February 22, 2019: Systems Approaches for Resilient Infrastructure

Hampton Roads Sea Level Rise/Flooding Adaptation Forum

2-22-2019

Pivoting to the Future: Resiliency Planning in Virginia Beach

Steven J. Poe

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Steven J. Poe, PE, City of Virginia Beach
Stormwater Engineering Center

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Agenda

- Project Overview
- Hazards and Risk
- Adaptation Strategy Approach
- Policy Document Overview
- City-wide Structural Alternatives
- Next Steps

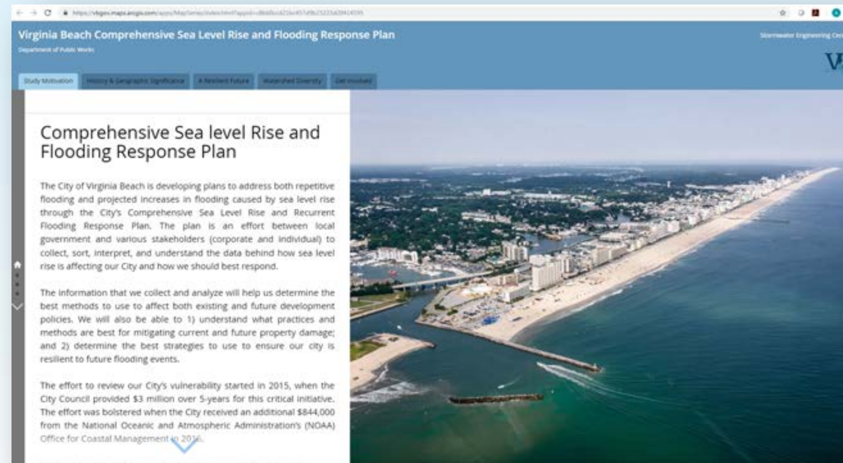
Project Overview

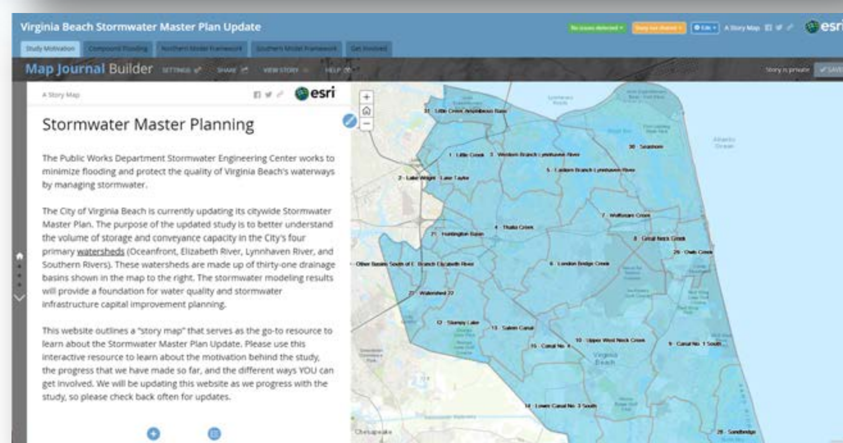
Ongoing Studies

- Comprehensive Sea Level Rise and Recurrent Flooding Study
  - Assessing existing and future flood vulnerabilities across the City's four unique watersheds
  - Identifying strategies to ensure our city is resilient to future flooding events

- Master Drainage Study
  - Detailed inventory of the City's stormwater system
  - Assessing the system's performance
  - Identifying deficiencies or needed improvements

Project Website:
http://www.vbgov.com/pwSLR





Study Approach

Timeline of Activities

2015 › 2016 › 2017 › 2018 › 2019

Planning (2015)
- Scenarios
- Conceptual model

Study Progression (2016)
- Grant award
- Hazard and risk assessment
- **Essential analysis to inform design**
- Stormwater coordination
- **Policy menu**

Strategy Focus (2017–2018)
- **Structural Alternatives**
  - **City-wide Concepts**
  - Performance
  - Down-selection
- **Policy refinement and rankings**

Synthesis (2019)
- Neighborhood and site alternatives
- Full Draft Adaptation Plan
- Stakeholder outreach and input

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Hazards and Risk

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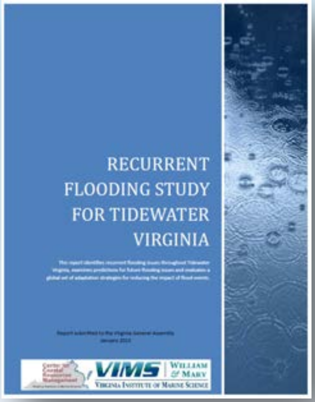
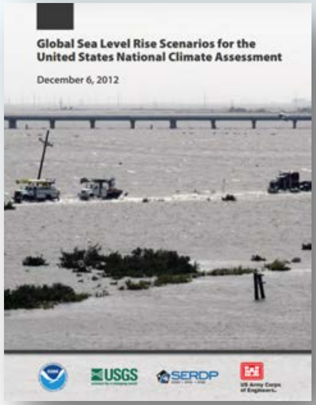
VB SLR Planning Scenarios

Life Cycle Alignment	Time Horizon/ Time Period	SLR Value	Relevance	Use
Municipal Planning	20-40 years 2035-2055	1.5 ft	Comprehensive Plan & Outcomes Commercial and Utility life-cycles	Vulnerability assessment Key planning value Basis for evaluation of all adaptation strategies
Critical Infrastructure Long-term awareness Adaptive Capacity	50-70 years 2065-2085	3.0 ft	Utility Infrastructure life-cycle Transportation infrastructure lifecycles Residential structure lifecycles	Secondary vulnerability assessment to provide insight into long-term risk Basis for long-term infrastructure decisions Evaluate cost-effectiveness of additional protection for adaptable resilience strategies






HAMPTON ROADS PDC

HAMPTON ROADS PLANNING DISTRICT COMMISSION
RESOLUTION 2018-01

RESOLUTION OF THE HAMPTON ROADS PLANNING DISTRICT COMMISSION ENCOURAGING LOCAL GOVERNMENTS IN HAMPTON ROADS TO CONSIDER ADOPTING POLICIES TO INCORPORATE SEA LEVEL RISE INTO PLANNING AND ENGINEERING DECISIONS

Whereas, the tide gauge at Sewell's Point in Norfolk has recorded nearly 1.4 feet of relative sea level rise since 1927, equivalent to a change of 1.52 feet per 100 years.

Whereas, reports by the Hampton Roads Planning District Commission staff have found the Hampton Roads region to be vulnerable to flooding and sea level rise.

Whereas, the "Recurrent Flooding Study for Tidewater Virginia," completed in 2013 at the request of the General Assembly by the Center for Coastal Resources Management of the Virginia Institute of Marine Science, found that "recurrent flooding is a significant issue in Virginia coastal localities and one that is predicted to become worse over reasonable planning horizons."

Whereas, several federal agencies have found, as described in the technical report, "Global and Regional Sea Level Rise Scenarios for the United States," published in 2017, that "long-term sea level rise driven by global climate change presents clear and highly consequential risks to the United States over the coming decades and centuries."

Whereas, the Virginia Institute of Marine Science published, in 2018, a "Sea-Level Report Card" for Norfolk, Virginia, that projected relative sea level rise of 1.61 feet of sea level rise between 1992 and 2050, with a 95% confidence that sea level will rise between 0.95 feet and 2.20 feet over the same interval.

Observed Acceleration

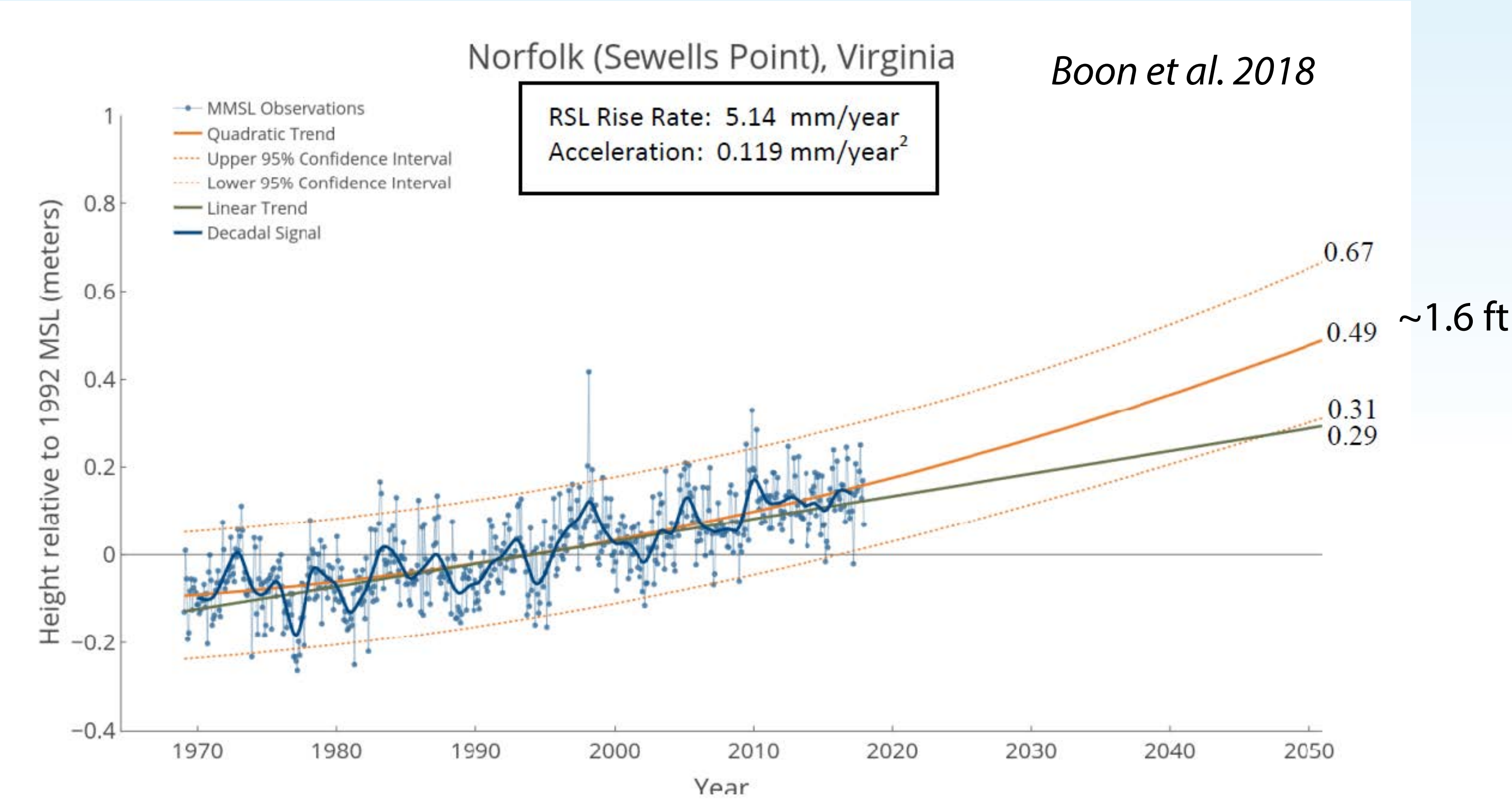
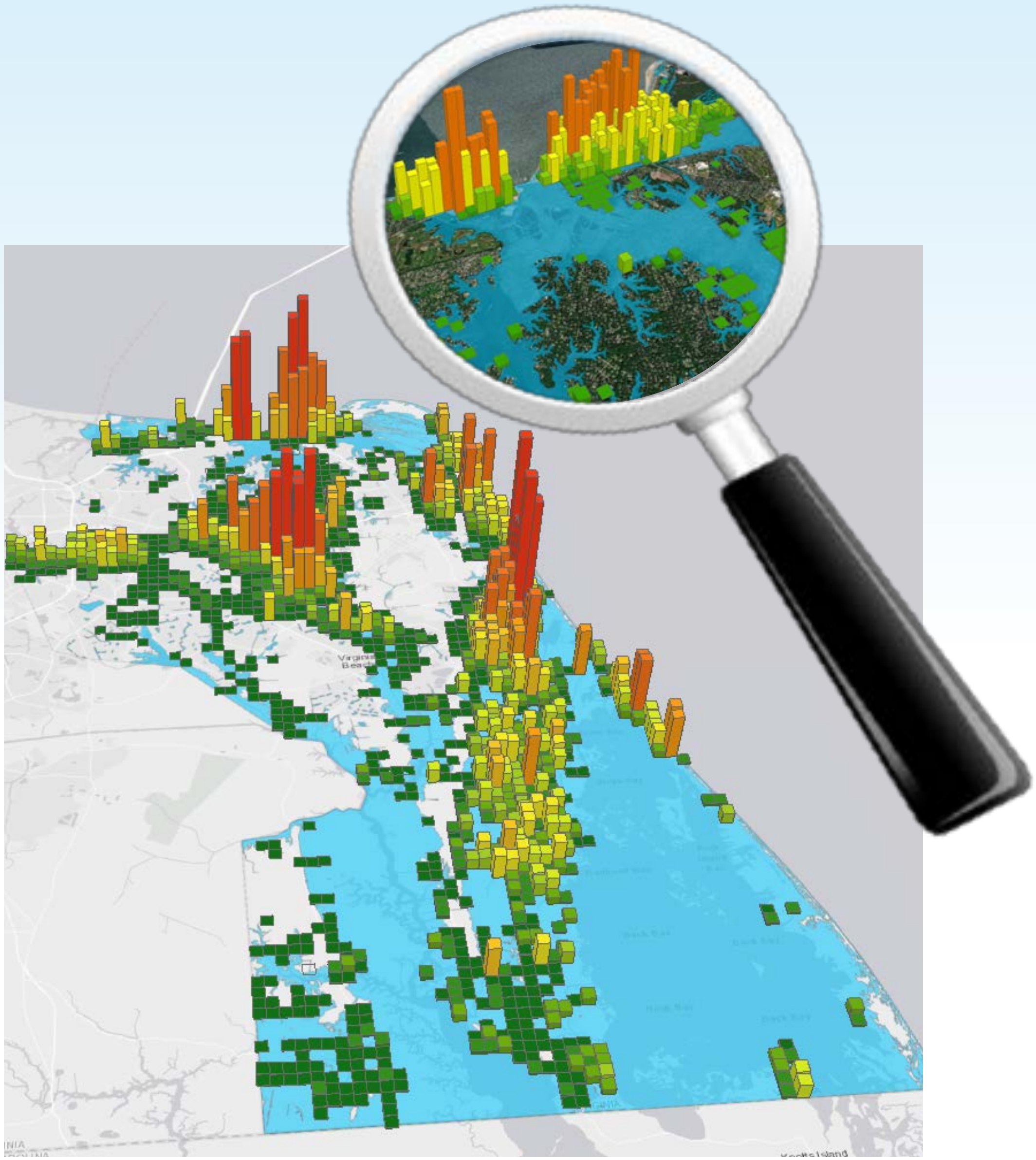


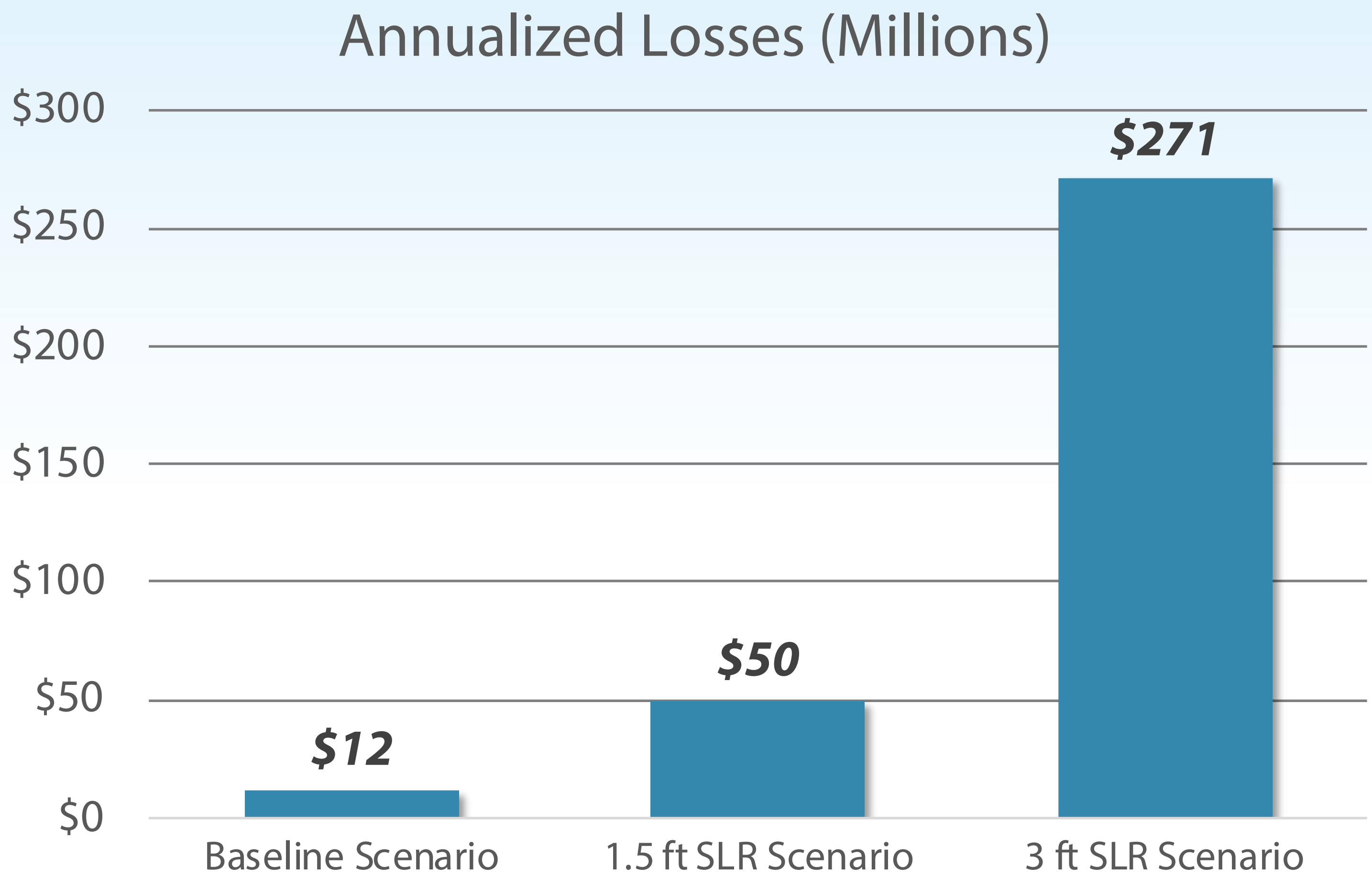
Figure III-4. Relative sea level trends, Norfolk, Virginia, 1969-2017 series

Impacts


HAZUS MH
EARTHQUAKE • WIND • FLOOD
Construction quality
Occupancy type
Replacement value
Contents value
Age
Finished floor elevation

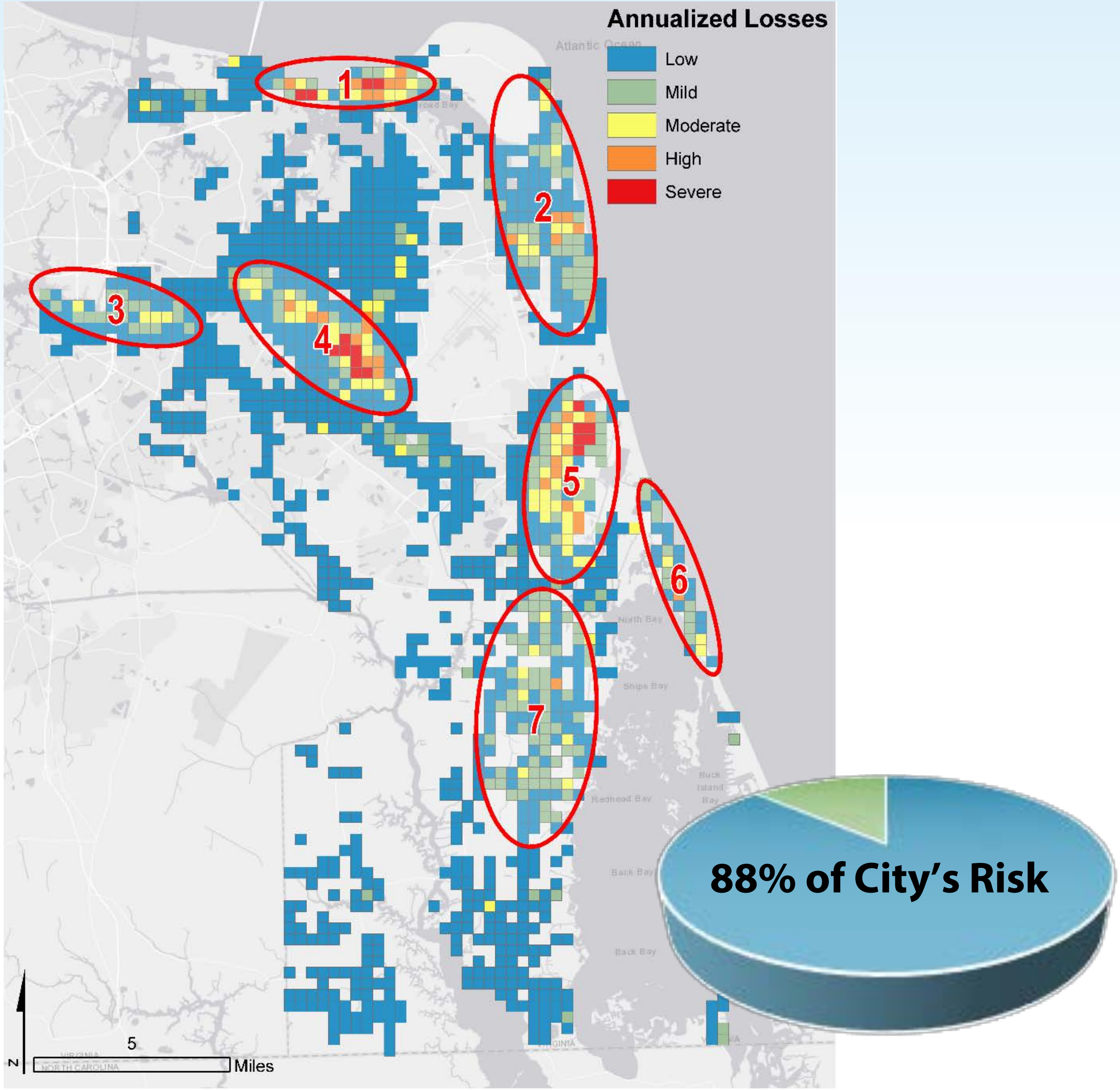


Consequences of Future Without Action



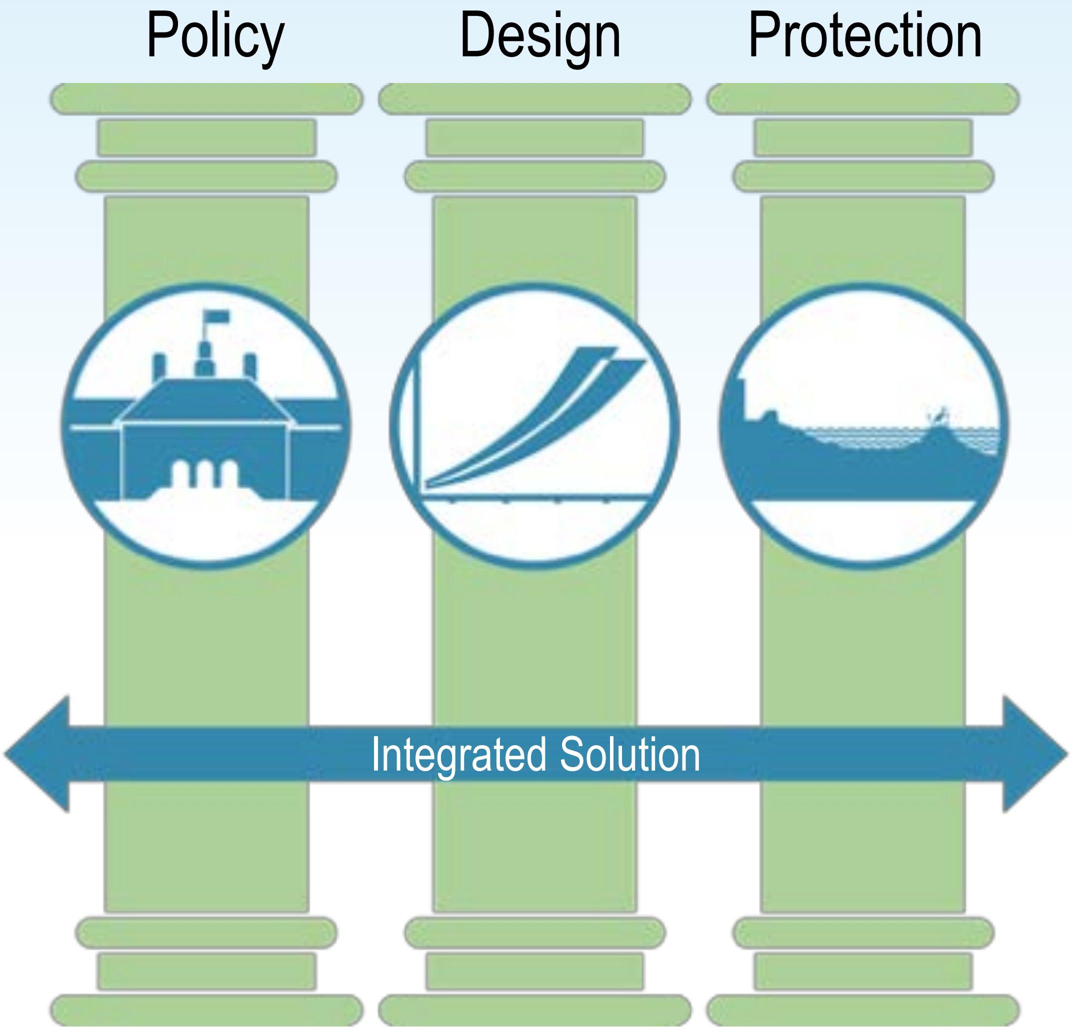
Compared to Today: ***4x increase*** ***23x increase***

Focus Areas for Adaptation



Adaptation Strategies

Adaptation Strategies



Policy Document Overview

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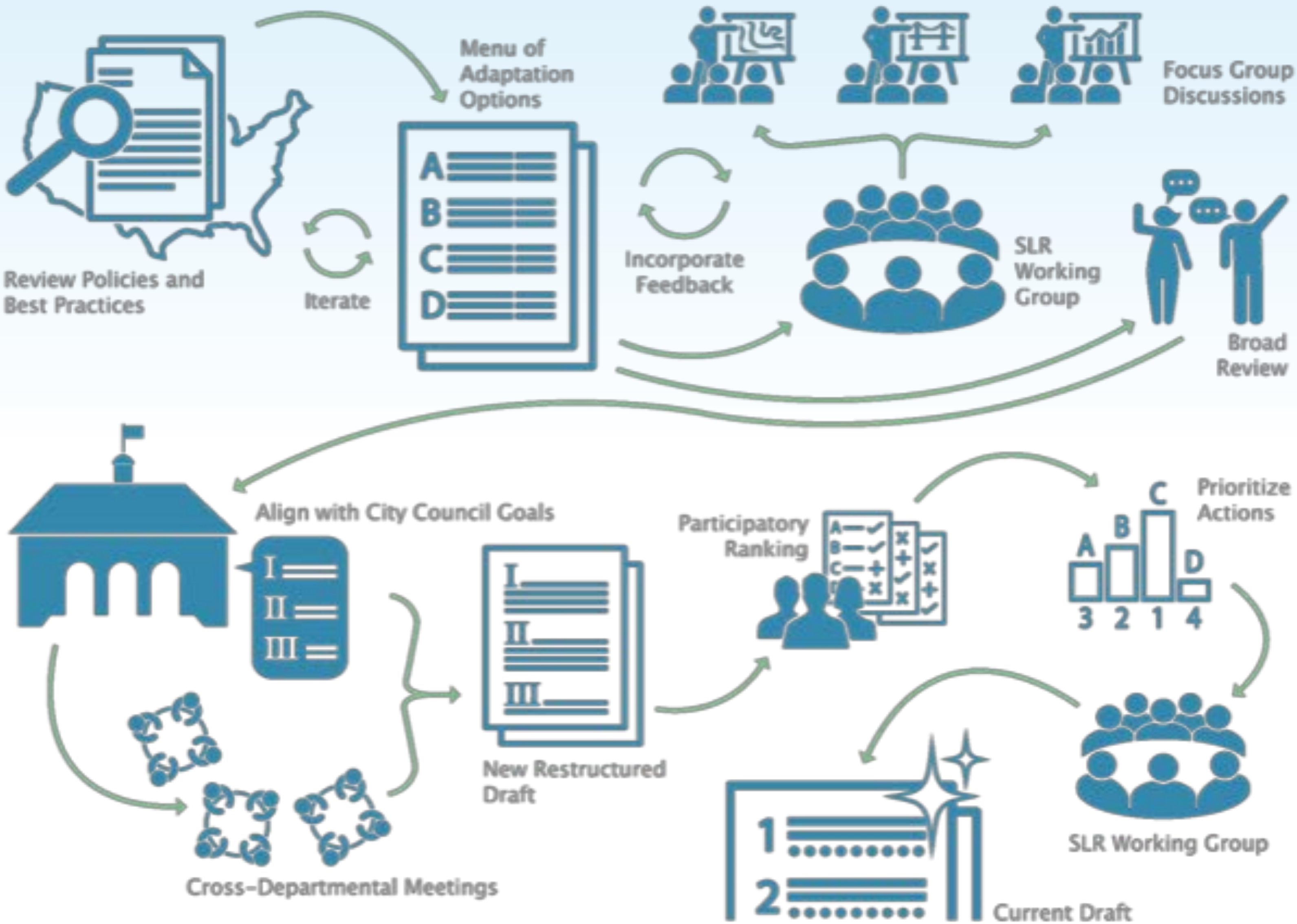
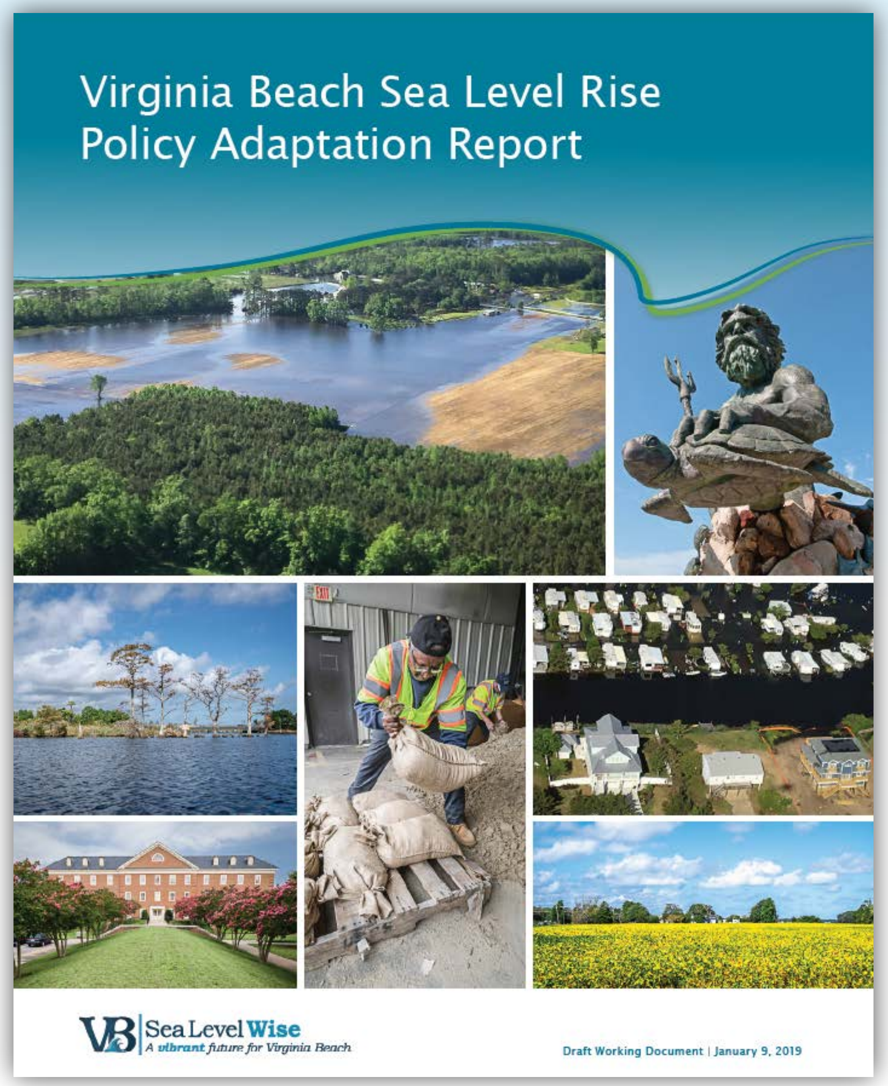
Policy Process



Policy Document

- What it represents:
  - Guidelines for instilling best practices to reduce long-term flood risk
  - Starting place for evaluation and implementation by City
  - Unique reflection of City staff perspective and priorities
  - Policy goals set up to match City Council goals*
- Not a prescriptive document to be followed “to the letter”



*A Strategic Plan to Achieve City Council's Vision for the Future and 2017 - 2022 City Council Goals

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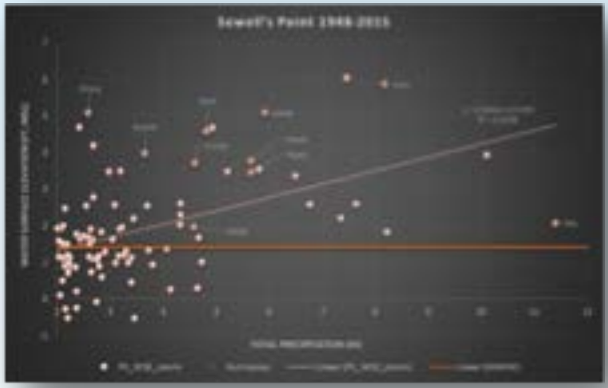
Implementation Vision

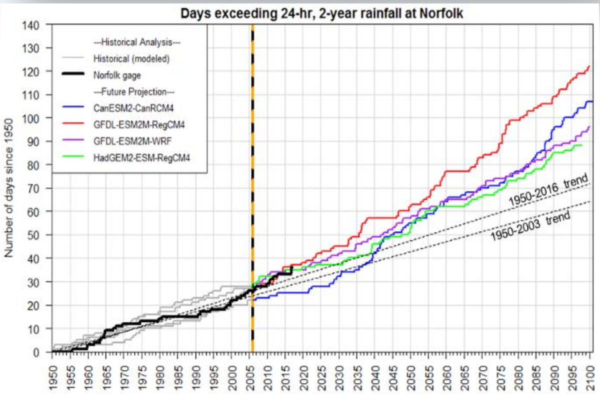
- Administered and monitored by the Deputy City Manager SLR Working Group
- Responsibility will be assigned for action items to City departments/staff
- City staff will interpret and evaluate the action items and implement the action in general reflection of priorities
- Implementation will occur after public comment

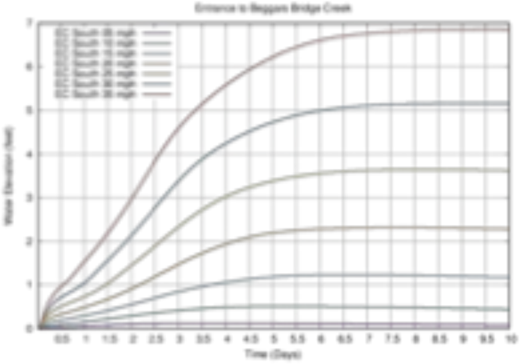
Informing Design

Informing Design

- Rainfall/surge correlation
  - >50% of rainfall events occur during elevated water levels
- Joint-probability of rainfall/storm surge
  - Concurrent rainfall/surge design values
- Regional Precipitation Trends
  - Atlas 14 outdated
  - Heavy rainfall increasing, 20% needed over design life cycle
- Probable maximum event precipitation
  - Design "check storm"
- Wind Tides
  - Water level response to wind tide conditions
  - Minimum design tailwaters







Stormwater Design Standard Outputs

Table VIII-0 Design Rainfall Depths for City of Virginia Beach (in.)		
Design Frequency	NOAA Atlas 14 Rainfall	**Design Rainfall (NOAA Atlas 14 + 20%)**
1-YR	3.00	**3.60**
2-YR	3.65	**4.38**
10-YR	5.64	**6.77**
25-YR	6.99	**8.39**
50-YR	8.16	**9.79**
100-YR	9.45	**11.34**

Note: NOAA Atlas 14 precipitation depths do not vary significantly across the City (generally < 0.1" difference). The NOAA 14 rainfall values shown above represent the area northeast of Naval Air Station Oceana.

Table VIII-1A
Design Storm/Tide Joint Probability Pairs for Determining Controlling Tailwater Elevation

10-YR Design		25-YR Design		50-YR Design		100-YR Design	
Tide	**Rain**	**Tide**	**Rain**	**Tide**	**Rain**	**Tide**	**Rain**
10-YR	1-YR	25-YR	1-YR	50-YR	1-YR	100-YR	1-YR
1-YR	10-YR	2-YR	25-YR	2-YR	50-YR	3-YR	100-YR

Note: Refer to ***Table J-12*** *Design Tidal Elevations for Virginia Beach* in ***Appendix J*** for corresponding tide elevations. Refer to ***Table 8III-0*** *Rainfall Depths for City of Virginia Beach* for corresponding rainfall depths and ***Table J-13*** *24-Hour Rainfall Distributions for Virginia Beach* in ***Appendix J*** for corresponding rainfall distribution.

Note: Joint probability pairs represent the highest-frequency tide with the lowest-frequency rainfall and the highest-frequency rainfall with the lowest-frequency tide for each design frequency, as informed by joint probability studies undertaken by the City. Please refer to the City of Virginia Beach study titled "Joint Occurrence and Probabilities of Tides and Rainfall," dated October 2017 (CIP 7-030, PWCN-15-0014, Work Orders 2 and 5A) for additional information.

Table J-12
Design Tidal Elevations for Virginia Beach
All Elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

Location	**Design Level**	**1-YR**	**2-YR**	**3-YR**	**5-YR**	**10-YR**	**25-YR**	**50-YR**	**100-YR**	**500-YR**
Lynnhaven Bay & River, Eastern Branch	Existing Condition	3.1	3.6	4.0	4.4	5.2	5.8	6.2	6.7	8.5
	1.5 ft SLR	4.6	5.1	5.5	5.9	6.7	7.3	7.7	8.2	10.0
	3.0 ft SLR	6.3	6.9	7.3	7.7	8.5	9.2	9.6	10.1	12.0
Lynnhaven Bay & River, Incl. all areas other than Eastern Branch	Existing Condition	3.2	3.9	4.3	4.8	5.5	6.3	6.9	7.4	9.3
	1.5 ft SLR	4.7	5.4	5.8	6.3	7.0	7.8	8.4	8.9	10.8
	3.0 ft SLR	6.4	7.2	7.6	8.1	8.8	9.7	10.3	10.8	12.8
Chesapeake Bay	Existing Condition	3.2	3.8	4.1	4.5	5.2	5.9	6.5	7.1	8.5
	1.5 ft SLR	4.7	5.3	5.6	6.0	6.7	7.4	8.0	8.6	10.0
	3.0 ft SLR	6.4	7.1	7.4	7.8	8.5	9.3	9.9	10.5	12.0
Atlantic Ocean & Rudee Inlet	Existing Condition	3.6	4.1	4.5	4.9	5.4	6.3	6.8	7.3	8.7
	1.5 ft SLR	5.1	5.6	6.0	6.4	6.9	7.8	8.3	8.8	10.2
	3.0 ft SLR	7.2	7.7	8.2	8.6	9.2	10.1	10.7	11.2	12.8
Back Bay, North of Beggars Bridge Creek	Existing Condition	-	-	-	-	2.4	3.4	4.2	4.9	6.4
	1.5 ft SLR	-	-	-	-	3.9	4.9	5.7	6.4	7.9
	3.0 ft SLR	-	-	-	-	7.6	9.0	10.1	11.1	13.2
Back Bay, South of Beggars Bridge Creek	Existing Condition	-	-	-	-	-	2.4	2.8	3.3	4.2
	1.5 ft SLR	-	-	-	-	-	3.9	4.3	4.8	5.7
	3.0 ft SLR	-	-	-	-	-	7.6	8.1	8.8	10.1
North Landing River	Existing Condition	-	-	-	-	-	2.8	3.4	3.9	4.9
	1.5 ft SLR	-	-	-	-	-	4.3	4.9	5.4	6.4
	3.0 ft SLR	-	-	-	-	-	6.3	6.9	7.5	8.5
Elizabeth River	Existing Condition	2.8	3.6	4.1	4.7	5.8	6.5	7.1	7.9	10.3
	1.5 ft SLR	4.3	5.1	5.6	6.2	7.3	8.0	8.6	9.4	11.8
	3.0 ft SLR	5.9	6.7	7.2	7.8	8.9	9.6	10.2	11.0	13.4

Notes:

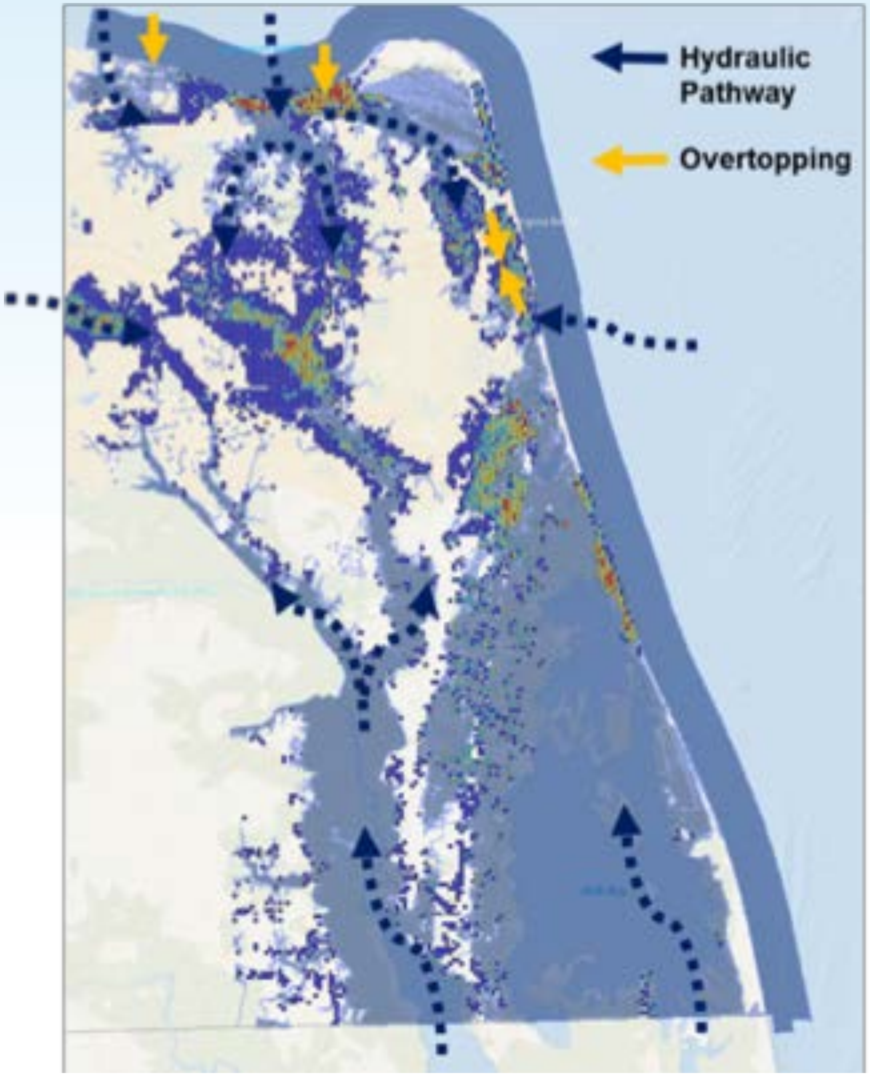
1. All elevations sourced from direct sampling and statistical analysis of the distribution of water elevations in each watershed
2. Lynnhaven, Elizabeth River, and Atlantic Ocean elevations were sourced from the 2015 FEMA Flood Insurance Study
3. Back Bay and North Landing River elevations were sourced from CIP 7-030, PWCN-15-0014, WO2A
4. The values do not represent potential wind-driven water levels in the Back Bay and North Landing River
5. Back Bay and North Landing River tailwater values have been limited to return periods where tailwater elevations are above recurring wind tides.
6. Conditions related to a 3-ft rise in sea level include non-linear increases derived from numerical modeling completed by the U.S. Army Corps of Engineers and the North Carolina Floodplain Mapping Program

Structural Protection

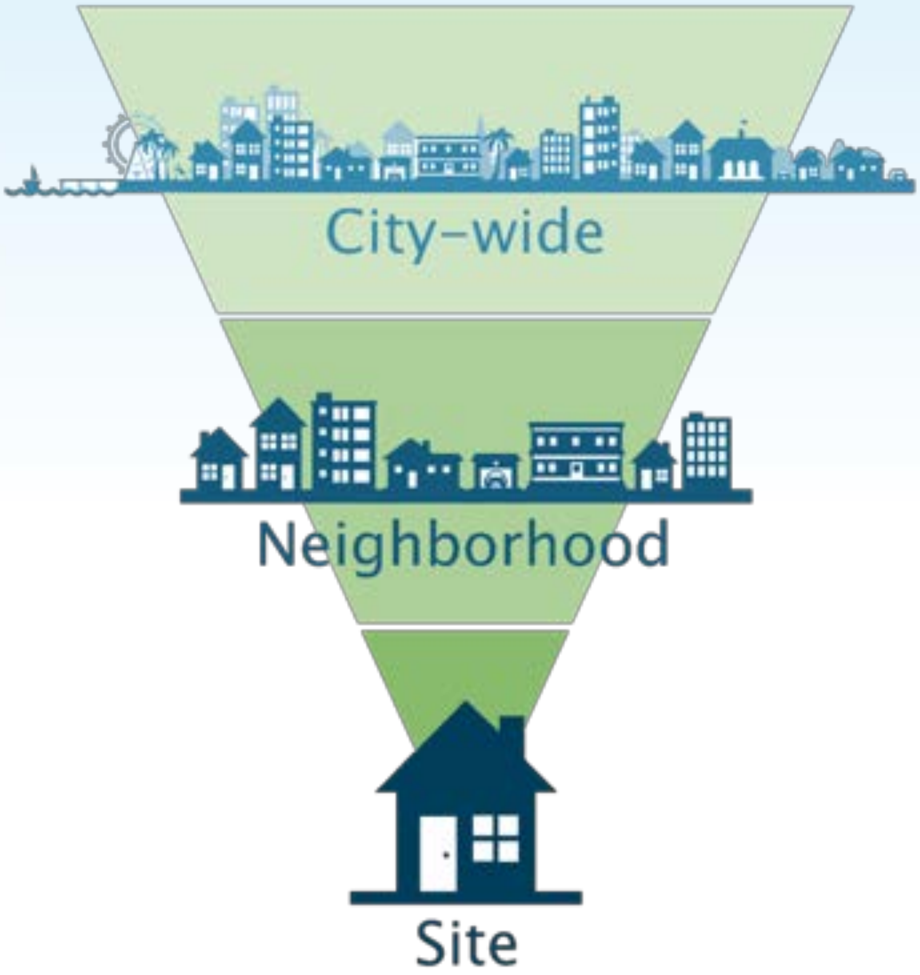
Structural Flood Risk Reduction

Key Activities:

- Investigate coastal flood pathways
- Identify locations for flood risk reduction
- Develop flood risk reduction alternatives
- Assess feasibility and performance
- Provide recommendations



Structural Alternative Levels



Protect Most of City
Designed to Future 100-yr flood
Cost: High (Billions)

Protect High Risk Areas
Designed to Future 10- to 50-yr flood
Cost: Moderate (100s Millions)

Address High Risk Properties
Alternative to Structures
Cost: Low to Moderate (Millions)

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City-wide Protection Alternatives

- Limitations:
  - High-level concepts
  - Alignments based on desktop analysis
  - Each alignment will have major impacts and concerns which are not captured in detail
    - Drainage, Environmental, Traffic and Circulation, Navigation, Real Estate, Costs, Constructability, etc…
  - *Initial results today – final results pending*

Coastal Flood Protection Toolkit

Putting the Pieces Together

- Collaborative review of possible alignments
- Identifying combinations of alignments
- Culling options

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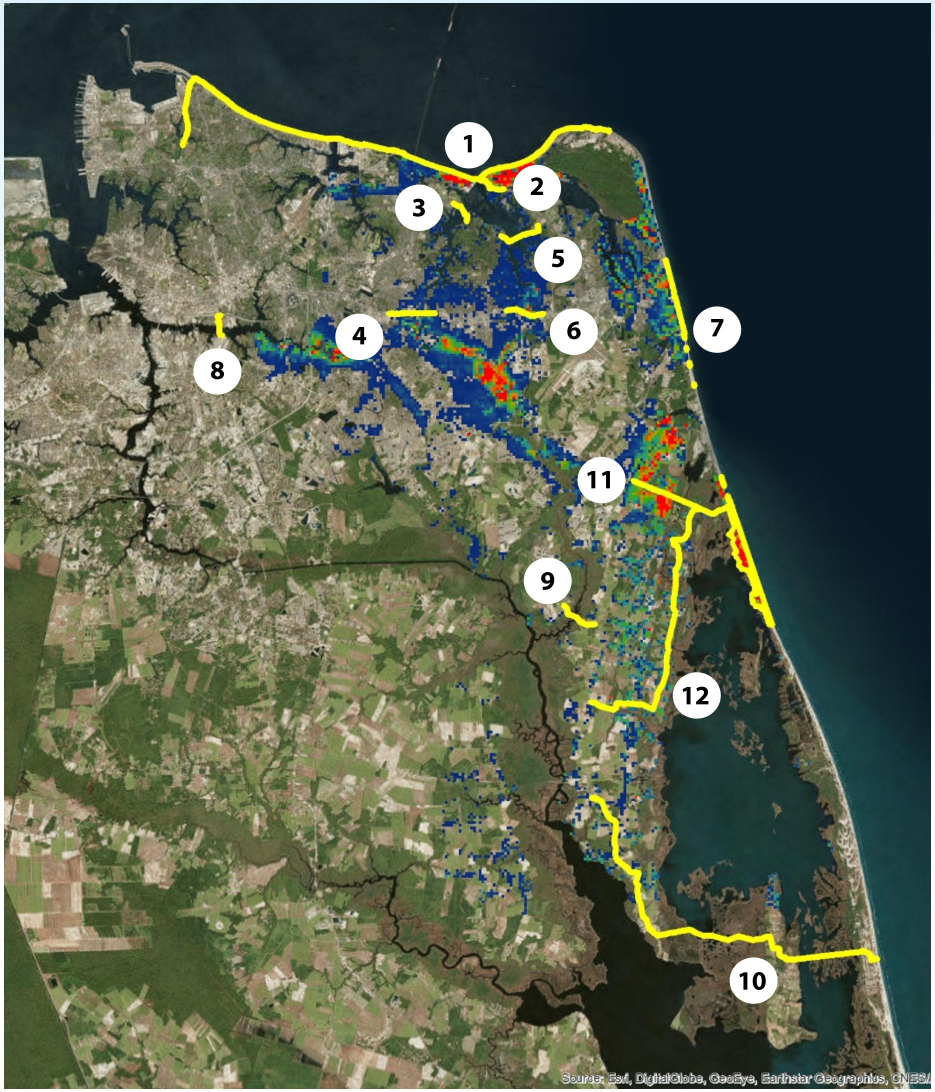
Conceptualized Alignment Locations

1. Lynnhaven Inlet
2. Long Canal
3. Upper West Branch Lynnhaven
4. ~~Lower West Branch Lynnhaven~~
5. Upper East Branch Lynnhaven
6. ~~Lower East Branch Lynnhaven~~
7. Rudee Inlet
8. Elizabeth River
9. West Neck Creek Bridge
10. Knotts Island
11. Sandbridge Road
12. Muddy Creek Road



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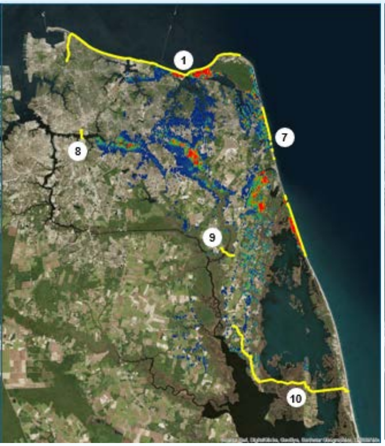
Combinations for Evaluation

Alternative 1



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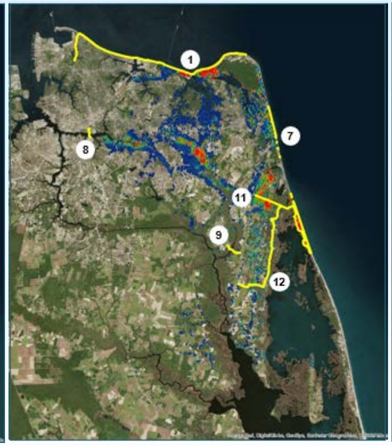

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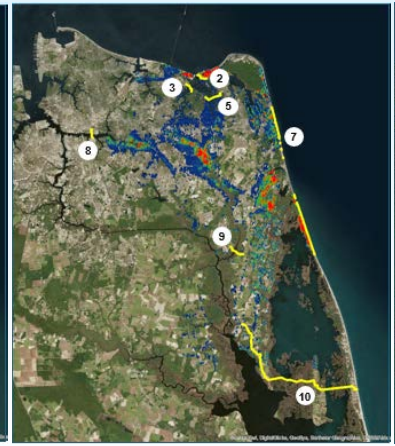

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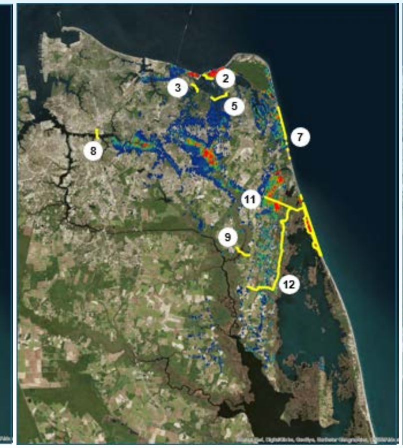
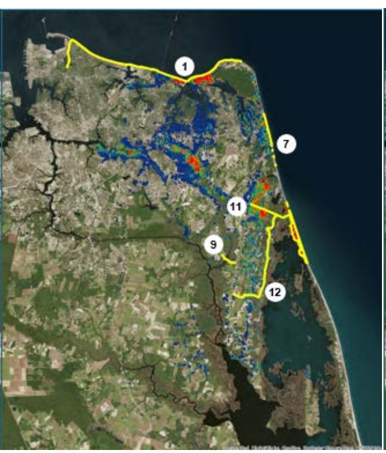


Alternative 5

Alternative 6



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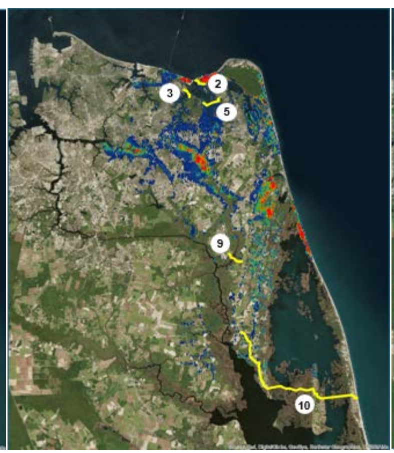

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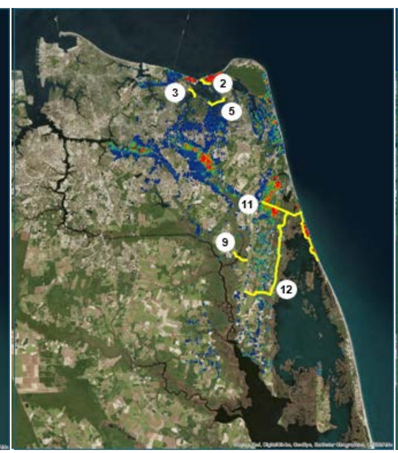

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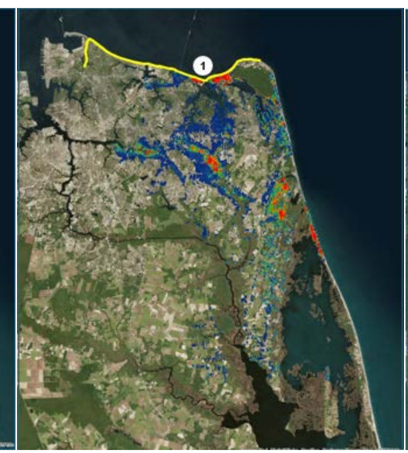

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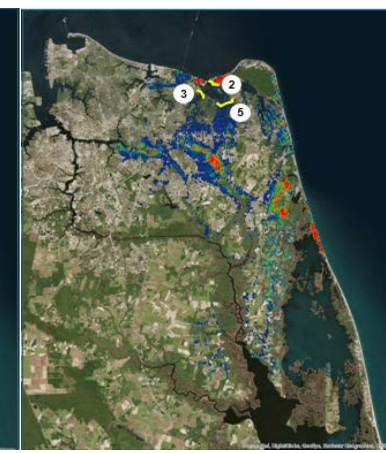
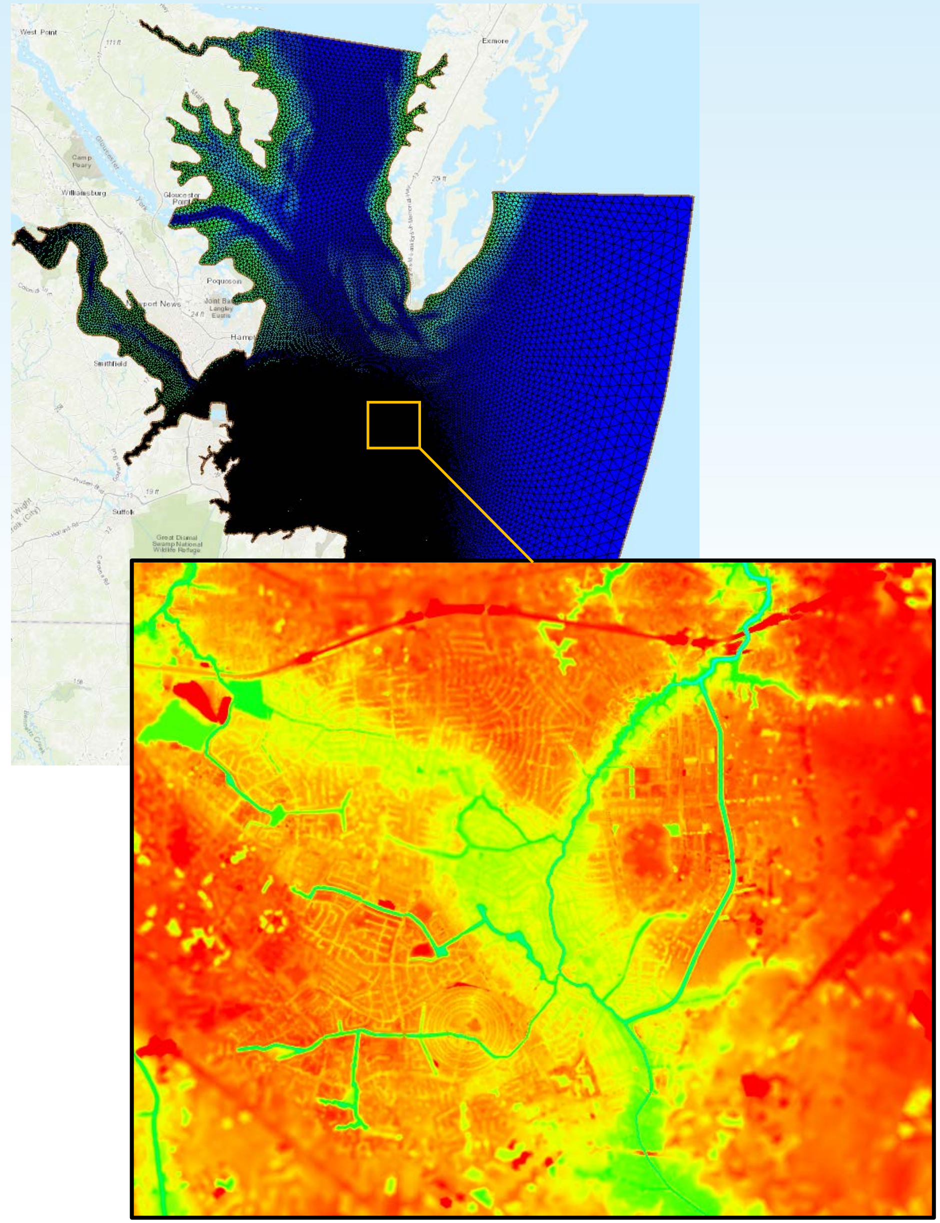


Model Evaluation

- DHI MIKE21
- Stormwater runoff via MIKE FLOOD
- Tidal calibrated, validated
- 10-/100-yr surge forcing with/without 10-yr runoff
- Structure implementation
- Flood depth benefits and adverse impacts



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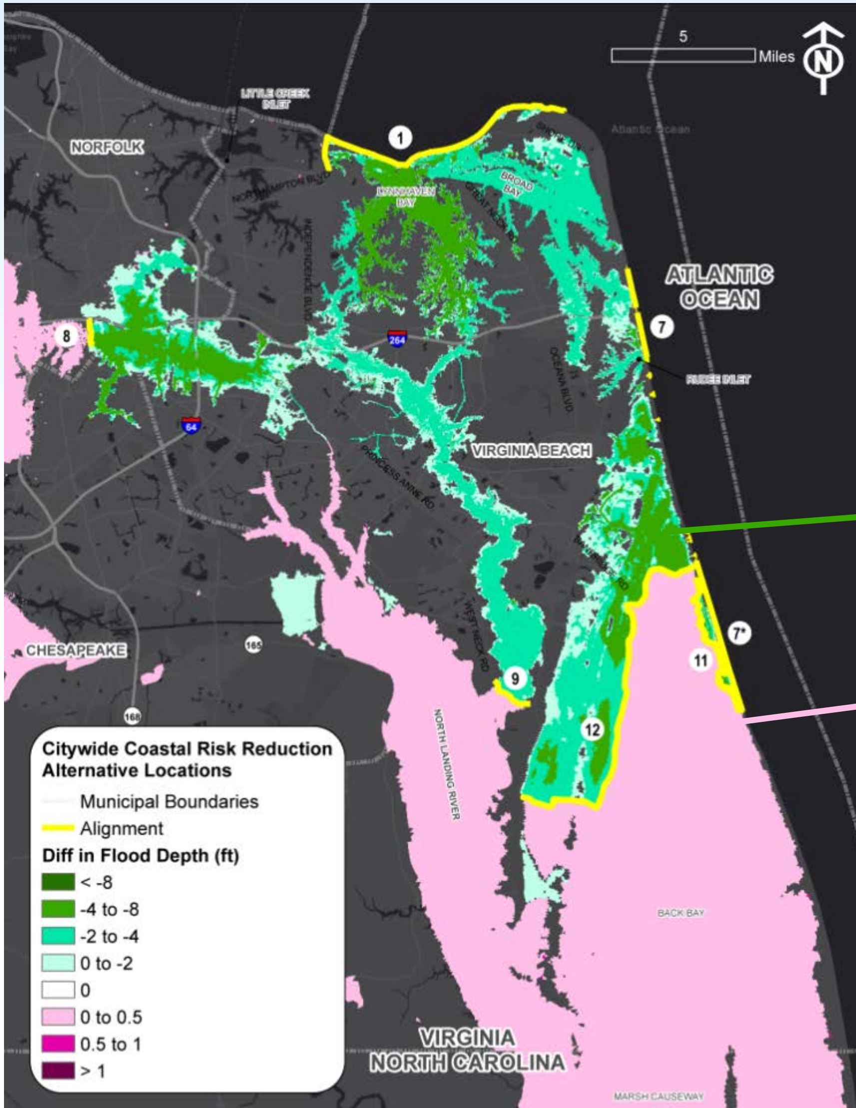
Model Evaluation Benefits and Impacts



Areas of Benefit (reduced flood depth)

Areas of Adverse Impact (increased flood depth)

FOR INFORMATIONAL PURPOSES
Initial values shown, currently under refinement

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Conceptual Alignments

1. Lynnhaven Inlet
2. Long Canal
3. Upper West Branch Lynnhaven
4. ~~Lower West Branch Lynnhaven~~
5. Upper East Branch Lynnhaven
6. ~~Lower East Branch Lynnhaven~~
7. Rudee Inlet
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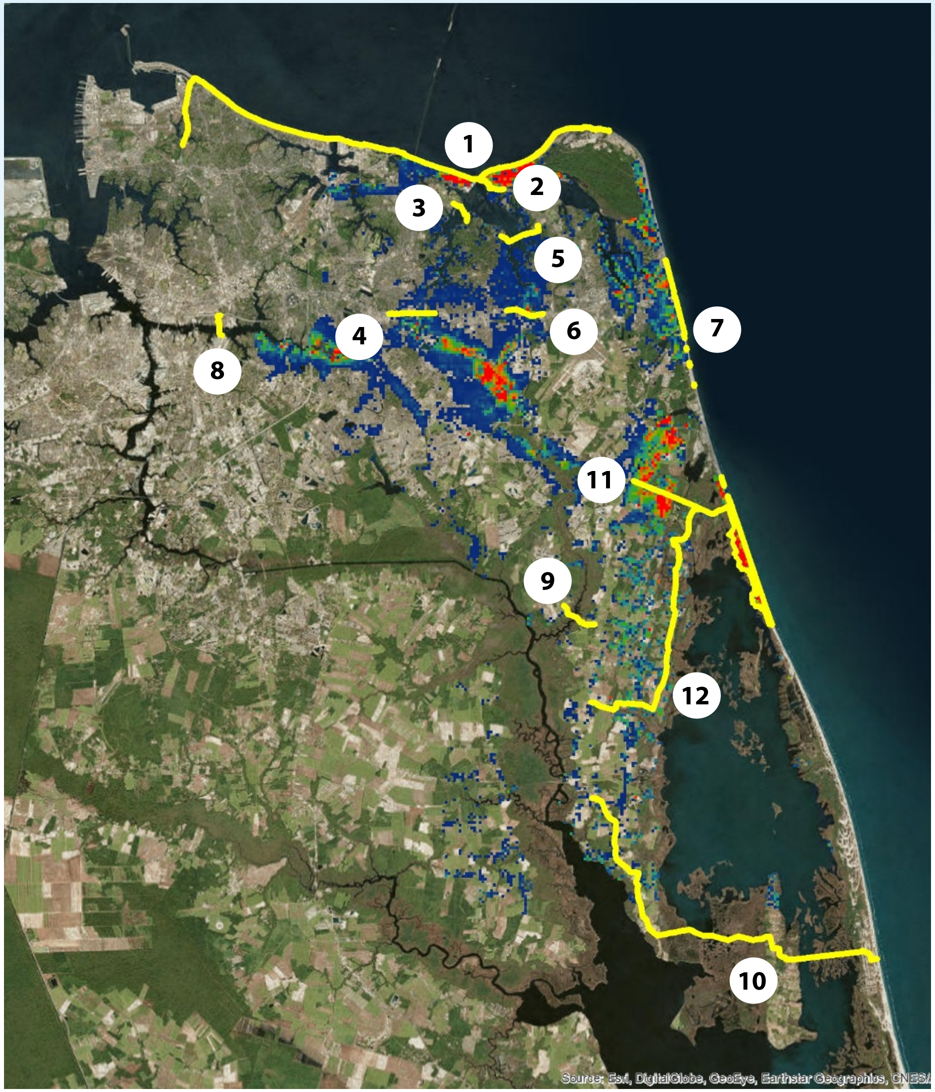

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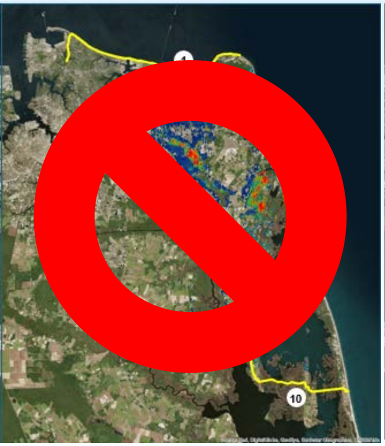
Down-selection of Alternatives

Alternative 1



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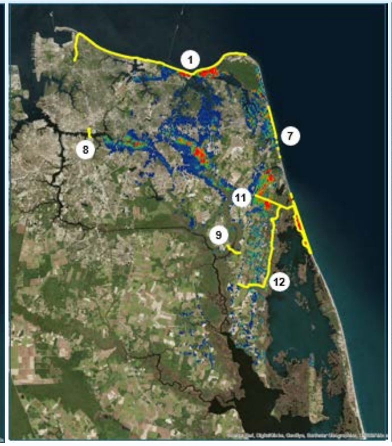
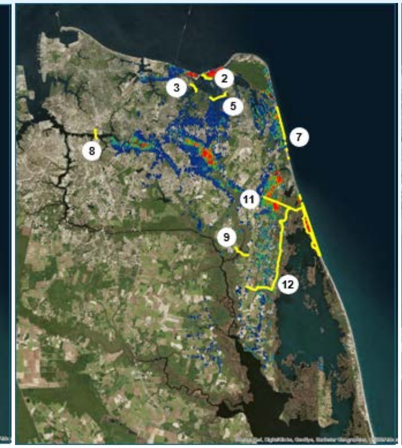


Alternative 3

Alternative 4



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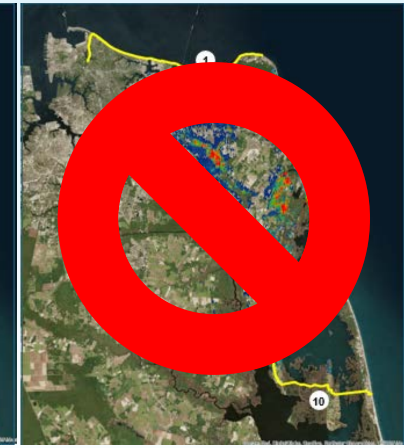

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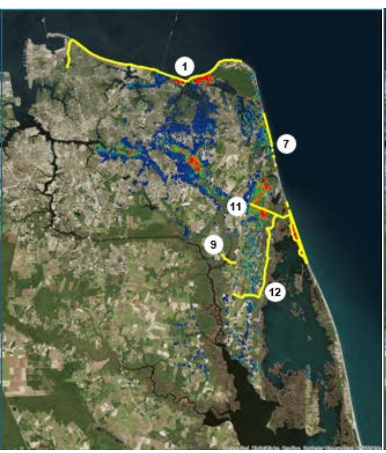
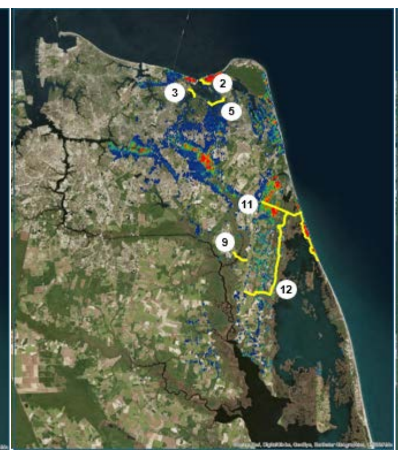


Alternative 7

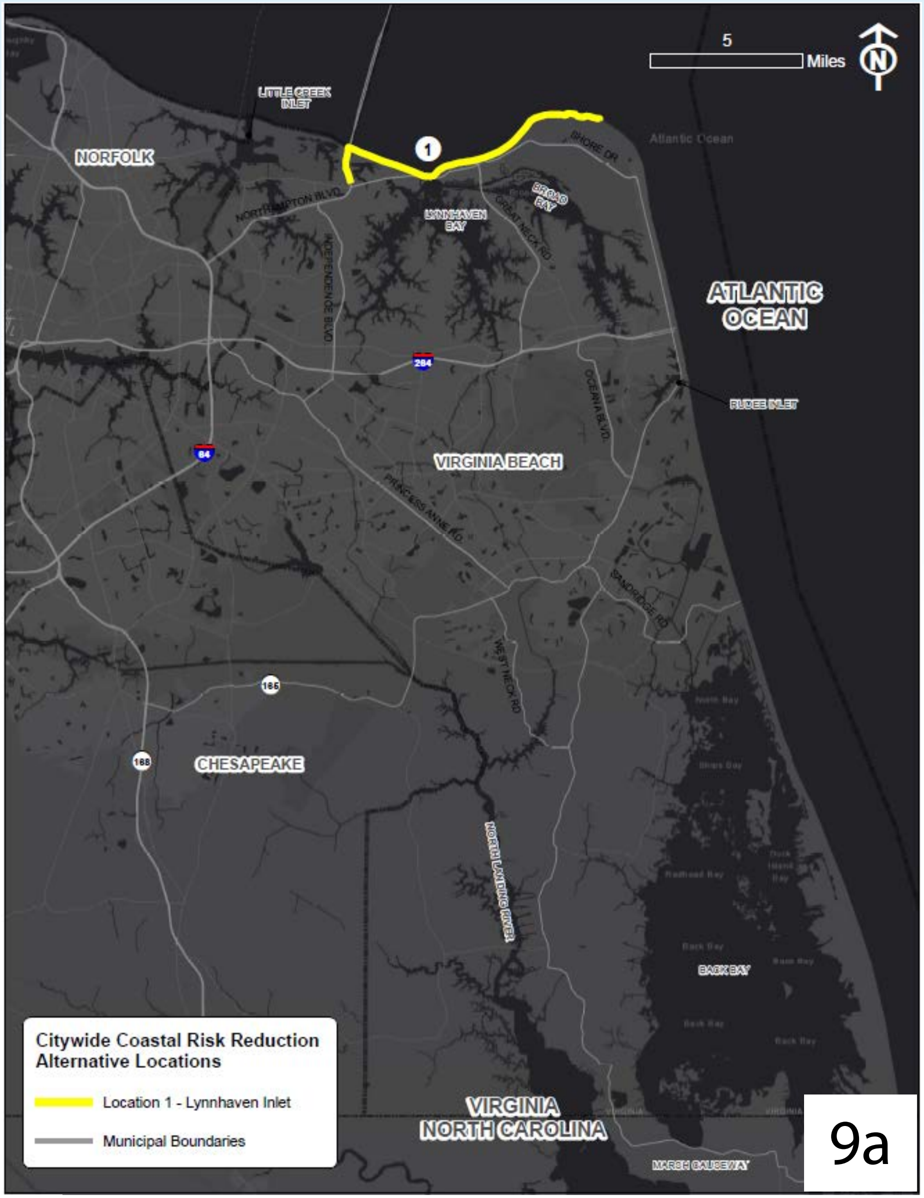
Alternative 8

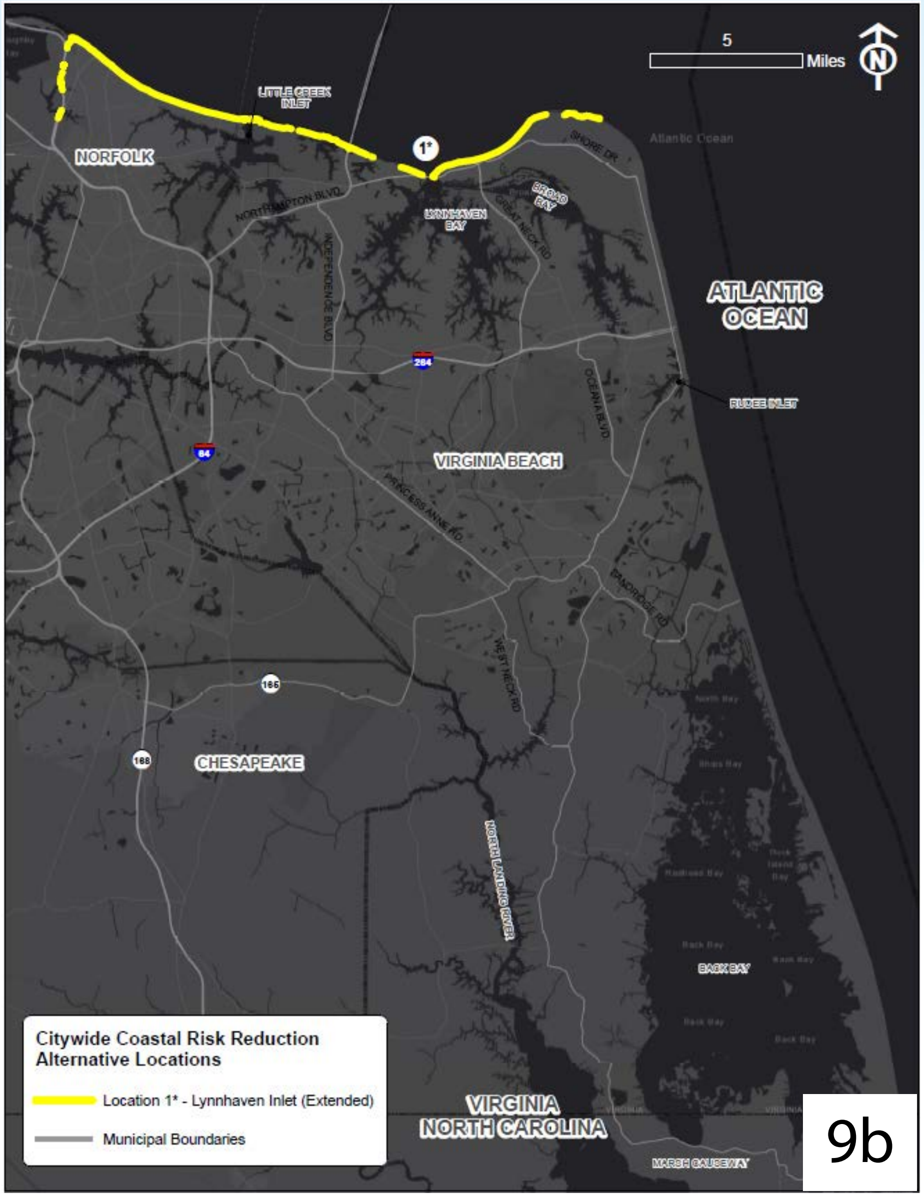


Alternative 9

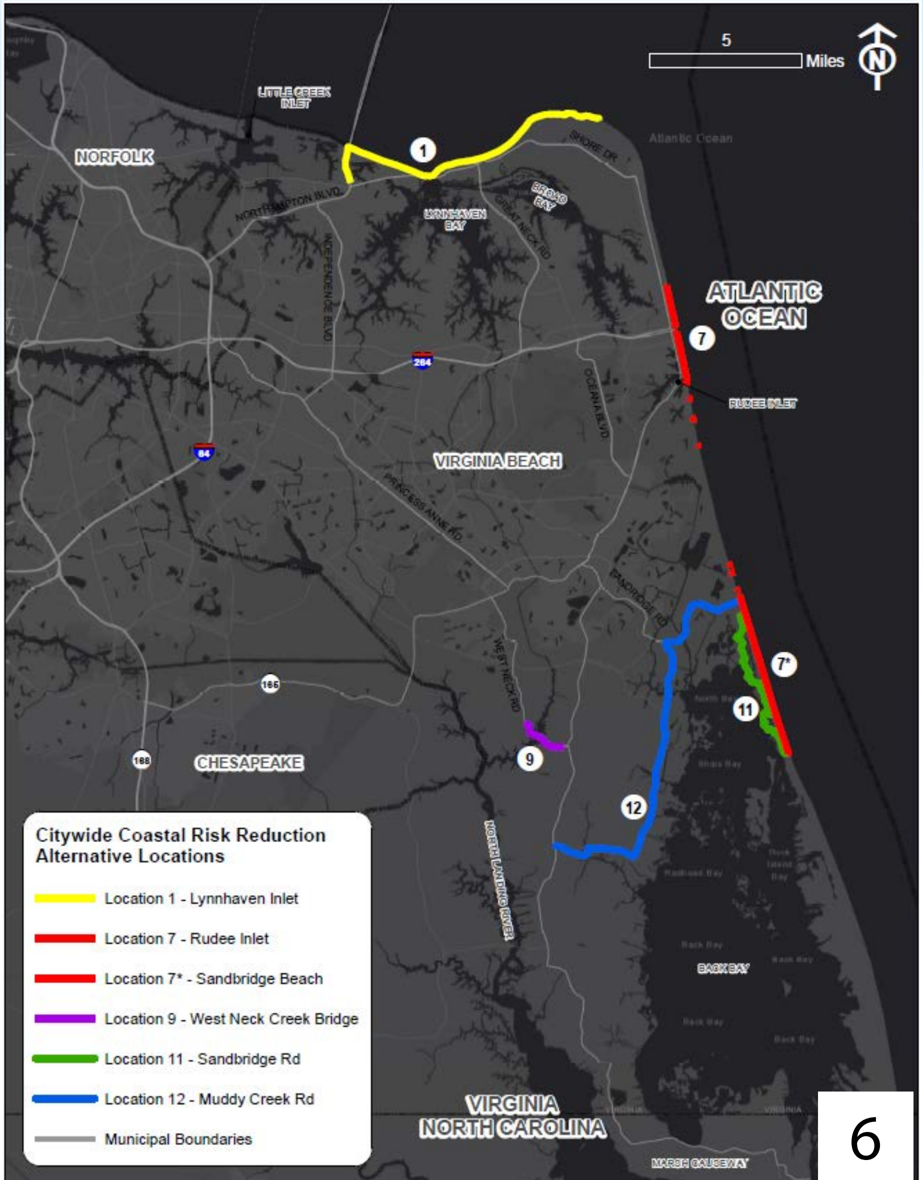
Alternative 10

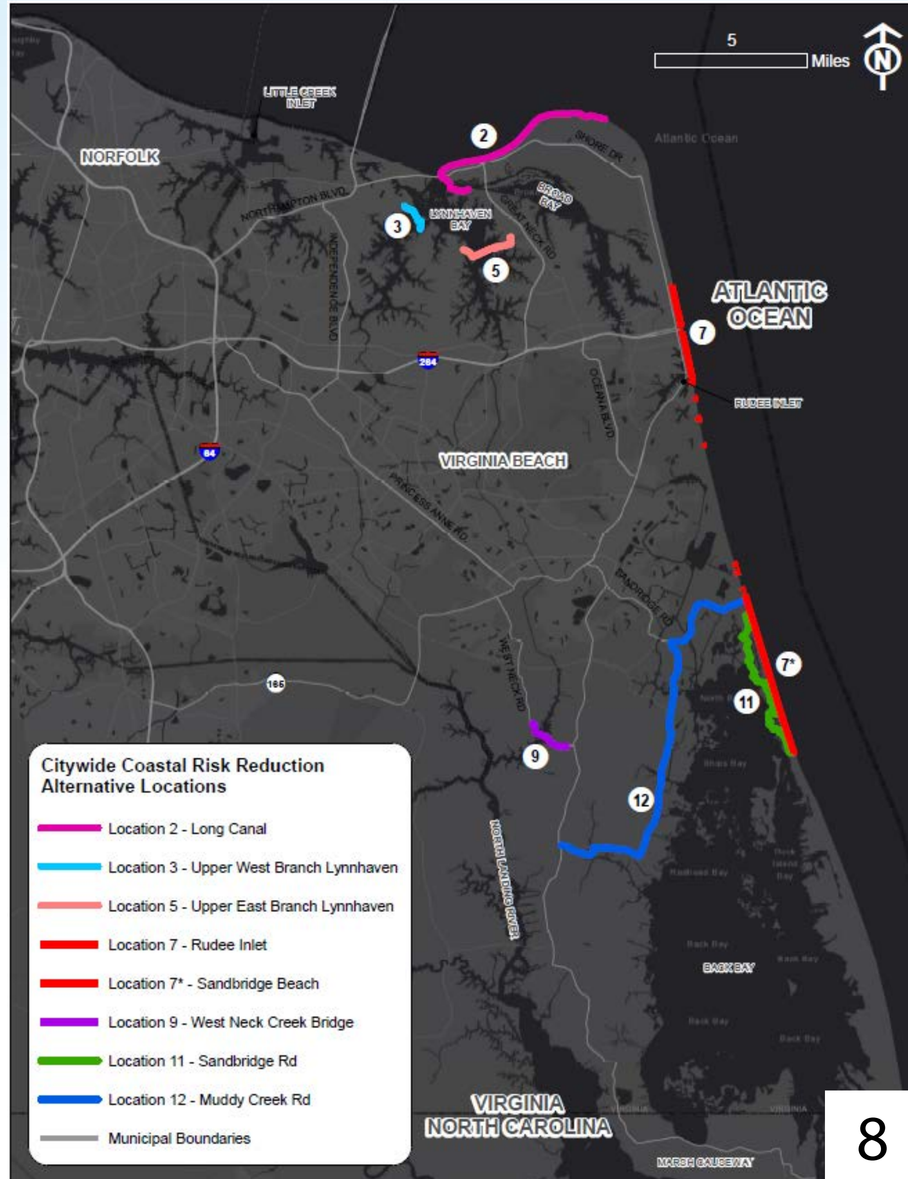
Down-selected Alternatives



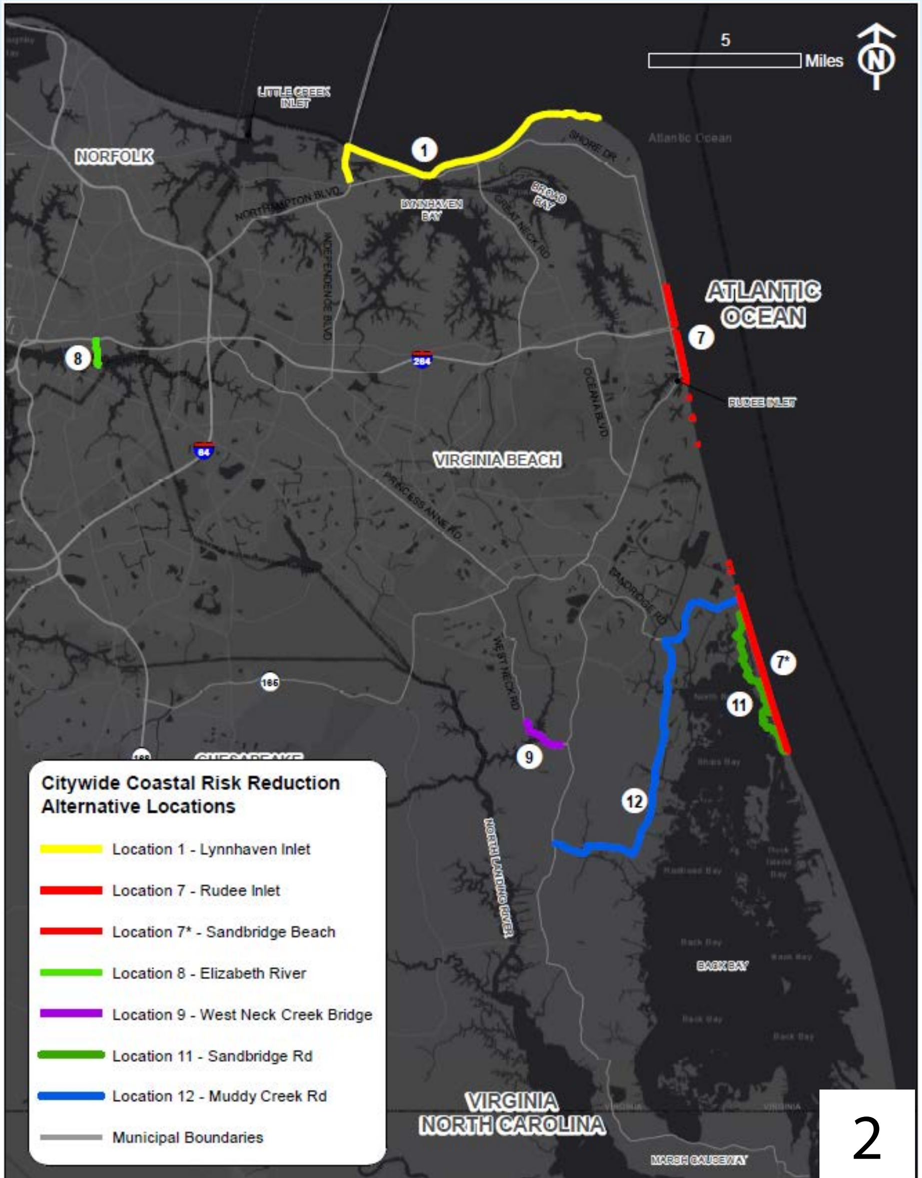


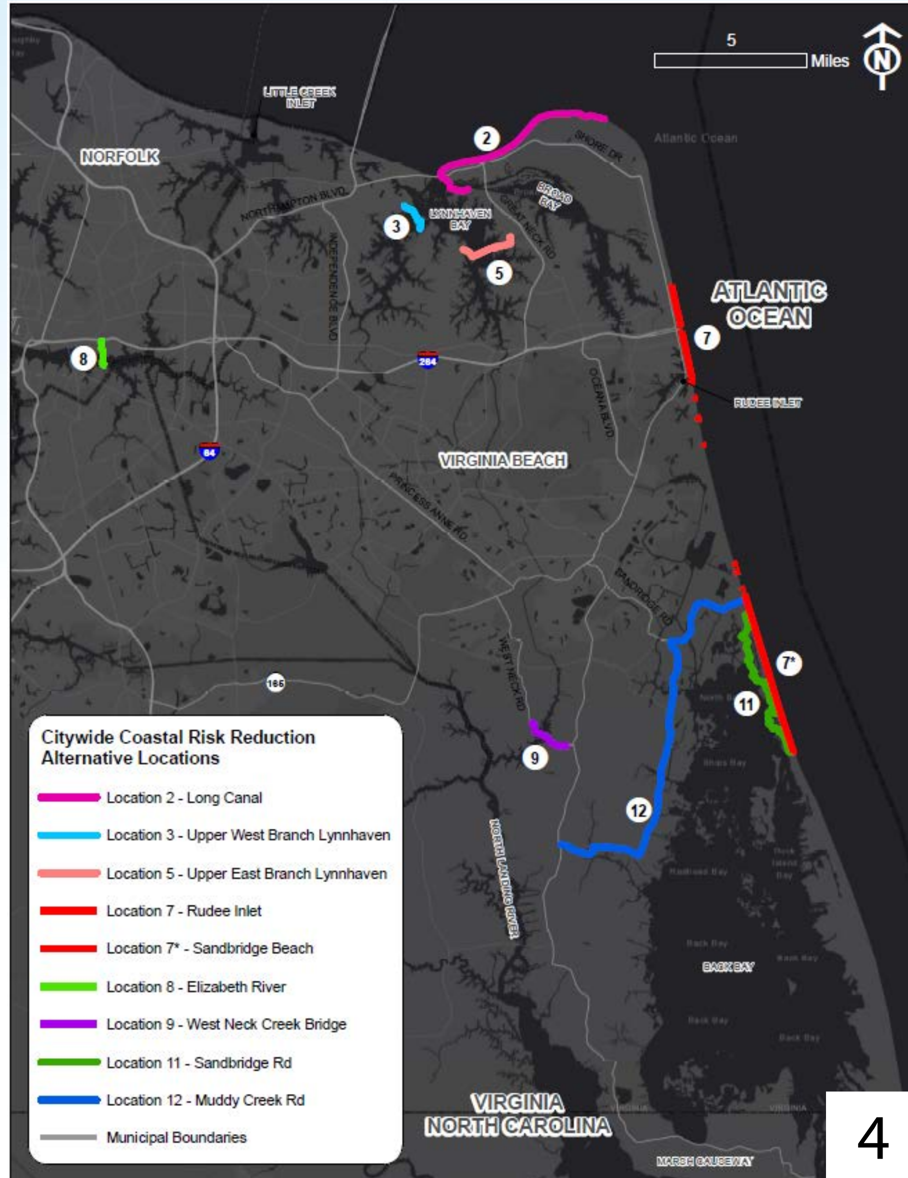
Down-selected Alternatives



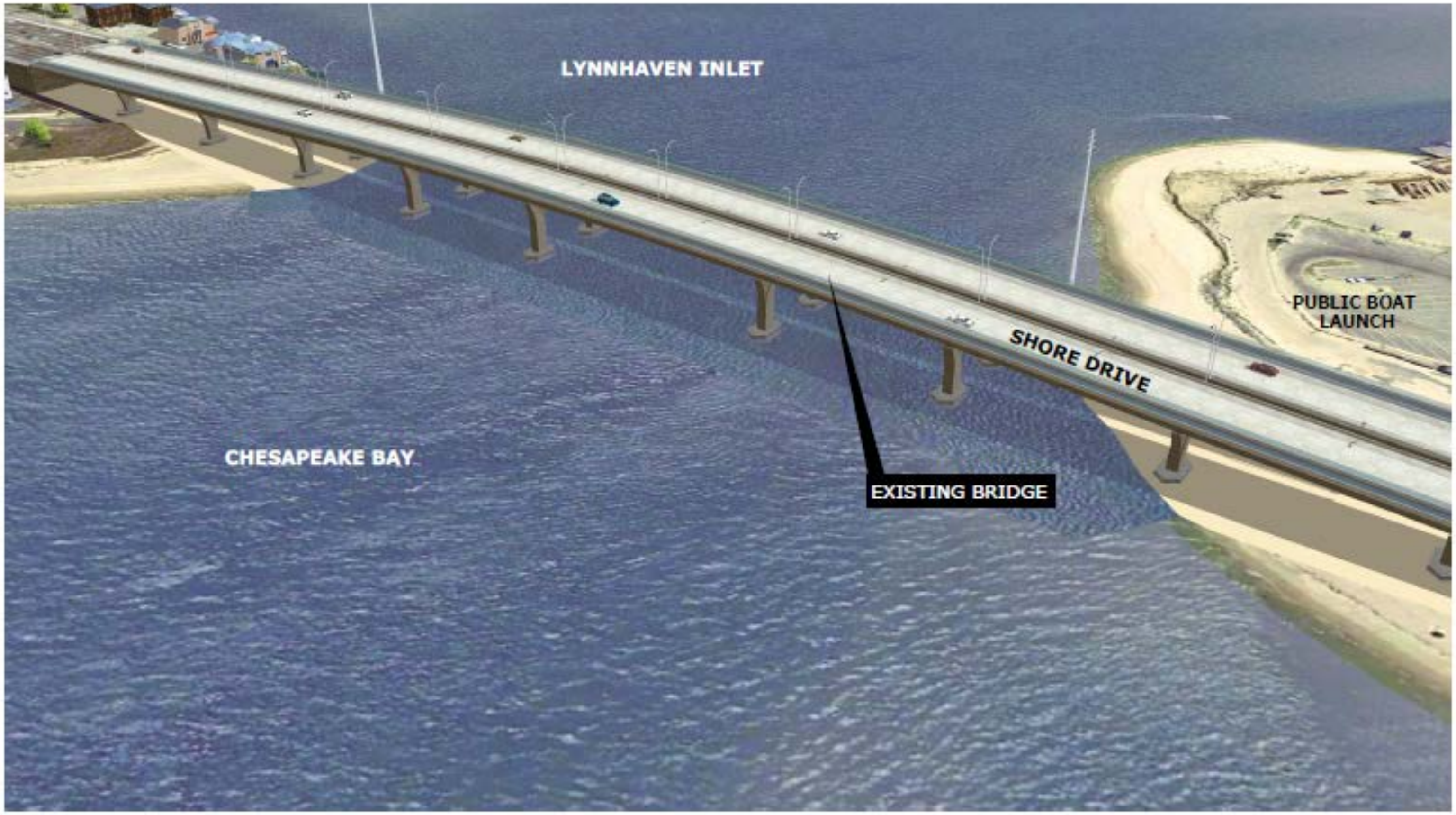


Down-selected Alternatives





Renderings – Lynnhaven Inlet

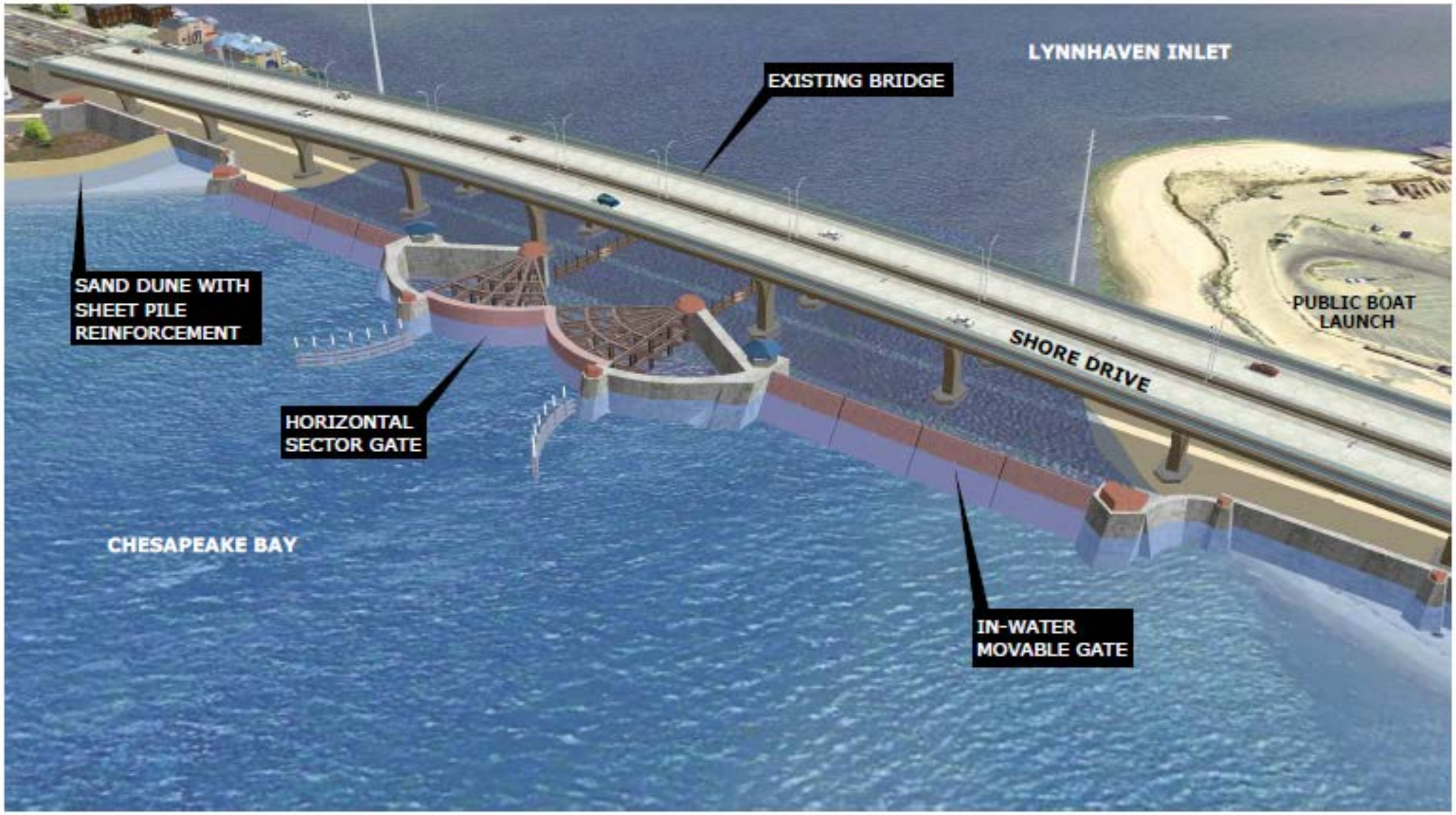


EXISTING CONDITIONS (ENLARGED)

LYNNHAVEN INLET

Dewberry wpl

Renderings – Lynnhaven Inlet



COMBINATION GATE SOLUTION (ENLARGED)

Dewberry wpl

LYNNHAVEN INLET

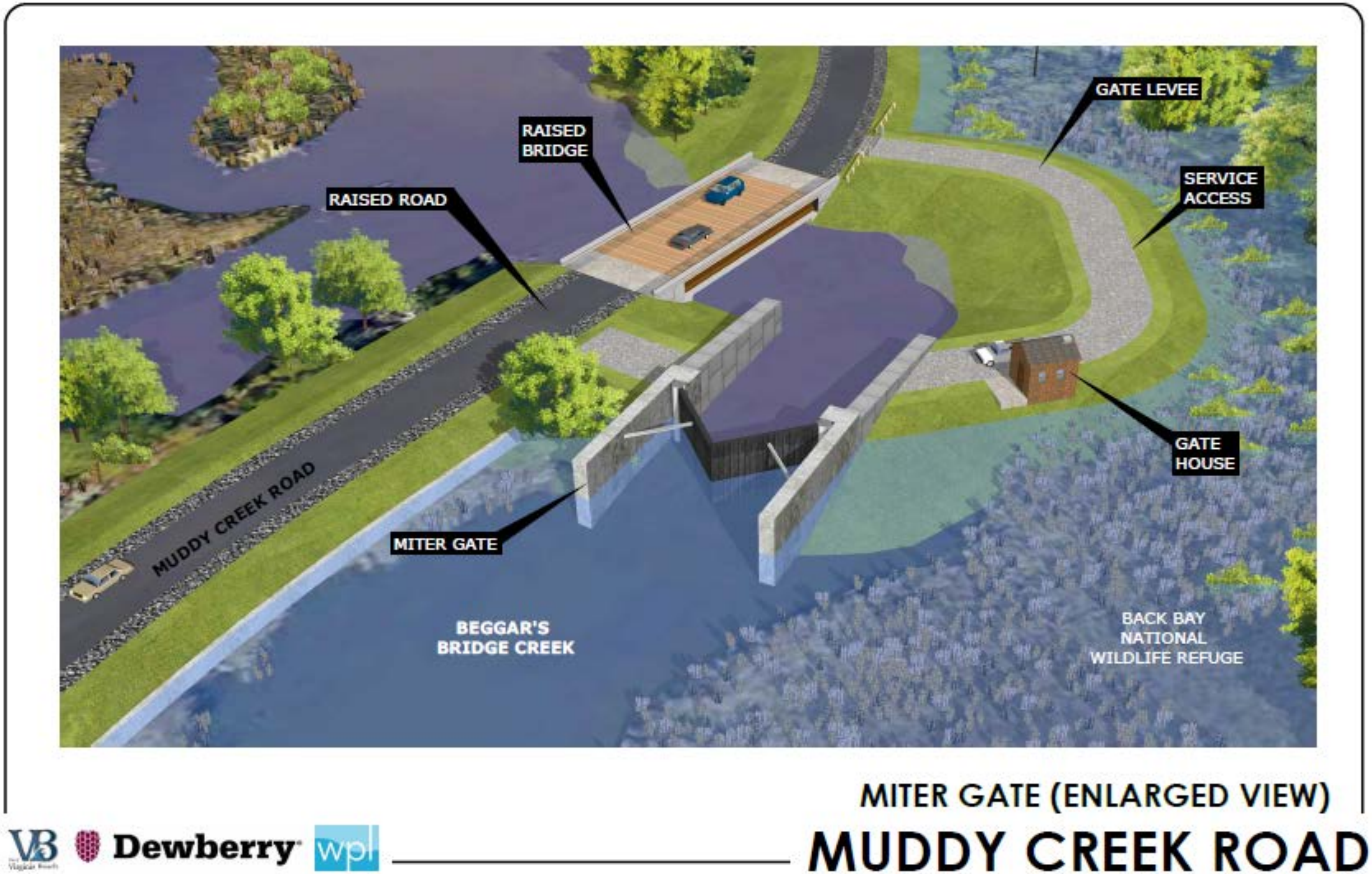
Renderings – Muddy Creek Rd

EXISTING CONDITIONS (ENLARGED VIEW)

Dewberry wpl

MUDDY CREEK ROAD

Renderings – Muddy Creek Rd



Cost Estimation

- Rough Order of Magnitude*
  - Utilized ArcGIS and AutoCAD
  - Units costs from USACE, PIANC, etc.
  - Average parameters by unit length
  - Contingencies for:
    - Hard Construction Cost
    - Soft Costs
  - Escalation for future date of construction

Intervention Location: 1 | **2** | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12

DFE Criteria: **A** | B

Alignment Option: **1** | 2

Total Length (feet): 18,038.0
Total Capital Cost: $187,881,115.13
Average Annual O&M Cost: $2,796,785.06

DFE Criteria A = (1% BFE) + (2.0' FB) + (1.5' SLR)
DFE Criteria B = (1% BFE) + (2.0' FB) + (3.0' SLR)

Note: This sheet is locked in a protected state. However, slicer controls are functional.

DFE (ft. NAVD)	From	To	Segment Type	Length (ft)	Area (sf)	Volume (cf)	Avg. Ground El. (ft. NAVD)	Avg. Structure Height (ft)	Acquisitions	Segment Cost	Avg. Annual O&M Cost
14.5	668+65.56	745+20.24	Earthen Levee	7,713.3			4.6	9.9		$ 13,073,117.90	$ 660,258.48
14.5	772+14.13	854+12.86	Earthen Levee	8,244.7			5.8	8.7		$ 12,279,985.97	$ 705,746.32
10.5	0+00.00	7+19.70	Floodwall	719.7			9.1	1.4		$ 571,398.62	$ 184,818.96
10.5	7+19.70	7+80.96	Deployable Floodwall	61.3			8.7	1.8		$ 108,225.15	$ 16,397.75
10.5	7+80.96	8+86.83	Floodwall	105.9			9.4	1.1		$ 66,061.48	$ 27,195.12
10.5	12+27.25	14+95.75	Floodwall	105.9			7.8	2.7		$ 162,150.90	$ 27,195.12
10.5	14+95.75	15+26.50	Deployable Floodwall	30.8			5.5	5		$ 151,048.33	$ 8,239.00
10.5	15+26.50	18+38.64	Floodwall	312.1			5.4	5.1		$ 902,658.74	$ 80,147.28
10.5	18+38.64	20+79.94	***Sector Gate***	241.3		***149,586.7***	***-27.3***	37.8		$ 159,111,686.40	$ 957,616.63
10.5	20+79.94	23+65.49	Floodwall	503.0			5.4	5.1		$ 1,454,781.63	$ 129,170.40

1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10

Citywide Alternative #1 Breakdown — Total Alternative Cost: $3,897,014,000.00

Components	Component DFE	Approx. Total Length (feet)	Hard Construction Cost	Hard Cost Contingency	Soft Cost Components	Soft Cost	Soft Cost Contingency	Approx. Total Cost (excluding O&M)
Inlet	18'	36,100	$1,422,494,000	$284,498,800.00	Design (includes field investigati	$142,249,355	$48,364,780.65	$2,239,005,000
West Beachfront	16'				Environmental assessment & miti	$213,374,032		
East Beachfront	16'				Drainage improvements	$39,574,540		
Inland	12'				Utility relocation	$20,449,071		
Inlet	18.0'	40,000	$121,765,000	$24,353,000.00	Design (includes field investigati	$12,176,496	$4,140,008.78	$187,518,000
Beachfront	14.0'				Environmental assessment & miti	$18,264,745		
					Drainage improvements	$8,523,547		
					Utility relocation	$2,435,299		
In-water Gate	12.5'	4,300	$651,170,000	$130,234,000.00	Design (includes field investigati	$65,116,993	$22,139,777.48	$1,024,942,000
Inland	11.5'				Environmental assessment & miti	$97,675,489		
					Drainage improvements	$45,581,895		
					Utility relocation	$13,023,399		
In-water Gate & Inland	9.0'	7,100	$15,062,000	$3,172,400.00	Design (includes field investigati	$1,586,195	$539,306.43	$24,967,000
					Environmental assessment & miti	$2,379,293		
					Drainage improvements	$1,110,337		
					Utility relocation	$317,239		
In-water Gate & Inland	9.0'	73,100	$267,206,000	$53,441,200.00	Design (includes field investigati	$26,720,582	$9,084,397.79	$420,582,000
					Environmental assessment & miti	$40,080,873		
					Drainage improvements	$18,704,407		
					Utility relocation	$5,344,116		
			$2,478,497,000	$495,699,400.00		$842,688,711	$84,268,871.13	$3,897,014,000

Citywide Alternatives Comparison			
Escalation 3.0%	Construction Year Costs		
Citywide Alternative	2018 Total Costs (Hard + Soft)	Future Year 2040	Difference (92% Increase)

*Approximate equivalent to Association for the Advancement of Cost Engineering Class 5 estimate for conceptual engineering phase

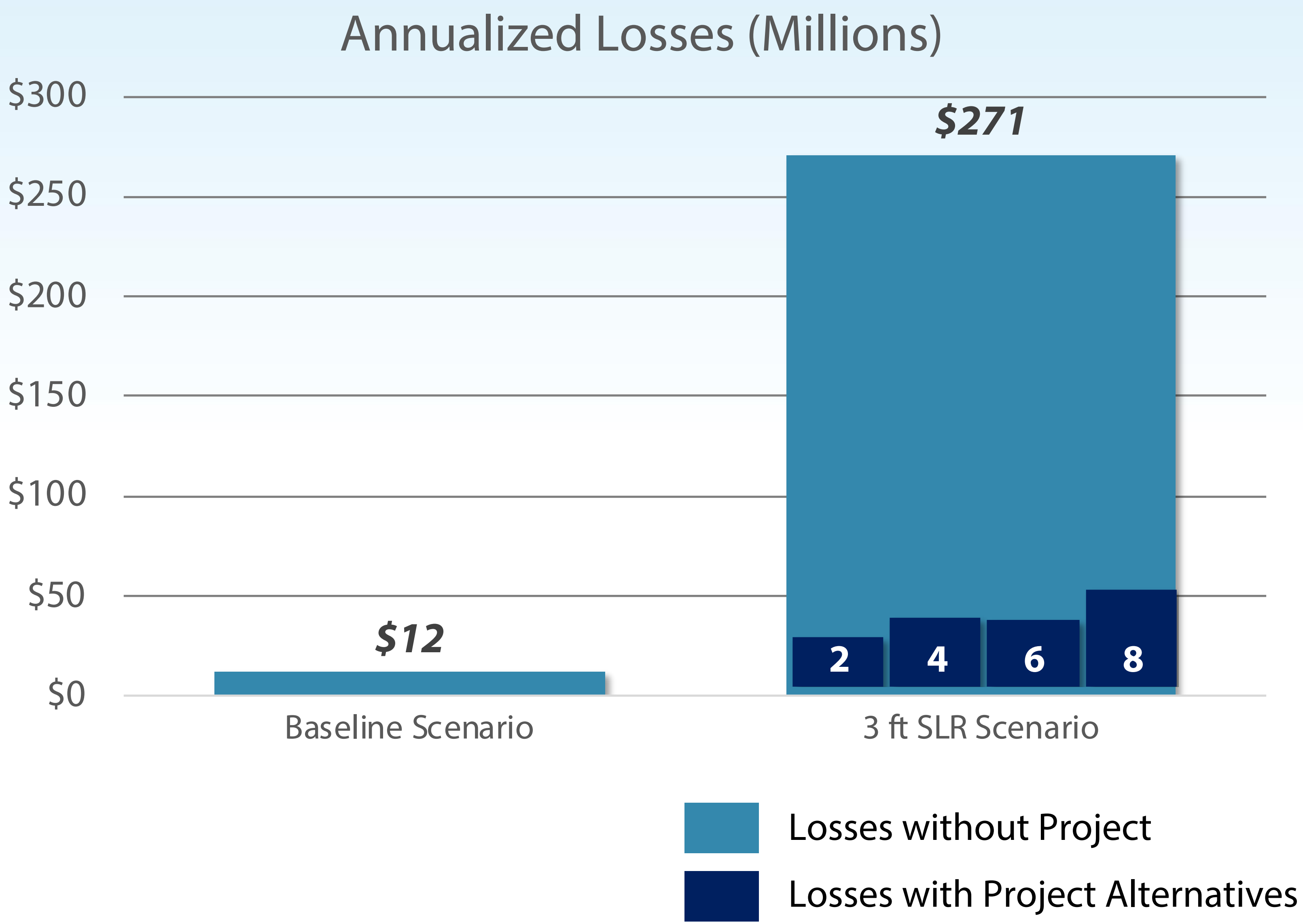
Down-Selected Alternative Summary

SUMMARY OF ALTERNATIVES*					
ITEMS	CITYWIDE ALTERNATIVES				
	2	4	6	8	9a
Approximate Overall Structure Length (miles)	33.8	34.5	33.0	26.1	11.1
Flooded Area Reduction (square miles)	-27	-28	-23	-24	-18
Mitigated Structures (thousands)	45.5	43.1	40.1	36.5	27-13.8***
Total Design & Construction Cost (Billion USD 2018)	$3.79**	$2.73**	$2.77	$1.71	$2.81
Adjacent Municipal Areas Affected	North Carolina, Norfolk, Chesapeake	North Carolina, Norfolk, Chesapeake	North Carolina, Norfolk	North Carolina, Norfolk	Norfolk

FOR INFORMATIONAL PURPOSES
Initial values shown, currently under refinement

**Values subject to change pending final modeling and cost adjustments for gate types*
***Cost includes flood barrier in Norfolk that benefits Virginia Beach, Norfolk, and Chesapeake*
****Final count to be determined from model runs*

Future With/Without Alternatives



Next Steps

City-wide Projection
- Finalize evaluation

Site/Parcel Strategies
- Key opportunities
- Aggregate Benefits over Areas

Neighborhood Protection
- Complete for 5 locations

Hybrid Alternatives
- What's the best mix?

Draft Adaptation Plan
- Study Synthesis

Review & Stakeholder Engagement

Next 3-4 Months

Discussion

VB Sea Level Wise
A vibrant future for Virginia Beach