COASTAL SURGE PROTECTION:

Galveston Bay Park Plan

City of Houston TTI Committee SSPEED Center

SSPEED Center
Severe Storm Prediction, Education, & Evacuation from Disasters Center

Agenda:

- Introductions
- Overview of Study and ADCIRC Modeling
  Jim Blackburn, SSPEED Center
- Conceptual Plan for Galveston Bay Park
  Rob Rogers, Rogers Partners
- Overview of Gate Design
  Melanie Galantino, Walter P. Moore Engineers
- Discussion

INTRODUCTION

GBPP Study for Stakeholders

(City of Houston, Harris County, Port of Houston Authority and Joe Swinbank)

Purpose:

- To document the feasibility of the Galveston Bay Park Plan (GBPP) and address questions previously raised in order to determine whether to proceed to next steps

Assumption:

- Designed to be compatible with coastal barrier

Questions:

- Need for the GBPP
- Cost of the GBPP
- Benefits of the GBPP
- Preliminary environmental Impacts (e.g. Oysters, Salinity)

Activities:

- Surge modeling of GBPP w/ and w/out Coastal Barrier
- Expanded conceptual design of GBPP, incl HSC Gate
- Refine cost estimates of GBPP and its benefits
- Evaluate potential impacts on Oysters and bay salinity
- Conduct public outreach to solicit comments

INTRODUCTION

GBPP Study Team

- **SSPEED Center/Rice University** – Management and Modeling
- **Rogers Partners** – Planning and Design
- **Walter P Moore / Martinez Moore / Cibor, Inc.** – Engineering
- **University of Texas at Austin** – Modeling
- **Matagorda Bay Foundation** – Oysters
- **Outreach Strategists, LLC** – Public Outreach
- **Blackburn Carter Law Firm** – Legal Analysis
- **Bryan French, Attorney** – Legal Analysis
- **Blake Eskew** – Economic Analysis

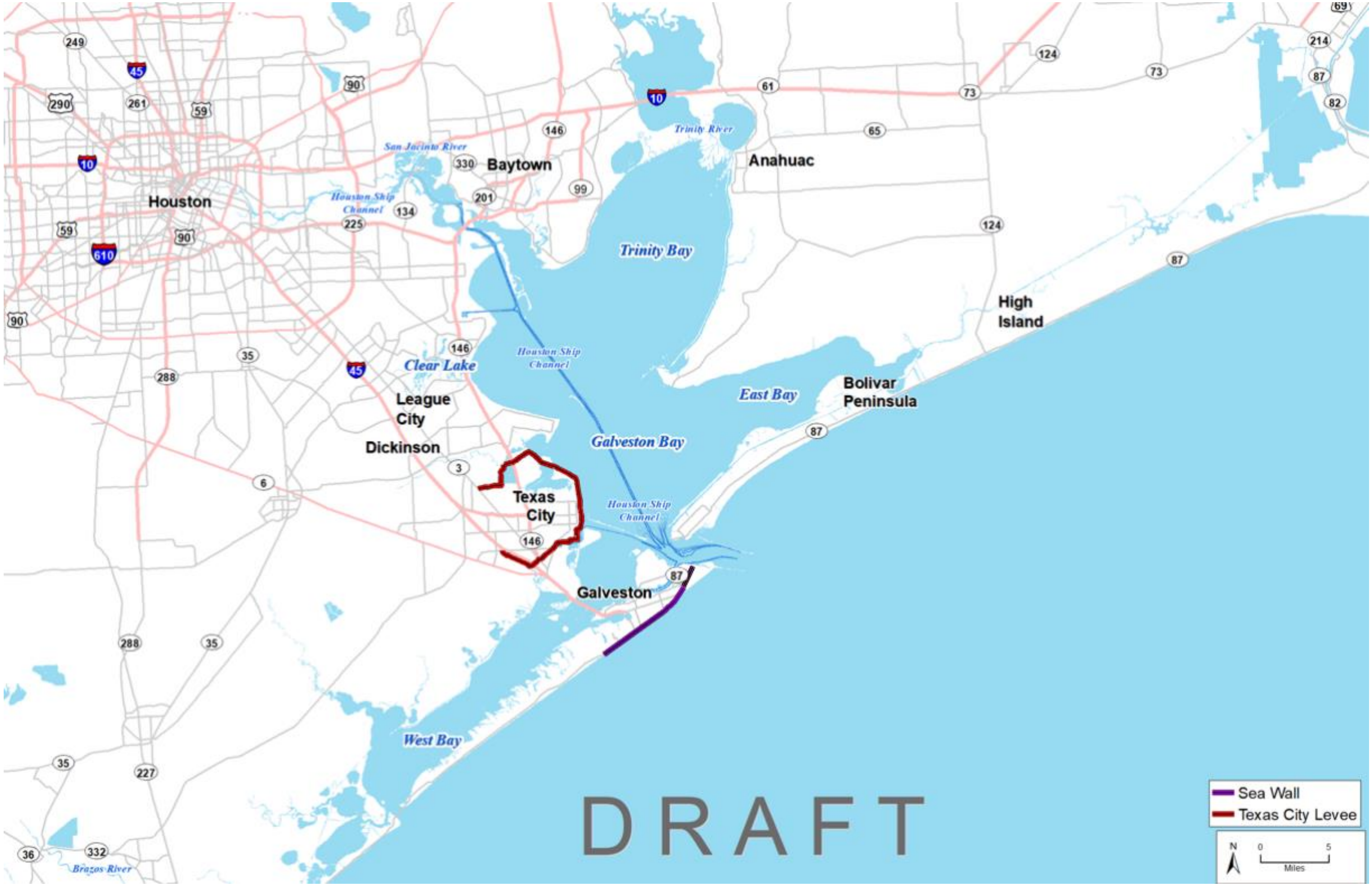
M O D E L I N G

ADCIRC Modeling of Coastal Surge Protection: Galveston Bay Park Plan

SSPEED Center

Severe Storm Prediction, Education, & Evacuation from Disasters Center

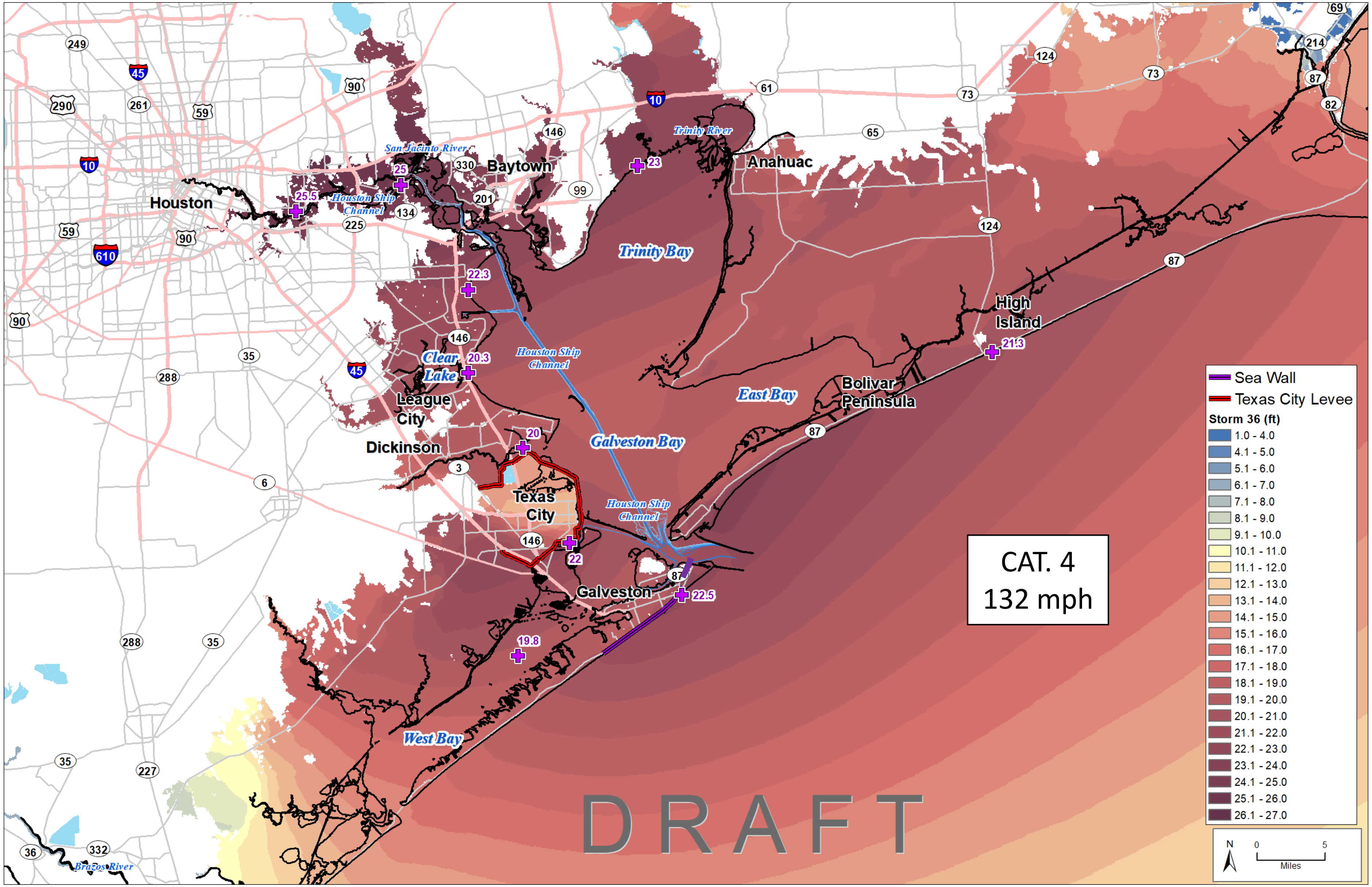
BASE MAP – EXISTING



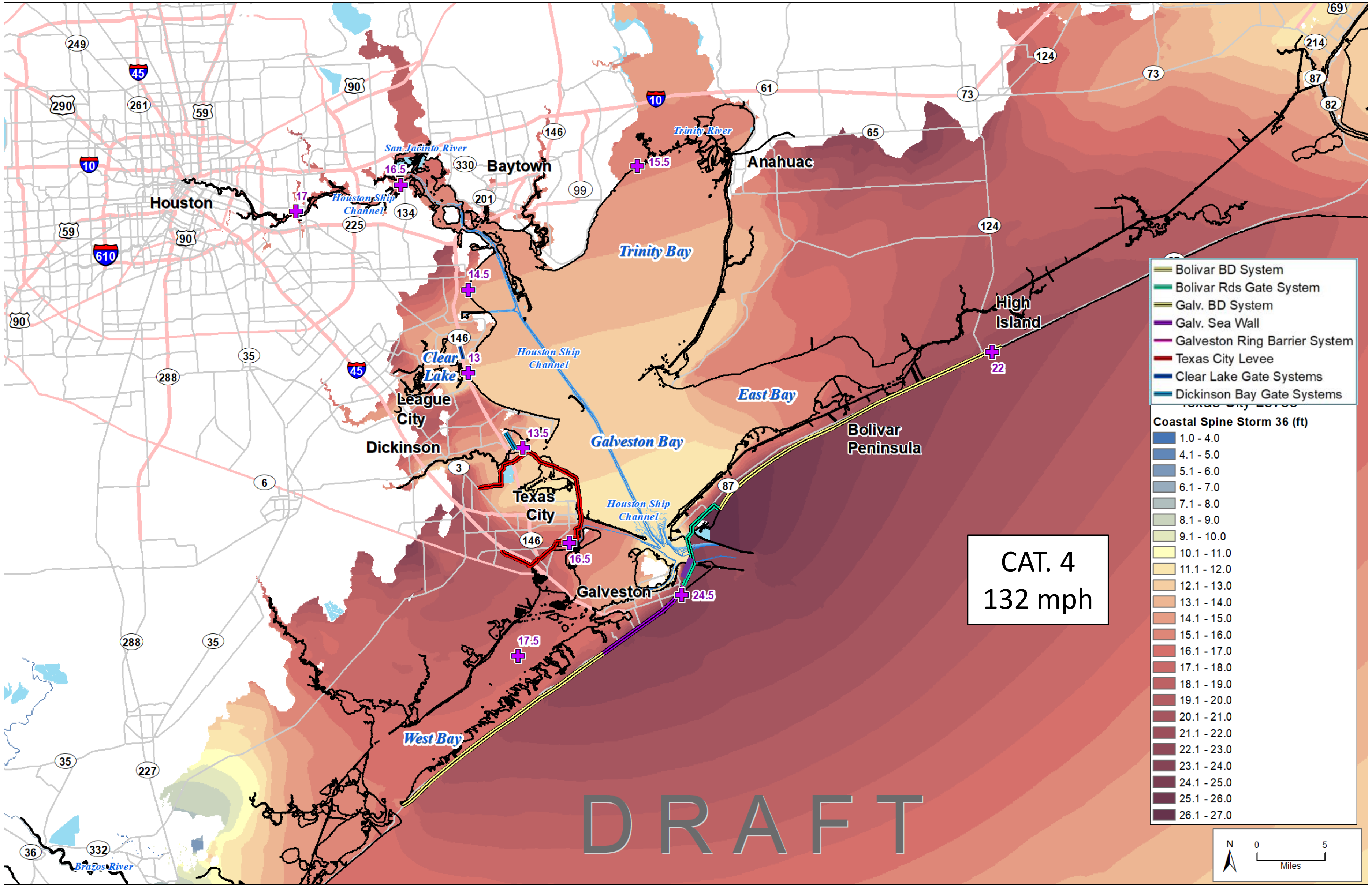
BASE MAP – EXISTING + COASTAL BARRIER

BASE MAP – EXISITNG + COASTAL BARRIER + GBPP

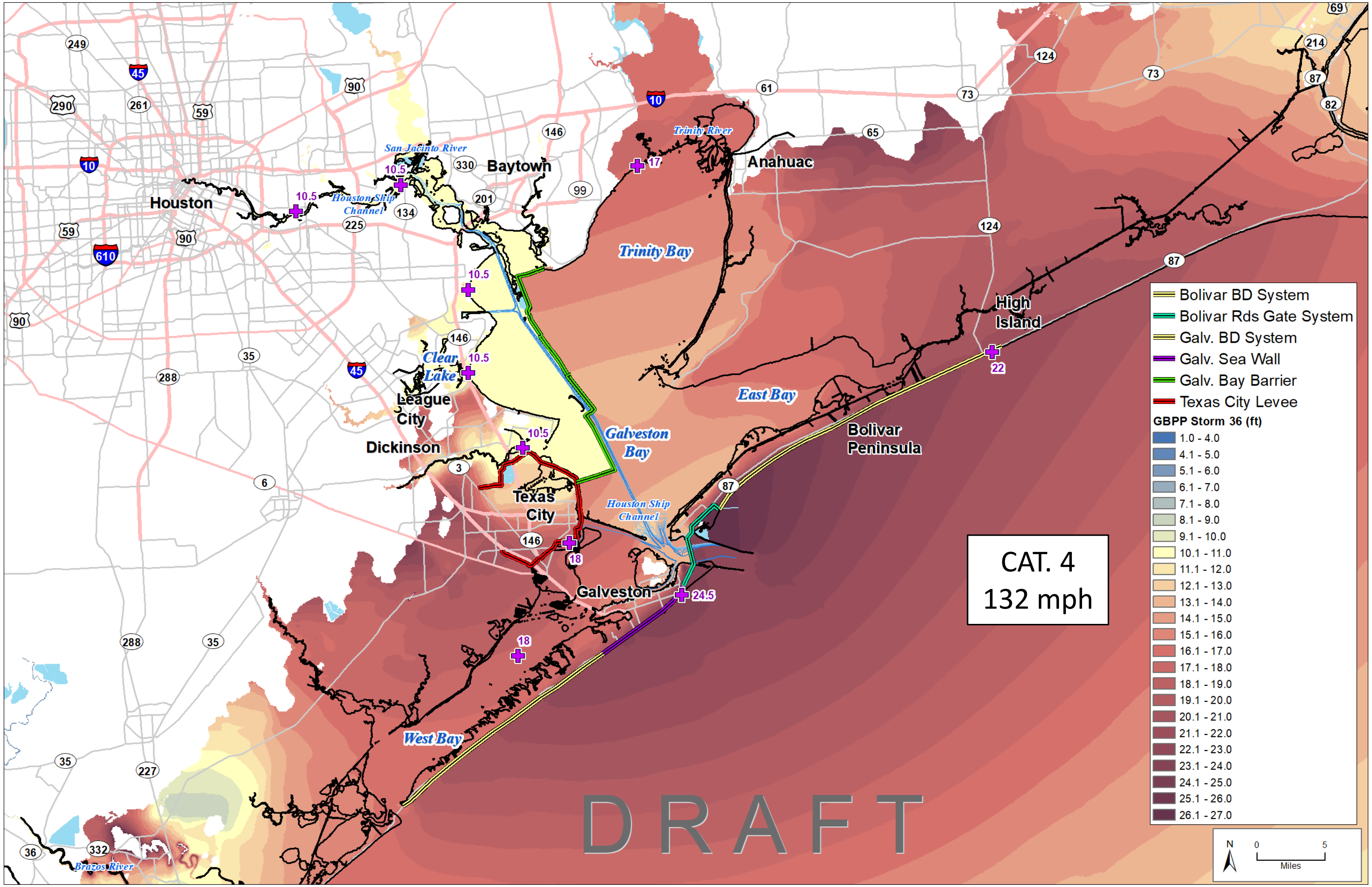
MAXIMUM STORM SURGE LEVELS - EXISTING



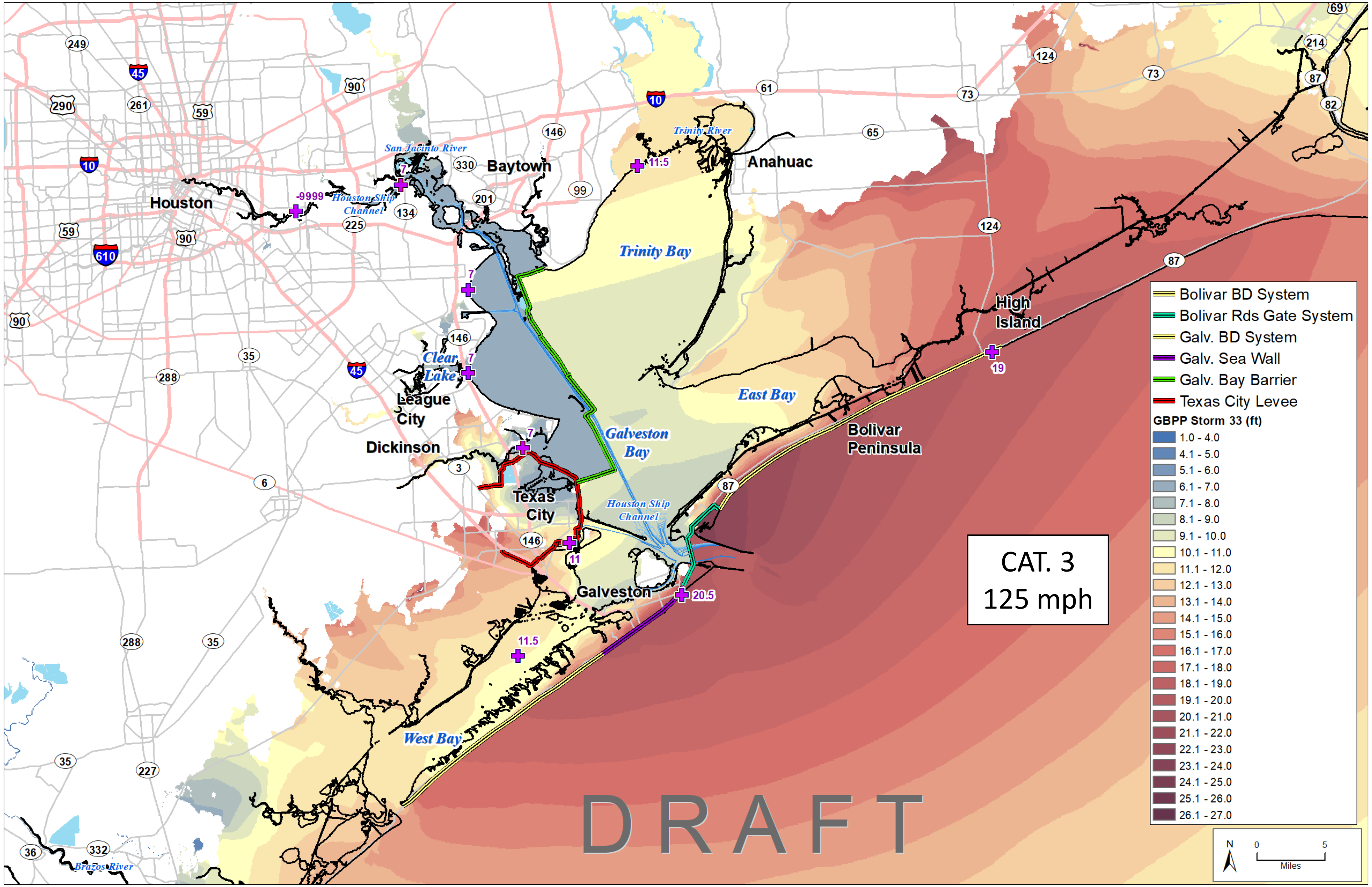
MAXIMUM STORM SURGE LEVELS – EXISTING + COASTAL BARRIER



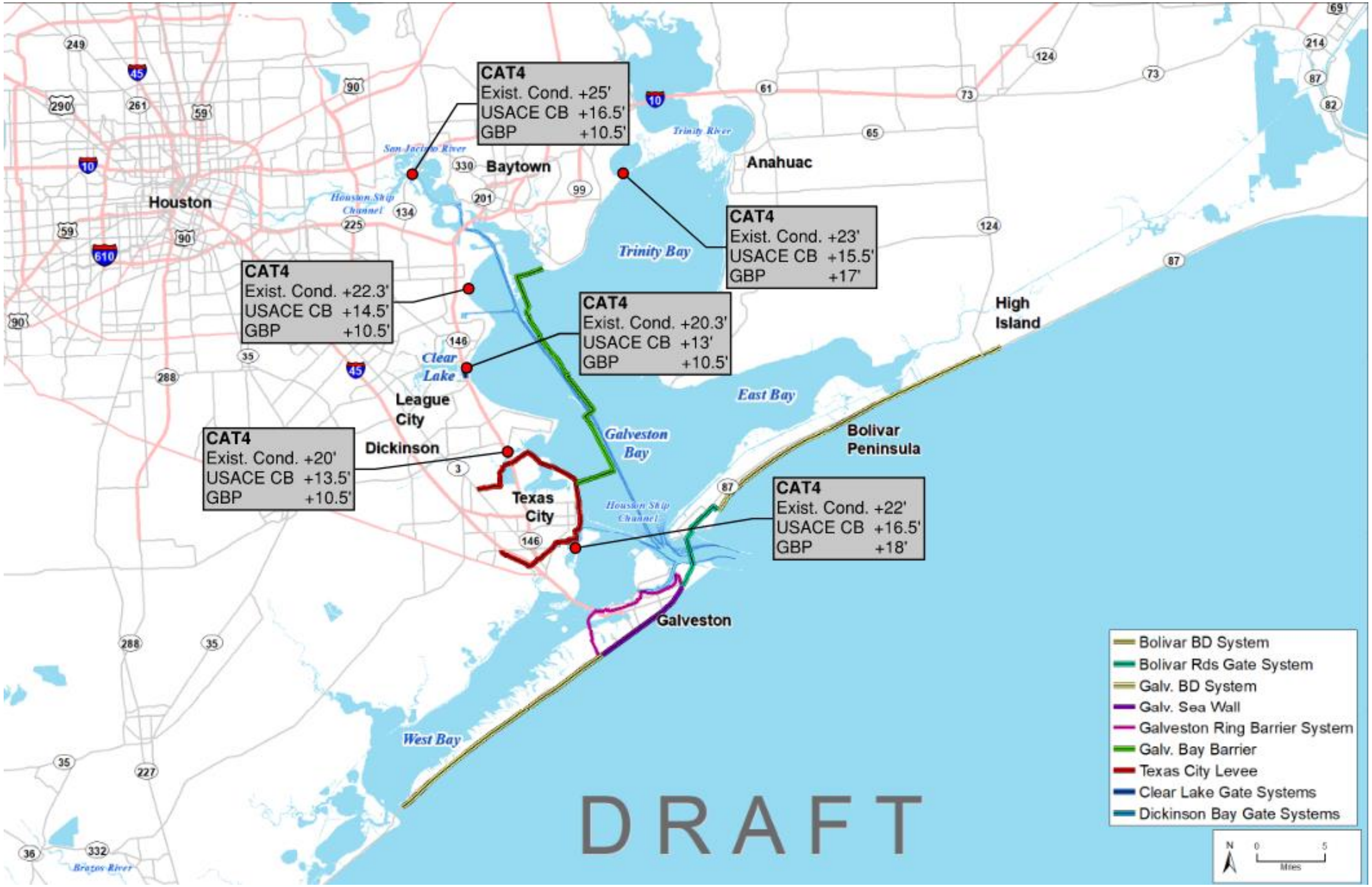
MAXIMUM STORM SURGE LEVELS – EXISTING + COASTAL BARRIER + GBPP



MAXIMUM STORM SURGE LEVELS – EXISTING + COASTAL BARRIER + GBPP



COMPARISON OF MAX. SURGE LEVELS AT KEY LOCATIONS




Galveston Bay Park
ROGERSPARTNERS
Architects+Urban Designers

MAPS

Ship Channel

Legend

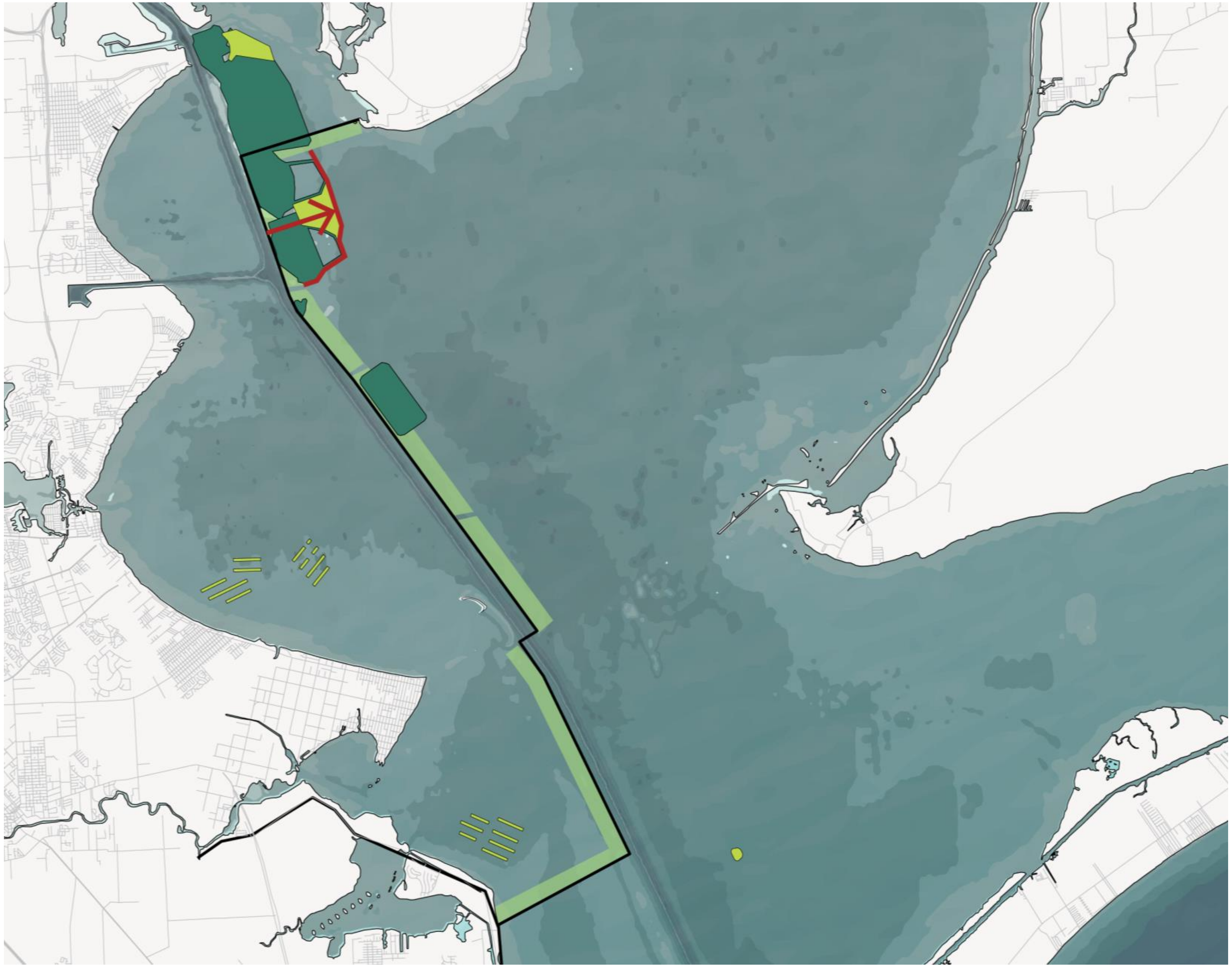
- Ship Channel
- Line of Protection
- Land Form

MAPS

Existing Land

Legend

- Existing Islands
- Project 11 Deposit Sites
- Potential Additional Deposit Sites

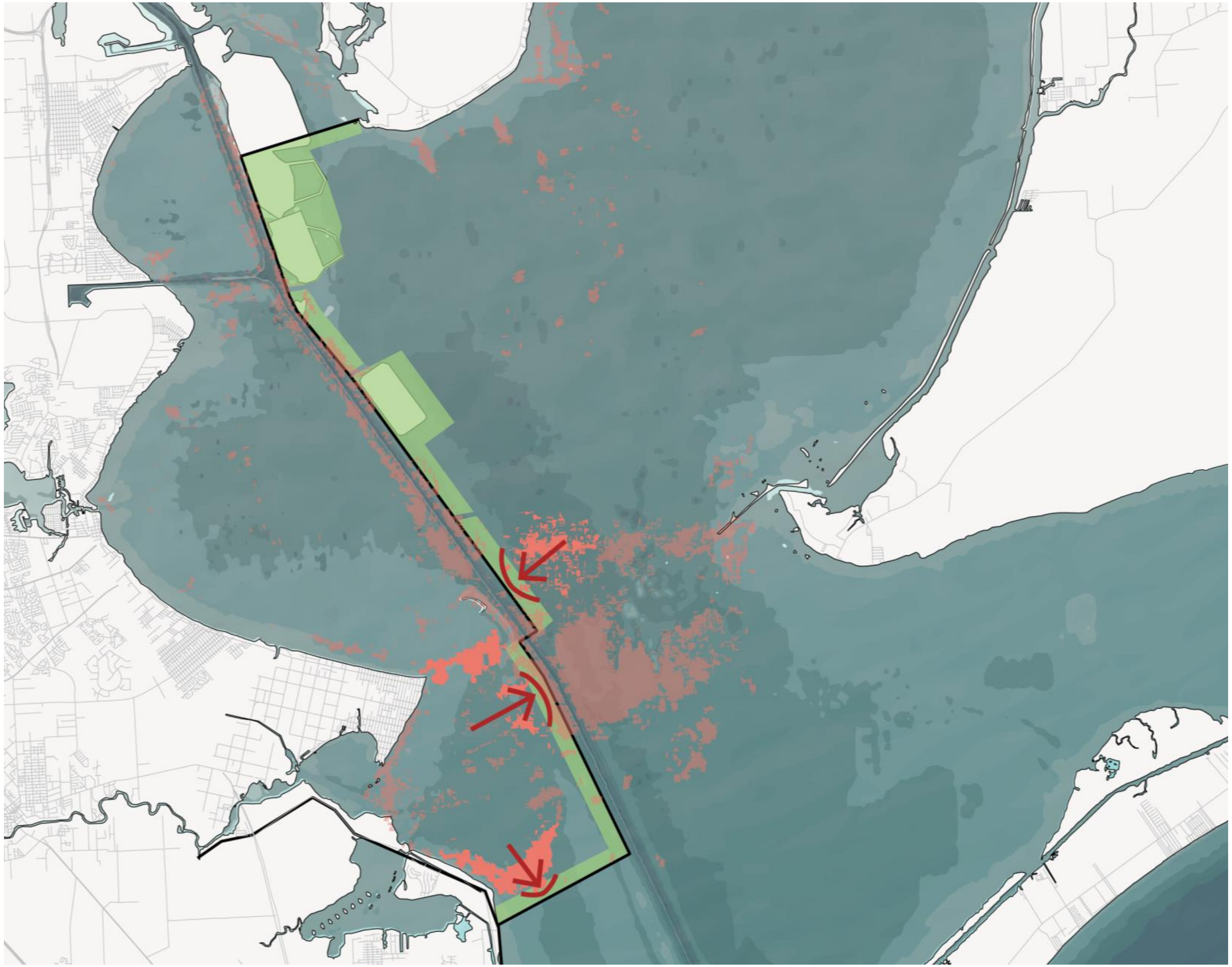


MAPS

Oyster Reefs

Legend

Oyster Reefs



MAPS

Wells and Pipelines

Legend

Wells

Pipelines

MAPS

Small Craft Navigation

MAPS

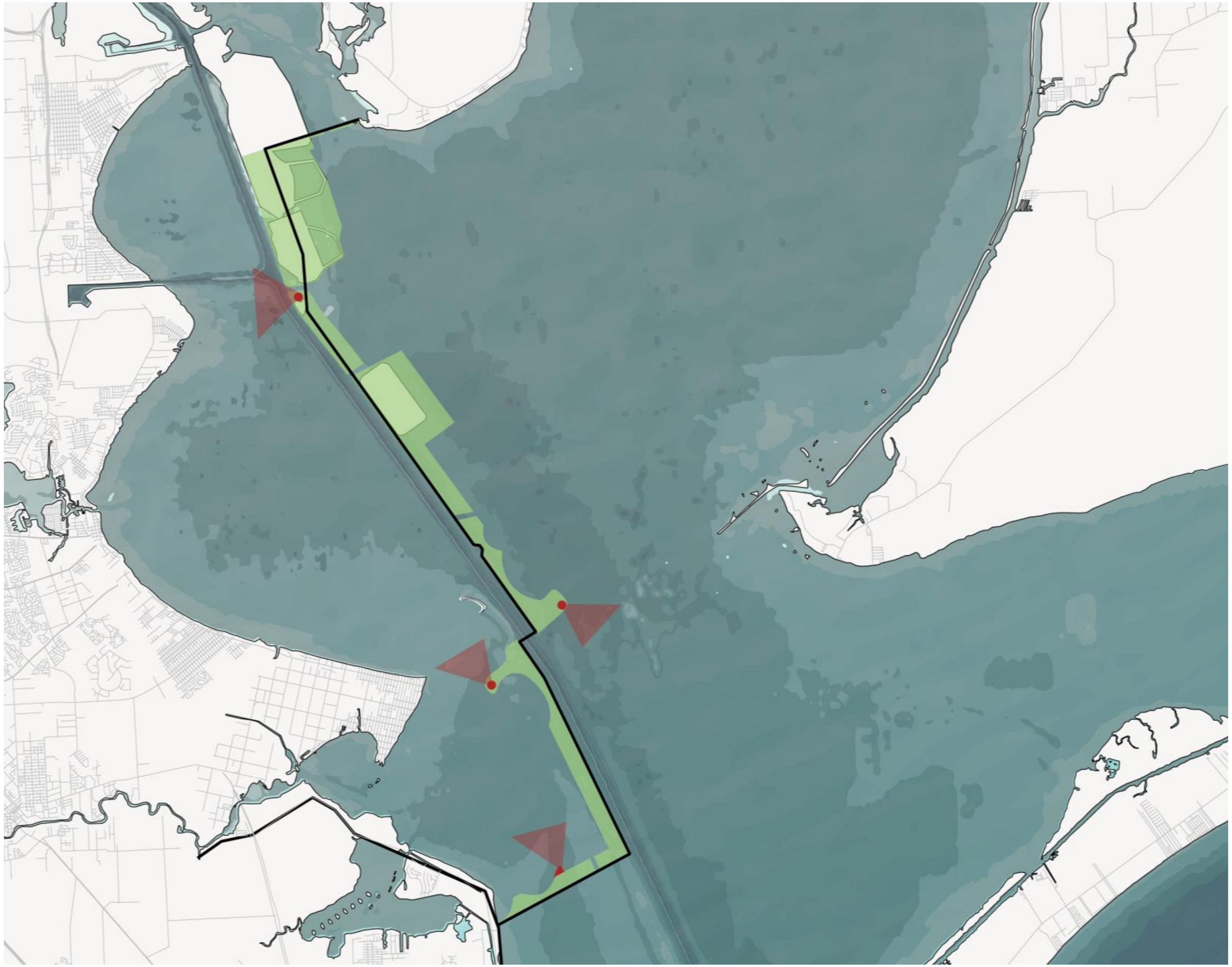
Land Form Distribution

MAPS

Scenic Overlooks

Legend

Viewpoint



MAPS

Water Circulation

Legend

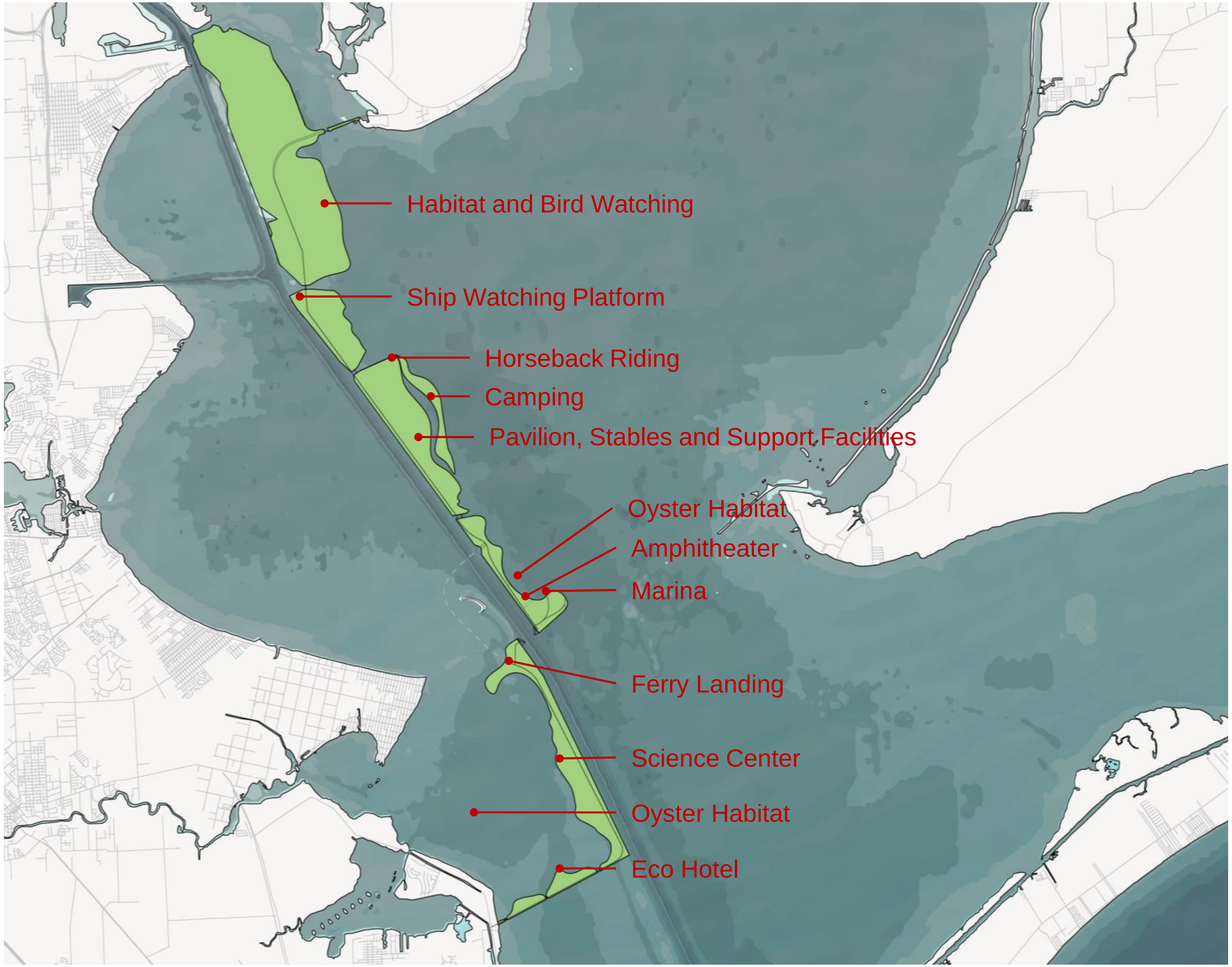
Water Circulation Through Islands

MAPS

Program

Land Mass (in acres)

Existing:	4,373	*47%*
Project 11:	613	*7%*
GBP:	4,271	*46%*
Total:	9,258	



MAPS

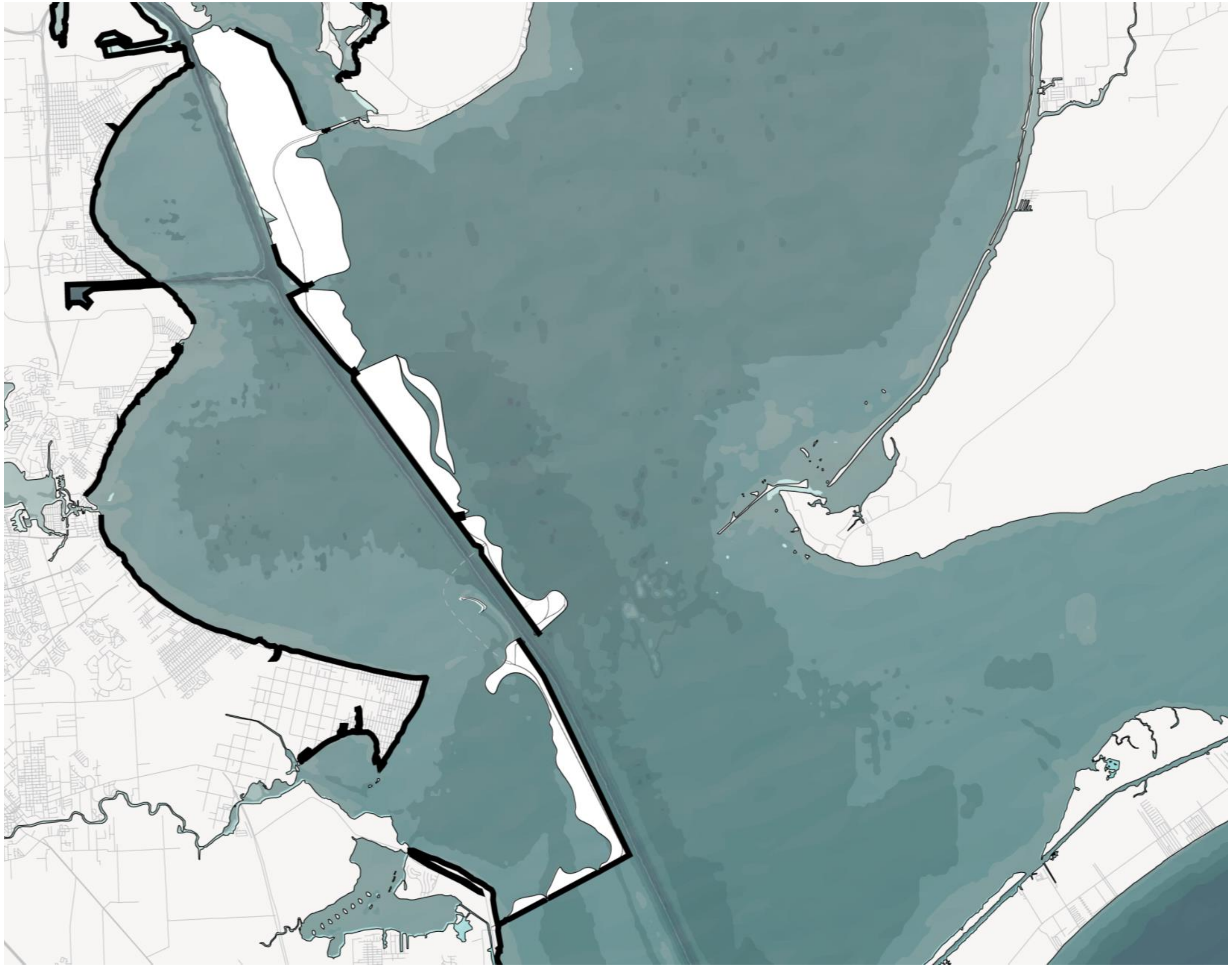
Regional Plan

MAPS

Shoreline

Legend

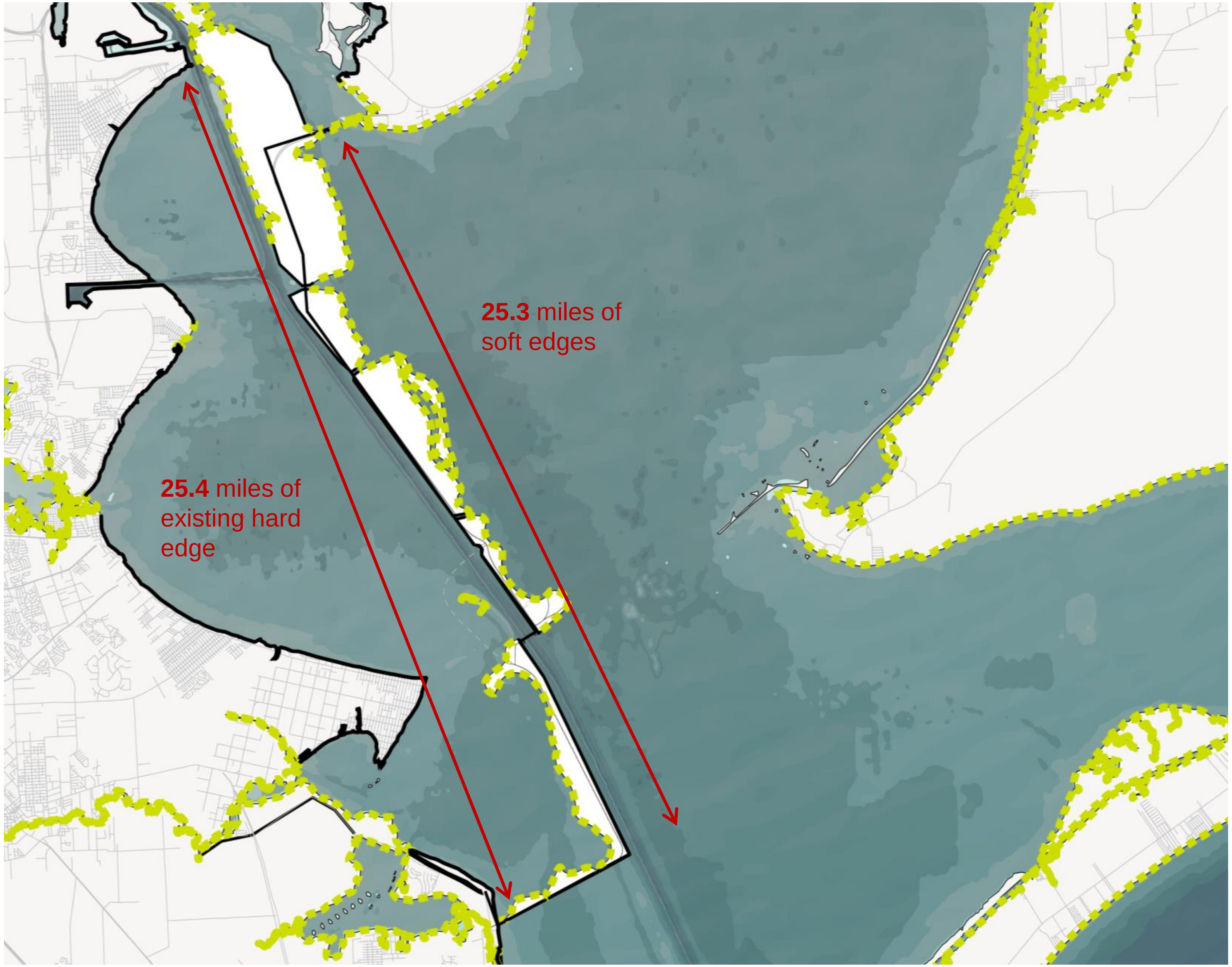
Hard Edge



MAPS

Shoreline

Legend



Hard Edge

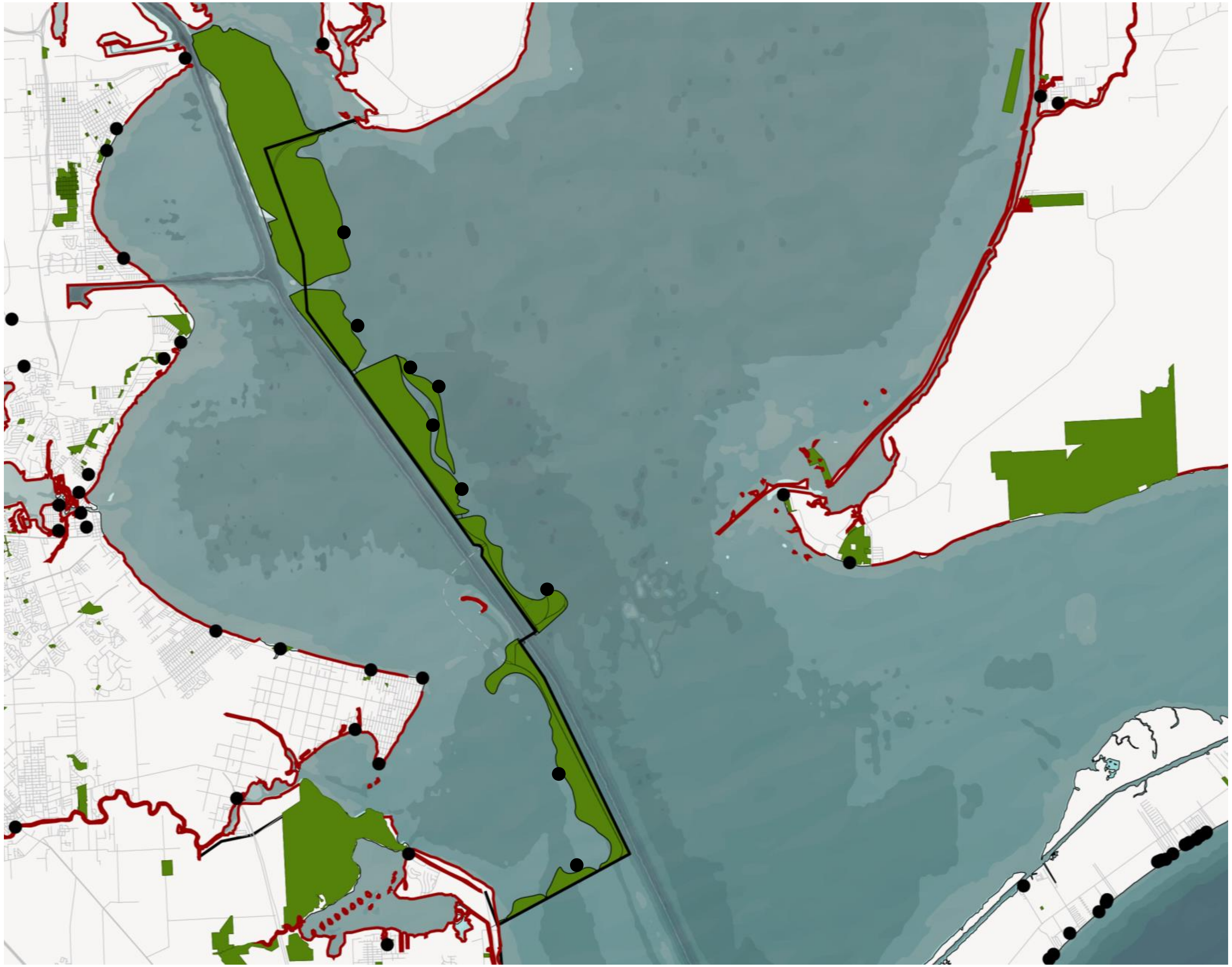
Soft Edge

MAPS

Public Access

Legend

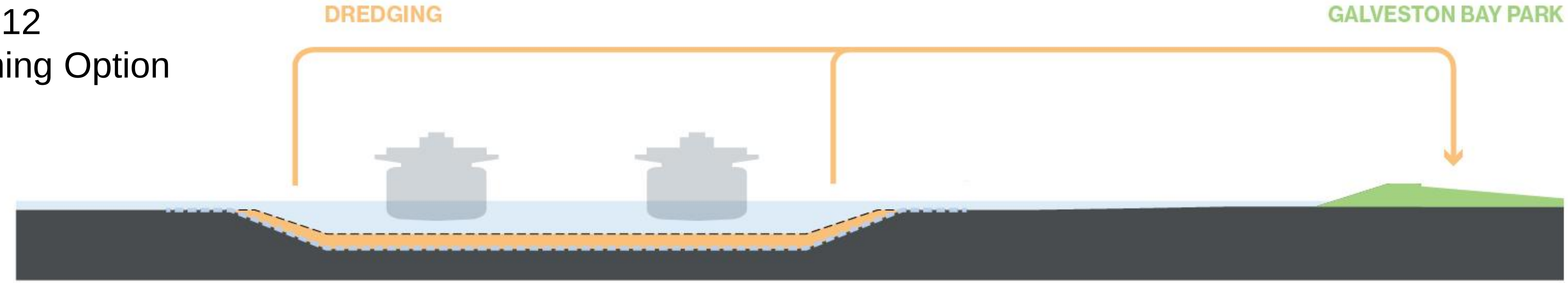
- Private Coast
- Full Public Access
- Boat Docks open to the Public



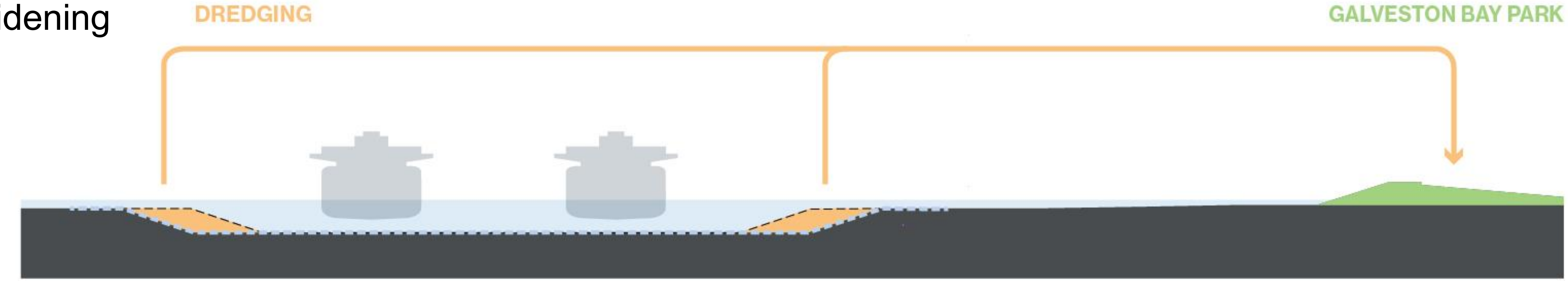
DIAGRAMS

Dredging

Project 12
Deepening Option

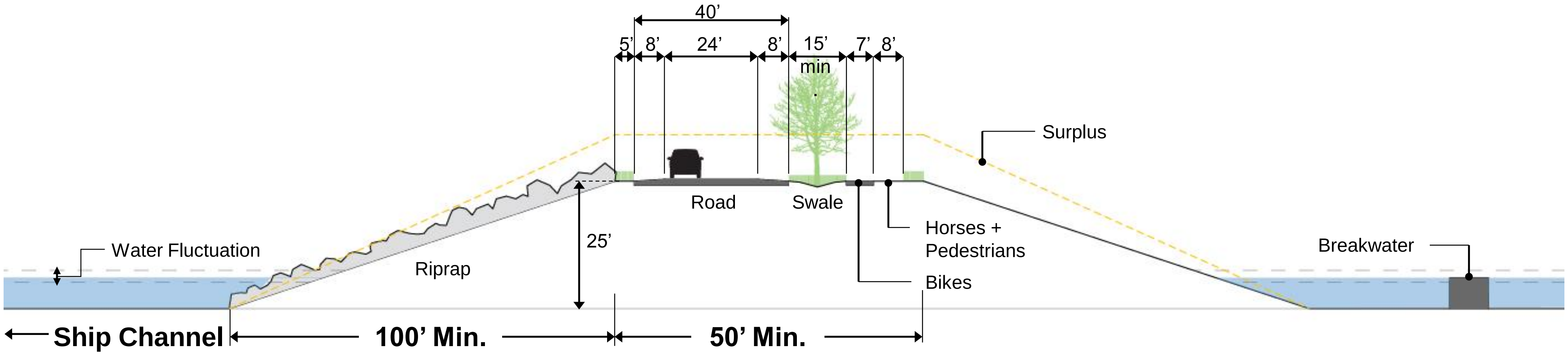


900’ Widening
Option



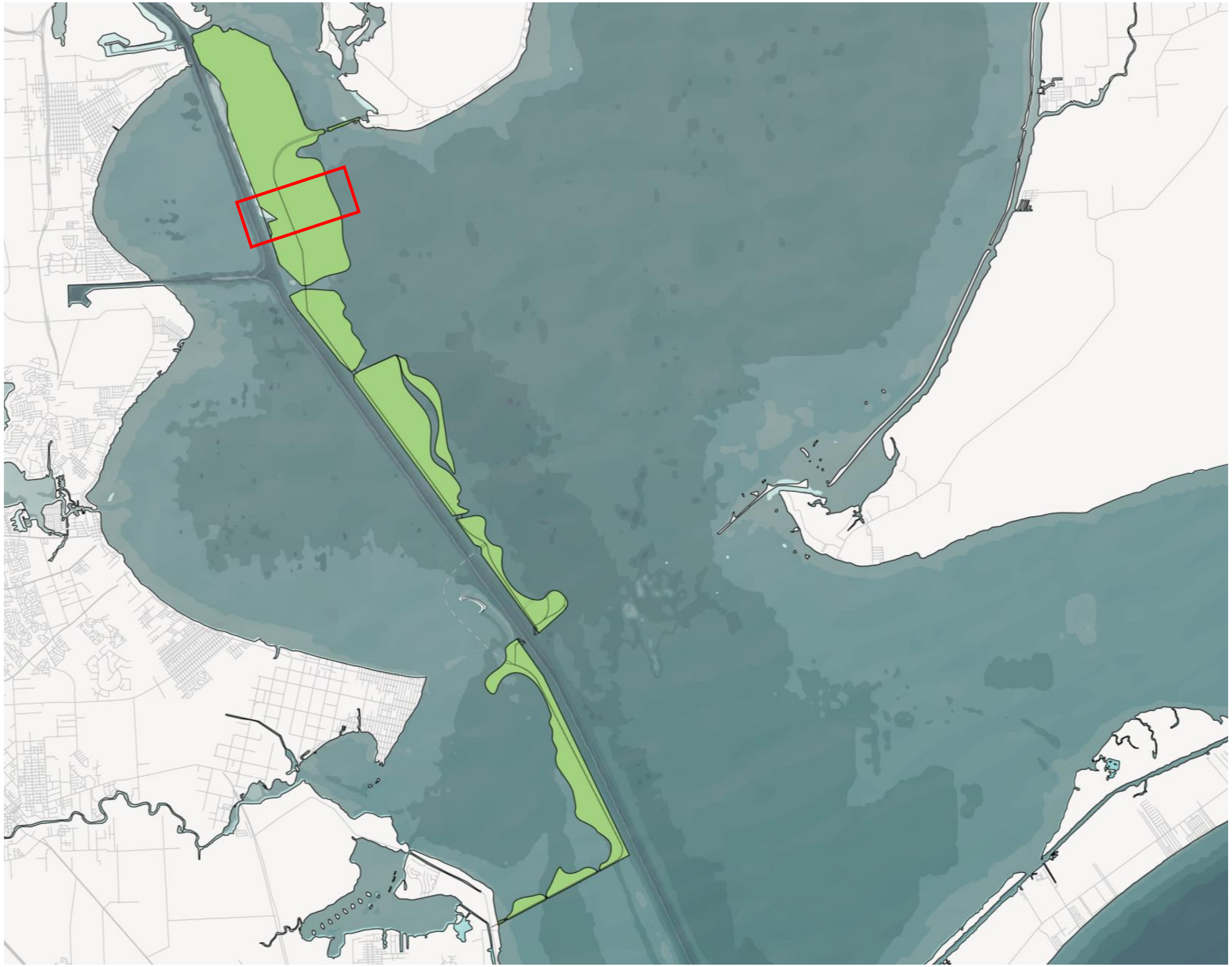
DIAGRAMS

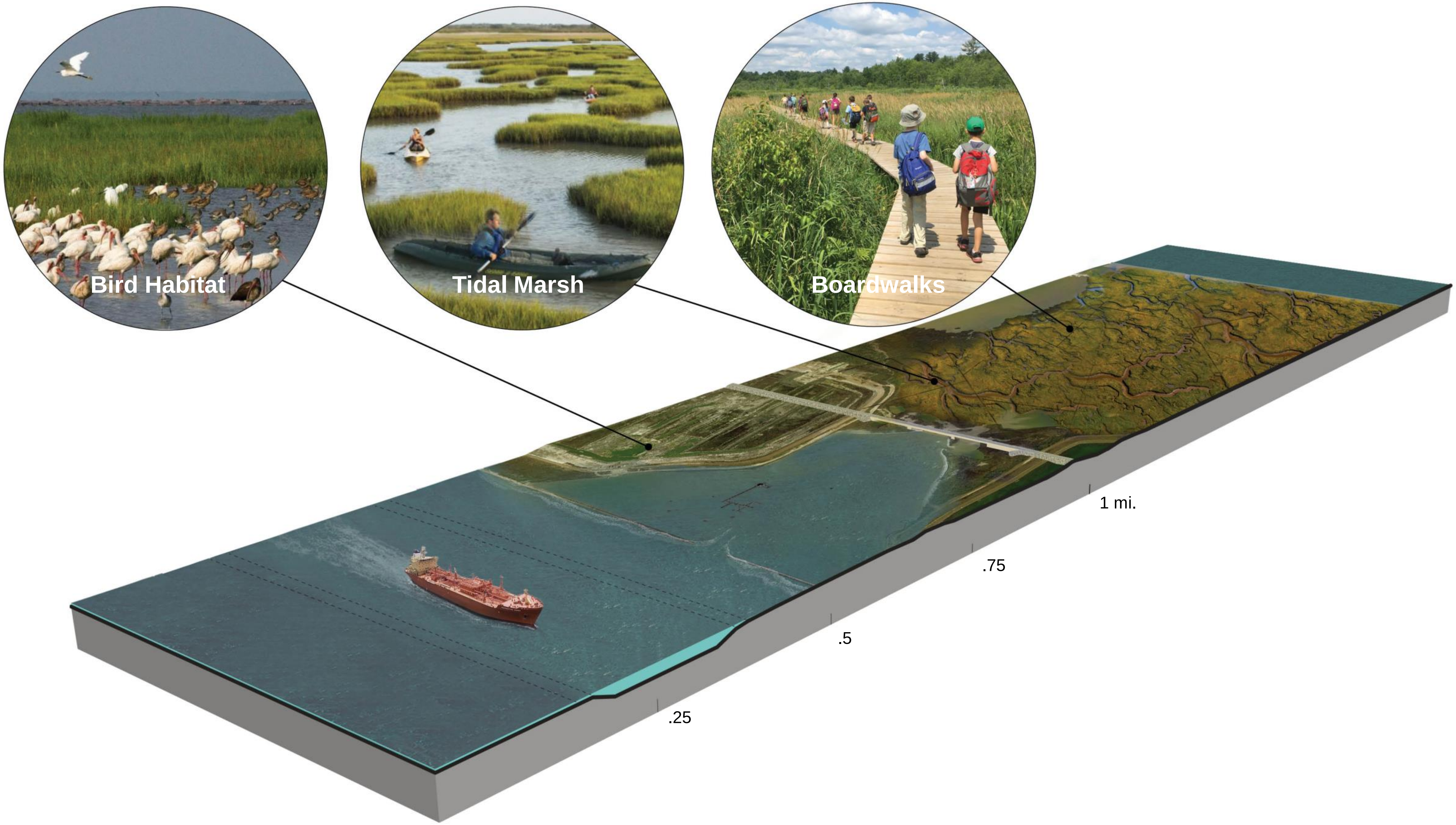
Road Section



KEY PLAN

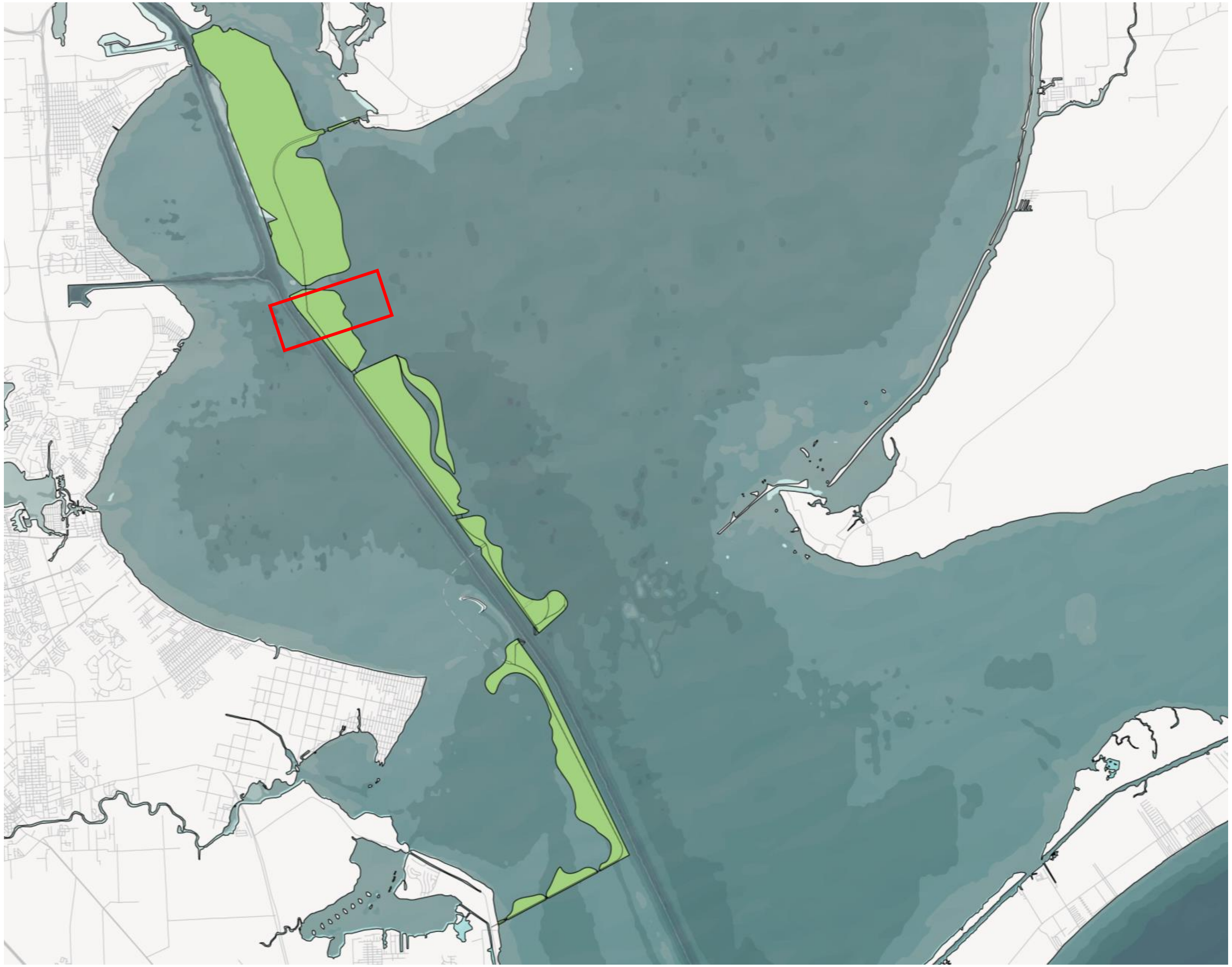
Habitat Creation

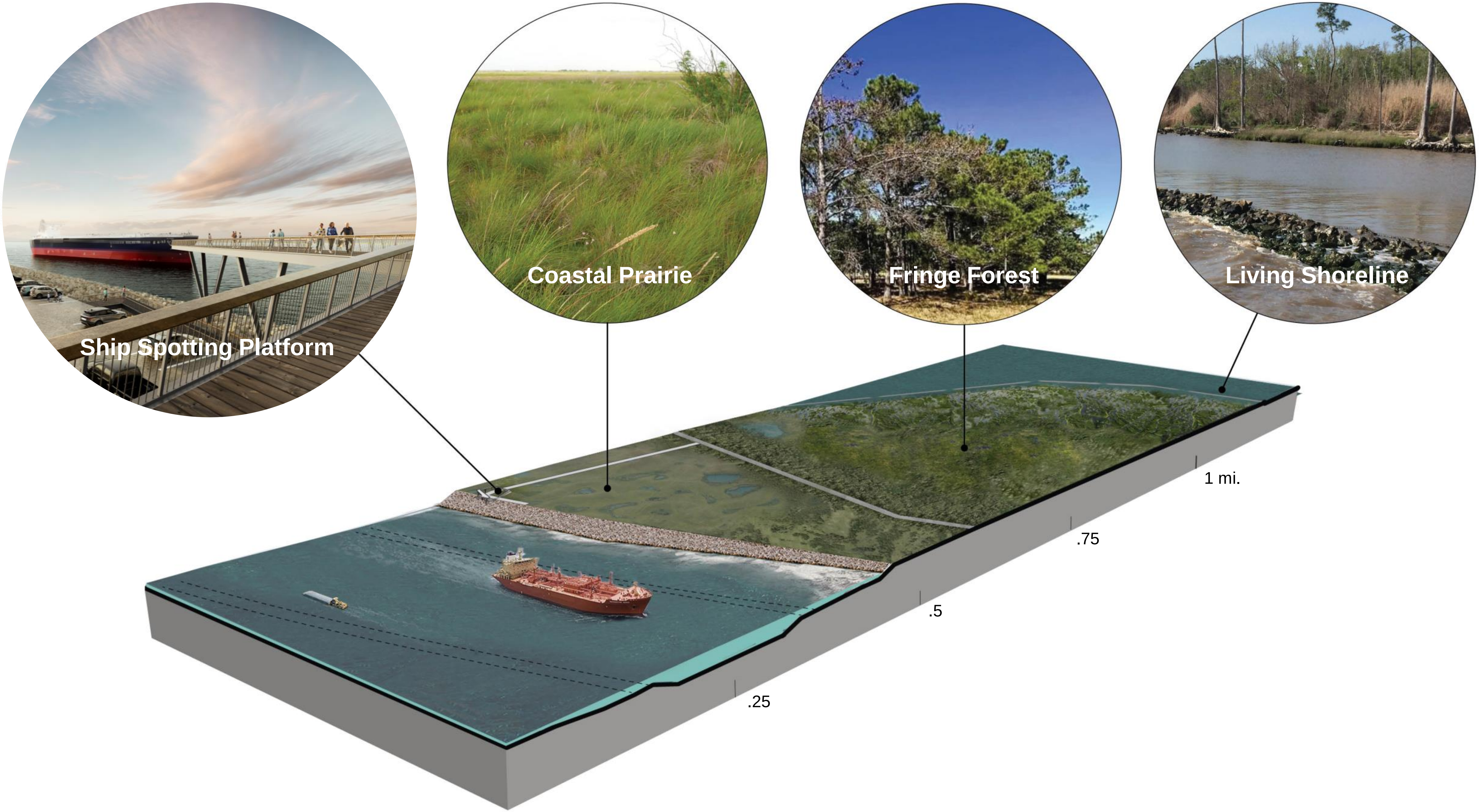



Bird Habitat
Tidal Marsh
Boardwalks
.25
.5
.75
1 mi.

KEY PLAN

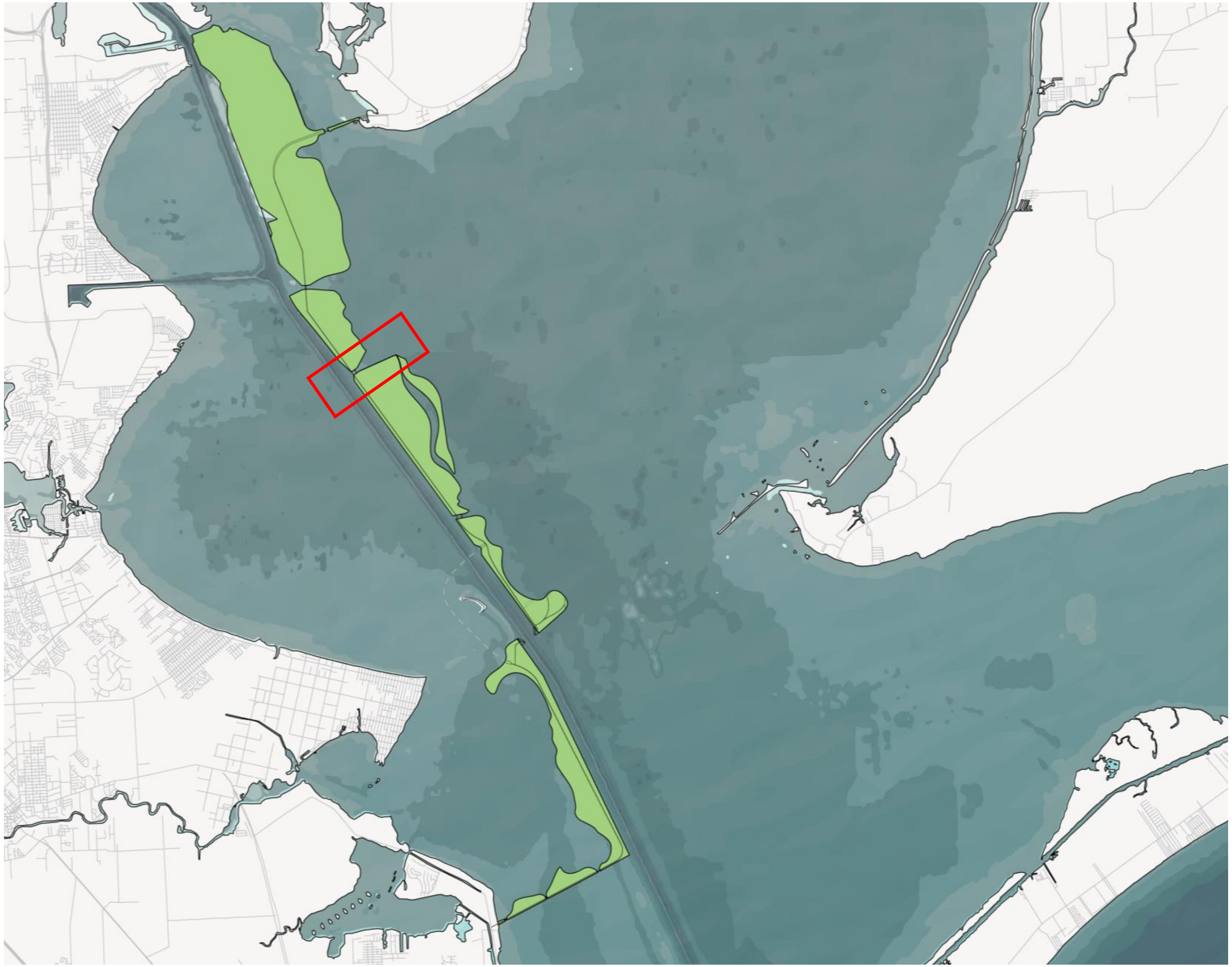
Ship Spotting

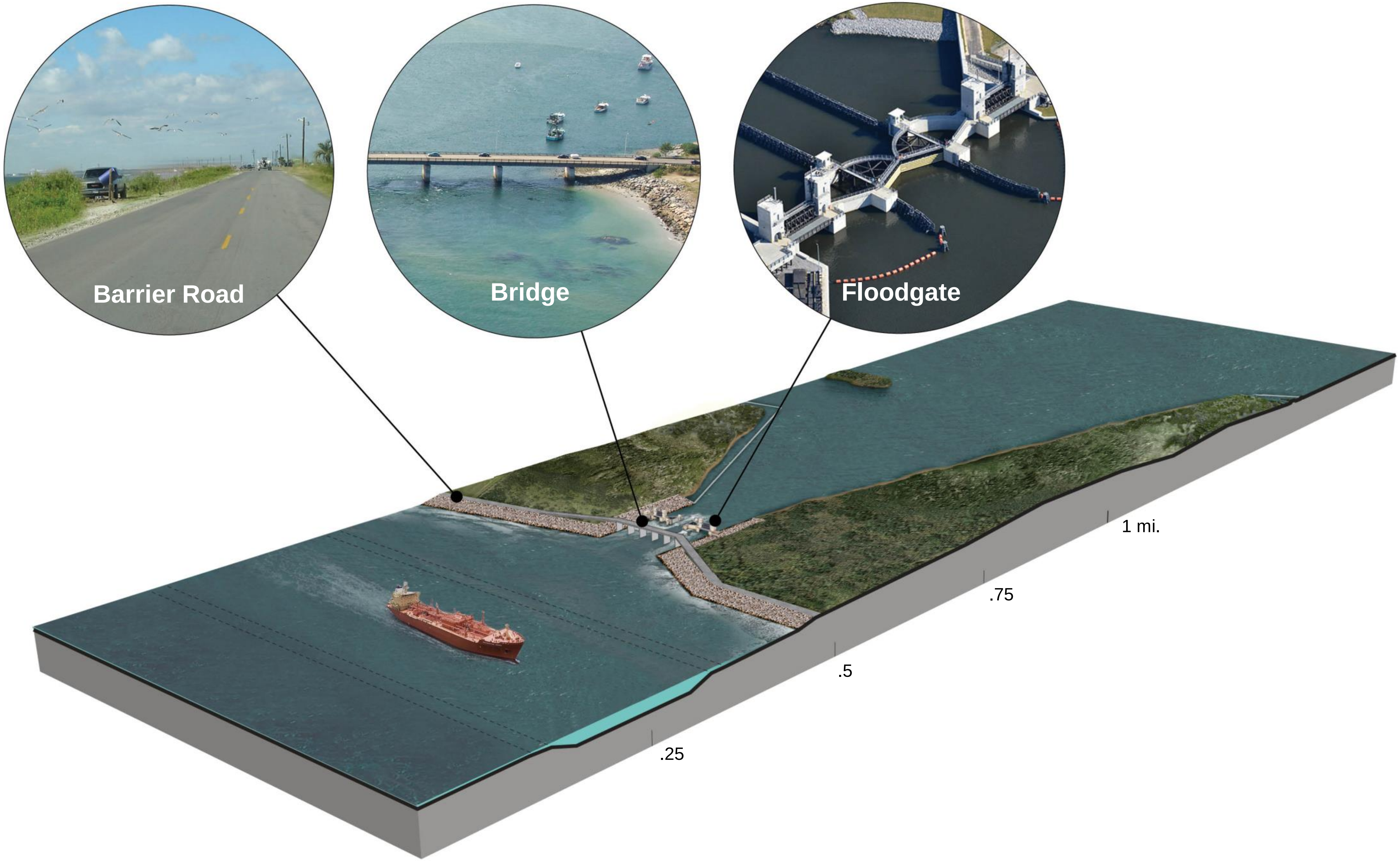



Ship Spotting Platform
Coastal Prairie
Fringe Forest
Living Shoreline
.25
.5
.75
1 mi.

KEY PLAN

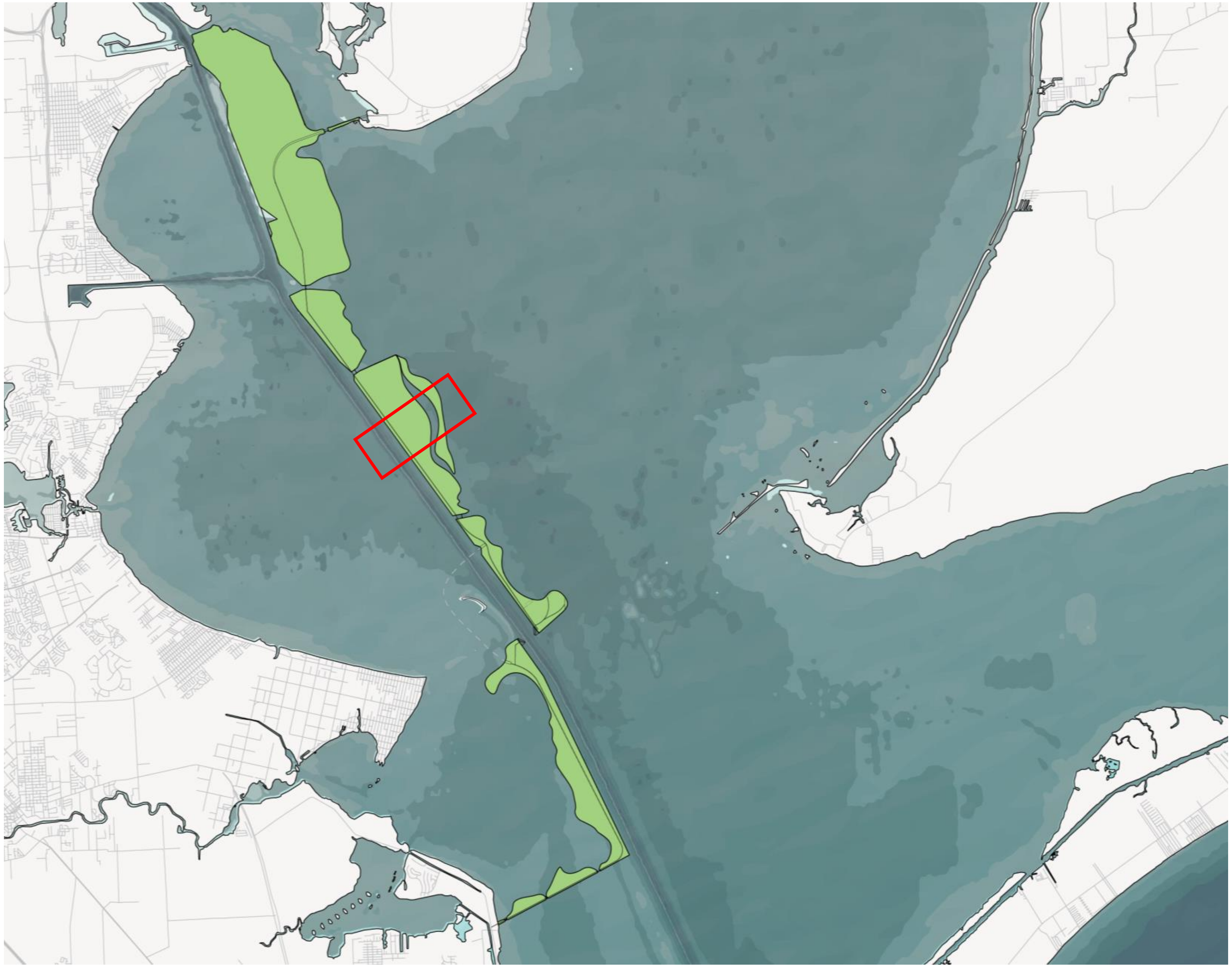
Small Craft Navigation Gate

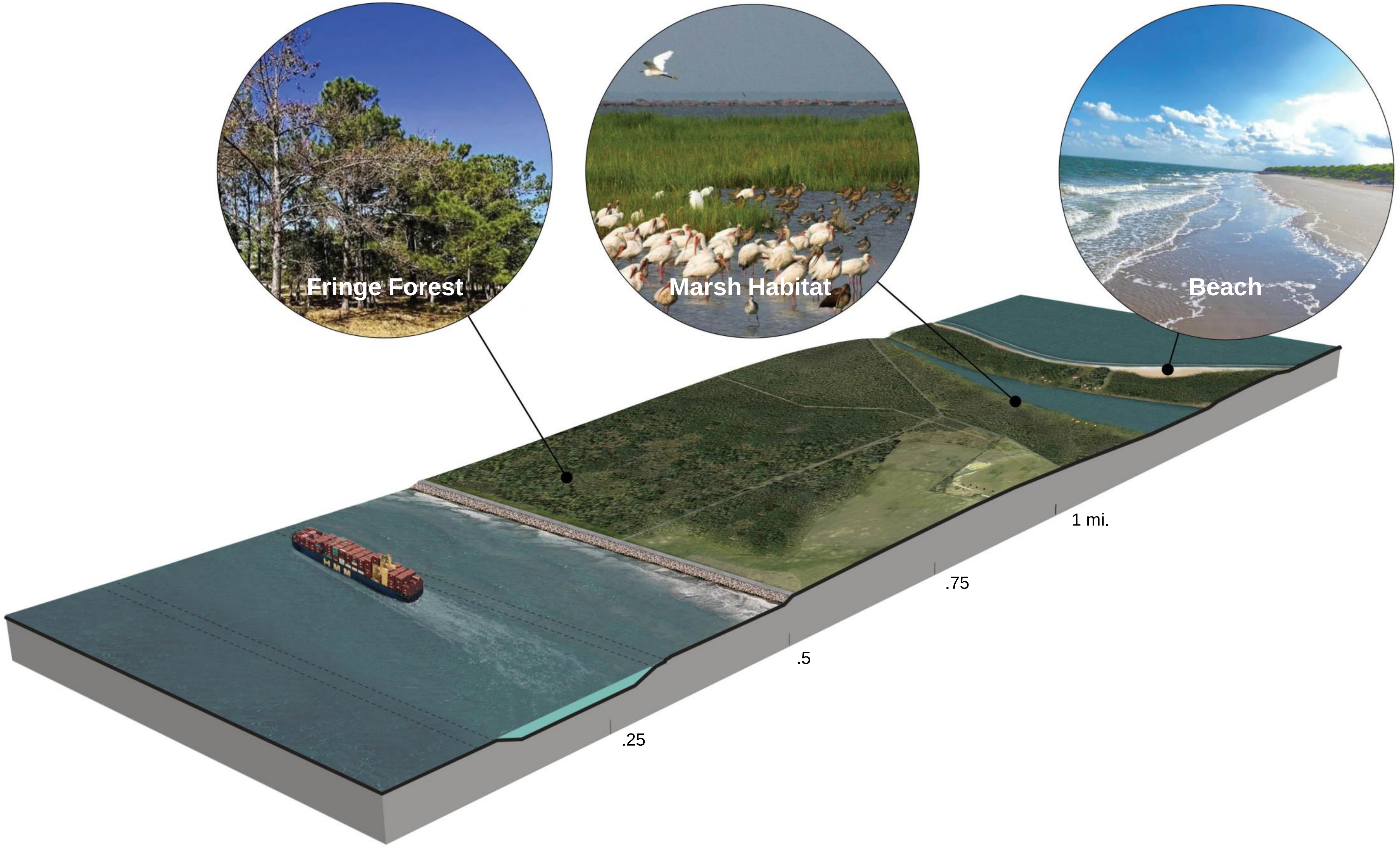



Barrier Road
Bridge
Floodgate
1 mi.
.75
.5
.25

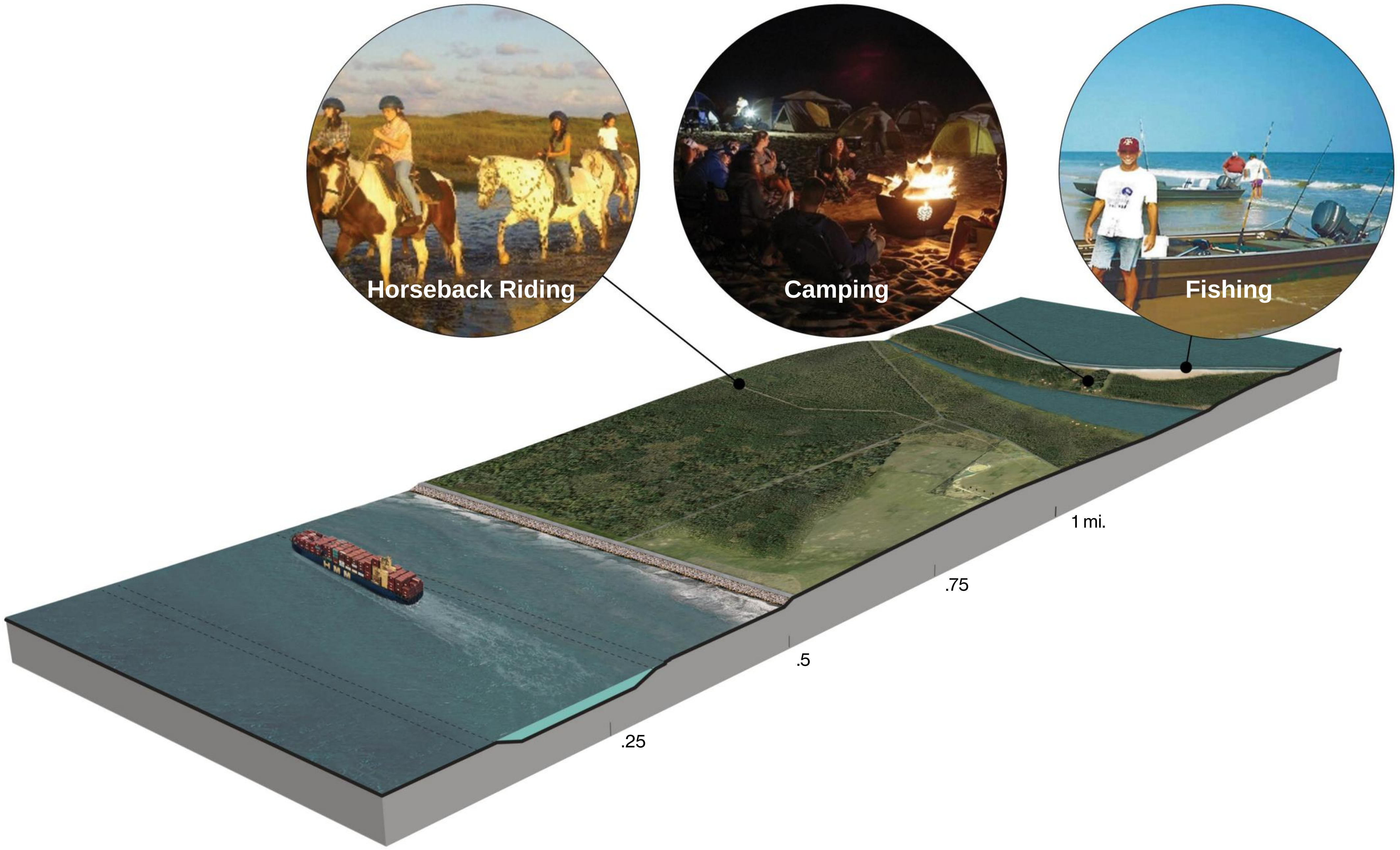
KEY PLAN

Campgrounds and Trails





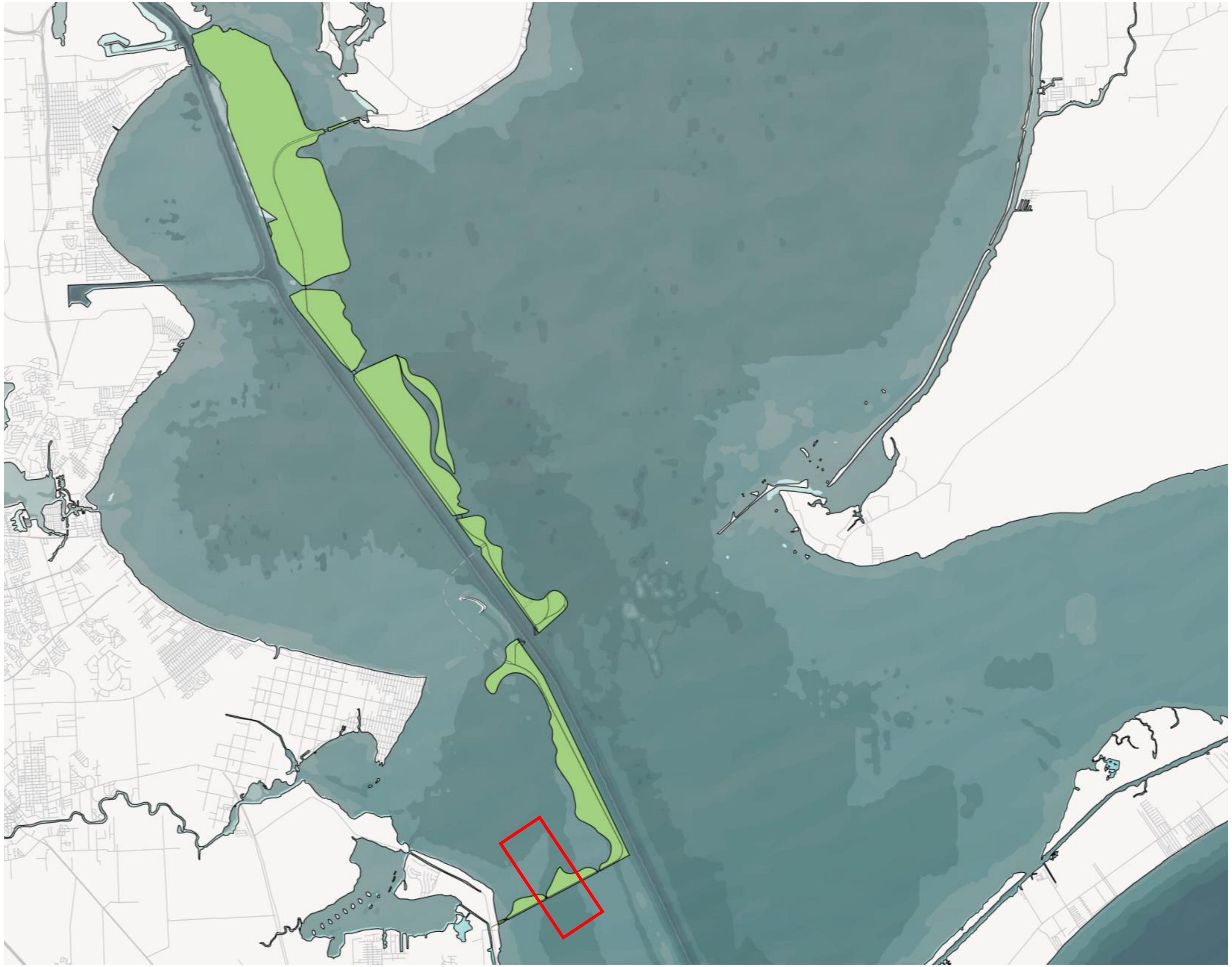
Fringe Forest
Marsh Habitat
Beach
.25
.5
.75
1 mi.

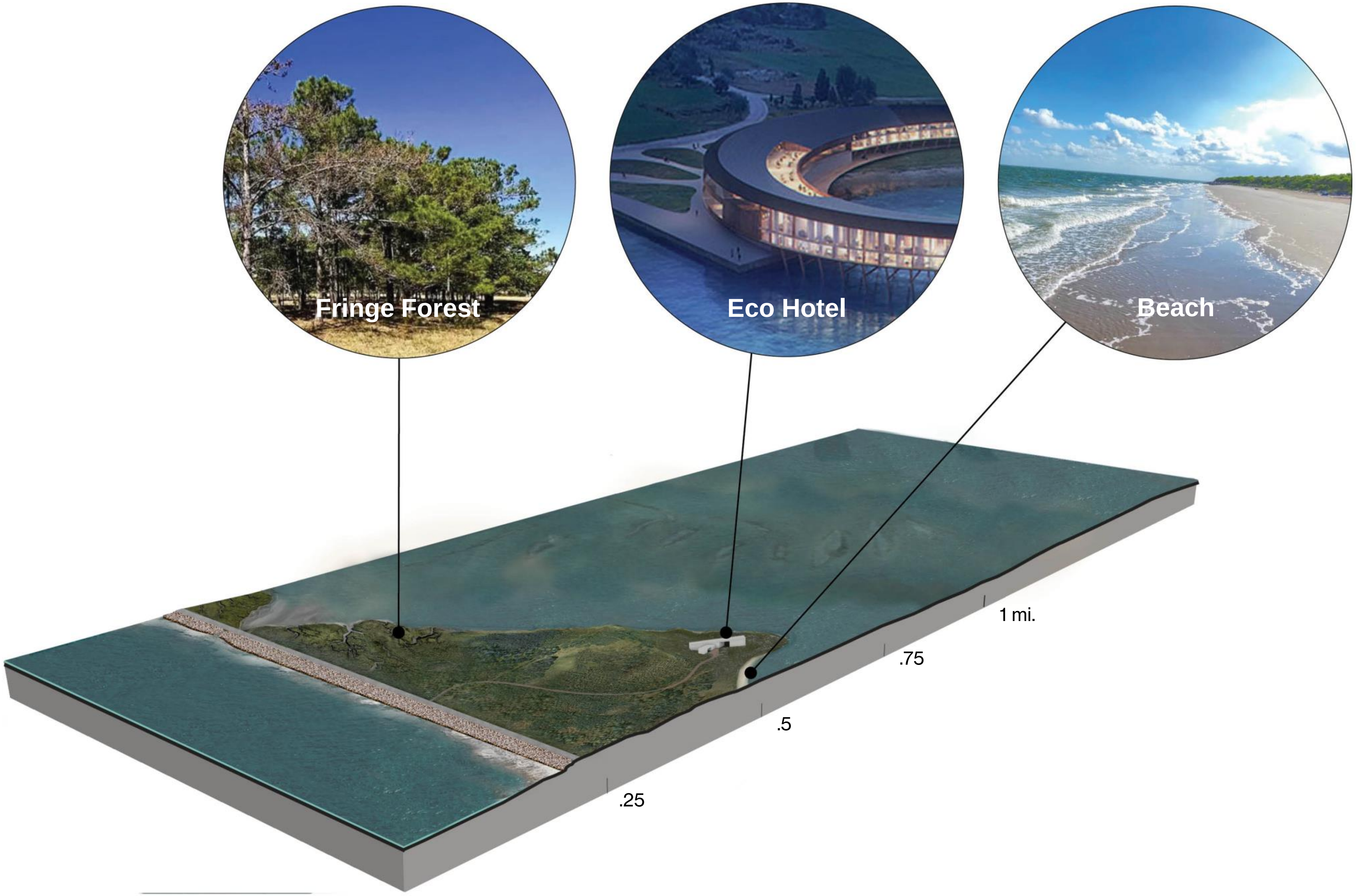


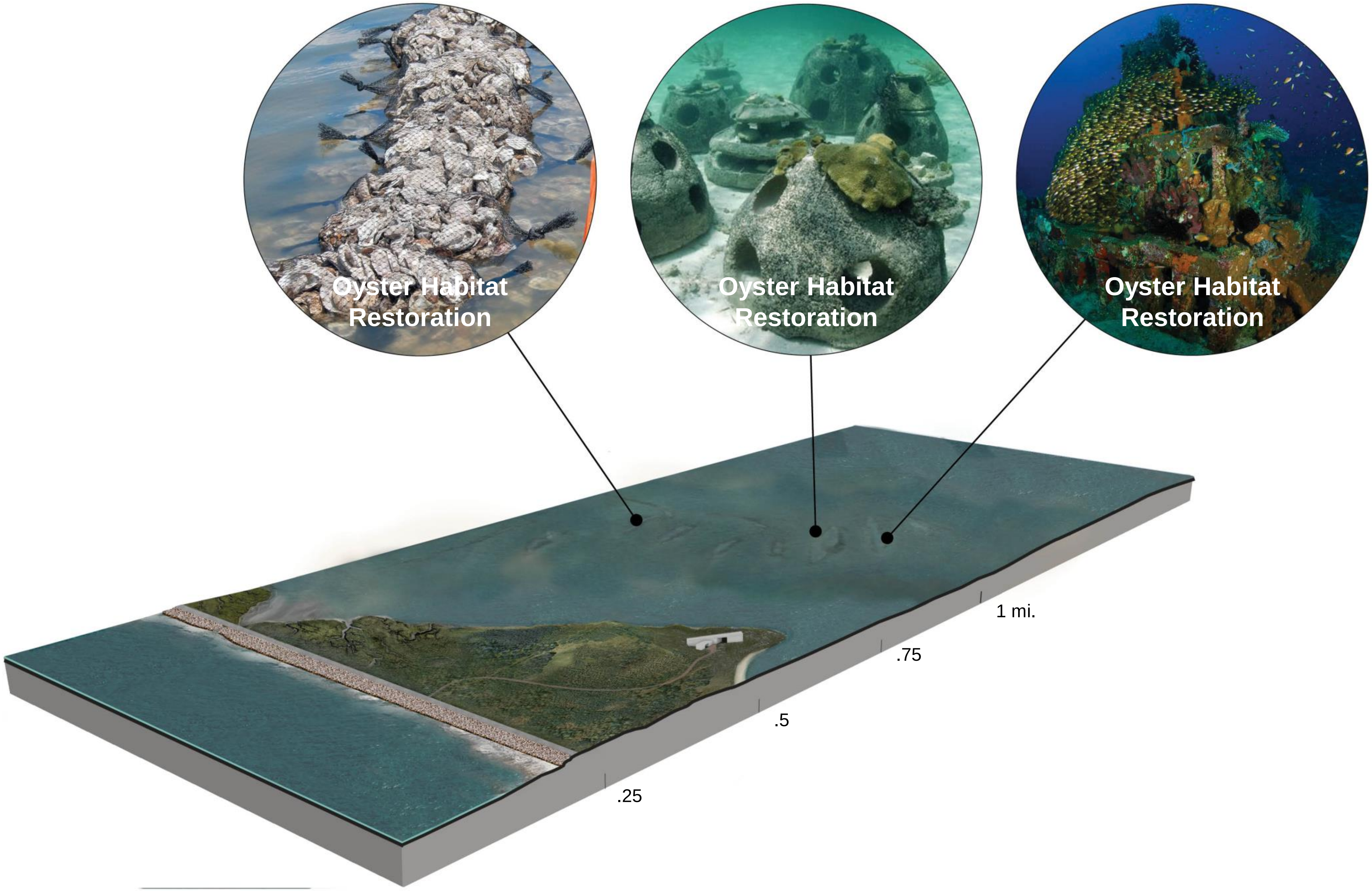
Horseback Riding
Camping
Fishing
.25
.5
.75
1 mi.

KEY PLAN

Environmental Restoration and Education

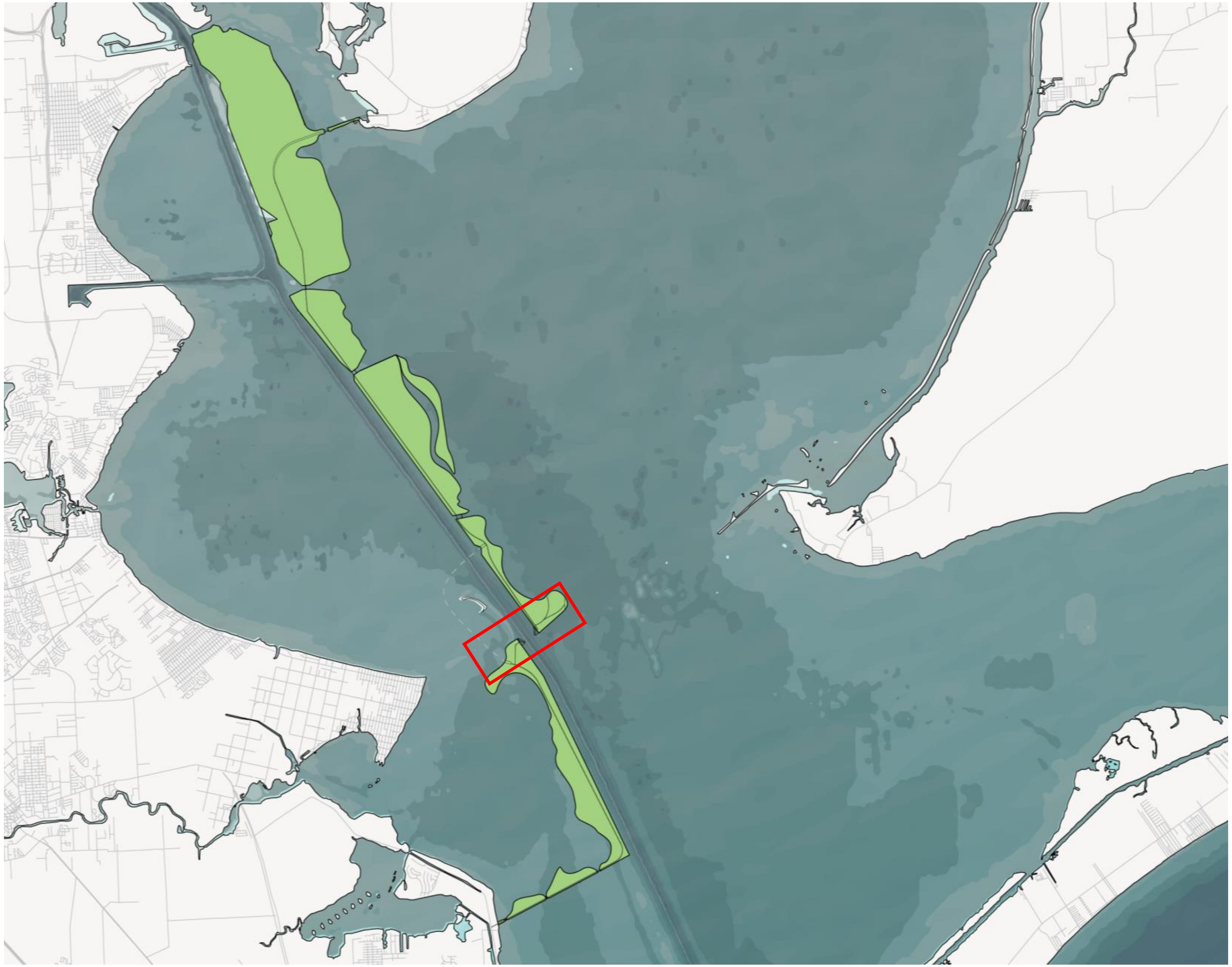


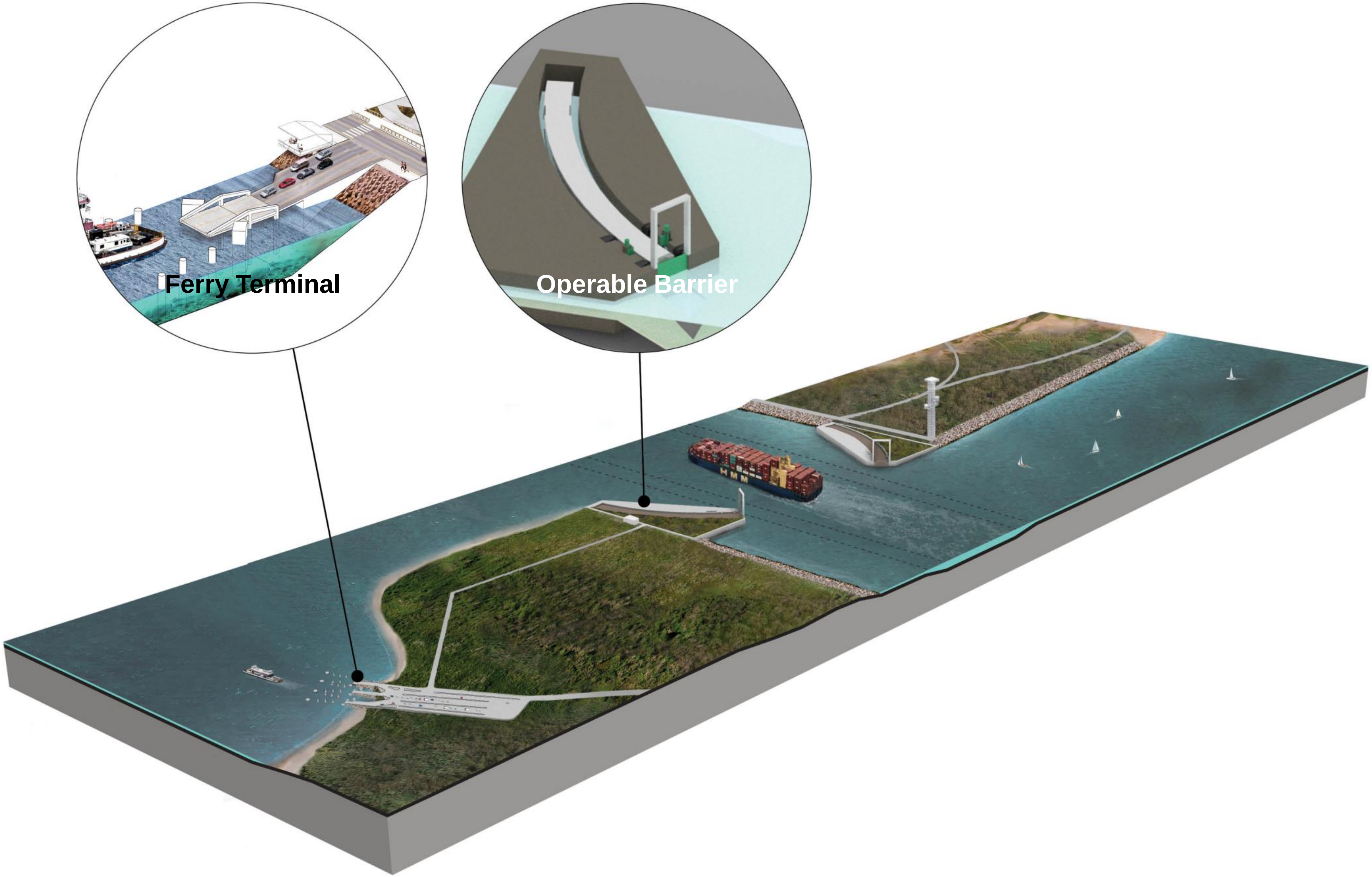

Fringe Forest
Eco Hotel
Beach
.25
.5
.75
1 mi.


Oyster Habitat Restoration
Oyster Habitat Restoration
Oyster Habitat Restoration
1 mi.
.75
.5
.25

KEY PLAN

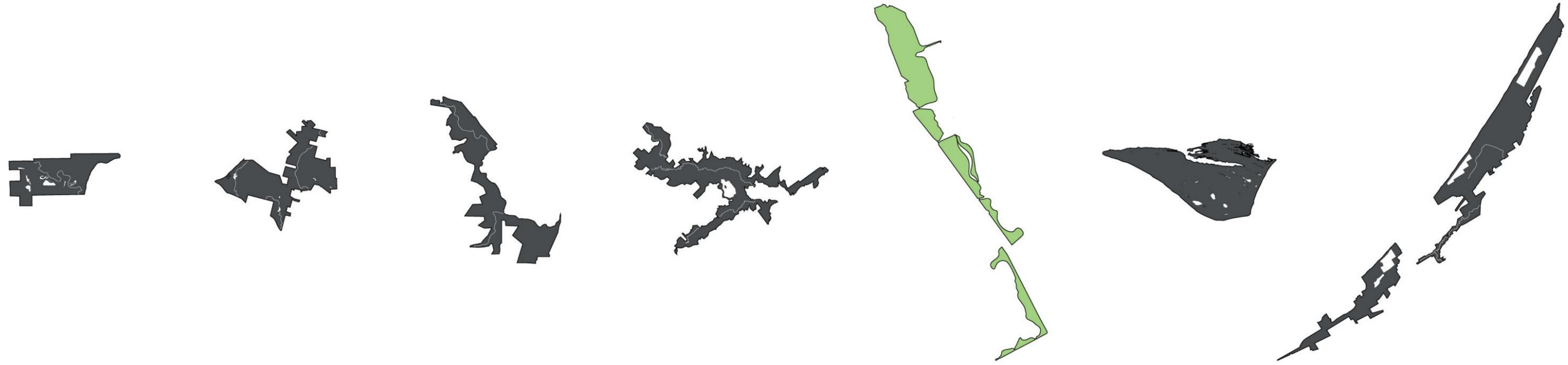
Main Gate and Ferry Crossing




Ferry Terminal
Operable Barrier

D I A G R A M S

Park Comparison



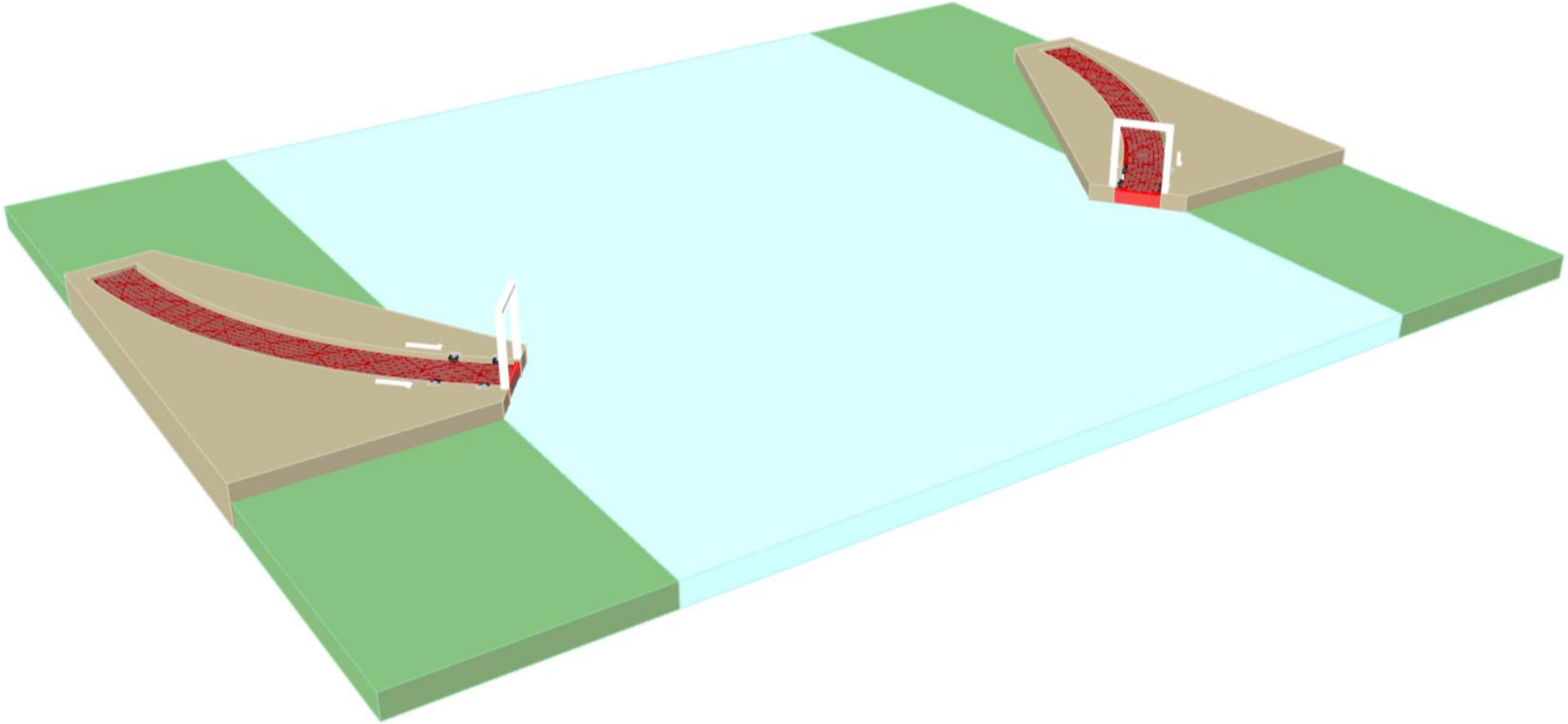
Brazos Bend State Park	Bastrop State Park	San Angelo State Park	Lake Somerville State Park	Galveston Bay Park	St. Vincent National Refuge	Indiana Dunes National Park
Texas	Texas	Texas	Texas	Texas	Florida	Indiana
4,897 Acres	7,580 Acres	7,677 Acres	8,700 Acres	9,258 Acres	11,800 Acres	15,066 Acres

Galveston Bay Park Plan
Operable Barrier

September 28, 2023

Current Design Concept

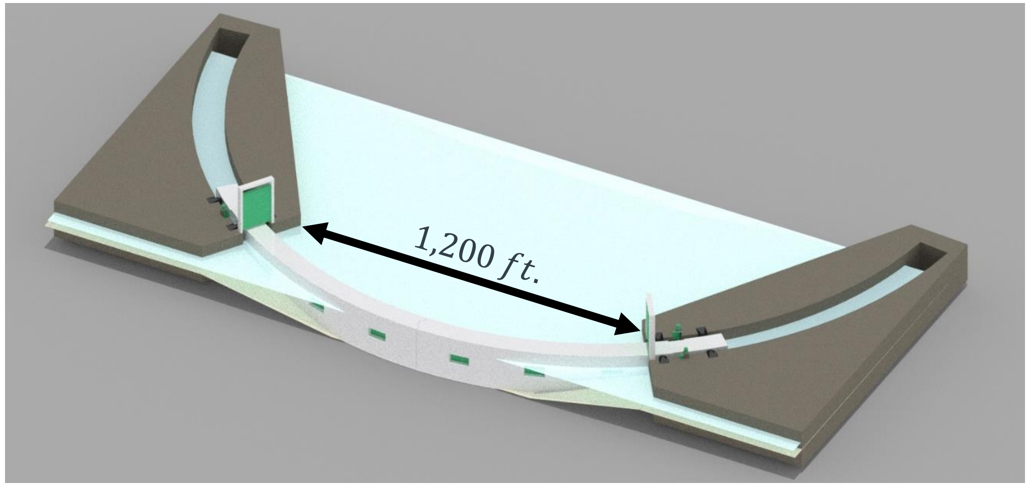
Phase 1: Doors lift to flood dry dock



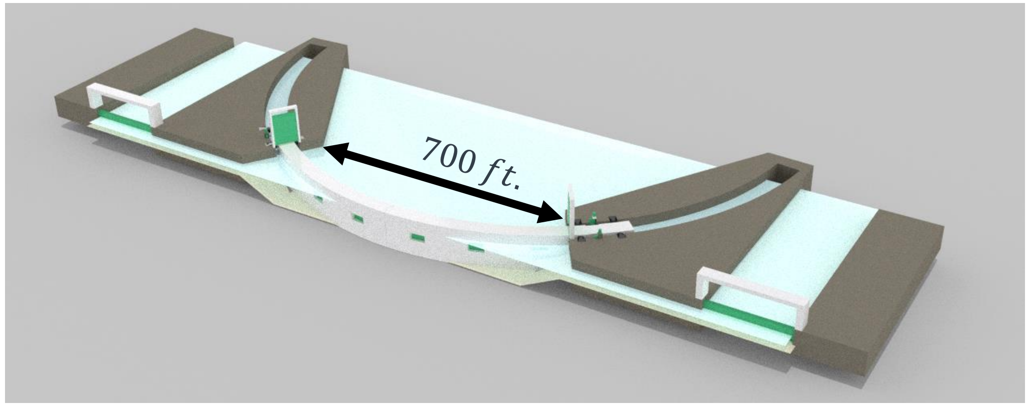
Channel Alternatives

OVERVIEW

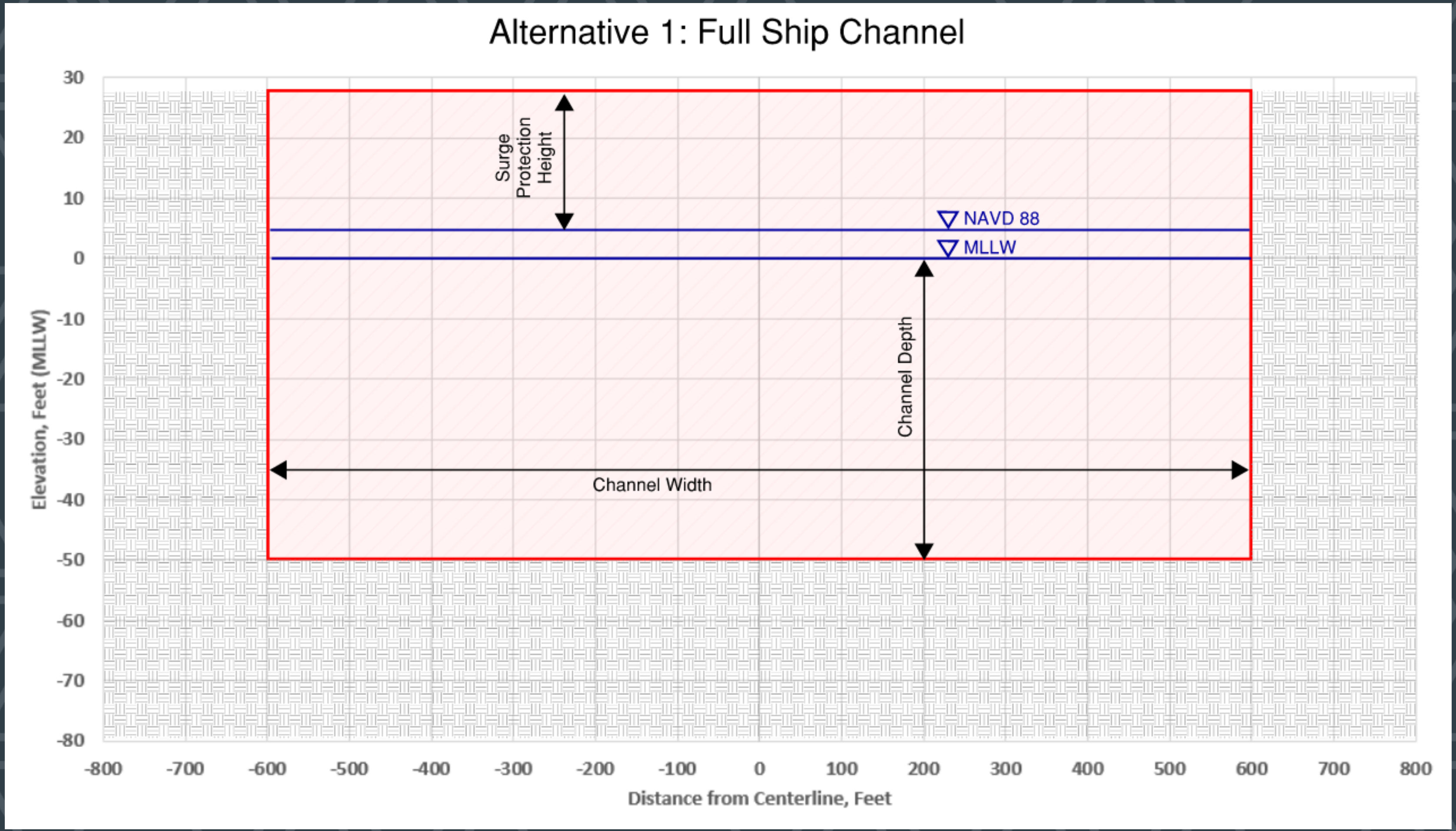
Channel Alternatives



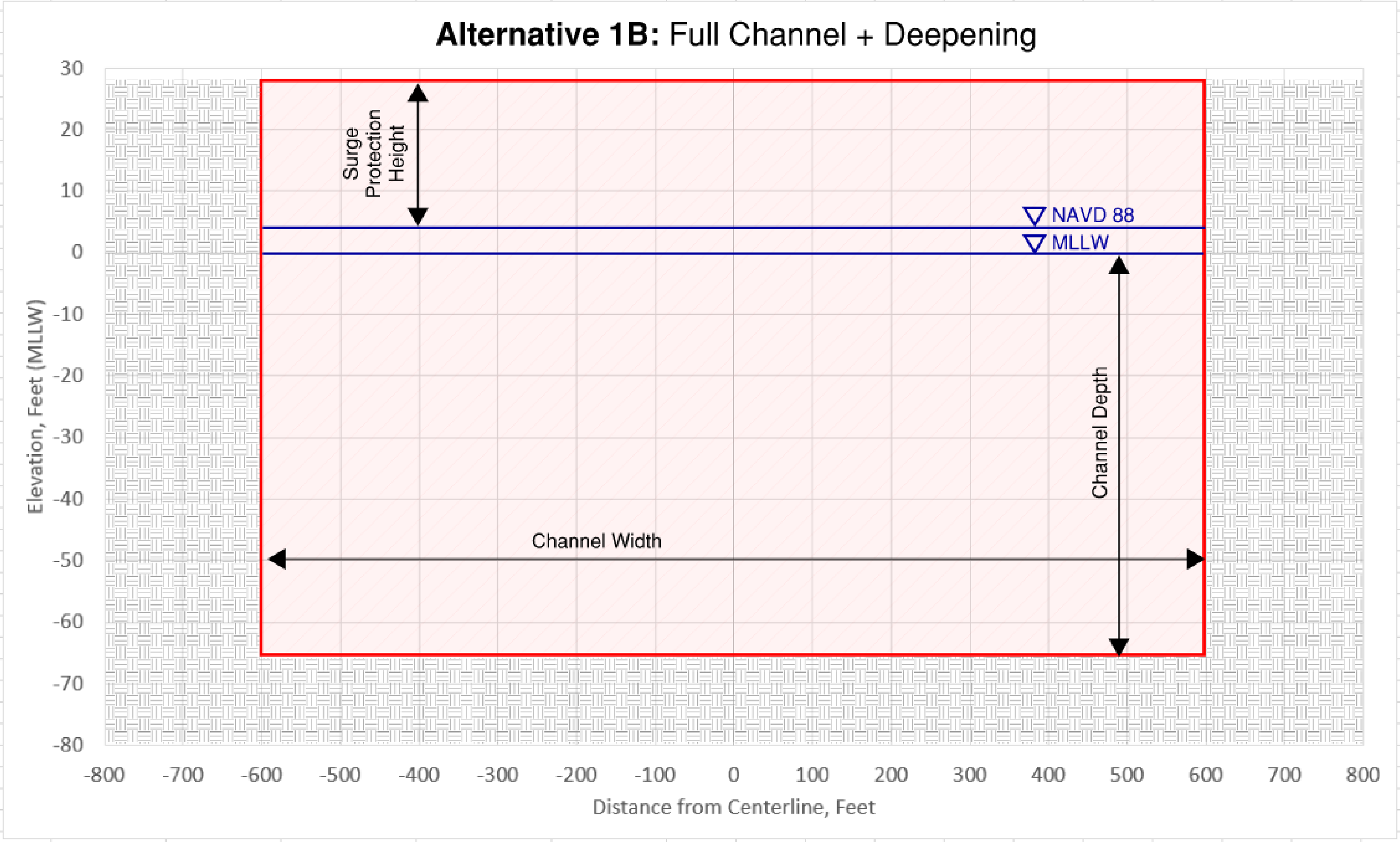
Alternative 1: Full Channel Width
(Houston Pilots' Strong Preference)



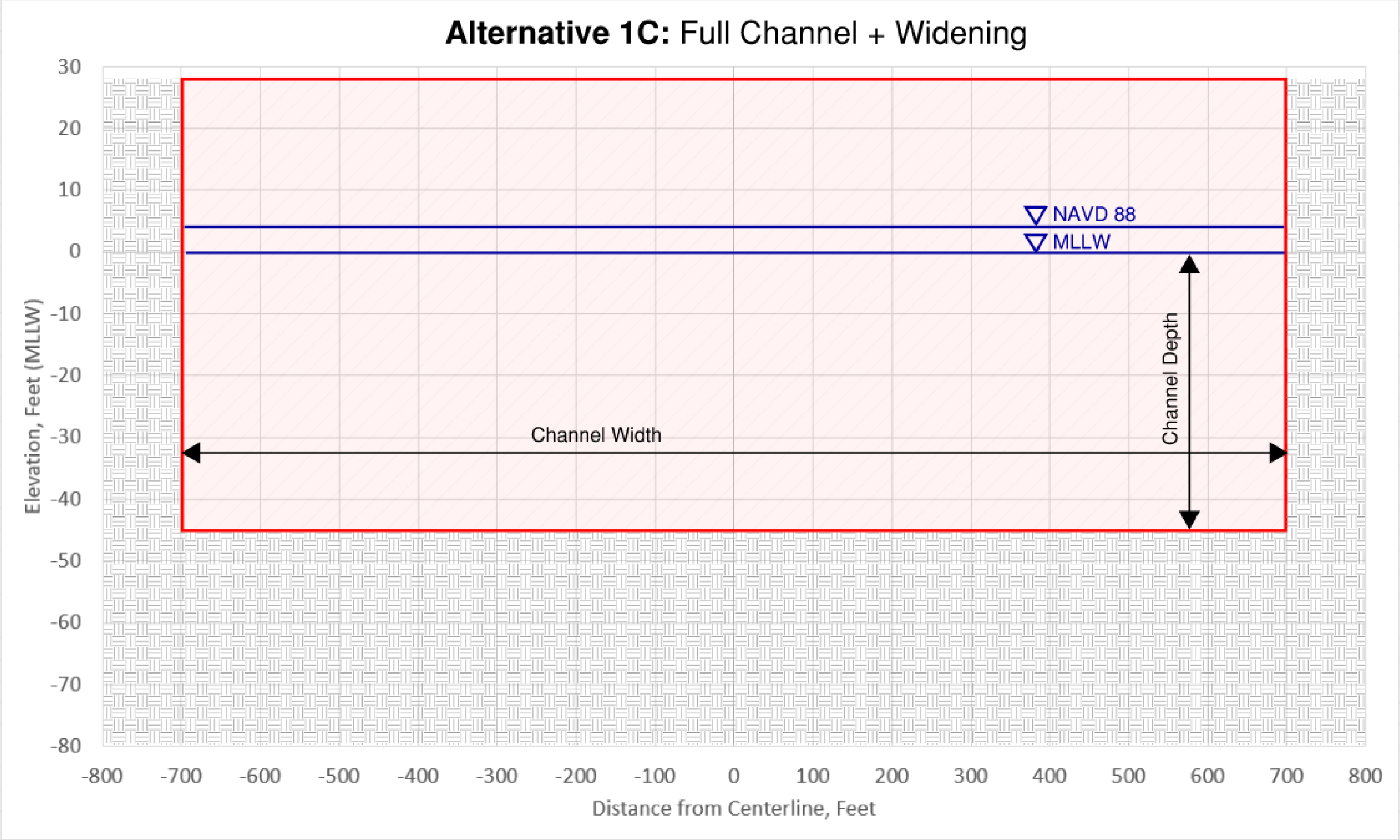
Alternative 2: Deepest Channel
Width with Separate Barge Lanes



Alternative 1: Full Ship Channel
Surge Protection Height
NAVD 88
MLLW
Channel Depth
Channel Width
Elevation, Feet (MLLW)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-800
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
400
500
600
700
800
Distance from Centerline, Feet

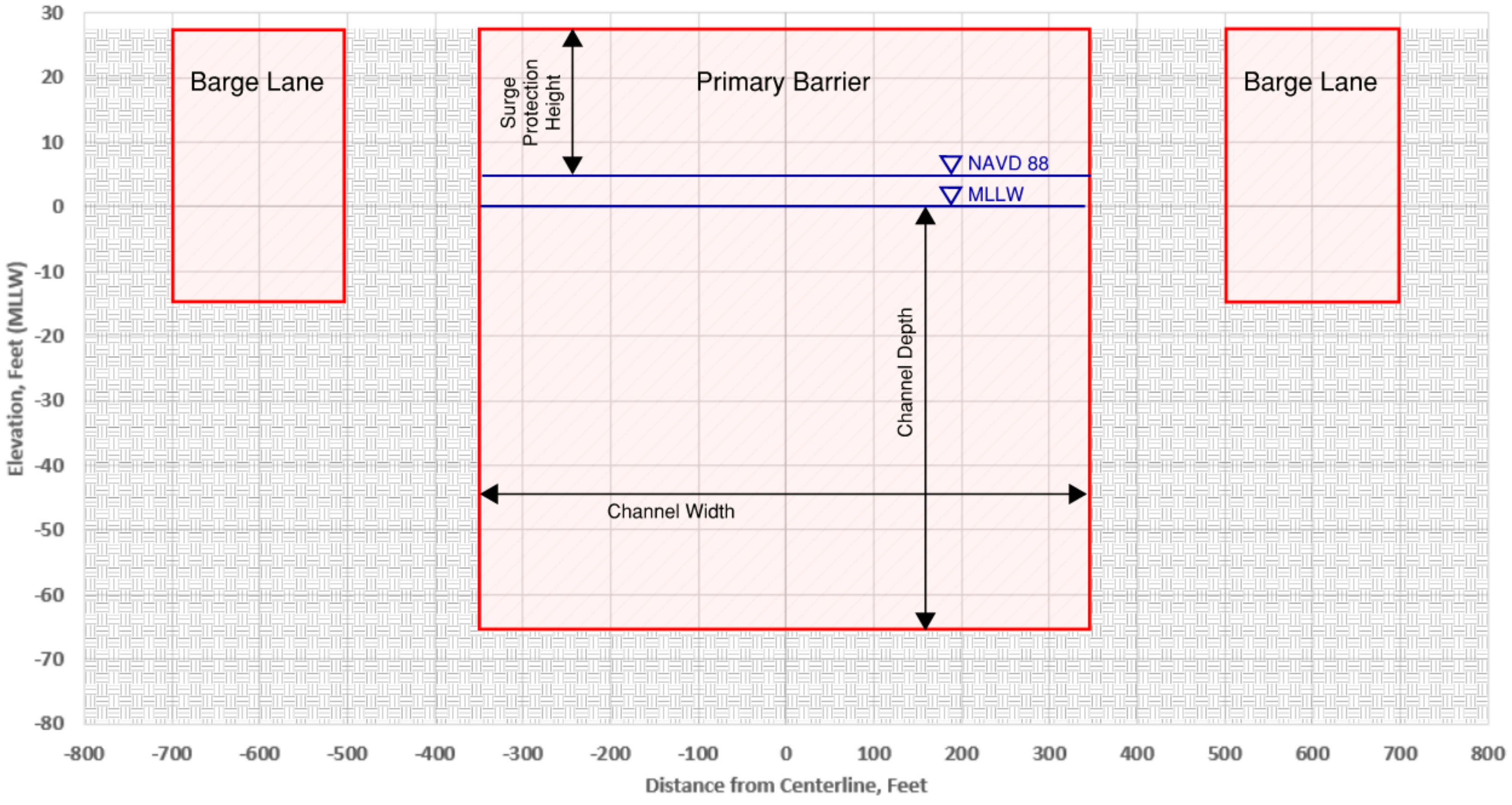


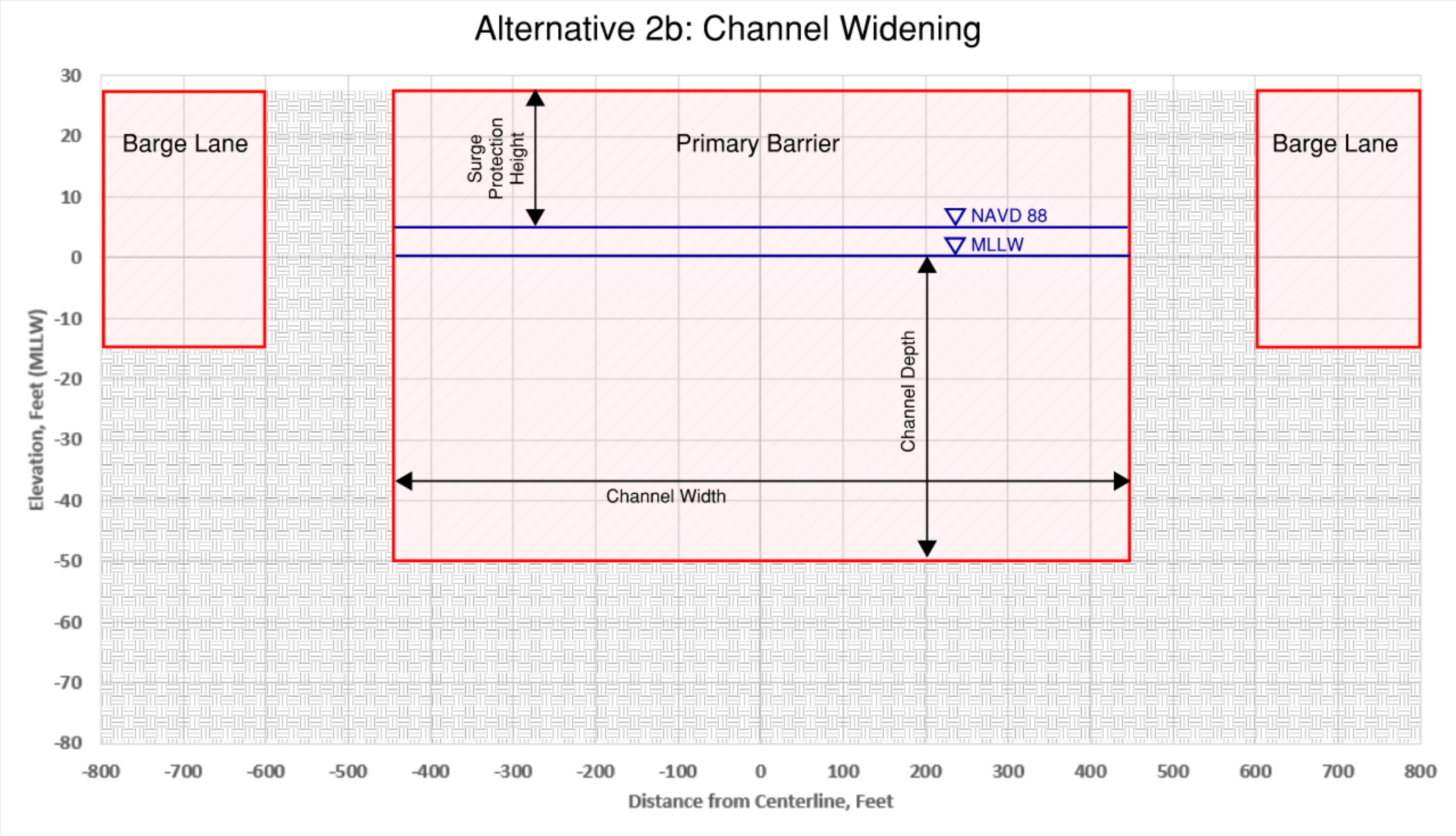
Alternative 1B: Full Channel + Deepening
Surge Protection Height
NAVD 88
MLLW
Channel Depth
Channel Width
Elevation, Feet (MLLW)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-800
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
400
500
600
700
800
Distance from Centerline, Feet



Alternative 1C: Full Channel + Widening
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
Elevation, Feet (MLLW)
NAVD 88
MLLW
Channel Width
Channel Depth
-800
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
400
500
600
700
800
Distance from Centerline, Feet

Alternative 2a: Channel Deepening

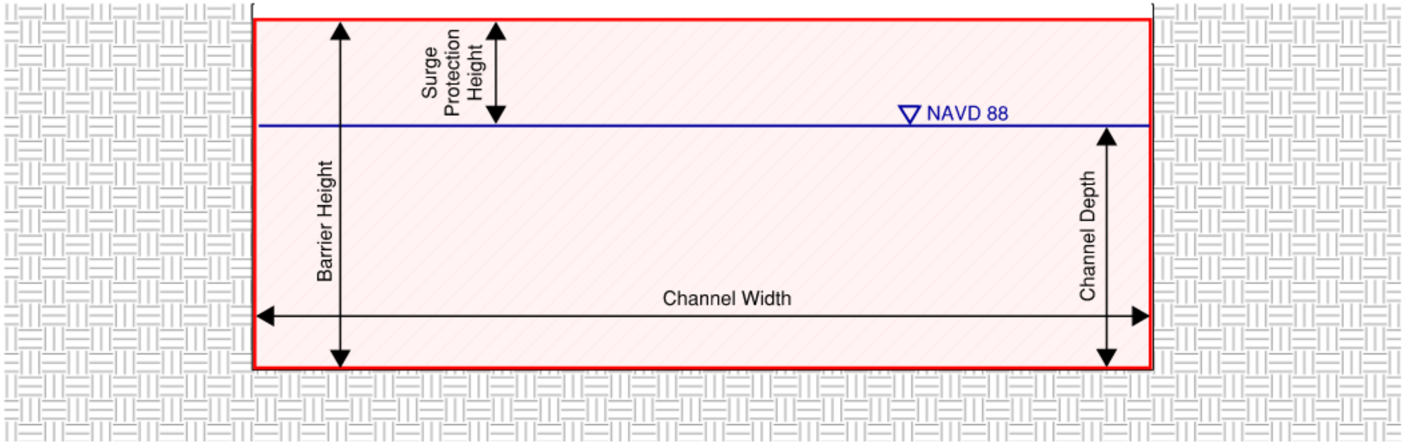




Alternative 2b: Channel Widening
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
Elevation, Feet (MLLW)
Barge Lane
Surge Protection Height
Primary Barrier
NAVD 88
MLLW
Channel Depth
Channel Width
Barge Lane
-800
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
400
500
600
700
800
Distance from Centerline, Feet

CHANNEL ALTERNATIVES

Main Barrier Scope



Elevation view of barrier face within channel

Quantity	**Alternative 1** (Full Channel)	**Alternative 2A** (Channel Deepening)	**Alternative 2B** (Channel Widening)
Channel Width (ft.)	1,200’	700’	900’
Channel Depth (ft.)	45’	65’	45’
Barrier Height (ft.)	70’	90’	70’
Total Load Path (kip-mi)	**22,600**	**10,100**	**12,700**

Cost Estimates of Channel Alternatives

Quantity	**Alternative 1A** (Full Channel)	**Alternative 1B** (Full Channel + Deepening)	**Alternative 1C** (Full Channel + Widening)	**Alternative 2A** (Channel Deepening + Barge Lanes)	**Alternative 2B** (Channel Widening + Barge Lanes)
Main Barrier Span (ft.)	1,200’	1,200’	1,400’	700’	900’
Main Barrier Depth (ft.)	45’	65’	45’	65’	45’
Barge Lane Barrier Spans (ft.)	N/A	N/A	N/A	2 x 235’	2 x 235’
Barge Lane Barrier Depth (ft.)	N/A	N/A	N/A	15’	15’
Parametric Cost Model (USD) (Kluijver et. al, 2019)	**$1.04 B** ± 400 M	**$1.51 B** ± 576 M	**$1.22 B** ± 470 M	**$1.01 B** ± 390 M	**$919 M** ± 350 M

Structural System Alternatives

EXISTING PRECEDENT:

The Maeslantkering, Rotterdam, NE

Undeployed

Deployed

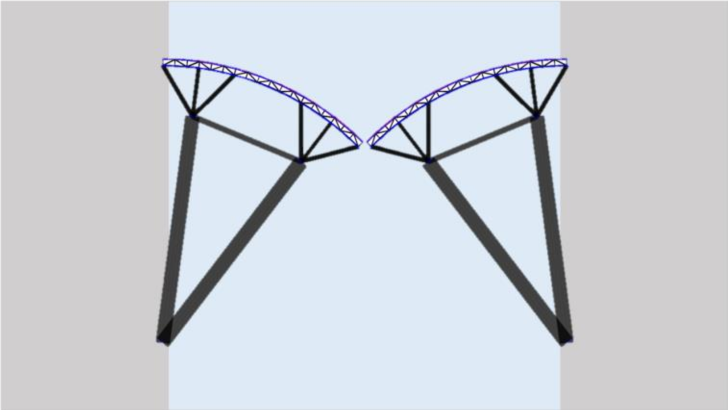
Double Leaf Sector Gate, 1,200 ft. span

EXISTING PRECEDENT:

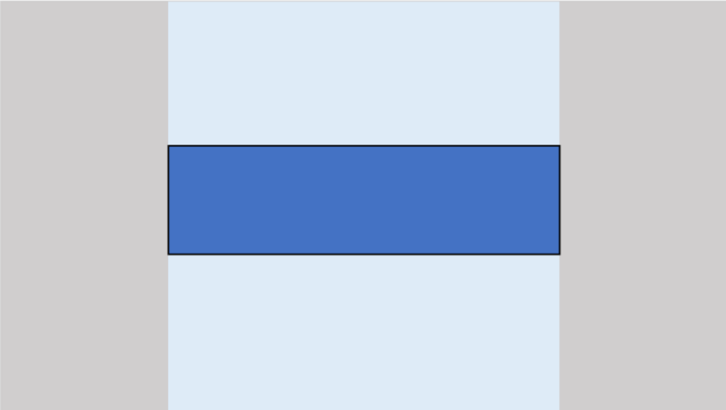
Bayou Chene Barrier, St. Mary Parish, Louisiana

Barge Gate, 446-foot Span

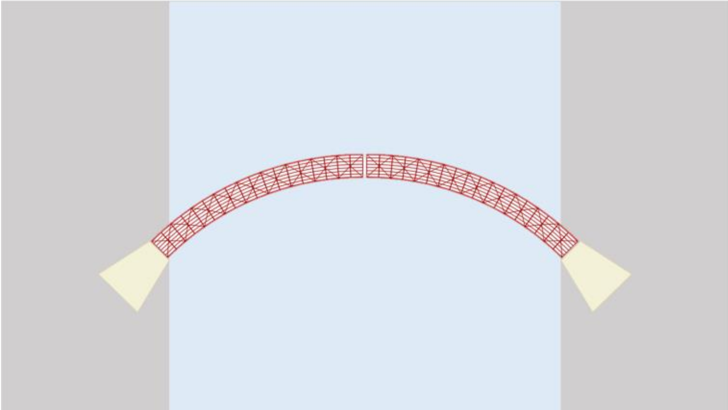
Structural System Alternatives



System 1: Sector Gates
(As seen in the Maeslantkering, Rotterdam, NE)

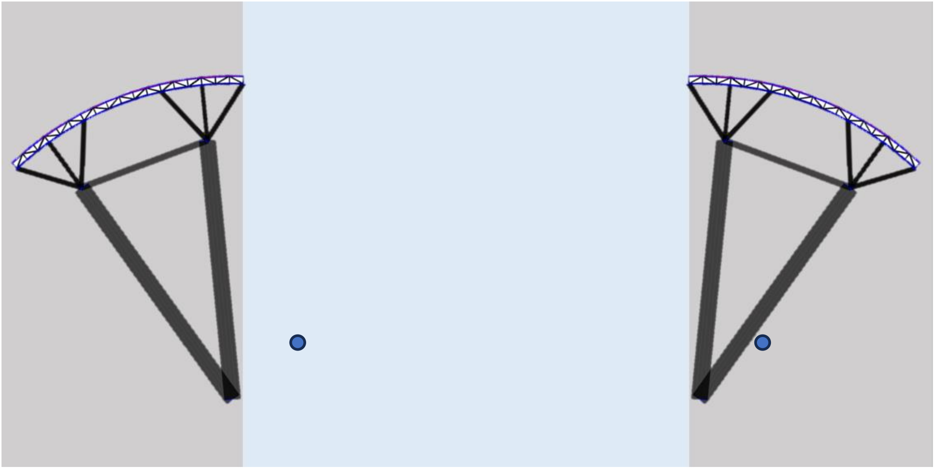


System 2: Sunken Barge
(As seen in the Bayou Chene, LA)

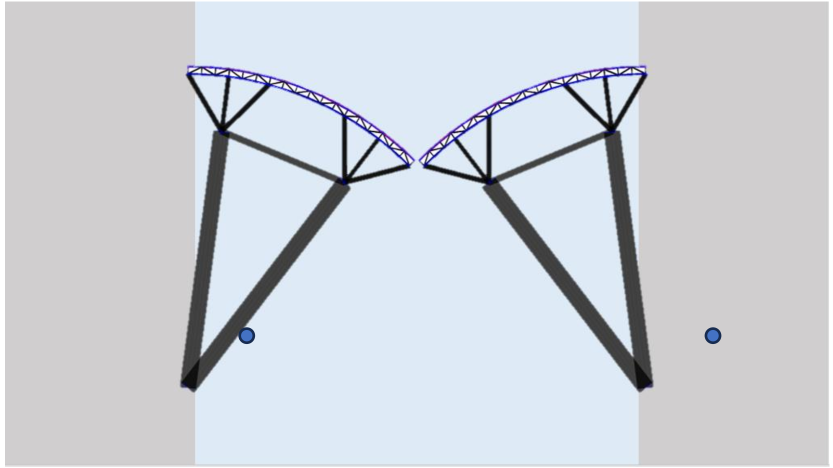


System 3: Barge Arc
(Novel Design)

System 1: Sector Gates



Undeployed



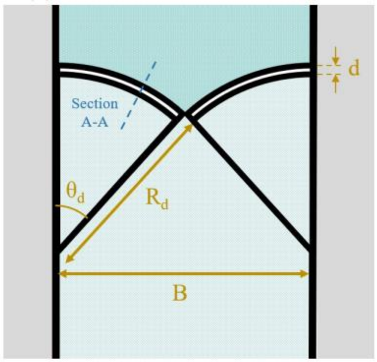
Deployed

Benefits:
- Only system with precedent at this scale
- Design and maintenance challenges are more easily predictable

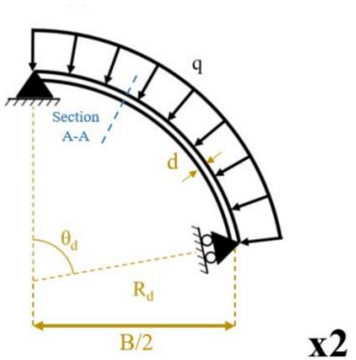
Challenges:
- High bending moments along the front faces
- Limiting scale of ball bearings is a documented concern
- Widest landing area for housing gate in open position

S T R U C T U R A L   S Y S T E M   A L T E R N A T I V E S

System 1: Global Behavior



(d) Double Arc Channel Geometry



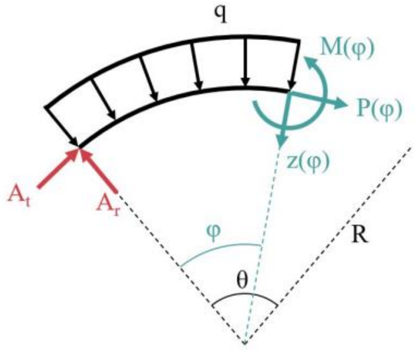
(e) Double Arc Loading

Table: Sector Gate Radii

		Alternative A (Channel Deepening)	Alternative B (Channel Widening)	Alternative C (Full Channel)
Channel Width B		**700′**	**900′**	**1, 200′**
Arc Angle θ_d	30°	700′	900′	1,200′
	45°	495′	636′	849′
	60°	404′	520′	693′
	90°	350′	450′	600′

Geometric Constraint: $R_d \sin\theta_d = \dfrac{B}{2}$

Unbraced Arc Segment:



Internal Loads between Supports:

$$P(\phi) = \frac{qR}{\sin\theta}\left[\sin\phi + \sin(\theta - \phi) - \sin\theta\right]$$

$$z(\phi) = \frac{qR}{\sin\theta}\left[\cos\phi - \cos(\theta - \phi)\right]$$

$$M(\phi) = \frac{qR^2}{\sin\theta}\left[\sin\phi + \sin(\theta - \phi) - \sin\theta\right]$$

Maximum Design Loads:

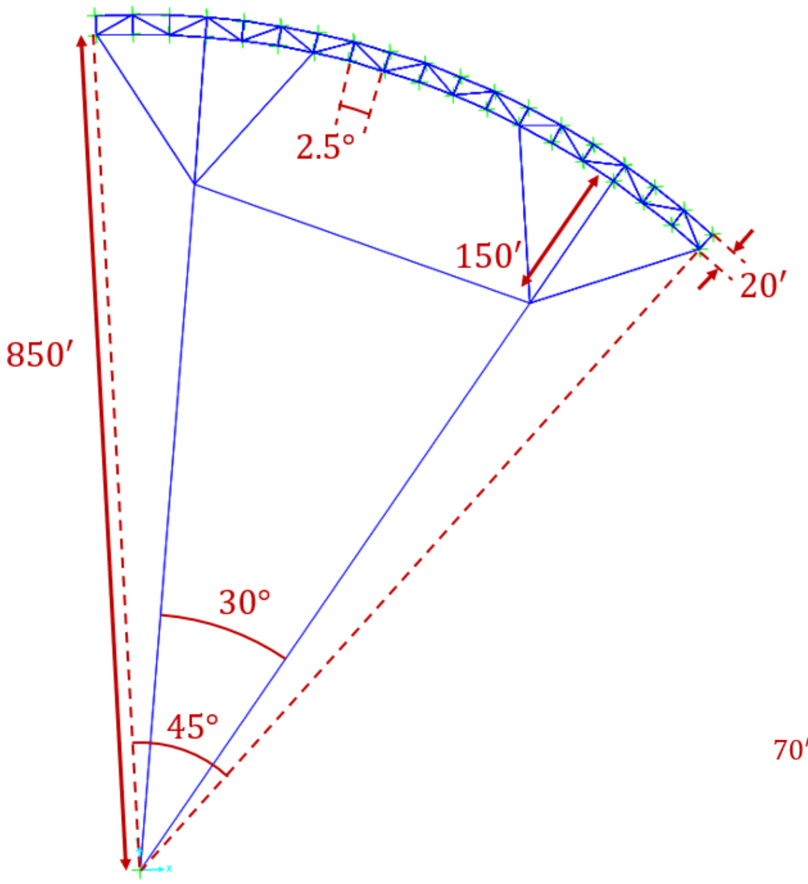
$$P(\phi) = qR\left[\sec\left(\frac{\theta}{2}\right) - 1\right]$$

$$z(\phi) = qR\tan\left(\frac{\theta}{2}\right)$$

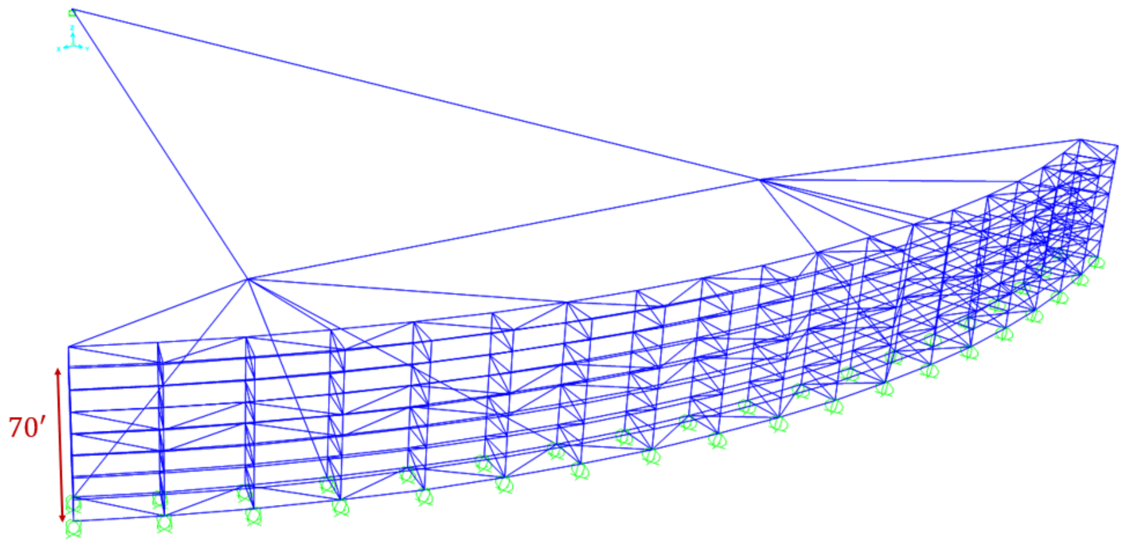
$$M(\phi) = qR^2\left[\sec\left(\frac{\theta}{2}\right) - 1\right]$$

STRUCTURAL SYSTEM ALTERNATIVES

System 1: Concept Model

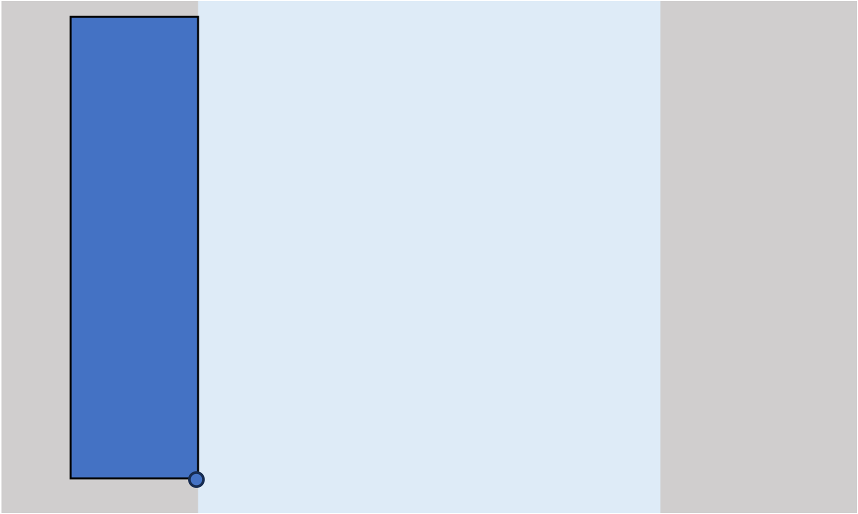


Estimated Minimum Structural Material:
30,300 US tons steel

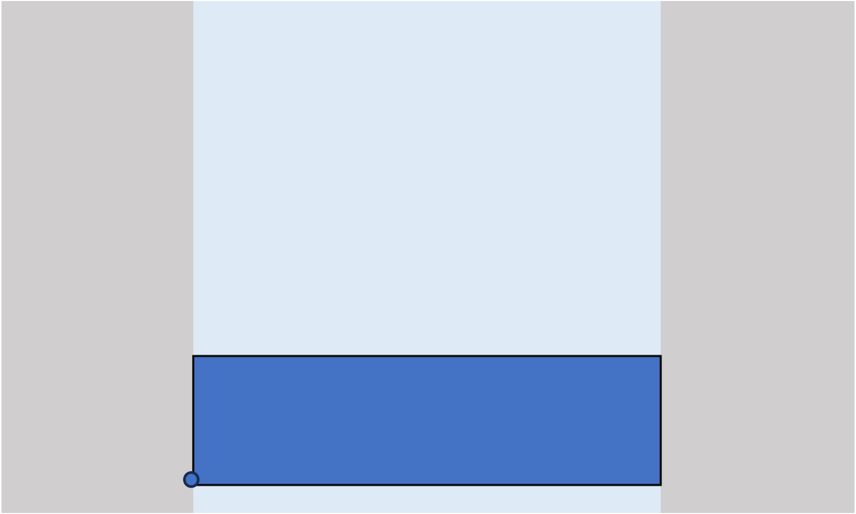


STRUCTURAL SYSTEM ALTERNATIVES

System 2: Barge Gate



Undeployed



Deployed

Benefits:

- Simple deployment
- Simple to maintain
- Load is resolved by gravity without significant abutments

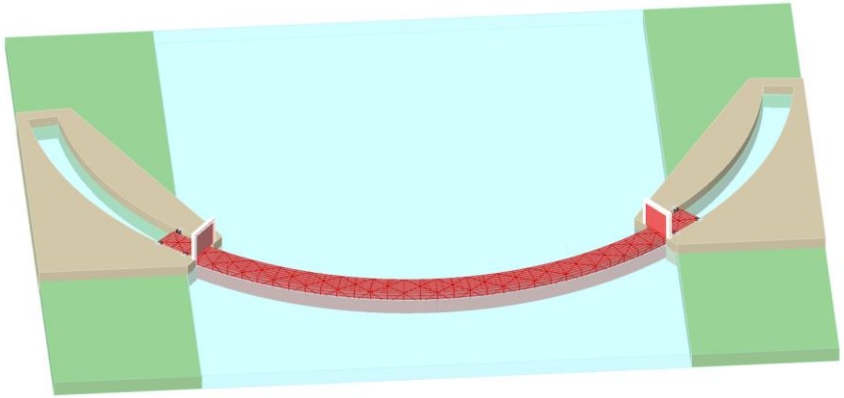
Challenges:

- Unprecedented at this scale
- Would increase material demand by up to 100% versus sector gate alternative
- Maintenance would be done in wet condition

STRUCTURAL SYSTEM ALTERNATIVES

System 3: Barge Arc (BArc)

Undeployed



Deployed

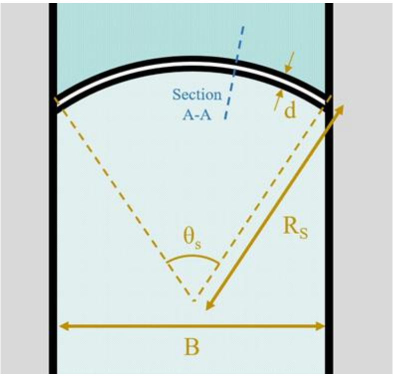
Benefits:

- Curvature eliminates bending stress in the barrier
- Reduces material demand by up to 50% versus sector gate alternative
- Similar deployment mechanism as sector gates
- No ball bearing needed

Challenges:

- Unprecedented design
- Would require a dry dock for maintenance
- Center point interlocking needed for eccentric loading
- Back-span needed for stability

System 3: Global Behavior



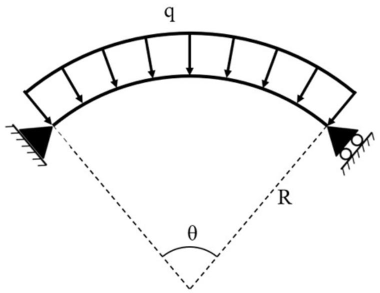
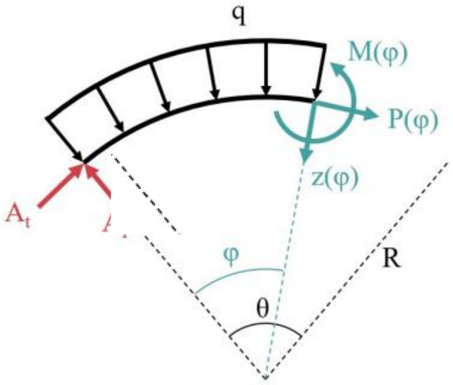


Table: Arc Gate Radius of Curvature

		Alternative A (Channel Deepening)	Alternative B (Channel Widening)	Alternative C (Full Channel)
Channel Width B		**700’**	**900’**	**1,200’**
Arc Angle θ_s	60°	700’	900’	1,200’
	90°	495’	636’	849’
	120°	404’	520’	693’
	150°	362’	466’	621’

Geometric Constraint: $2R_s \sin\left(\frac{\theta_s}{2}\right) = B$

Unbraced Arc Segment:



Internal Loads between Supports:

$$P(\phi) = -qR$$

$$z(\phi) = 0$$

$$M(\phi) = 0$$

Table: Total Axial Thrust in Arc (kips)
Using q as defined in Appendix A

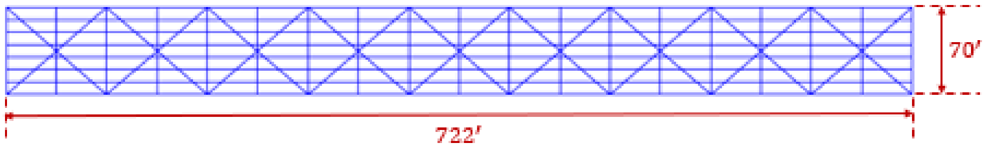
		Alternative A (Channel Deepening)	Alternative B (Channel Widening)	Alternative C (Full Channel)
Channel Width B		**700’**	**900’**	**1,200’**
Barrier Depth h_{wall}		**90’**	**70’**	**70’**
Arc Angle θ_s	60°	97,300	95,000	126,700
	90°	68,800	67,200	89,600
	120°	56,200	54,900	73,200
	150°	50,400	49,200	65,600

STRUCTURAL SYSTEM ALTERNATIVES

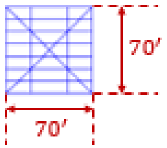
System 3: Concept Model

Estimated Minimum Structural Material:
15,900 US tons steel

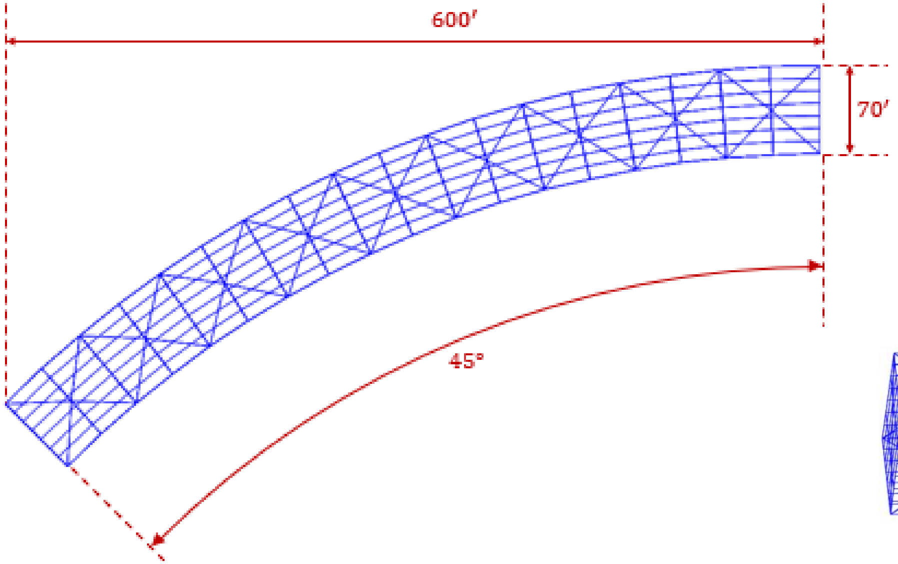
Front View (Projected):



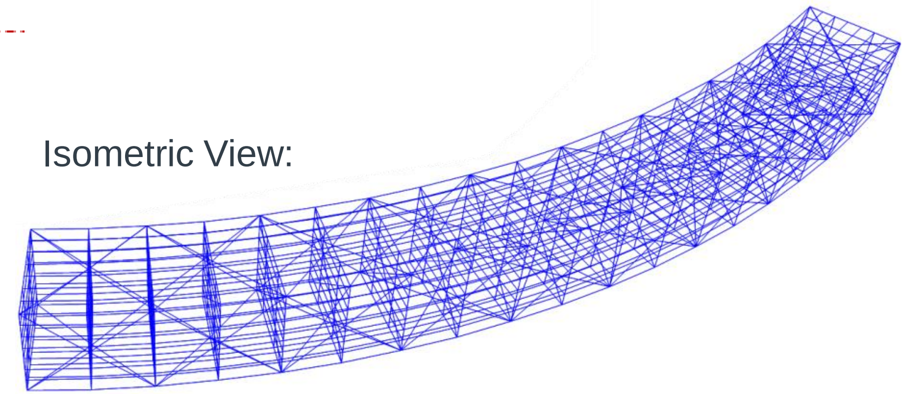
Side View:



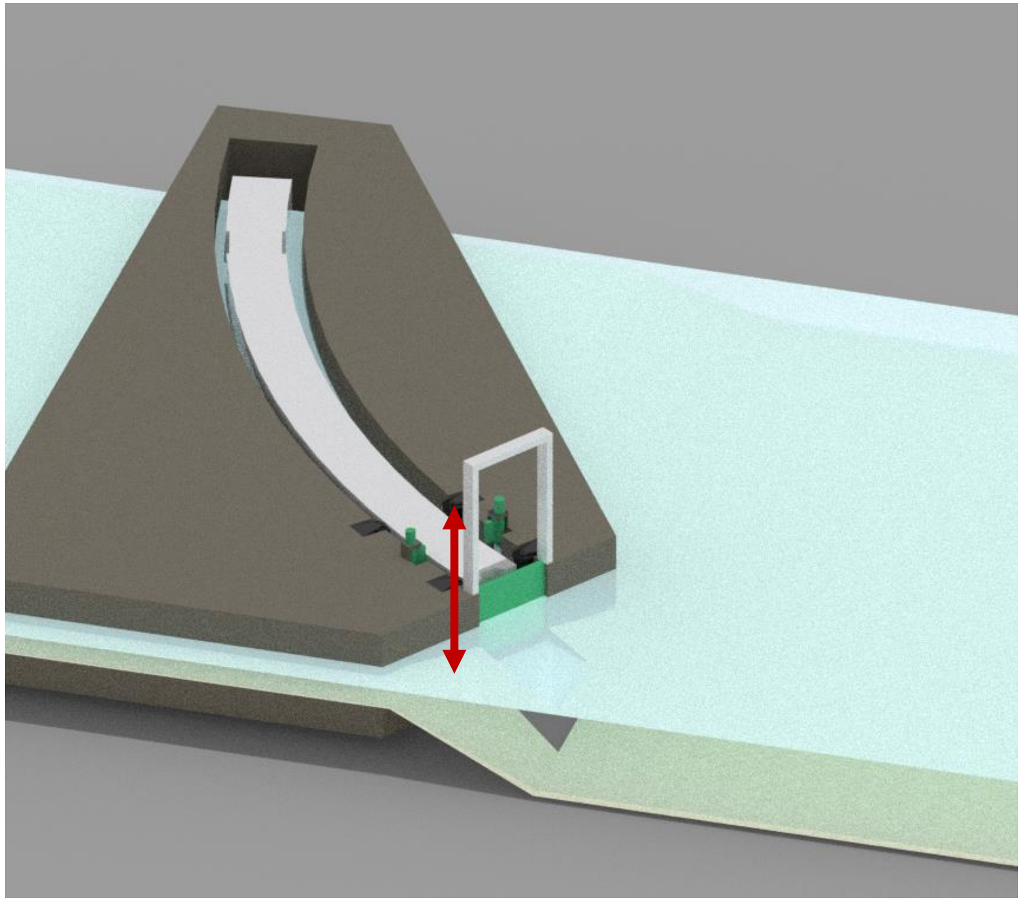
Top View:



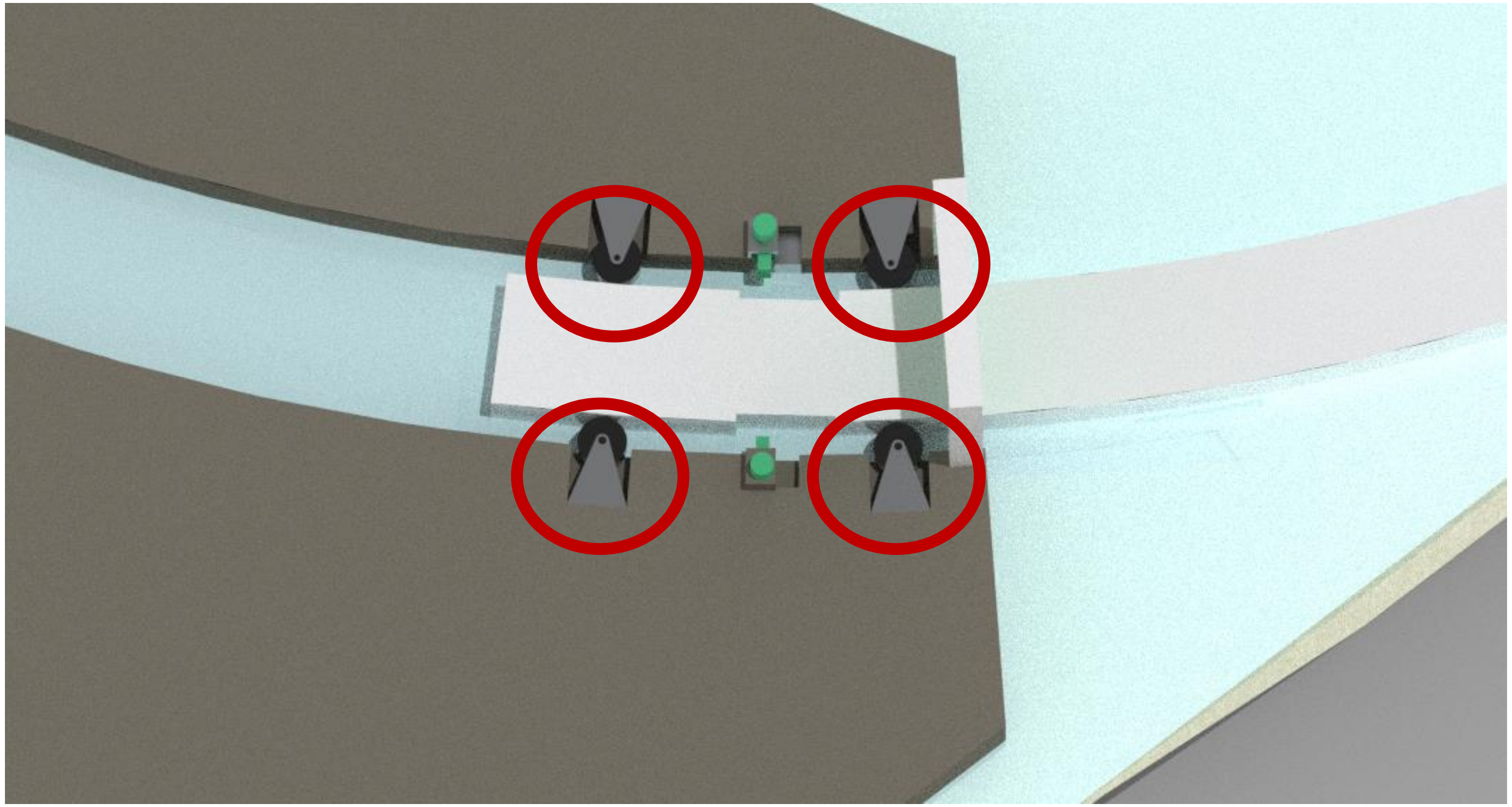
Isometric View:



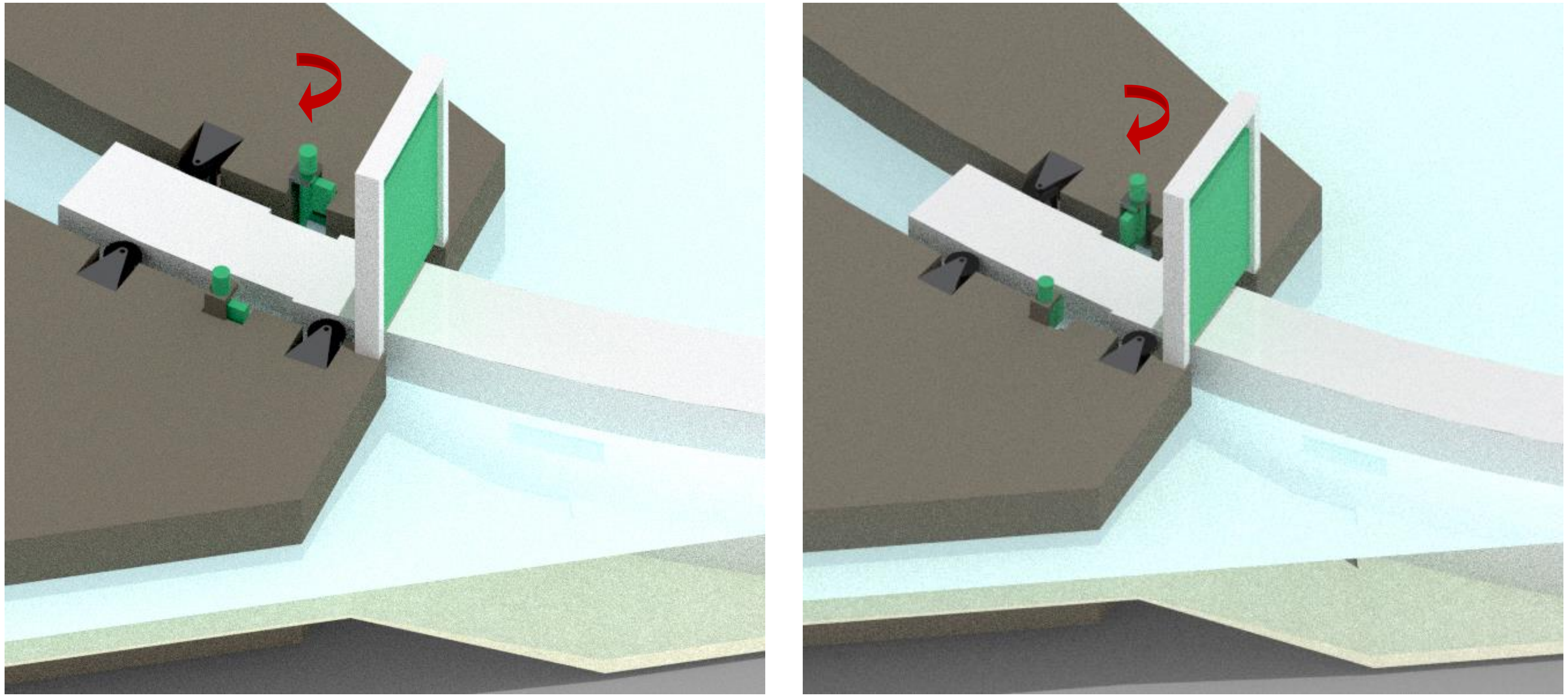
BArc Deployment System



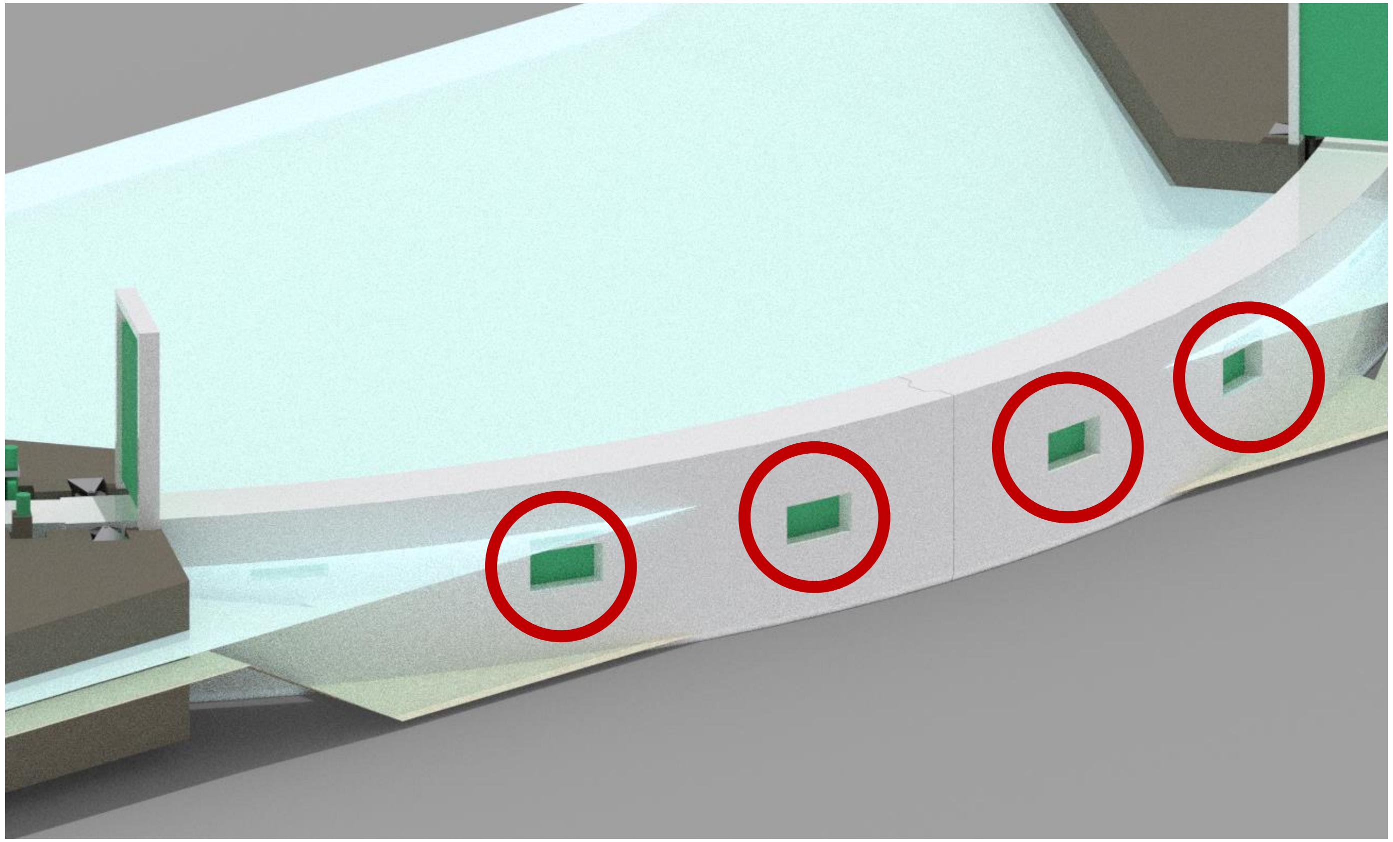
Doors to seal dry dock while barrier is stored



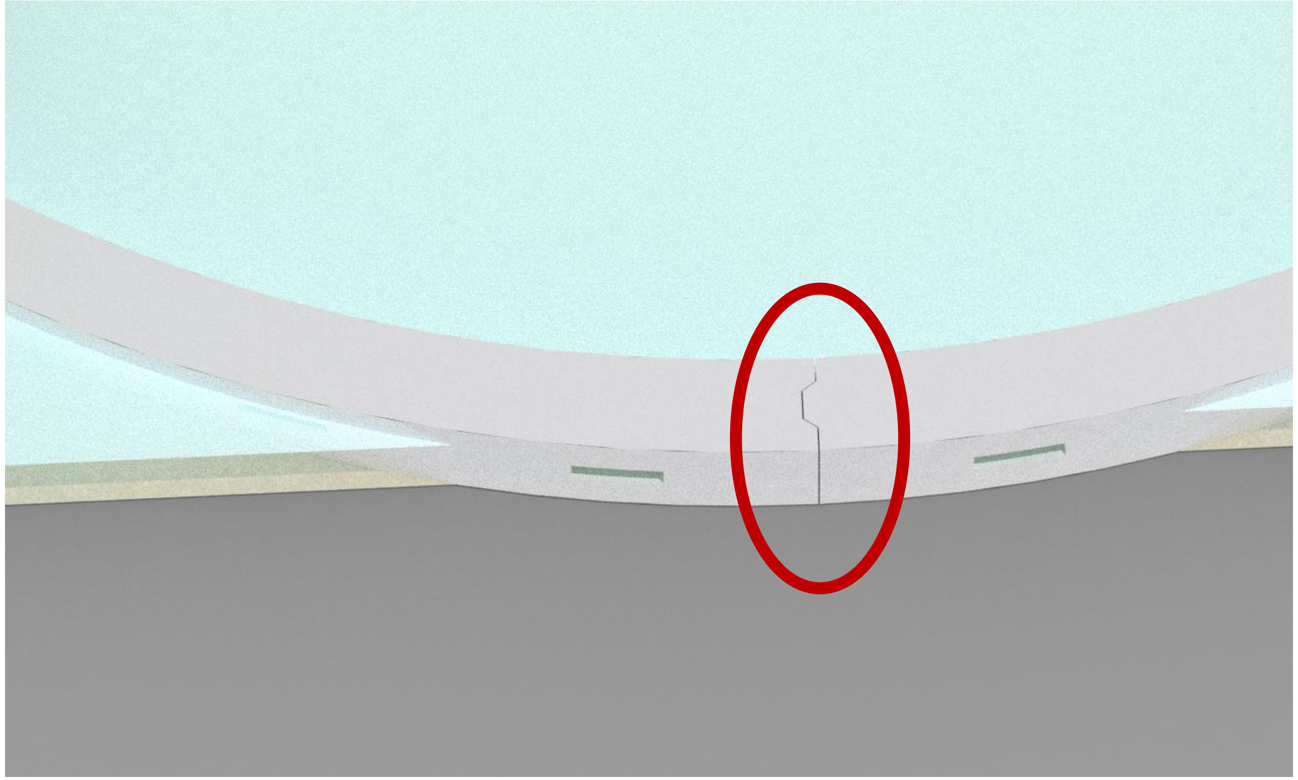
Rollers guide the arc into place during deployment



Pins engaging to provide axial thrust



Sluice Doors for Submerging and Backwater Release

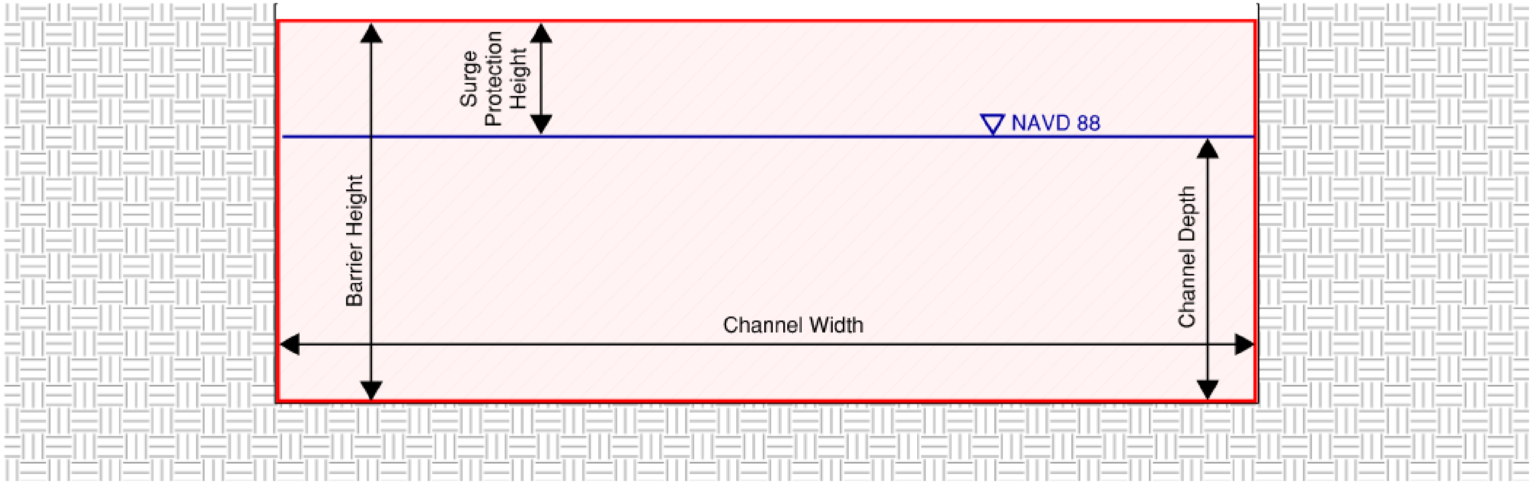


Segment Interlocking for Eccentric Loading

Appendix A: Load Calculations

LOAD CALCULATIONS

Barrier Scope



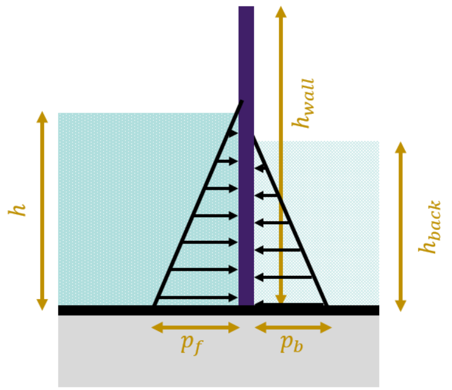
Elevation view of barrier face within channel

Quantity	**Alternative 1** (Full Channel)	**Alternative 2A** (Channel Deepening)	**Alternative 2B** (Channel Widening)
Channel Width (ft.)	1,200’	700’	900’
Channel Depth (ft.)	45’	65’	45’
Barrier Height (ft.)	70’	90’	70’
Surge Protection Height (ft.)	25’	25’	25’

LOAD CALCULATIONS

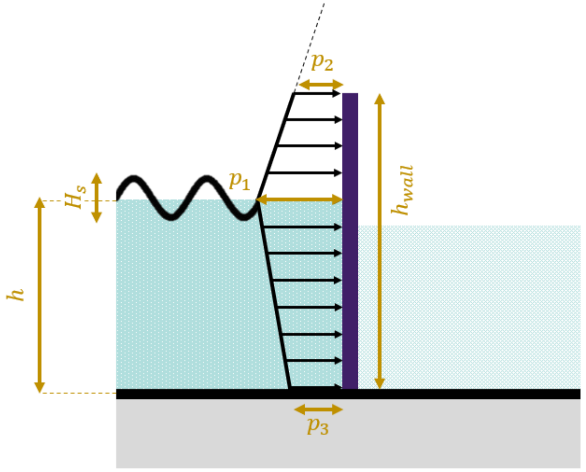
Alternative Design Scopes

Quantity	Working Value	Notes
Barrier Height h_{wall}	**Alt. 2A:** 90 $ft.$ **Alt. 1 & 2B:** 70 $ft.$	Chosen to allow a surge protection height of 25 $ft.$
Design Water Level h	**Alt. 2A:** 90 $ft.$ **Alt. 1 & 2B:** 70 $ft.$	Setting still water level $h = h_{wall}$ is conservative in design against barrier rupture
Significant Wave Height H_s	5 $ft.$	Assumed to be low because of position within bay*
Back Water Level h_{back}	**Alt. 2A:** 65 $ft.$ **Alt. 1 & 2B:** 45 $ft.$	Would be at least NAVD88



Static Load

Quantity	Units	Alternative 1 (Full Channel)	Alternative 2A (Channel Deepening)	Alternative 2B (Channel Widening)
Peak Wave Pressure (p_1)	psf	347	339	347
Top Wave Pressure (p_2)	psf	347	339	347
Base Wave Pressure (p_3)	psf	108	64	108
Uplift Wave Pressure (p_u)	psf	108	64	108
Total Wave Force per unit Barrier Length (q_w)	klf	16	18	16
Total Hydrostatic Force per unit Barrier Length (q_s)	klf	90	121	90
Total Projected Force Resisted	$\boldsymbol{kips}$	**132, 000**	**97, 300**	**95, 400**



Hydrodynamic Load