Collaboration between Engineering with Nature and Landscape Architects

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I. DESIGN WITH NATURE

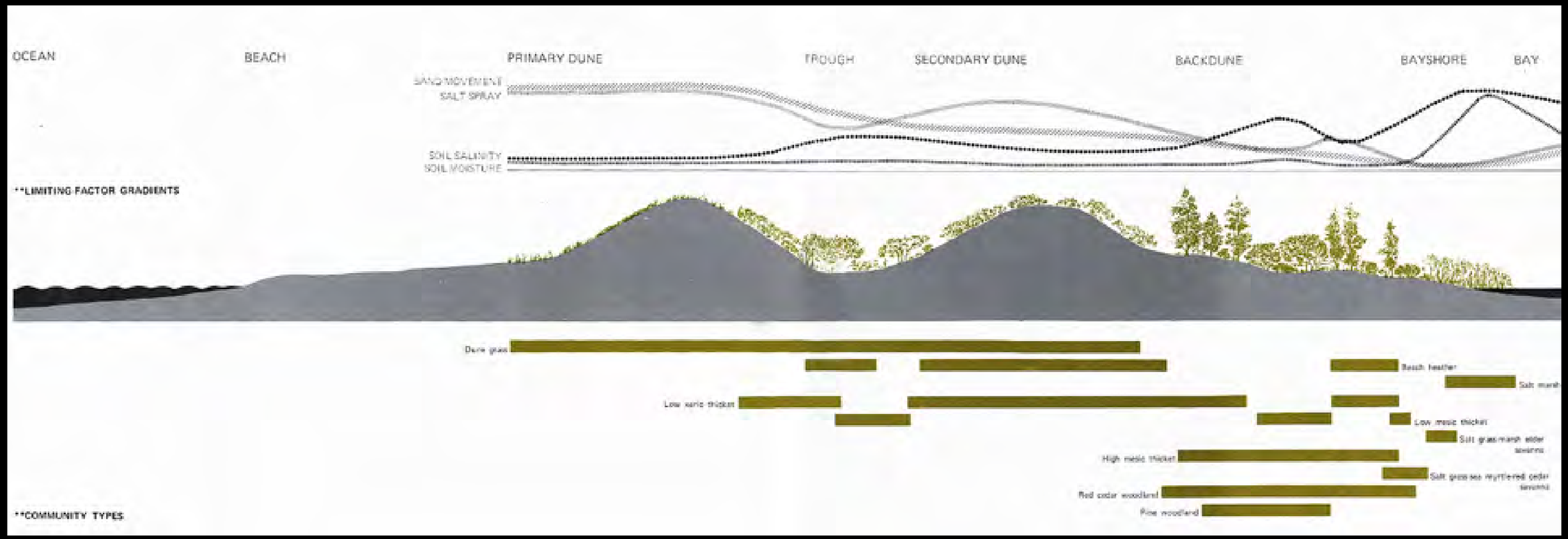
DESIGN WITH NATURE

IAN L. McHARG

DOUBLEDAY / NATURAL HISTORY PRESS

[Drawing: *Design with Nature*]

[Drawing: *Design with Nature*]



NNBF on the Jersey Shore

[Photos: Renaturation of the River Aire | Atelier Descombes Rampini]

[Drawing: Living Breakwaters | SCAPE Landscape Architecture]

Growing Ecological Resiliency

Breakwaters are designed to avoid critical habitat and integrate micro-complexity for a diversity of species. Living Breakwaters provides habitat throughout the water column, from subtidal structure to upland islands. Underwater, small-scale reef streets are incorporated into the breakwater and provide foraging and shelter for juvenile fish. Above water, the breakwaters can host harbor seals and nesting birds, again providing habitat away from predators. Other species, such as muddy bottom-loving eelgrass and hard clams, thrive in lightly sedimented zones in the lee of the breakwater.

SUBTIDAL ROCKY SUBSTRATE
Subtidal shallow-water rock enhancements for juvenile finfish, lobsters, and shellfish.

INTERTIDAL REEF STREET
Intertidal shallow-water rock enhancements for juvenile fish, lobsters, and mussels.

UPLAND ISLAND
Exposed island habitat free from predators. Used by harbor seals and colony nesting birds.

MUDFLATS
Zones of moderate sedimentation create habitat for hard clams, benthic fish, and eelgrass.

[Photo: Qunli Wetland Park | Turenscape]

[Photos: Room for the River, Njimegen | H+N+S Landscape Architecture]

EWN+LA WORKSHOP ERDC VICKSBURG, MS JULY 2017

Dredge Research Collaborative

EWN ENGINEERING WITH NATURE

US Army Corps of Engineers

// USACE / Landscape Architecture
Workshop on Engineering with Nature
Vicksburg, MS | July 25-27, 2017

BOTTOM LINE UPFRONT

The US Army Corps of Engineers (USACE), the Dredge Research Collaborative (DRC), and a diverse group of landscape architects (LA) held an Engineering with Nature (EWN) workshop at the US Army's Engineer Research and Development Center (ERDC) in Vicksburg, MS. The workshop introduced the respective communities and offered an opportunity to identify potential working relationships. Specifically, participants explored potential collaborations through discussions and exercises that prioritized EWN approaches for new and/or existing water infrastructure projects and operations. Throughout the meeting, participants developed and refined ideas that established/integrated EWN approaches and designs into water dependent projects. Ultimately, workshop participants were able to define more than 40 clear, prioritized activities that will form the basis for future collaboration. Four projects were chosen for focused attention and development during the workshop.

BACKGROUND

Co-organized by USACE and The DRC, the USACE and LA Workshop on EWN was attended by 35 total participants. USACE participants (17 total) originated from Headquarters, Engineer Research and Development Center, Institute for Water Resources, Buffalo District, Philadelphia District, Charleston District, Galveston District, New Orleans District and Chicago District). Of the previously identified representatives, several were also members of the USACE's Landscape Architecture-Community of Practice (COP). Participants from outside the USACE consisted of 18 landscape architects representing a diverse number of universities (Harvard, University of California-Davis, Rhode Island School of Design, Cornell, SUNY Buffalo, University of Toronto, Louisiana State University, Auburn University, and University of Southern California), private sector firms (SCAPE, SWA Group, AECOM and ENE), and a state government agency (Louisiana's Coastal Protection and Restoration Authority). The DRC is a non-profit organization focused on advancing public knowledge of sediment management and envisioning/realizing preferred sedimentary futures. It was represented by ten individuals that were affiliated with the previously identified universities and SCAPE.

Over a period of two and a half days, participants gained a greater understanding of how USACE missions are executed. They also learned more about the USACE's EWN Program and the associated EWN research/project portfolio. Likewise, participants gained insight into the expertise and valuable contributions that landscape architects provide when developing and/or designing sustainable solutions that are applicable to the EWN Program and USACE's business lines. The workshop included plenary presentations and discussions that focused on project-specific vignettes and historic/current EWN work within the EWN Proving Grounds (i.e. Philadelphia, Galveston and Buffalo Districts). Breakout exercises were intermixed with the plenary sessions. The four breakout groups were comprised of a mixture of USACE and LA participants. In the first session, groups were charged with identifying specific project opportunities that integrate approaches to landscape architecture and incorporate EWN principles/practices into water-infrastructure projects (design, development and operations). The second breakout activity concentrated on integrating applications of landscape architecture and EWN on the scale of systems (i.e., a network of individual projects operating within a large geographical area (e.g., watershed, estuary coastline)). Galveston District's Coastal Texas Project was offered as an example for the breakout groups to consider when developing/designing potential EWN solutions that would maximize engineering and ecosystem service benefits for the large Corps project. In the final breakout session, groups were asked to pick one of their working ideas and advance it as far as they could towards a realized proposal.

OUTCOMES

The high quality of engagement among USACE and LA participants was evidenced by the focused, energetic and productive dialogue, which resulted in the identification of more than 40 high-priority project ideas and opportunities. Projects were discussed and prioritized within the breakout group sessions and results were presented to all attendees during the plenary sessions. The breakout exercise on the final day of the workshop asked the four teams to refine and advance one project idea of their choosing. During this phase, project ideas were expanded to consider timing (immediate, short-term, or long-term opportunities), resource needs, geographical scale, project scope, anticipated engineering and ecosystem service benefits, potential concerns, information gaps, design considerations, regulatory challenges, interagency/stakeholder involvement and next steps. The four groups were then asked to report their final project analysis to all workshop attendees. The following descriptions highlight the four projects that were prioritized and advanced by each of the respective breakout group teams:

1. **Utilize EWN Strategies to Conduct Maintenance Dredging of the South Carolina Section of the AIWW**
The DMMAs that have traditionally received South Carolina's AIWW maintenance dredging material are at full capacity. The proposed project would leverage EWN principles/techniques to develop alternative placement sites adjacent to the AIWW. Thus, projects like thin-layer placement, dune construction and other NNBF alternatives would be realized.

2. **Central Valley/California Delta Multi-benefit Flood Infrastructure**. This project builds off of strong local initiatives to retrofit this region's extensive and vulnerable flood management infrastructure. The team suggested using EWN strategies to inform levee setbacks and other "room for the river" type projects to create multi-functional floodplains that benefit a variety of species and surrounding communities, and that will serve as a model for other parts of the US. Suggested engagement includes an EWN demonstration at the project-scale, such as within the Sacramento Flood Control Project (given its proximity to urban areas and human uses) and a broader envisioning project that would assist stakeholders and communities imagine how multiple EWN features throughout the region would benefit the larger system.

3. **Incorporating EWN Solutions into Texas Coastal Initiative** A Systems Approach That Seeks Alternatives to Currently Planned Hardened Structure(s). Galveston Bay is scheduled for a major effort to improve resilience to extreme weather events and storm surges. Currently, four approaches are being considered, all of which emphasize hardened edges (seawalls etc). The team worked up a schedule for how a team of LAs could be brought online to explore and propose alternatives more in line with EWN principles. The approach would be to work with the District and local stake holders to gather ideas and put together a set of EWN-first proposals that would then be tested against established performance requirements.

4. **Establish a EWN/LA Tiger Team** This project/initiative would ultimately create a working group that consists of a diverse team of scientists, engineers, landscape architects, etc. that assemble to to perform design-driven research that will support the incorporation of EWN approaches into Corps-based, water-resources projects and support the use of EWN strategy more broadly by providing research and testing of EWN approaches. Teams would operate on 2-3 year cycles and would work on a focused design research topic / question, with impacts ideally reaching multiple Corps District projects. Subjects would be chosen by EWN and DRC representatives, and could begin with a focus on some of the core themes that precipitated out of the other breakout sessions and groups. Promising subject areas for initial Tiger Teams include 1) passive sediment management strategies focused on inland waterways and 2) layered coastal defense strategies. The team would convene for an approximately one-month) period each year to consider overall objectives for Corps projects and offer innovative project designs/alternatives that maximize EWN principles/concepts.

NEXT STEPS

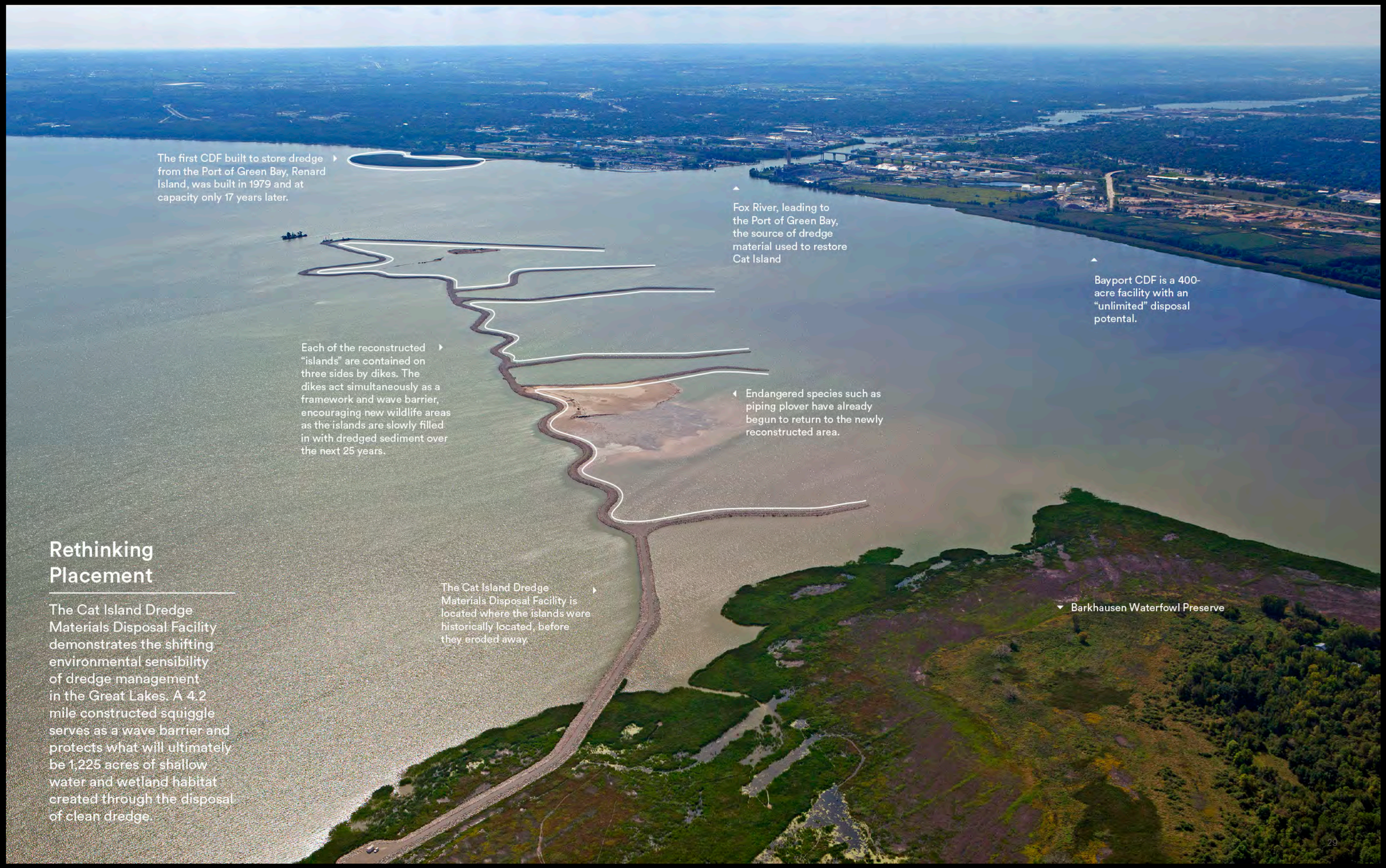
The immediate next steps that will be taken include:

1. Prepare an executive summary of the workshop (present document);
2. Distribute a draft workshop proceedings report to participants for feedback by September 30, 2017, to be followed by report finalization and joint publication;
3. Breakout Groups continue to elaborate/expand prioritized project and develop a 2-3 page white paper that characterizes needs, issues, challenges and proposed recommendations for pursuing projects by September 2, 2017. When applicable, design renderings will also be provided that highlight the EWN strategies that are recommended.
4. Host follow-up teleconference by September 15, 2017, between USACE and DRC leadership to track progress and identify any future action items that are needed.

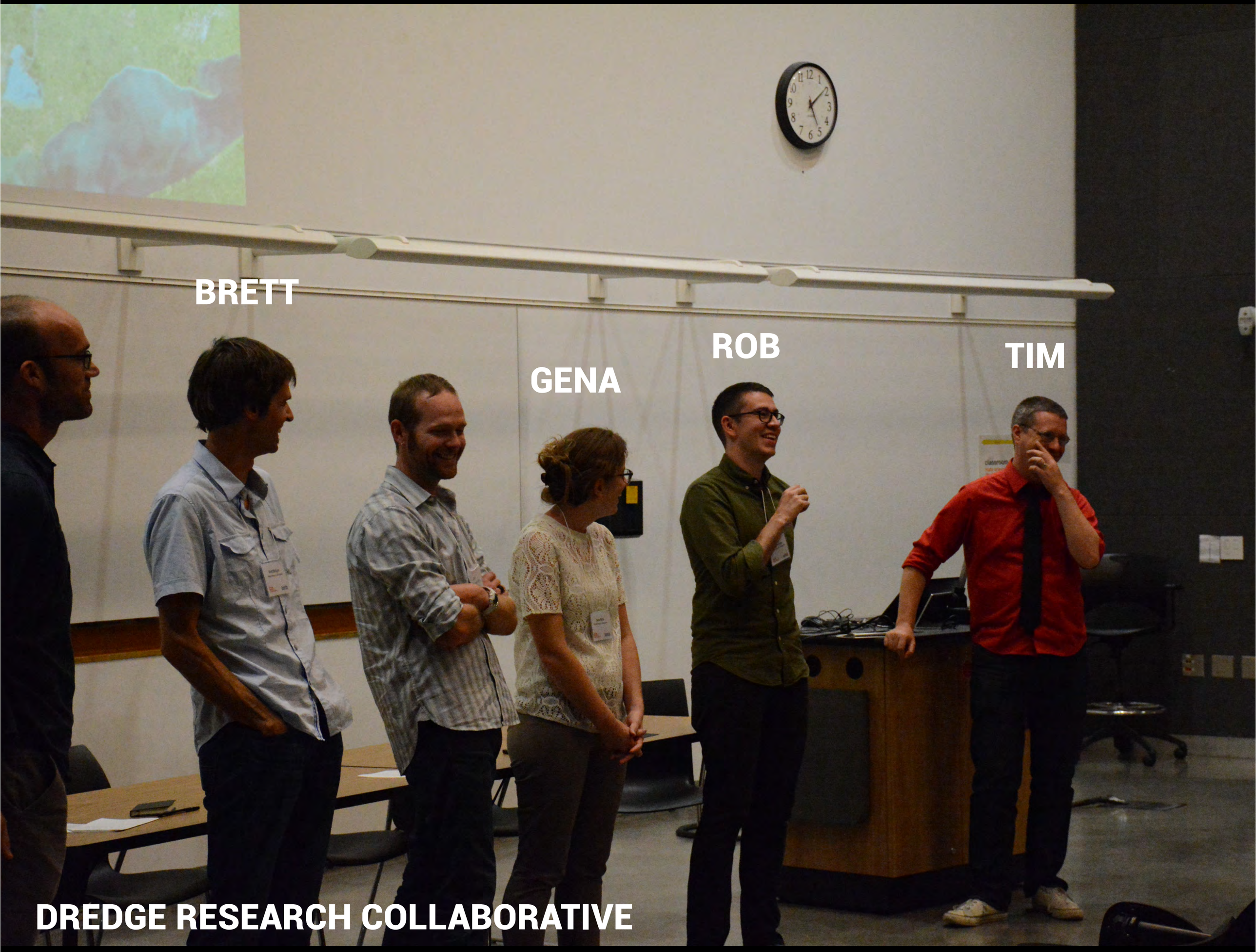
EWN+LA WORKSHOP ERDC VICKSBURG, MS JULY 2017

II. THE DRC

[spread: Dredge Research Collaborative]



THE DRC 501c3 SEDIMENT + INFRASTRUCTURE



DREDGE RESEARCH COLLABORATIVE

DREDGE RESEARCH COLLABORATIVE

[Drawing: DRC]

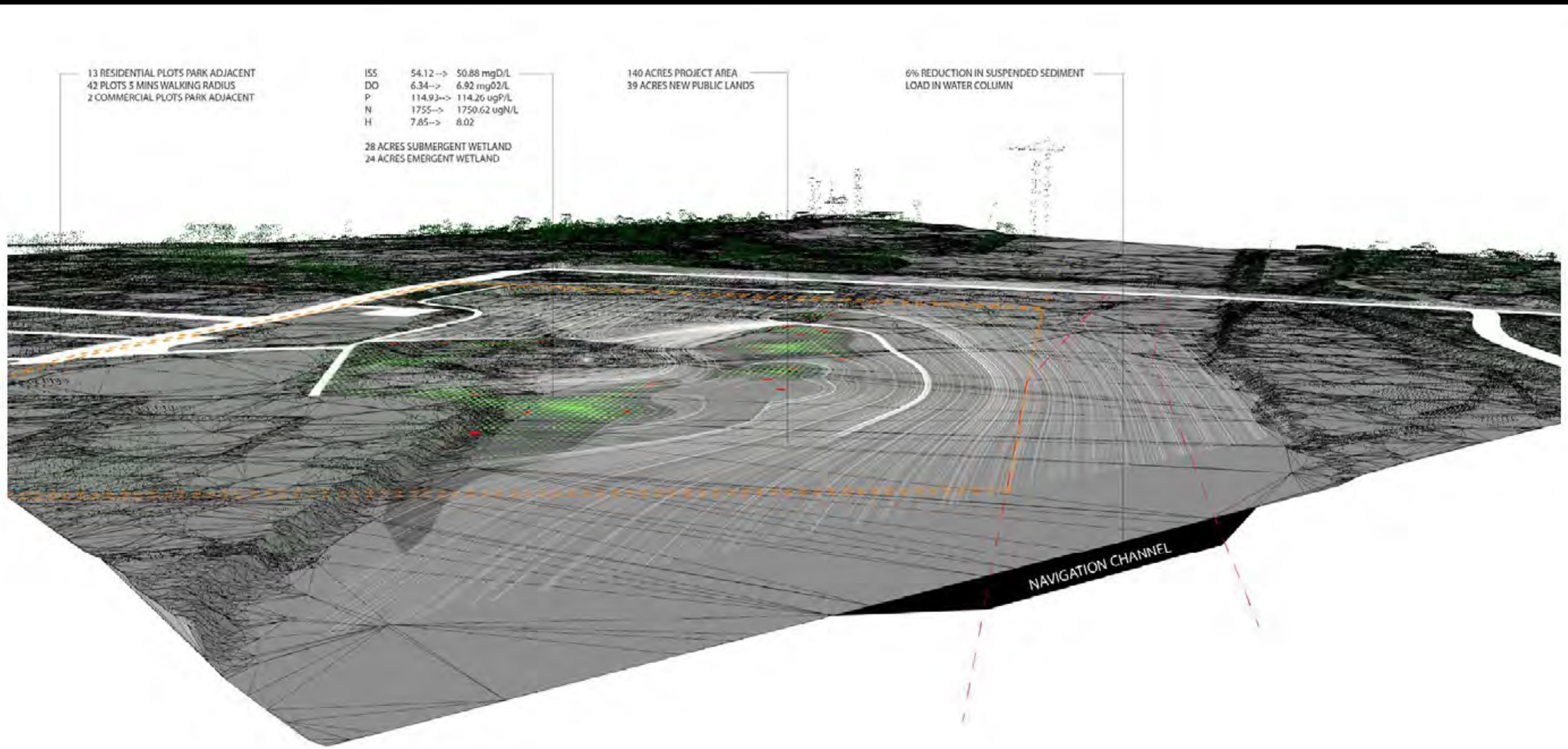
DREDGEFEST

Interdisciplinary conversations

Curated public tours

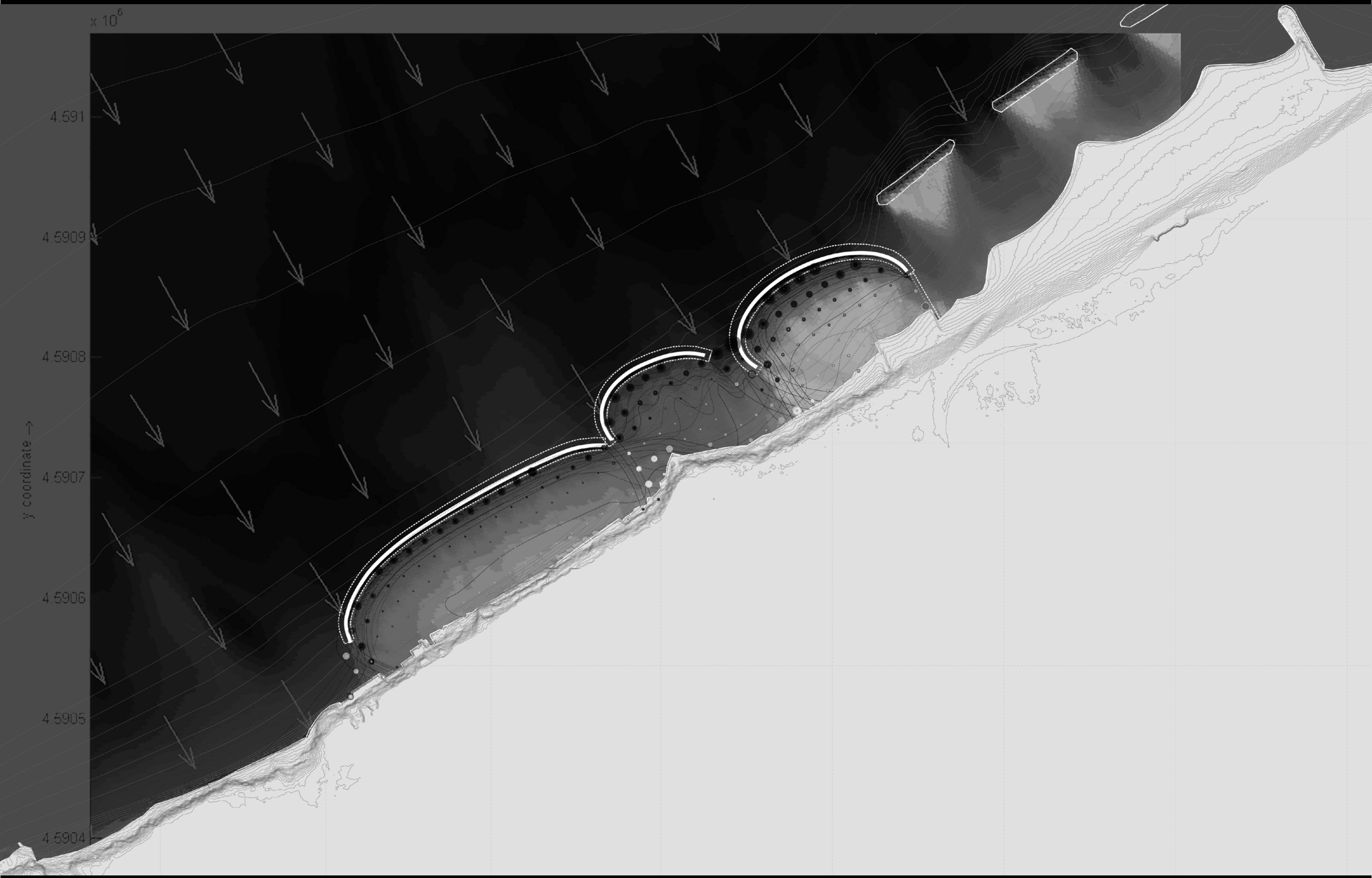
Design research

[Drawings: DRC]



HEALTHY PORT FUTURES

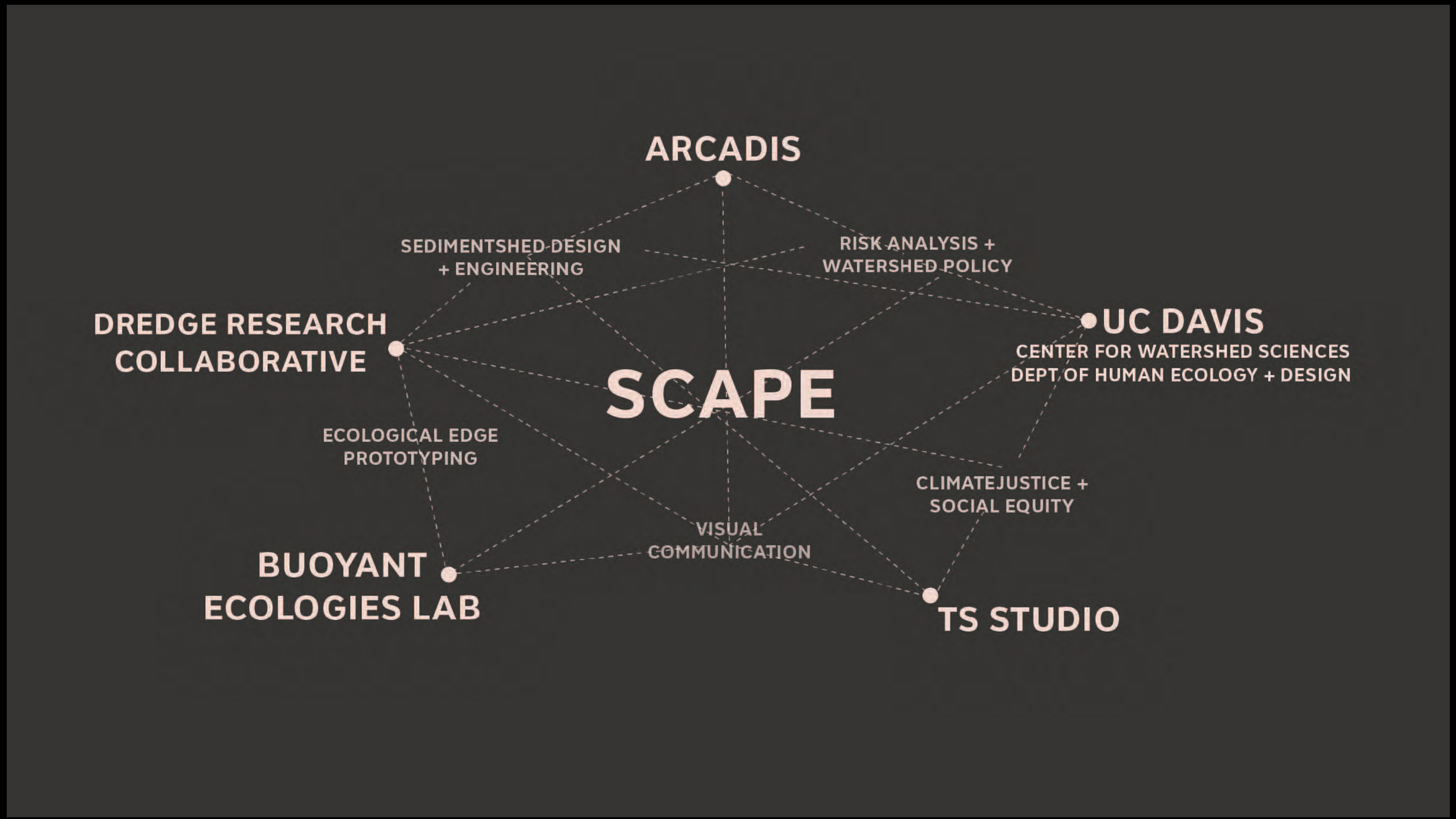
[Drawings: DRC]



Accretionary ‘laquestrine’ landforms

PUBLIC SEDIMENT

[image: SCAPE Landscape Architecture]

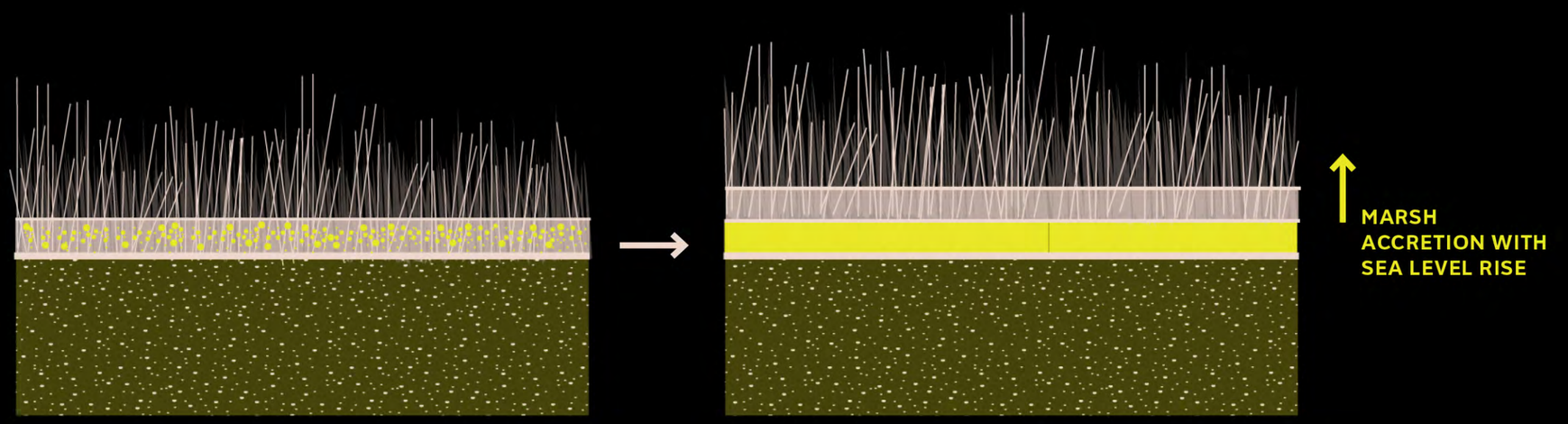


Workshops at DredgeFest California

BAYLANDS 2100 WITH 7' SLR

LOW SEDIMENT SUPPLY

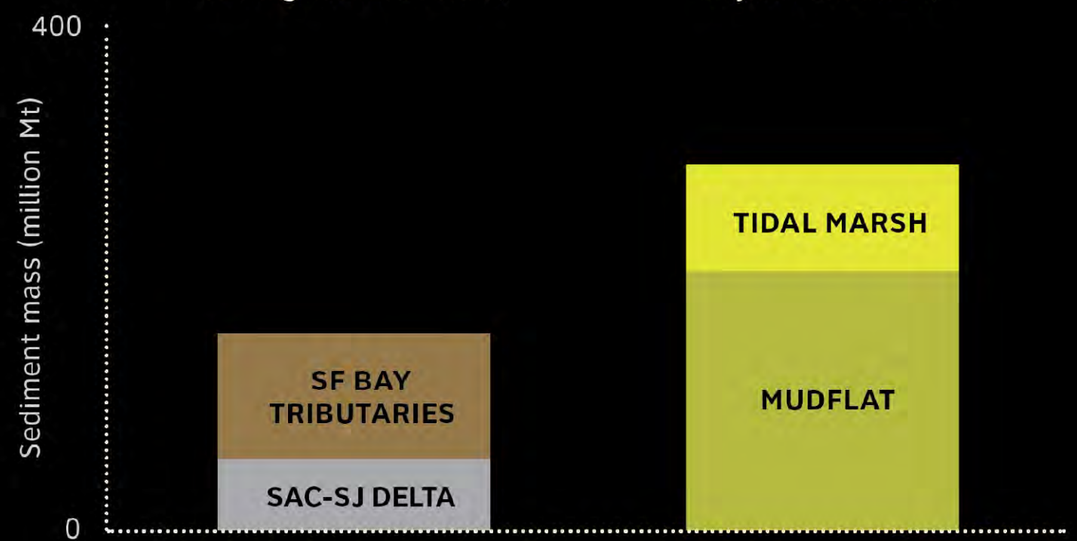
SEDIMENT BUILDS BAYLANDS



2100, 3.5 ft SLR

ESTIMATE OF POSSIBLE FUTURE BAYLAND SEDIMENT SUPPLY[1]
(assuming current average annual load)

ESTIMATE OF POSSIBLE FUTURE BAYLAND SEDIMENT DEMAND[2]
(assuming current baylands extent)



Based on preliminary analysis by SFEI. A more detailed analysis is being conducted as part of the Healthy Watersheds Resilient Baylands project (hwrb.sfei.org)

[1]Sediment supply was estimated by multiplying the current average annual sediment load values from McKee et al. (in prep) by the number of years between 2017 and 2100.

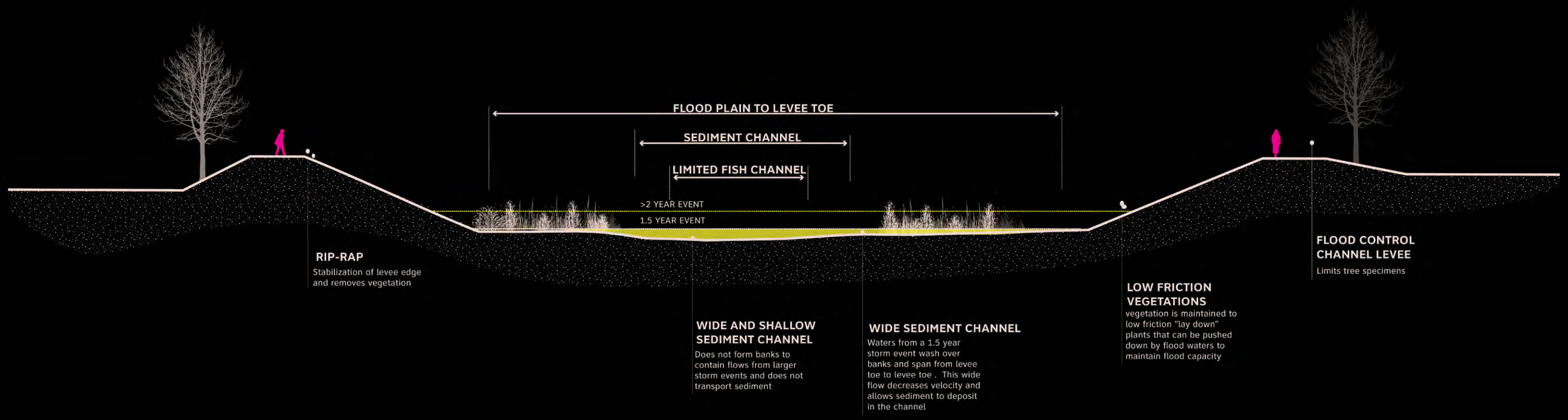
[2]Sediment demand was estimated using a mudflat soil bulk density of 1.5 g sediment/cm^3 soil (Brew and Williams 2010), a tidal marsh soil bulk density of 0.4 g sediment/cm^3 soil (Callaway et al. 2010), and baywide mudflat and marsh area circa 2009 (BAARI v1).

ALAMEDA CREEK WATERSHED - 660 SQ MI


SEDIMENT IS STUCK
HERE


SEDIMENT IS NEEDED HERE

THE FLOOD CONTROL CHANNEL



RIP-RAP
Stabilization of levee edge and removes vegetation

WIDE AND SHALLOW SEDIMENT CHANNEL
Does not form banks to contain flows from larger storm events and does not transport sediment

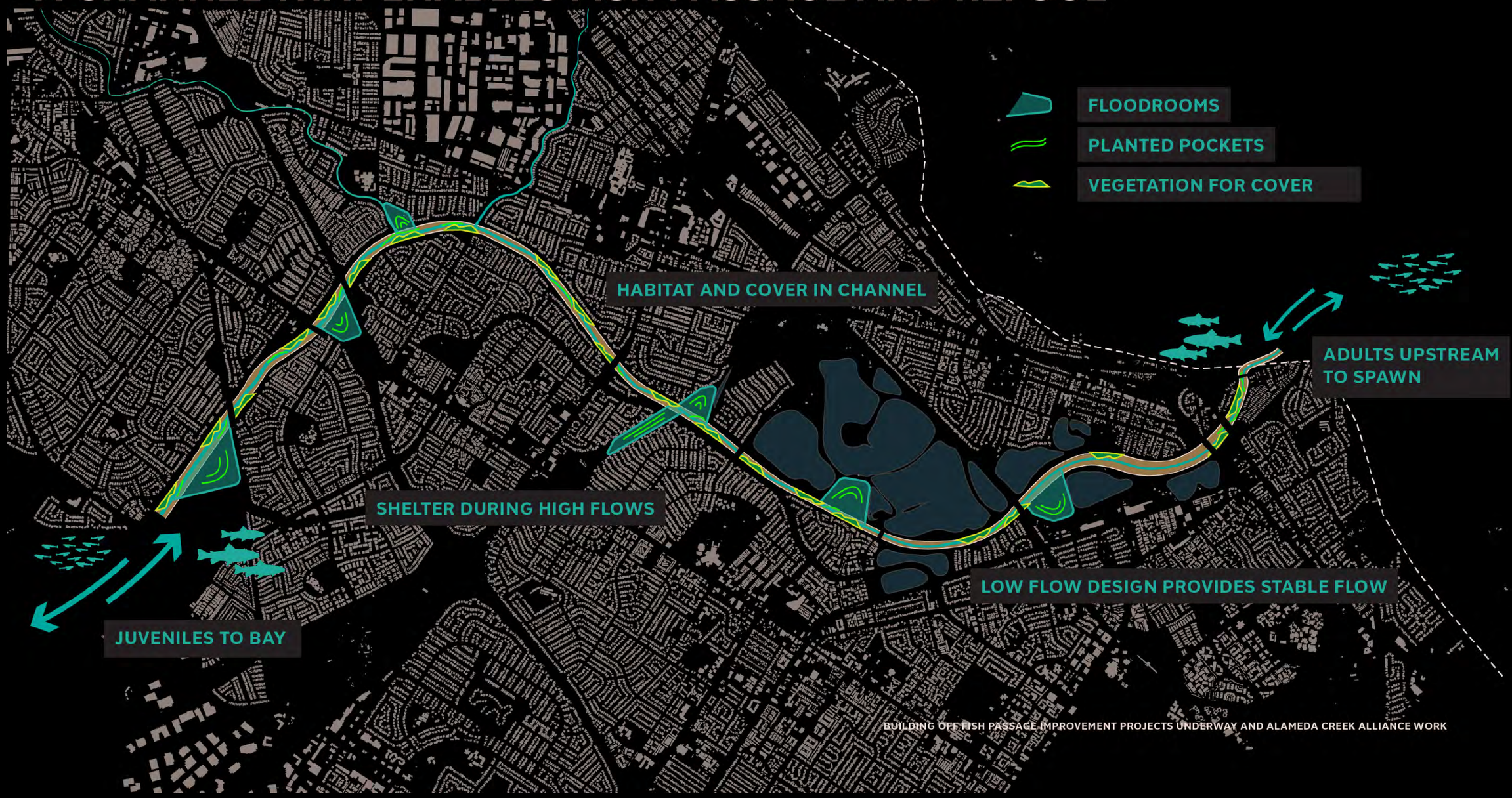
WIDE SEDIMENT CHANNEL
Waters from a 1.5 year storm event wash over banks and span from levee toe to levee toe . This wide flow decreases velocity and allows sediment to deposit in the channel

LOW FRICTION VEGETATIONS
vegetation is maintained to low friction "lay down" plants that can be pushed down by flood waters to maintain flood capacity

FLOOD CONTROL CHANNEL LEVEE
Limits tree specimens

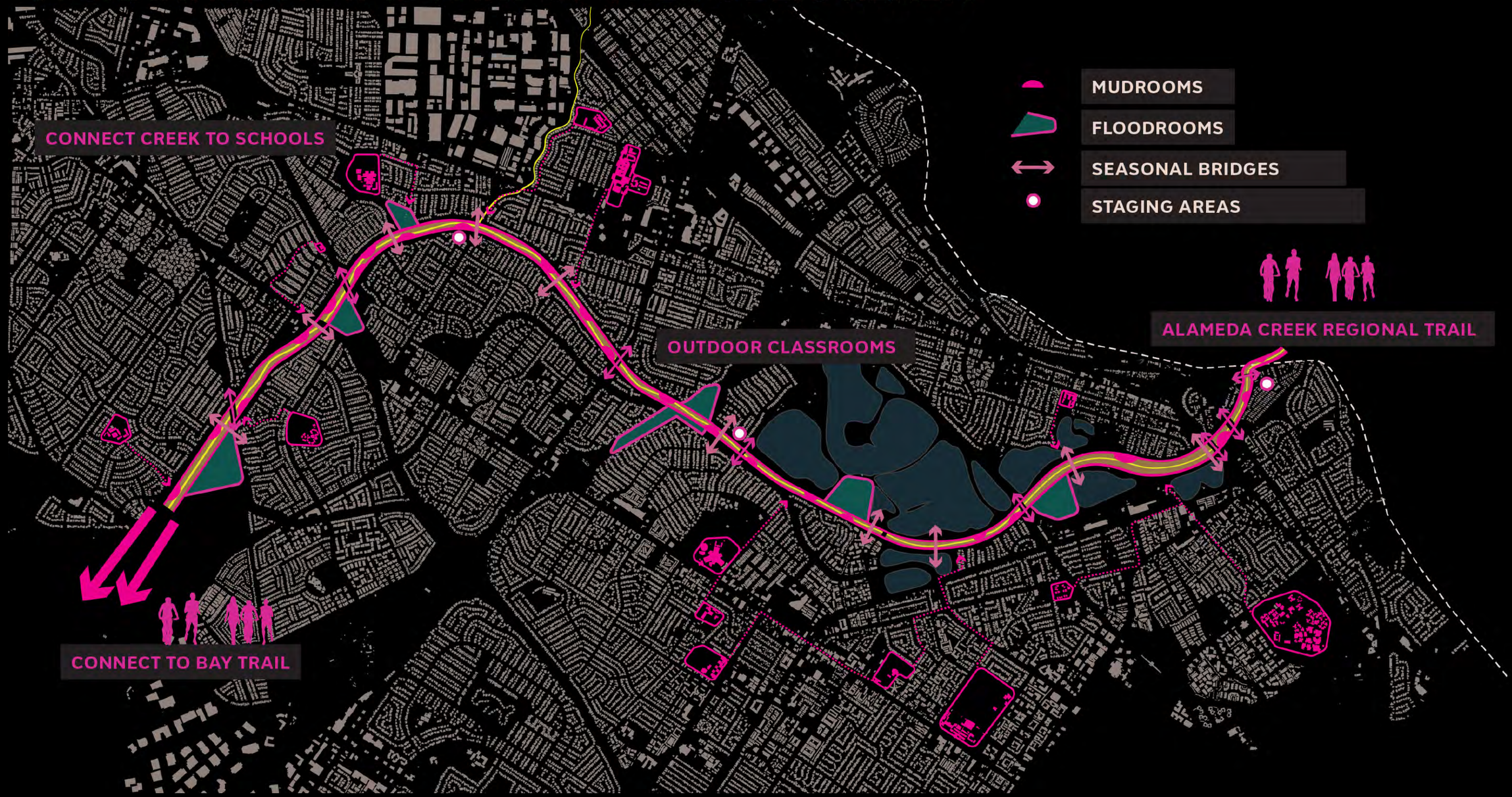
CREATE A CHANNEL THAT MOVES SEDIMENT

A CHANNEL THAT ENABLES FISH PASSAGE AND REFUGE



BUILDING OFF FISH PASSAGE IMPROVEMENT PROJECTS UNDERWAY AND ALAMEDA CREEK ALLIANCE WORK

A CHANNEL THAT IS PART OF THE PUBLIC REALM



MORE PUBLIC SEDIMENT 1:30 PM ROOM 203B

III. ENGINEERING WITH NATURE + LANDSCAPE ARCHITECTURE

BEYOND BARRIERS GALVESTON BAY, TEXAS SPRING 2018

mapping

historic storms and storm impacts

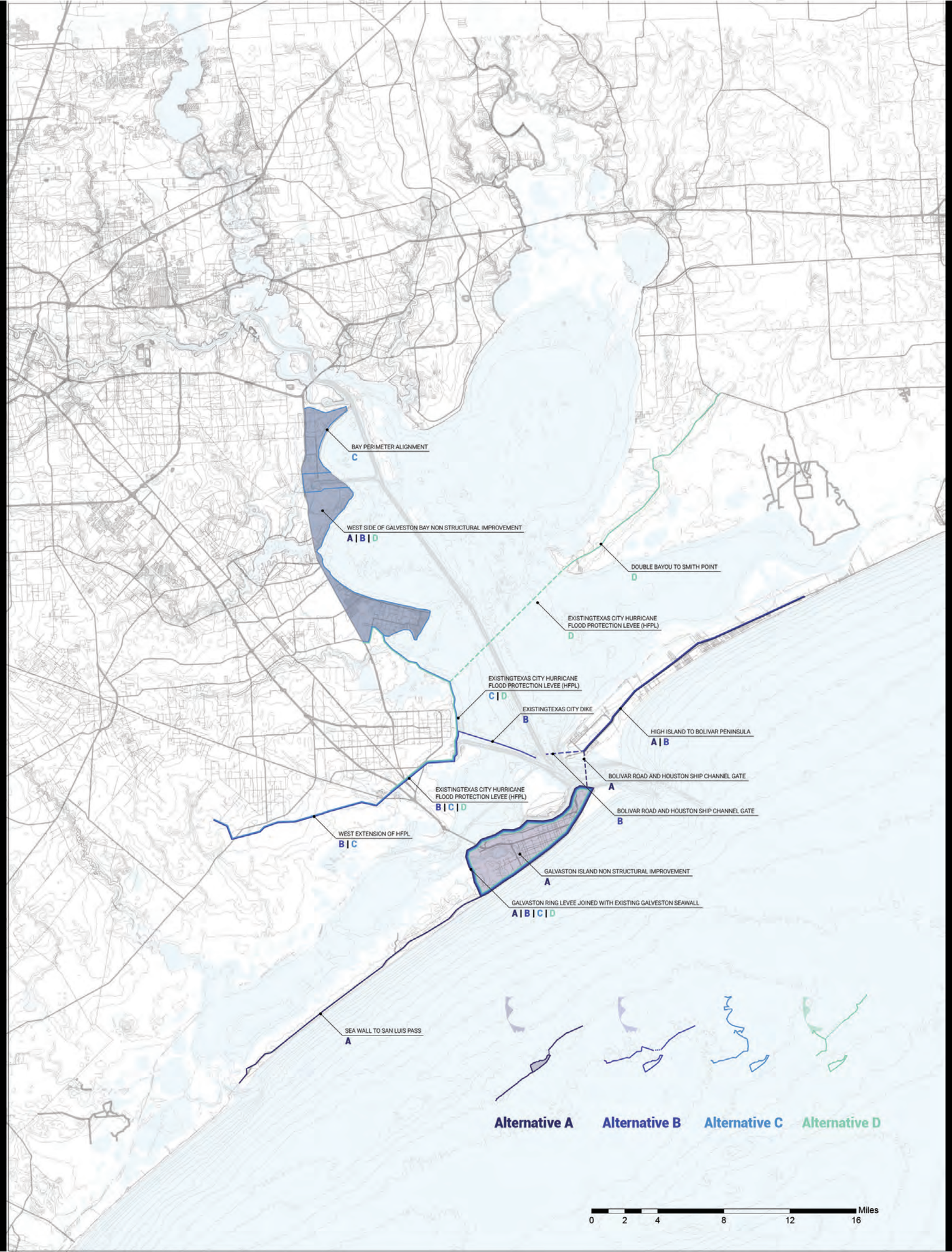
1942
1949
1959
2008
1989
1989
1943
1932
1983
1900
1915

HURRICANE IKE (2008)
Casualty 46
Surge 22 feet
Damage $37.5 billion USD

GREAT GALVESTON HURRICANE (1900)
Casualty 6000- 12000
Surge 15 feet
Damage $605 million USD

LEGEND
- Catagory 1
- Catagory 2
- Catagory 3
- Catagory 4
- Catagory 1 Risk Zone
- Catagory 2 Risk Zone
- Catagory 3 Risk Zone
- Catagory 4 Risk Zone
- Catagory 5 Risk Zone

0 2 4 8 12 16 Miles

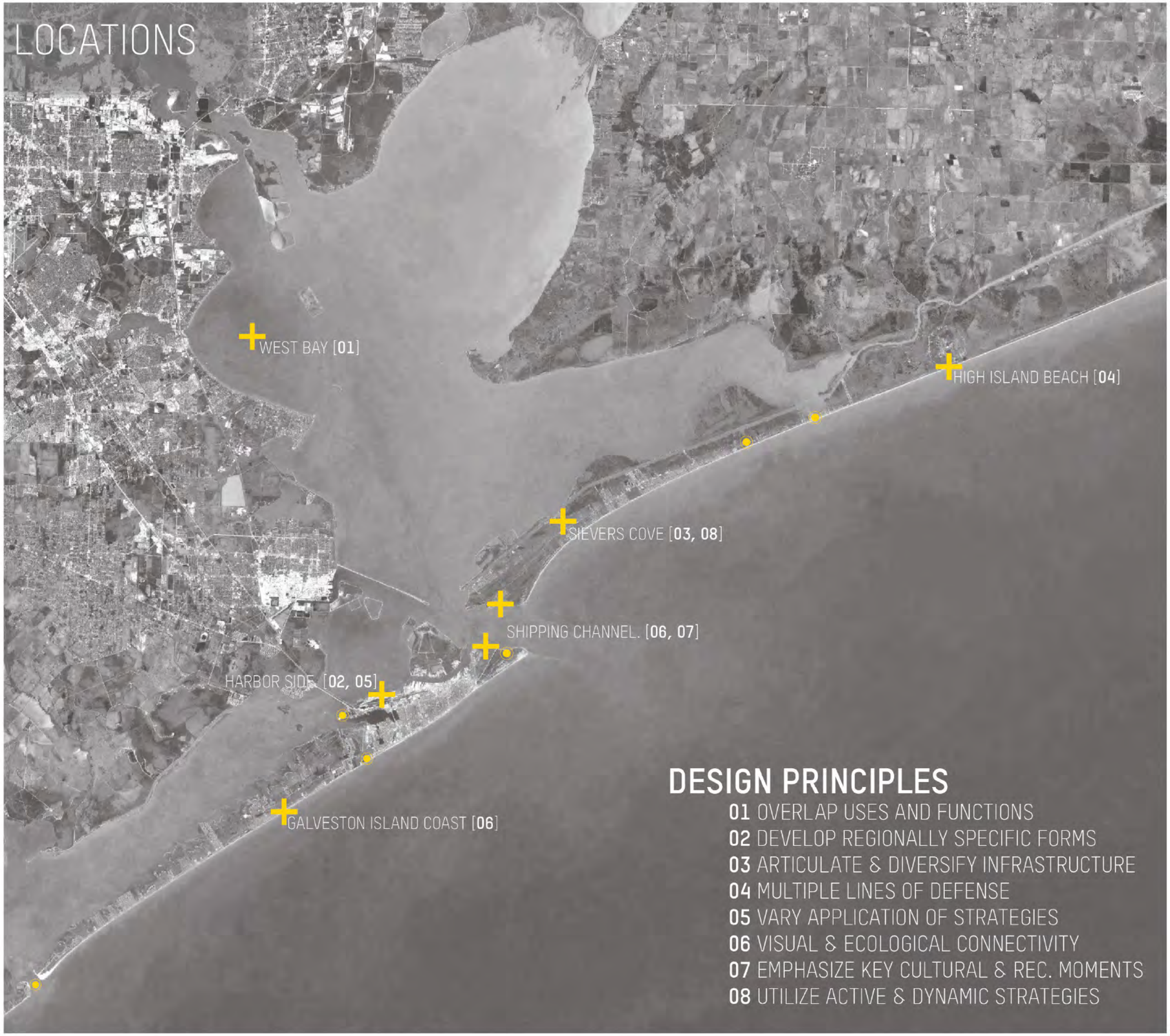

BAY PERIMETER ALIGNMENT
C
WEST SIDE OF GALVESTON BAY NON STRUCTURAL IMPROVEMENT
A | B | D
DOUBLE BAYOU TO SMITH POINT
D
EXISTINGTEXAS CITY HURRICANE FLOOD PROTECTION LEVEE (HFPL)
D
EXISTINGTEXAS CITY HURRICANE FLOOD PROTECTION LEVEE (HFPL)
C | D
EXISTINGTEXAS CITY DIKE
B
HIGH ISLAND TO BOLIVAR PENINSULA
A | B
BOLIVAR ROAD AND HOUSTON SHIP CHANNEL GATE
A
BOLIVAR ROAD AND HOUSTON SHIP CHANNEL GATE
B
EXISTINGTEXAS CITY HURRICANE FLOOD PROTECTION LEVEE (HFPL)
B | C | D
WEST EXTENSION OF HFPL
B | C
GALVASTON ISLAND NON STRUCTURAL IMPROVEMENT
A
GALVASTON RING LEVEE JOINED WITH EXISTING GALVESTON SEAWALL
A | B | C | D
SEA WALL TO SAN LUIS PASS
A
Alternative A
Alternative B
Alternative C
Alternative D
Miles
0
2
4
8
12
16

Partners

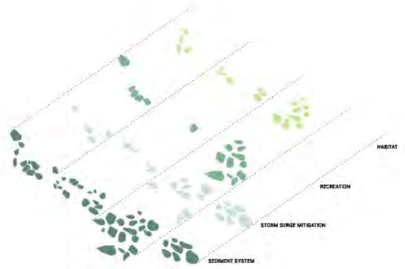
Starting points

PROJECT LOCATIONS

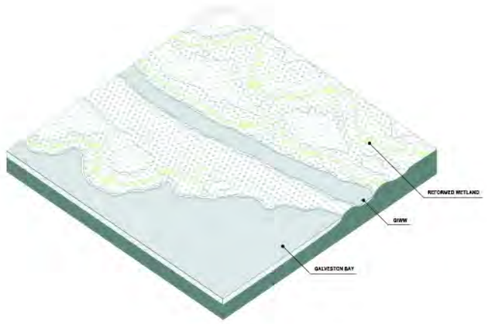
Student design projects were spread across a variety of sites, selected by the students and faculty based on discussions with SWG, EWN, and the GLO. Those individual design projects all demonstrated one or more of the general design principles we have developed, as shown in the map at right. Large crosses represent projects featured in this document, while the yellow dots and crosses together represent the total number of locations studied through student projects.



EIGHT PRINCIPLES



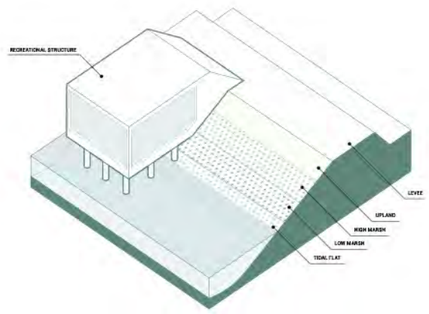
1 OVERLAP USES & FUNCTIONS
Wherever possible, new infrastructure should be designed for multiple forms of value, including coastal protection, habitat, recreation, and aesthetic value.



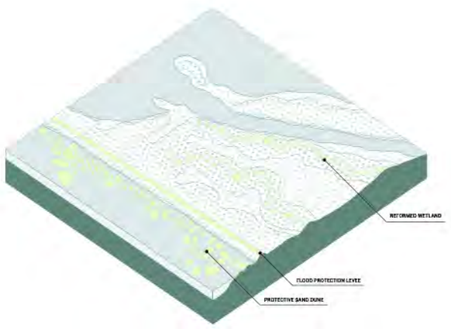
2 DEVELOP REGIONALLY-SPECIFIC FORMS
Specificity to Galveston Bay can begin with careful examination of existing landforms and ecological patterns of the Texas Coast for patterns, forms, and tactics that can be deployed in infrastructure design.

5 VARY APPLICATION OF STRATEGIES
When an infrastructure like a levee is deployed across a big and diverse region like Galveston Bay, it should be modified at key cultural and ecological sites to respond to the differing ways those sites relate to the region.

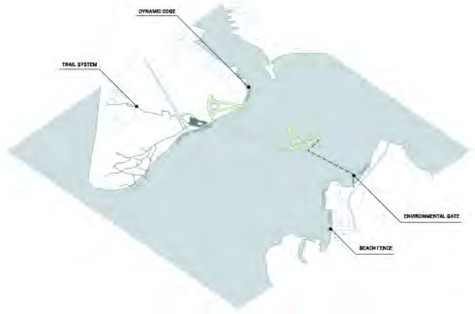
6 VISUAL & ECOLOGICAL CONNECTIVITY
Poorly-designed protective infrastructures can function as barriers, cutting communities off from water bodies or separating communities from one another. Consider opportunities to integrate infrastructure into existing transportation systems to facilitate valuable new opportunities for connection and recreation.



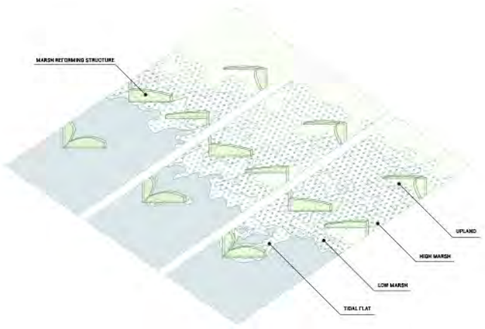
3 ARTICULATE & DIVERSIFY INFRASTRUCTURE
Recreational and ecological value can often emerge from finding strategic opportunities to articulate protective infrastructure with more diverse forms.



4 CONSTRUCT MULTIPLE LINES OF DEFENSE
Rather than relying on a single, hardened line of protection that is susceptible to catastrophic failure, invest in multiple lines of that include both conventional and landscape-based features and are adaptable to rising sea levels.



7 EMPHASIZE KEY MOMENTS
The points where the line starts or stops are often critical linkages or vulnerable areas in an infrastructure system. They demand special attention and integration into surrounding context through the design of public accessibility, view enhancement, recreational opportunities, and multiple lines of defense.

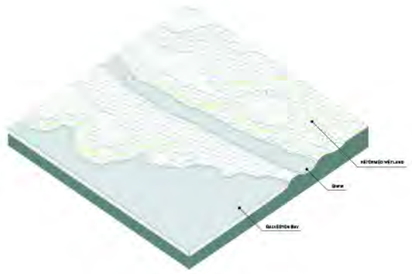


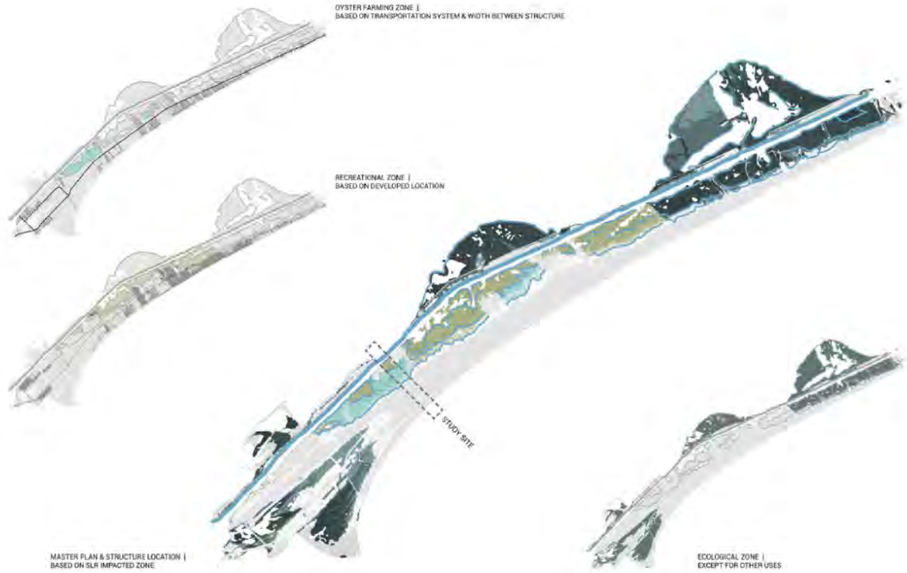
8 UTILIZE ACTIVE AND DYNAMIC STRATEGIES
Infrastructures that accommodate and take advantage of dynamic landscape processes, such as the accretion-enhancing propensities of marsh communities, can simultaneously provide recreational and ecological value now while being more adaptive to change over long spans of time than static or fixed forms of infrastructure.

2 DEVELOP REGIONALLY-SPECIFIC FORMS OF NNBF

Principle

The design of Natural and Nature-Based Features can and should look to regional landscapes for inspiration. Local salt marshes, oak mottes, and beach geomorphology can all provide clues for future infrastructure design. As a result, specificity to Galveston Bay can begin with careful examination of existing landforms and ecological patterns of the Texas Coast for patterns, forms, and tactics that can be deployed in protective infrastructures.

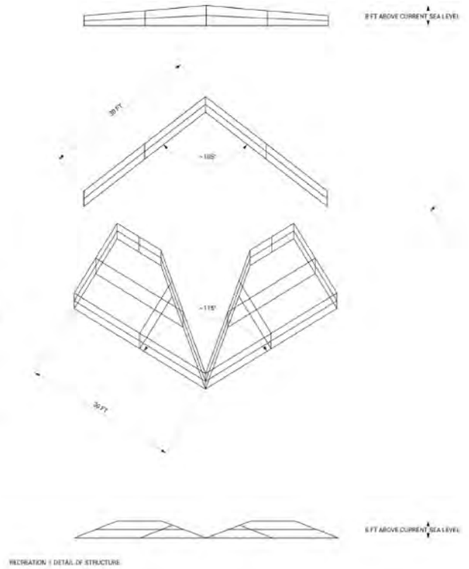


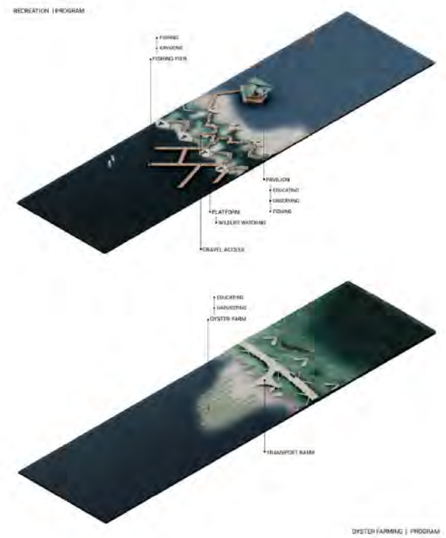


Example

Yuzhou Jin's proposal for Bolivar Peninsula (right and bottom left) draws on regional geomorphology, looking to the landforms of beach ridges as morphological inspiration for a system of modular sediment-capturing infrastructures. Jin proposes deploying these modules in thick bands along the backside of the Bolivar Peninsula, where they could facilitate marsh accretion over time, hopefully keeping pace with sea level rise, at least along the bands.

Jin also proposes placing a levee on the bayward side of the Gulf Intracoastal Waterway (following pages), where it would protect the people and communities of the Bay without incentivizing development in the most hazardous zones of the Peninsula.





IF CHOOSE TO KEEP DEVELOPING MORE **RESIDENTIAL** AREA ON THE PENINSULA: OVER **5400 ACRES** OF THE RESIDENTIAL AREA WOULD BE THREATENED BY SEA LEVEL RISE.

OYSTER FA

100 YEARS ECOLOGICAL PATTERNS | ONLY WITH LEVEE

IF CHOOSE TO CONSERVE THE **WILDLIFE HABITATS** : OVER **4500 ACRES** OF MARSHLANDS WOULD BE SAVED AND ENHANCE THE CAPABILITY OF STORM SURGE PROTECTION AS WELL

STORM SURGE PROTECTION | WILDLIFE HABITAT

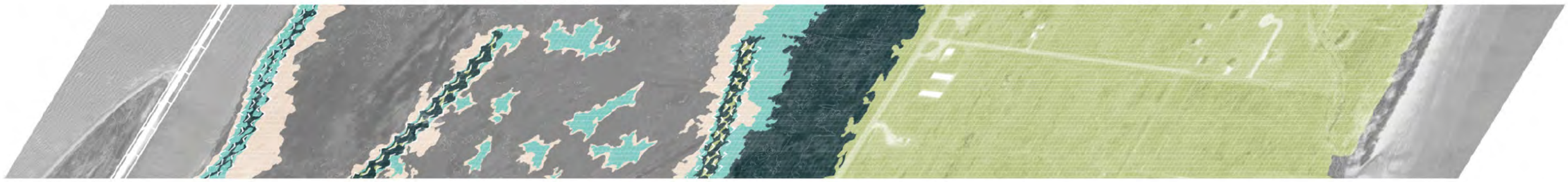
THE STRUCTURE WILL CREATE

OVER **1125** ACRES
TIDAL FLAT

OVER **2025** ACRES
LOW MARSH

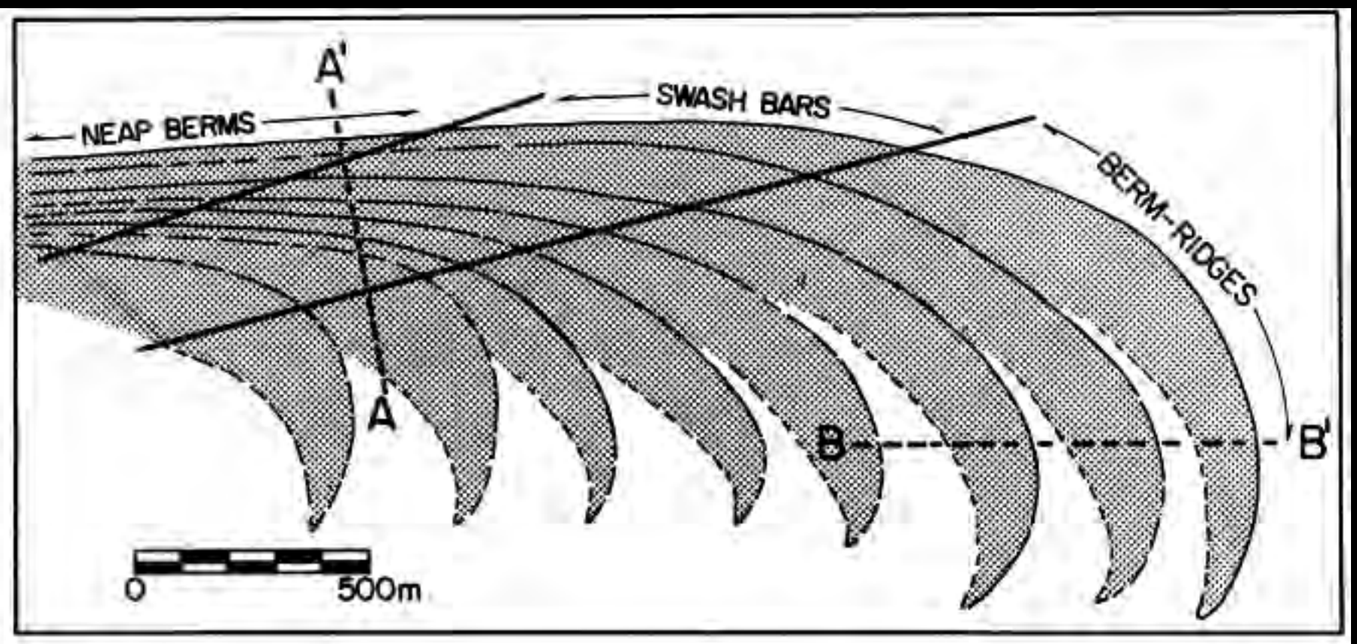
OVER **1350** ACRES
HIGH MARSH

IN HUNDRED YEARS

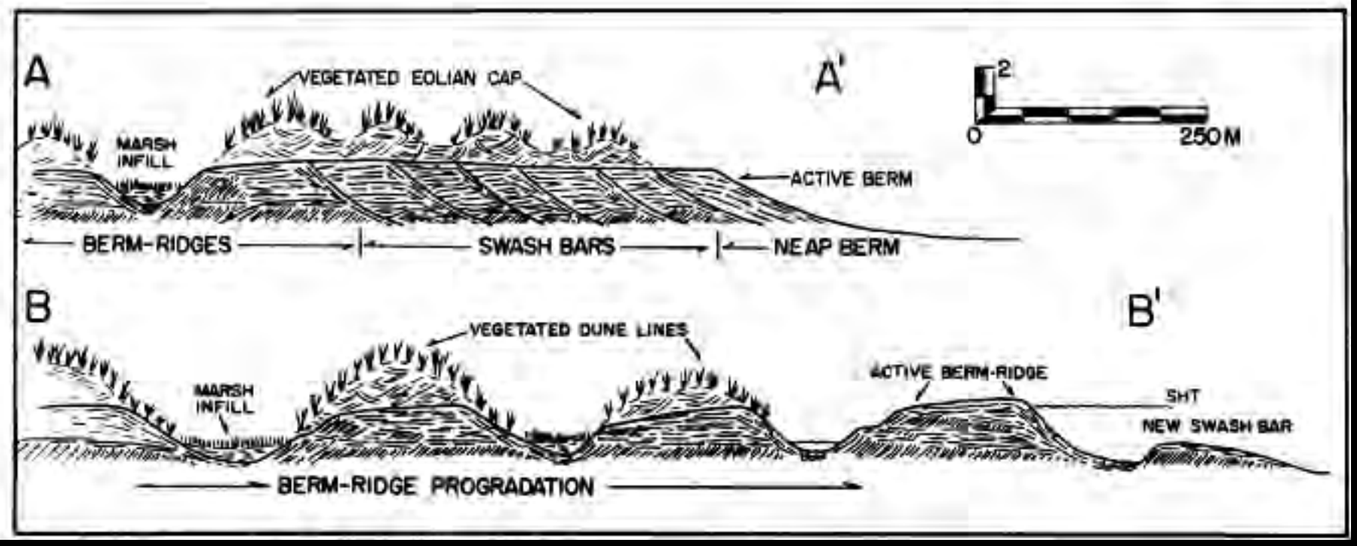


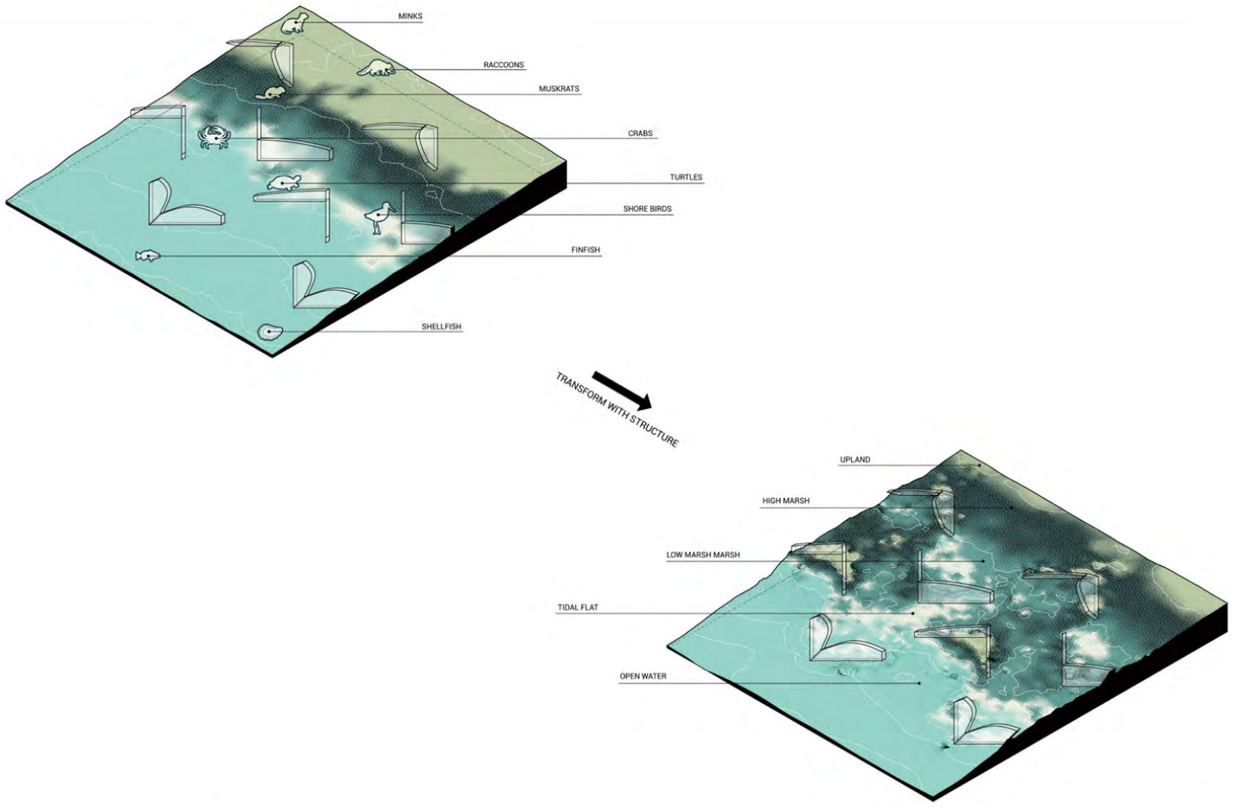
100 YEARS ECOLOGICAL PATTERNS | 3.5 FT ABOVE CURENT SEA LEVEL | WITH SUPPLEMENTAL STRUCTURE

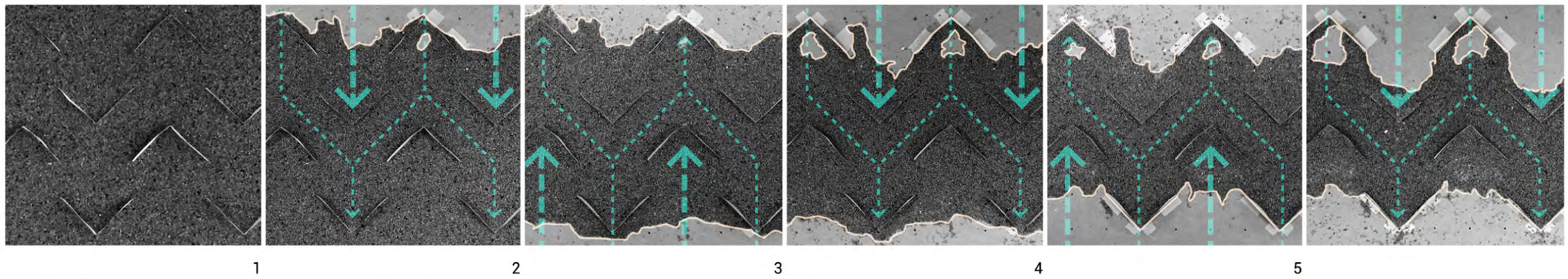
(a)

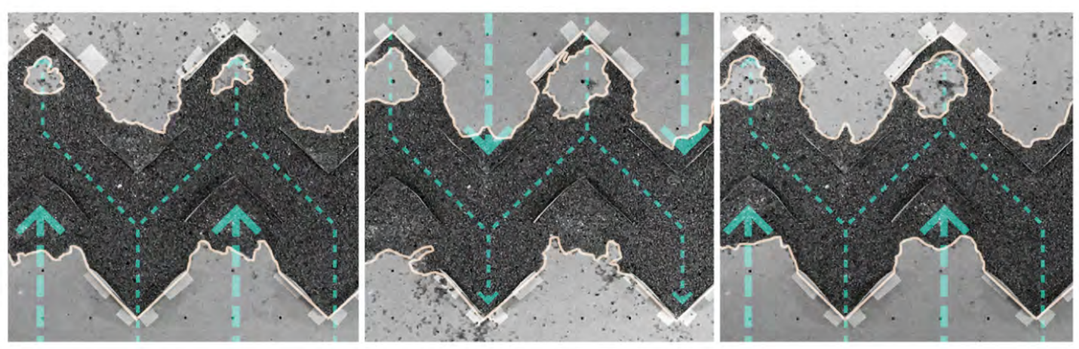

A'
NEAP BERMS
SWASH BARS
BERM-RIDGES
A
B
B'
0
500m

(b)


A
VEGETATED EOLIAN CAP
A'
2
0
250M
MARSH INFILL
ACTIVE BERM
BERM-RIDGES
SWASH BARS
NEAP BERM
B
VEGETATED DUNE LINES
B'
ACTIVE BERM-RIDGE
MARSH INFILL
SHT
NEW SWASH BAR
BERM-RIDGE PROGRADATION







ABOUT **36,800 CY** SEDIMENT ARE NEEDED FOT THE DESIGN SITE

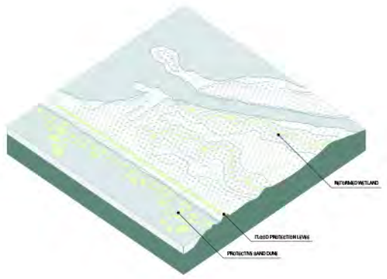
4,000,000 CY SEDIMENT ARE NEEDED FOR THE WHOLE PENINSULA

SEDIMENT GATHERING PROCESS | SAND MODEL

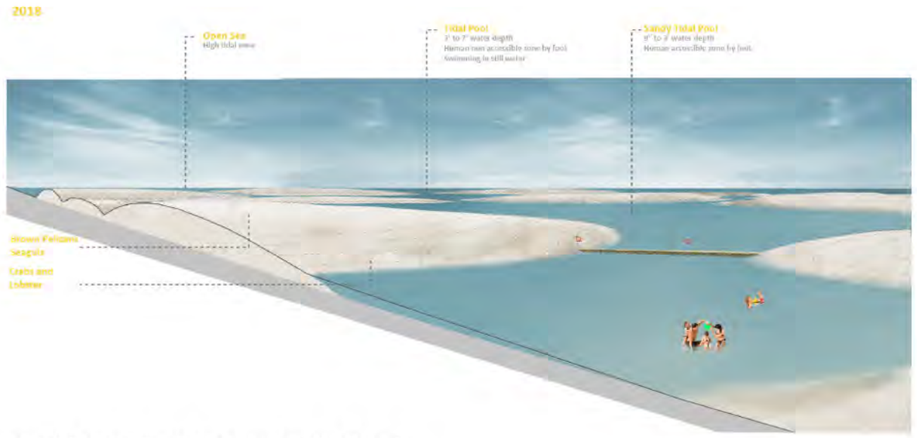
4 CONSTRUCT MULTIPLE LINES OF DEFENSE

Principle

Rather than relying on a single, hardened line of protection that is susceptible to catastrophic failure, invest in multiple lines of that include both conventional and landscape-based features and are adaptable to rising sea levels. This principle is not only a key principle of the student work, but has been articulated and prioritized within the planning principles of the Coastal Texas Study.



Plan view of islands serving as a new line of defence



Aerial diagram illustrating constructed islands

Example

Looja Shakya's proposal for the eastern portion of the Bolivar Peninsula considers the potential recreational, ecological, economic, and risk reduction benefits of constructing onshore dunes and staging additional sand in nearshore islands in anticipation of storm events. This proposal hinges on the understanding that lack of local sand supply makes the use of dunes for risk reduction itself risky -- though dunes have proven risk-reduction capacity, an early-season hurricane could wipe out a dune formation and a late-season hurricane could follow through that hole, threatening communities that might depend on such a dune. This danger is exacerbated by the fact that the Bolivar Peninsula lacks significant nearshore sand deposits that could be dredged to replenish damaged dunes.

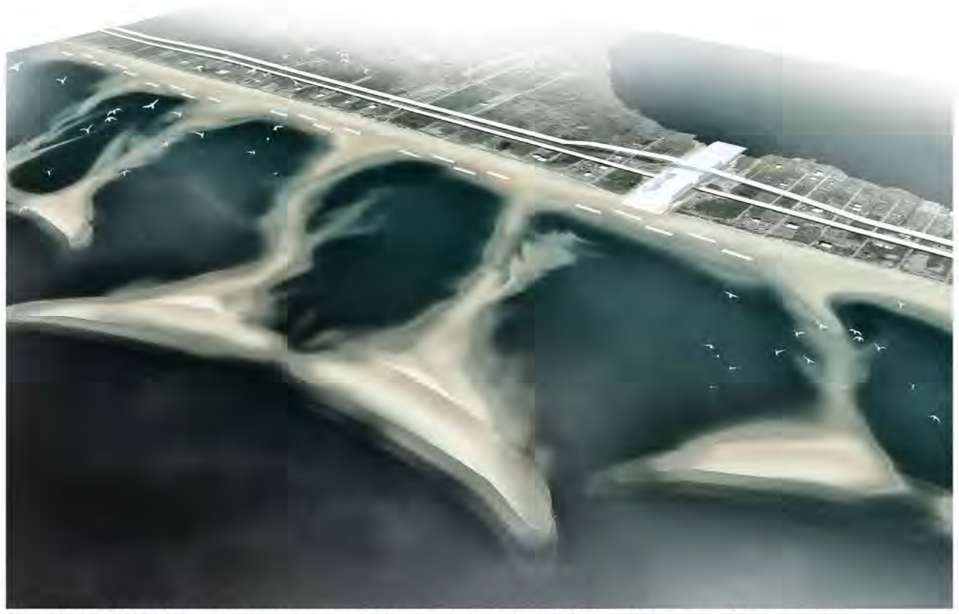
Shakya's proposal responds by proposing to pair onshore dunes with nearshore berms, which would be similar in concept to the Dutch Zandmotor. In event of a major storm, these berms could be quickly mined for sand to replenish the onshore dunes; between storm events, the berms would create habitat and be augmented with a few recreational structures, providing recreational opportunities.

Example

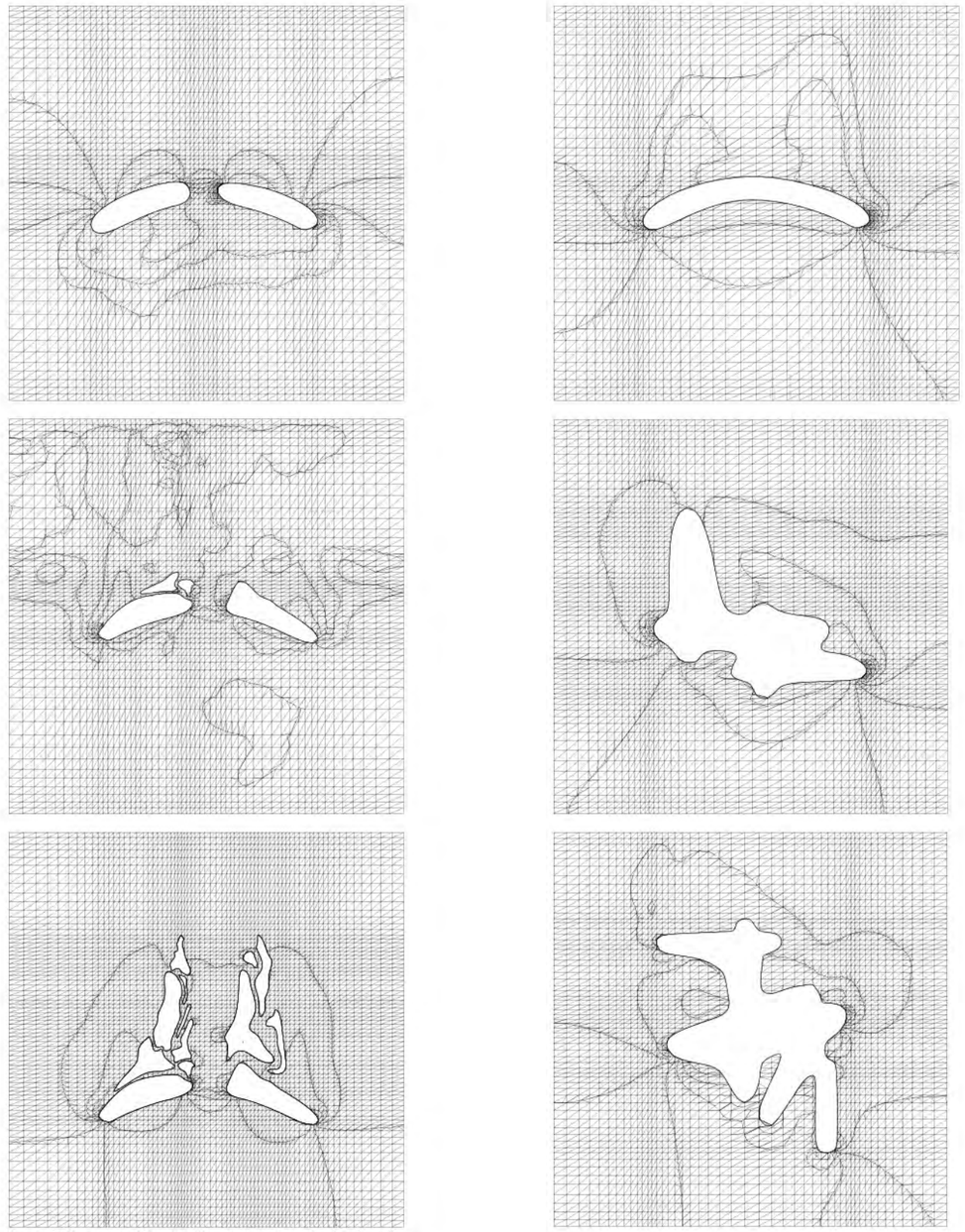
Woo Choi's project (Cornell) looks at a series of lines parallel to the coast that are intended to be built up and changed over time though currents and the application of dredged material. Complexity increases and the defenses work together and adaptively. As the stable berms and offshore islands diminish they feed the beach dune system, allowing for longer life spans and additional failure while lessening the risk explsure of homes and critical infrastructure.

Below, parallel lines are designed to work in concert over time: stable berms, offshor islands, beach dunes, and levee infrastructure.

On the opposite page simple hydrodynamic studies are used to try and find a shape for the offshore berms that can work with longshore currents and wave action to increase habitat complexity over time while still maintain some level of storm protection.

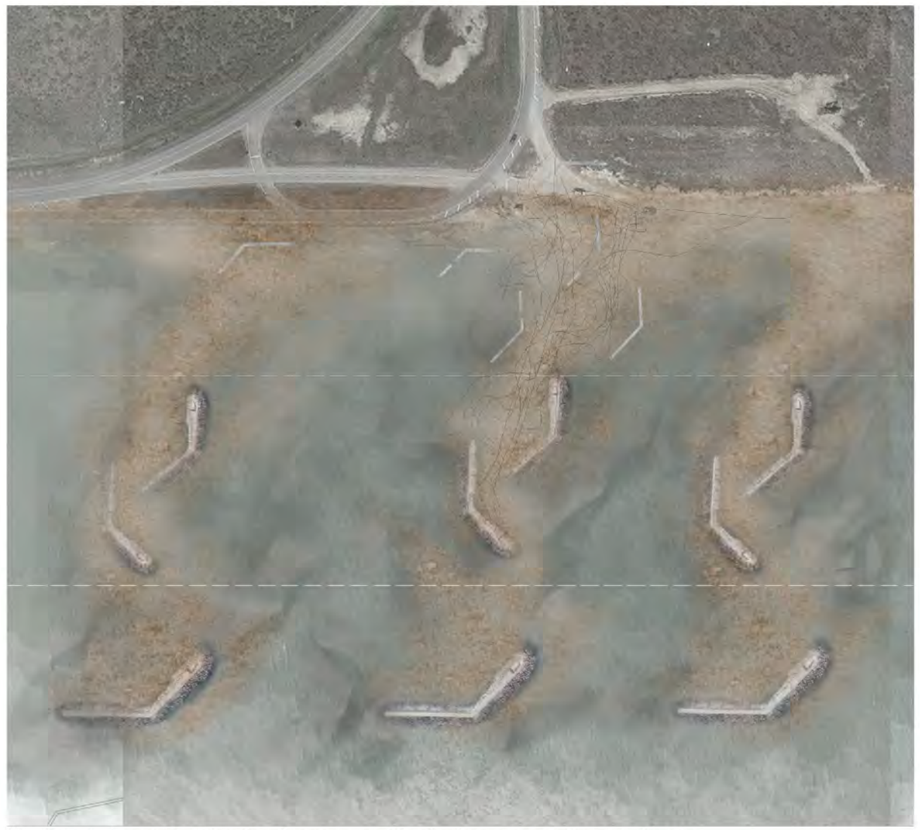


Plan view of islands and stable berms working in conjunction with beach dunes and levee system



Aerial diagram illustrating constructed islands

Example
Treavn Signorelli's project (Cornell) looked at the vulnerable Highway 87/124 intersection on the Bolivar Peninsula. This area is currently subject to erosion and the highway is the main Hurrican Evacuation route off of the Peninsula. This project proposed a series of open, partially submerged breakwaters to protect this pinch point. The intent was to make this area into a placement site for dredged material to minimize beach nourishment problems to the west and create habitat and recreational opportunities. The exact placement and size of the structures is not proposed, but the intent is to create a large, low-energy area that would offer protection and a safe transition between the erosive environment to the east and the critical highway corridor to the east. This would also create differences in habitat and beach to the east and west, creating a more varied condition for habitat and recreation.

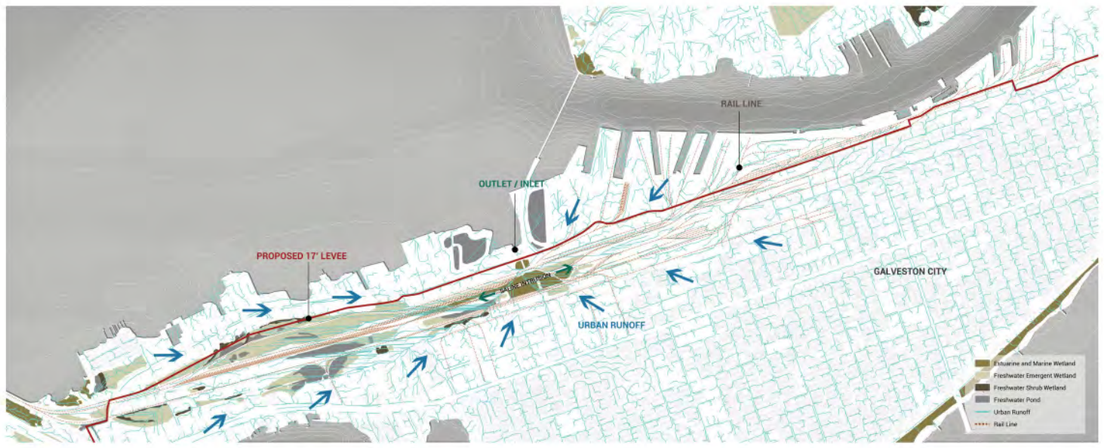


Illustrated plan view of low breakwaters and feeder berms on Bolivar Peninsula

5 VARY APPLICATION OF STRATEGIES TO RESPOND TO SITE SPECIFICITY

Principle
When an infrastructure like a levee is deployed across a big and diverse region like Galveston Bay, it should be modified at key cultural and ecological sites to respond to the differing ways those sites relate to the region.

Example
Yuna Gao's project, described in more detail under principle 3, takes a singular infrastructure, a levee, and modifies its deployment to respond to the existing conditions it encounters along its length. It becomes wide and ecologically-integrated in its western extents, where it runs through low-lying marshes. To the east, it becomes narrow, harder, and more intensively-programmed for recreational use where it runs through the urban fabric of Galveston.

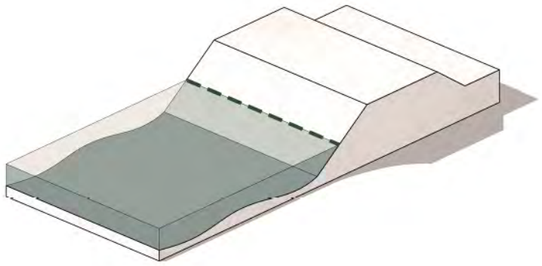


Plan view showing the response of the level to local environmental and social conditions.

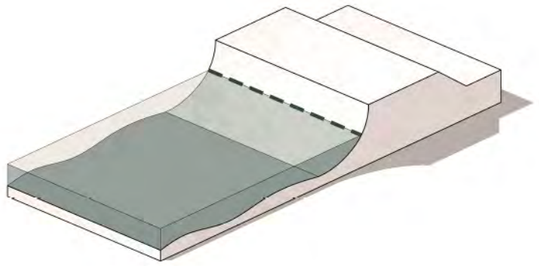
3' ELEVATED TRAIL

RAILROAD TRAIL

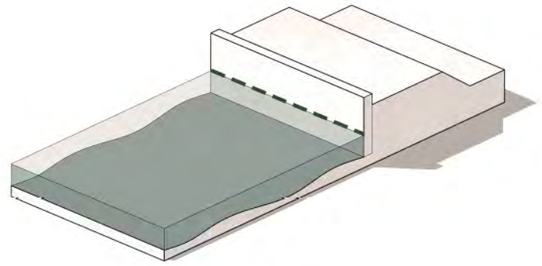
TYPICAL LEVEE



rubble-mound

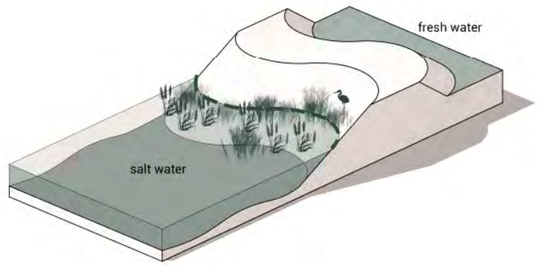


curved



vertical

LEVEE FOR ECOLOGY



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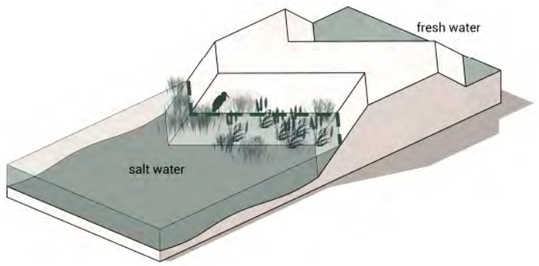
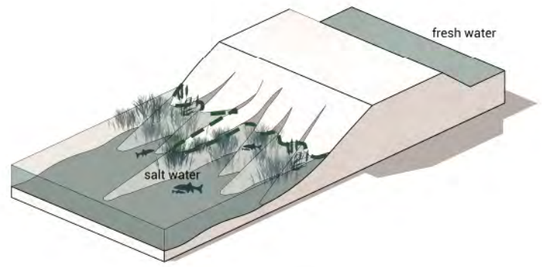
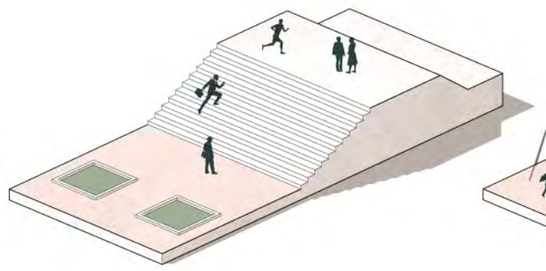


zigzag

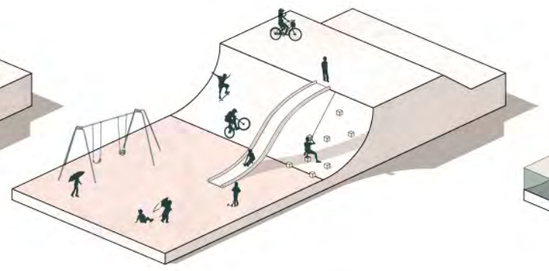


irregular boundary

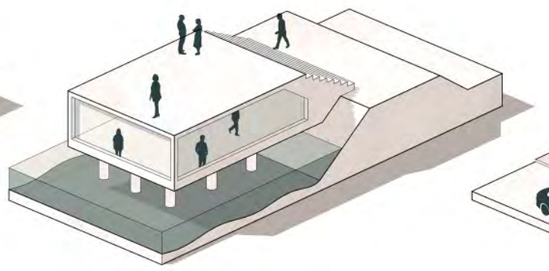
LEVEE FOR PEOPLE



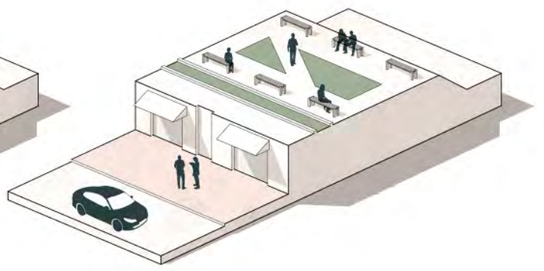
accessible



recreation



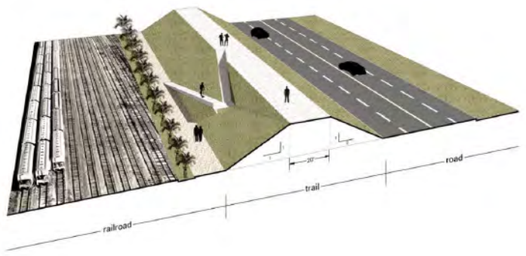
viewing point



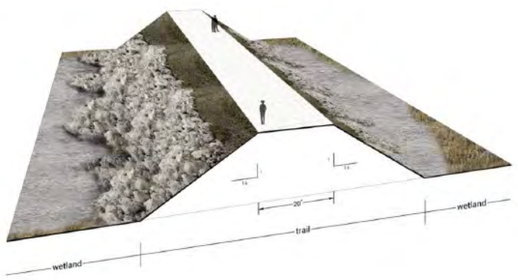
integrate with the city

RECREATION

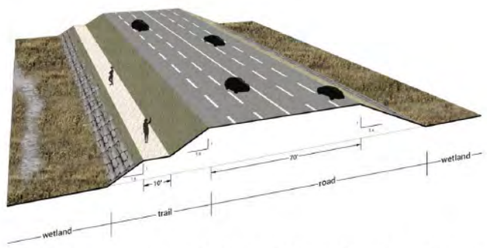
TRAIL



WETLAND



ROAD



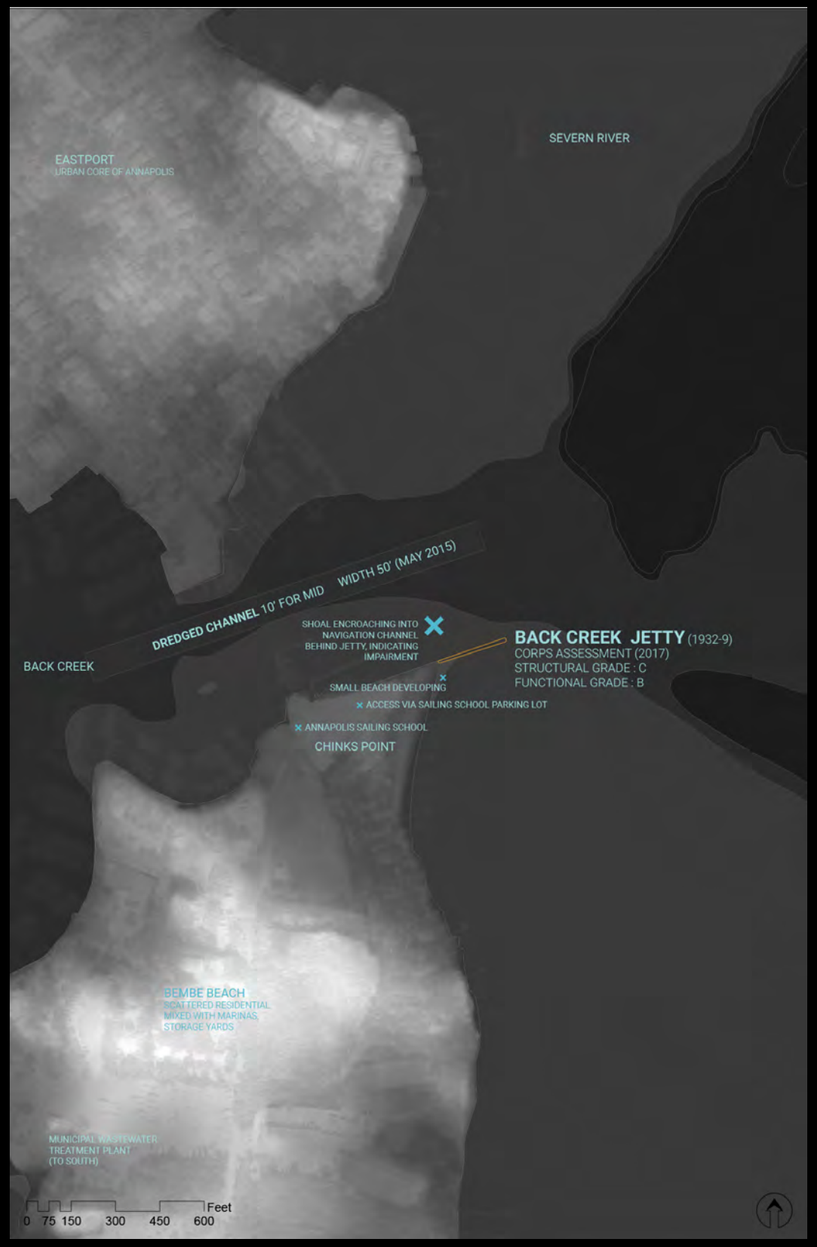
Axonometric diagrams illustrating different levee conditions

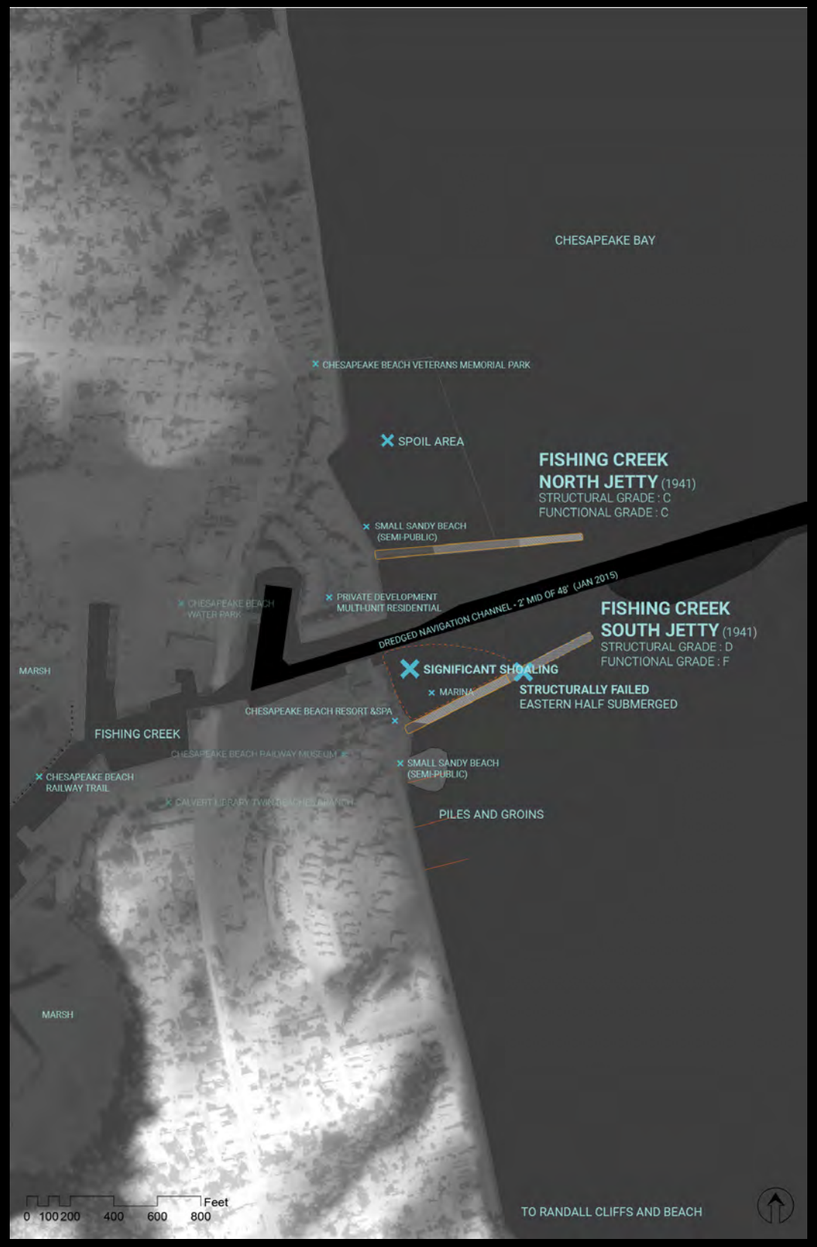
Aerial perspectives illustrating levee and surrounding new functions.


BEYOND BARRIERS

EWN+ INFRASTRUCTURE PROJECTS 2018-2019

[Drawings: DRC]





EWN+ INFRASTRUCTURE PROJECTS 2018-2019

Collaboration between Engineering with Nature and Landscape Architects

12 Dec 2018
9th National Summit on Coastal and Estuarine Restoration and Management
Long Beach, California

Rob Holmes
Assistant Professor, Auburn University
Member, Dredge Research Collaborative
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