroded "scallops," and then bringing the area behind those breakwaters up to marsh elevation using dredged material. Small weirs in the breakwaters could facilitate access in and out of these marshes for juvenile fish.

Freeport. The third and final area of focus for the EWN + LA S2G study was Freeport. Like Orange, Freeport is low-lying and flat, and similarly at risk of compound flooding. Where Orange is drained primarily by two bayous, Cow and Adams, Freeport lies between two major drainages, the Brazos River and Oyster Creek. For this reason, a different approach to alleviating bidirectional storm risk is required. Moreover, major coastal ecosystems, including marshes and coastal prairies, lie just on the other side of those two drainages. Consequently, Freeport is flanked by broad expanses of active, dynamic natural systems. The EWN + LA team argued that an NNBF approach can and should take into account opportunities to actively engage these systems, supporting them and enhancing their CSRM value, habitat value, and long-term sustainability (Holmes et al., 2019).

NNBF strategies for Freeport were explored only at a relatively preliminary level, as it was determined during the workshop that the Orange and Port Arthur components of S2G were advancing more rapidly, and thus in more immediate need of evaluation. Options identified, however, included the use of setback levees to provide expanded floodplain along the two major drainages and the potential construction of hydrological and/or sediment diversions on the Brazos River to alleviate pressure on the downriver levees and reconnect the river with adjacent, subsiding coastal prairie. Similar concepts have been employed in Washington and Iowa (Dahl et al., 2017) and Louisiana (Gagliano et al., 1973; Kearney et al., 2011; Paola et al., 2011).

OUTCOMES AND LESSONS

After the period of strategy development, these strategies for Orange, Port Arthur, and Freeport were collected in a report summarizing the PDT's findings and recommendations (Holmes et al., 2019). This report was delivered to SWG, and at the time of writing, SWG is working to advance the recommendations as a component of the broader S2G CSRM project. The report was successful in its stated goal of identifying feasible and site-specific NNBF to meet CSRM goals, and thus evidences the effectiveness of EWN + LA's working process. However, it was also clear at the conclusion of the report both that further work is needed to evaluate NNBF on level terms with traditional structural or nonstructural measures and that further scientific study could enable multidisciplinary teams featuring scientists, engineers, and landscapes architects to consider additional forms of NNBF that more thoroughly incorporate natural processes. These lessons are elaborated here.

First, the EWN + LA team's approach depended on being able to rapidly synthesize the input of disparate organizations and disciplines toward feasible and site-specific NNBF recommendations. The workshop format, and, in particular, the use of drawing in the workshops, was central for that synthesis. By working together over plans, maps, and drawings, drawing and discussing simultaneously, the workshop teams were able to test ideas visually and spatially, with live expert review and input as design concepts (literally) took shape. Through drawing, the intent was clarified, highlighting issues that might remain unnoticed in verbal discussion, such as how a geomorphologist and an engineer might be discussing a similar feature, but conceptualizing it in somewhat different ways. Although these hypothetical workshop participants might seem to be in verbal agreement, drawing clarifies precisely what is being proposed and accelerates the recognition of differing conceptions that need to be reconciled or adjusted. Thus, drawing served not only as a medium for recording and illustrating ideas, but also to synthesize disparate disciplinary perspectives.

Second, the team identified a lack of detailed scientific information particular to the study regions. For instance, in the case of Sabine Lake and its associated aqueous and terrestrial ecosystems, there is a lack of fine-grained, spatially specific knowledge about sediment flows and processes. Although it is evident that there has been significant wetland change in the region over recent decades, there have not been detailed scientific investigations of the processes that underlie that change, such as local sediment surpluses and deficits, nor is there presently the ability to identify where important sediment processes like accretion and erosion are occurring within existing wetlands. Without this basic information, it is difficult to effectively engage natural processes in building and maintaining NNBF as components of living, dynamic ecosystems. As a result, only NNBF that rely on operational synergies can be feasibly proposed. Such synergies, like the beneficial use of dredged material, are contingent on ongoing funding for infrastructure maintenance and reliant on substantial fossil-fuel energy inputs, which can be expected to become increasingly expensive in coming decades (Rutherford et al., 2018). More region-specific knowledge of how natural processes are functioning would facilitate the design of dynamic NNBF that takes advantage of natural processes to build, grow, and sustain those NNBF over multiyear and decadal time scales.

Third, the ability to quantify the risk reduction value of NNBF was an outstanding task that the EWN + LA team

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identified as necessary before the value of the proposed NNBF could be fully evaluated. Although the general principles underlying the deployment of NNBF for CSRM purposes are well-attested in scientific literature, much more research is needed in order to both precisely quantify the value of various types of NNBF and to be able to rapidly and effectively gauge the CSRM effects of NNBF in particular geographic circumstances.

Many of the planning processes that determine and evaluate alternatives for CSRM are ultimately governed by tightly defined cost–benefit analyses. Cost–benefit analyses for traditional structural and nonstructural measures are relatively straightforward, as these measures provide a single type of benefit (protection from storm risk), are engineered to provide that benefit to precise levels of risk, and are constructed using highly standardized methods whose costs are clearly established by precedent. The risk reduction value of NNBF, by contrast, is usually more complex to evaluate. Understanding the risk reduction value of a constructed marsh, for instance, requires not only sophisticated hydrological and hydrodynamic modeling to understand how the marsh will interact with waves and storms at a particular point in time, but also further geomorphological and ecological modeling to understand how the marsh itself will evolve and transform over time.

Much of the benefit of NNBF relative to traditional structural measures is that NNBF provide additional social and ecological value in addition to storm risk reduction. Both social and ecological value are more difficult to quantify than risk reduction. While this issue of valuation was not within the scope of the EWN + LA process for S2G and did not hinder the ideation of NNBF options, it will likely be necessary for SWG to demonstrate cost–benefit before obtaining approval to implement NNBF for CSRM. And, in future circumstances where there are opportunities to deploy NNBF in lieu of traditional structure measures, it will be all the more necessary to be able to fully quantify the benefits of NNBF, so as to give decision makers confidence in selecting NNBF alternatives.

Some of the challenges faced within the EWN + LA process for S2G were relatively particular to the institutional context of this work—the particular challenges of integrating assessment of ecological value into USACE CSRM work are shaped by a legal framework, institutional context, and set of cultural norms that is specific to the United States. More broadly, though, the challenges of assessing multiple forms of value simultaneously, obtaining adequate environmental data to make sound decisions, and finding ways to rapidly synthesize the input and expertise of multiple disciplines are common to most, if not all, NNBF work. Of these three challenges, the challenge of synthesis is the one that the EWN–LA team's work directly demonstrates replicable methods for addressing, methods that should be applicable in a broad range of legal, institutional, and cultural contexts. The inclusion of disciplines, like landscape architecture, that are trained in drawing as a means of visual discovery is relatively rare in NNBF work but has the capacity to accelerate synthesis in interdisciplinary contexts and contribute to the development of innovative design concepts.

CONCLUSION

The S2G EWN + LA project demonstrates how a multidisciplinary team featuring scientists, engineers, and landscape architects can effectively collaborate to incorporate NNBF into an ongoing CSRM planning study, ultimately expanding the range of value that will be provided to local communities by the proposed CSRM infrastructure. The development of “integrated policies and plans” that support resilience to the disasters that coastal regions like Texas' Gulf Coast face, while providing equitable access to natural landscapes, sustaining life below water, and sustaining life on land, as called for in Sustainable Development Goals 11, 14, and 15, can be facilitated by such multidisciplinary collaborations.

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CONFLICT OF INTEREST

The authors declare that there are no conflict of interests.

DATA AVAILABILITY STATEMENT

Data are available upon request from author Rob Holmes (rob.holmes@auburn.edu).

SUPPORTING INFORMATION

TABLE S1. Participants in the Engineering With Nature® Landscape Architecture (EWN + LA) Sabine-to-Galveston (S2G) project workshop.

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