

Pivoting to the Future: Resiliency Planning in Virginia Beach

Bayfront Advisory Commission

February 21, 2019

C.J. Bodnar, PE, City of Virginia Beach
Stormwater Engineering Center

Agenda

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

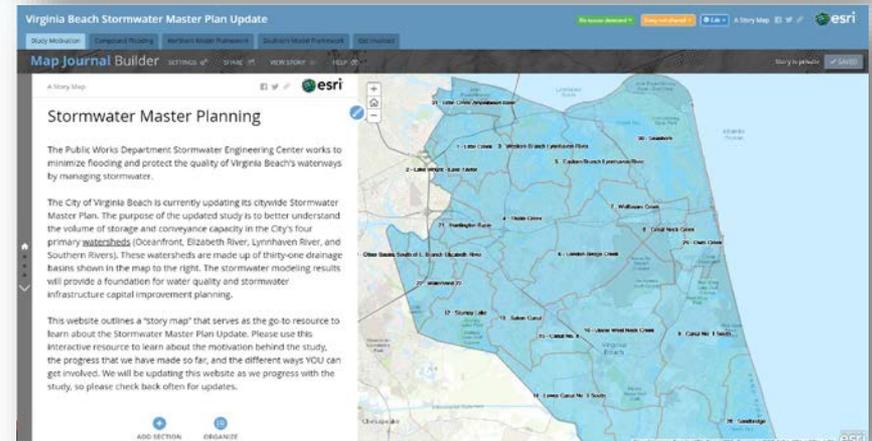
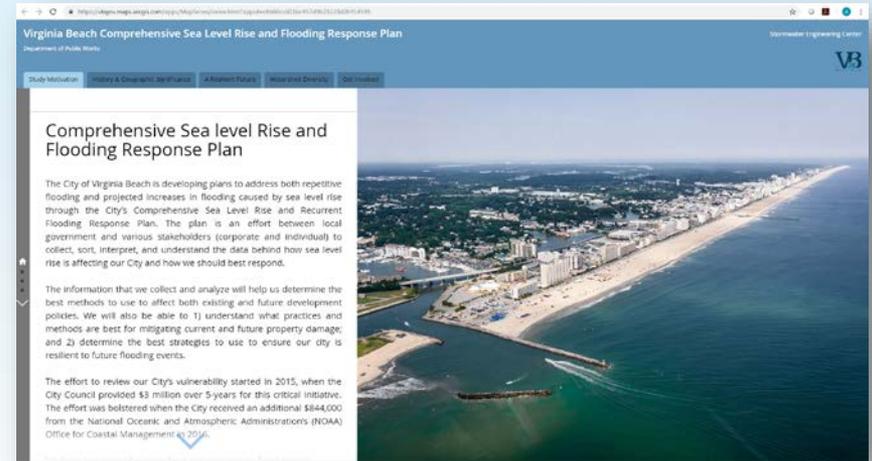
Project Overview

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



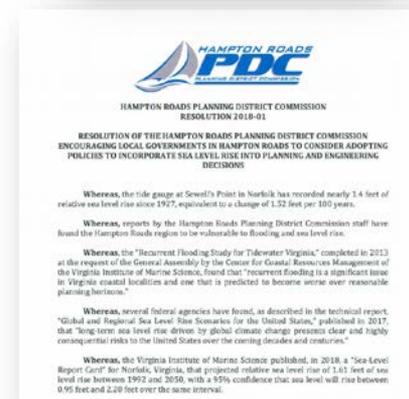
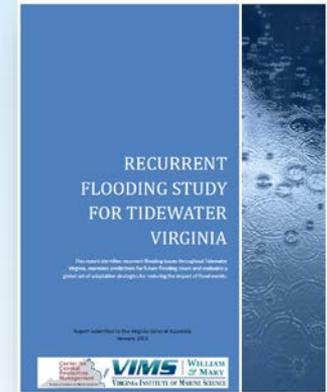
Timeline of Activities



Hazards and Risk

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



Observed Acceleration

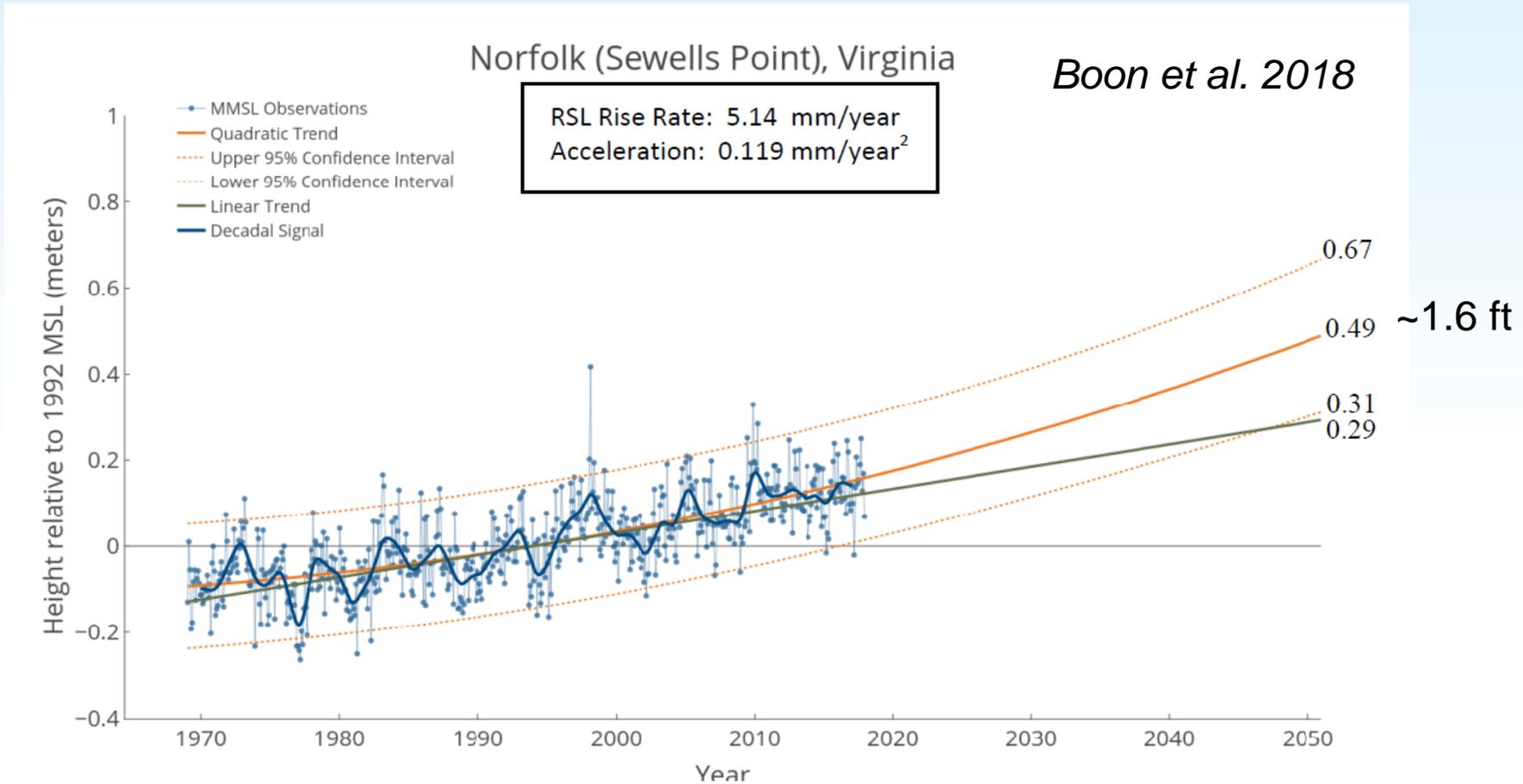
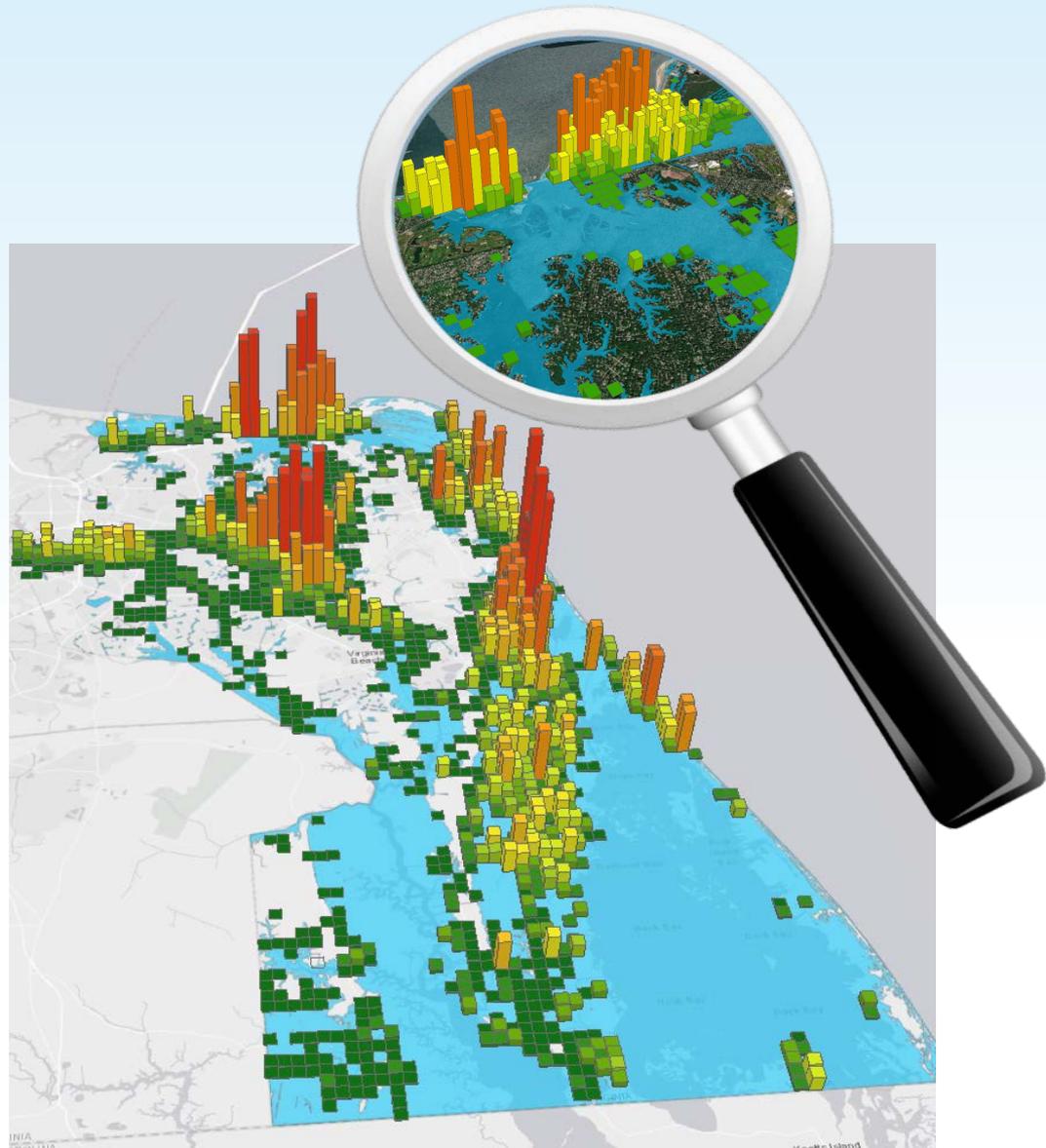


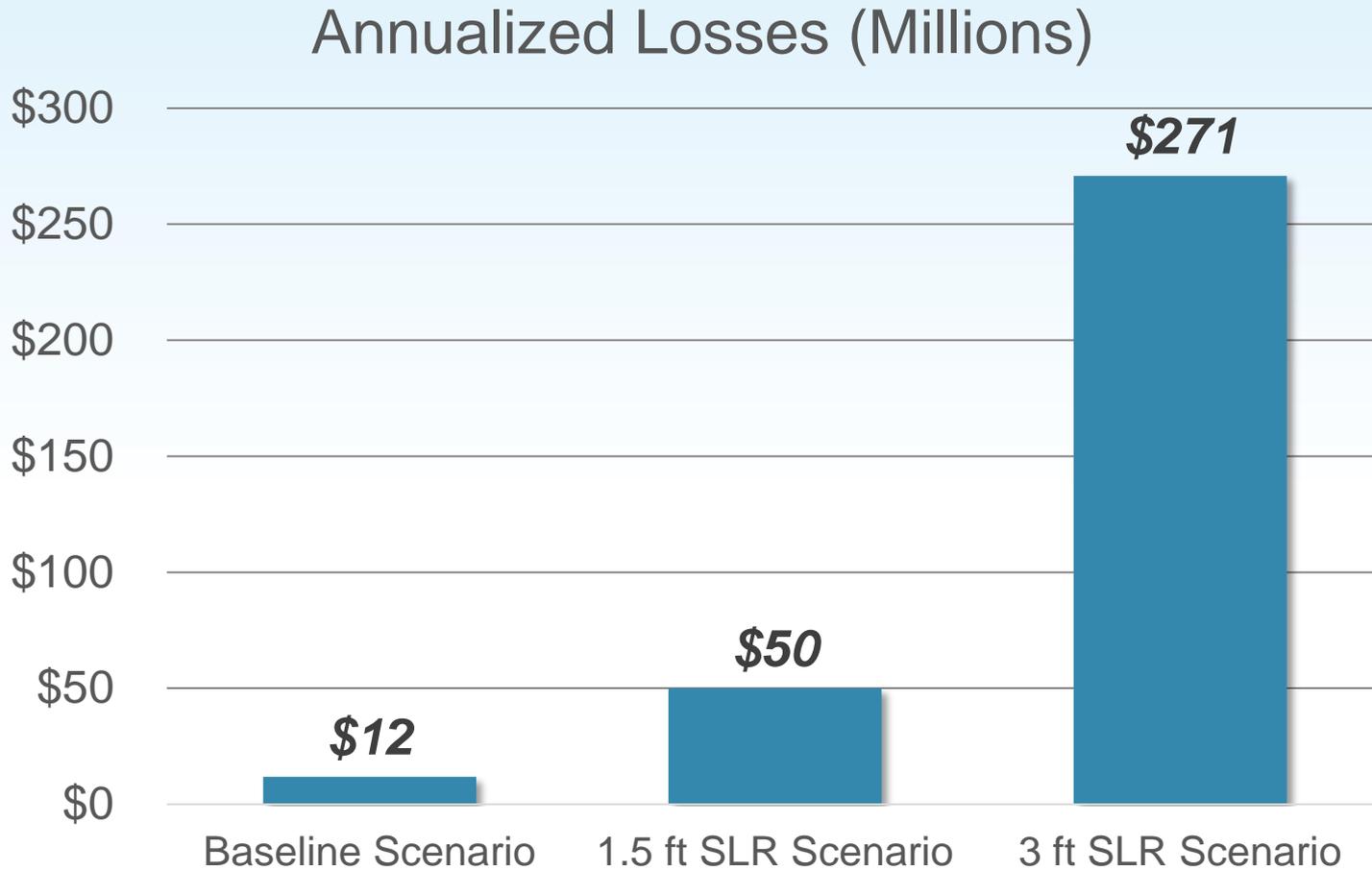
Figure III-4. Relative sea level trends, Norfolk, Virginia, 1969-2017 series

Impacts

HAZUS[®]
EARTHQUAKE • WIND • FLOOD **MH**



Consequences of Future Without Action

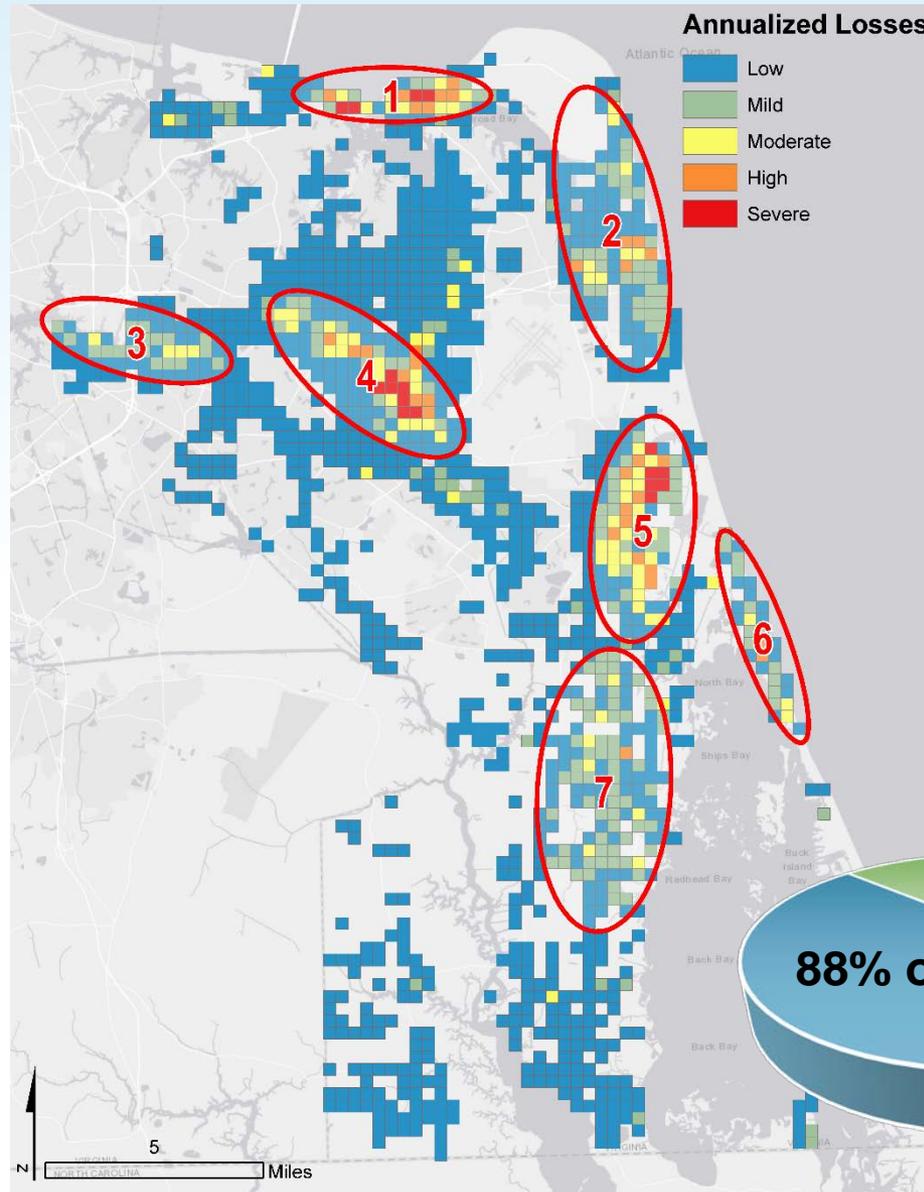


Compared to Today:

4x increase

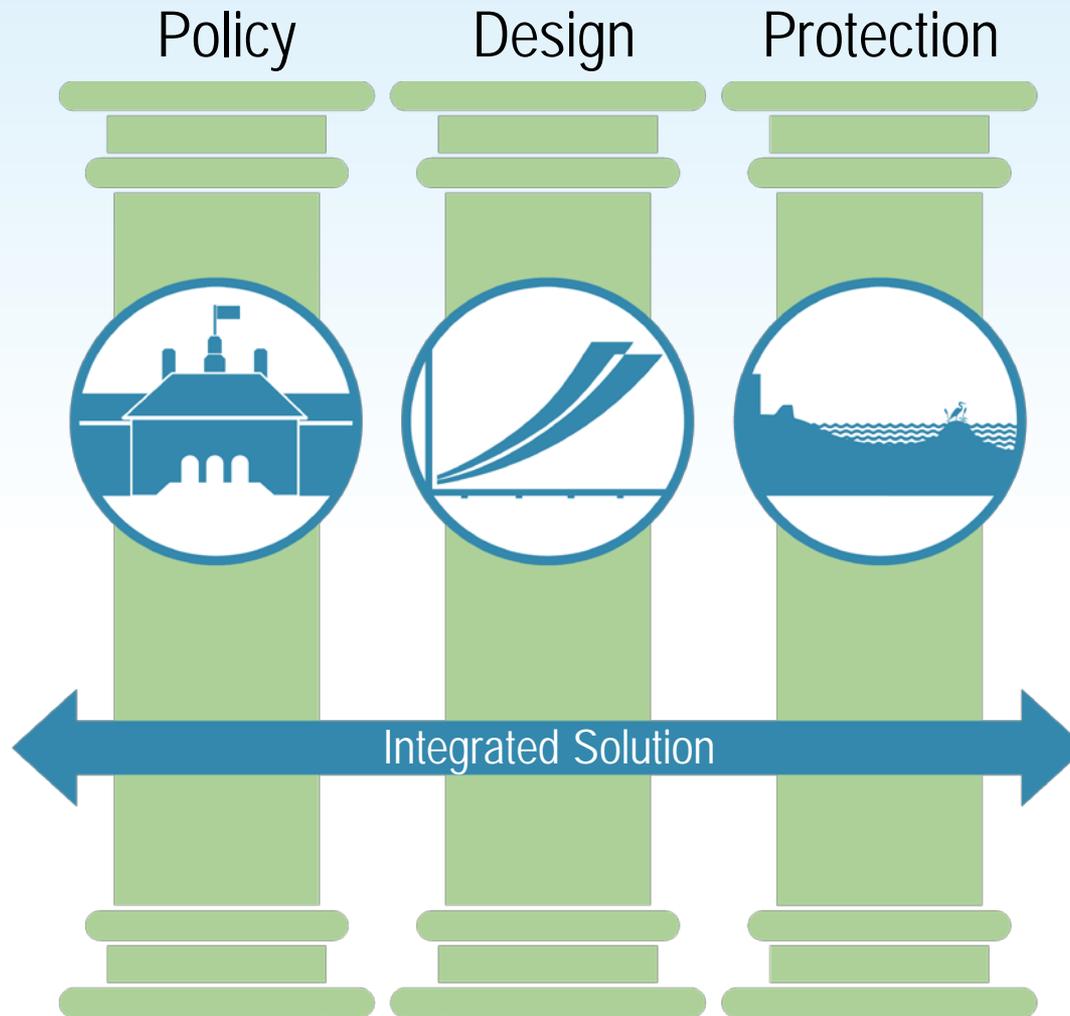
23x increase

Focus Areas for Adaptation



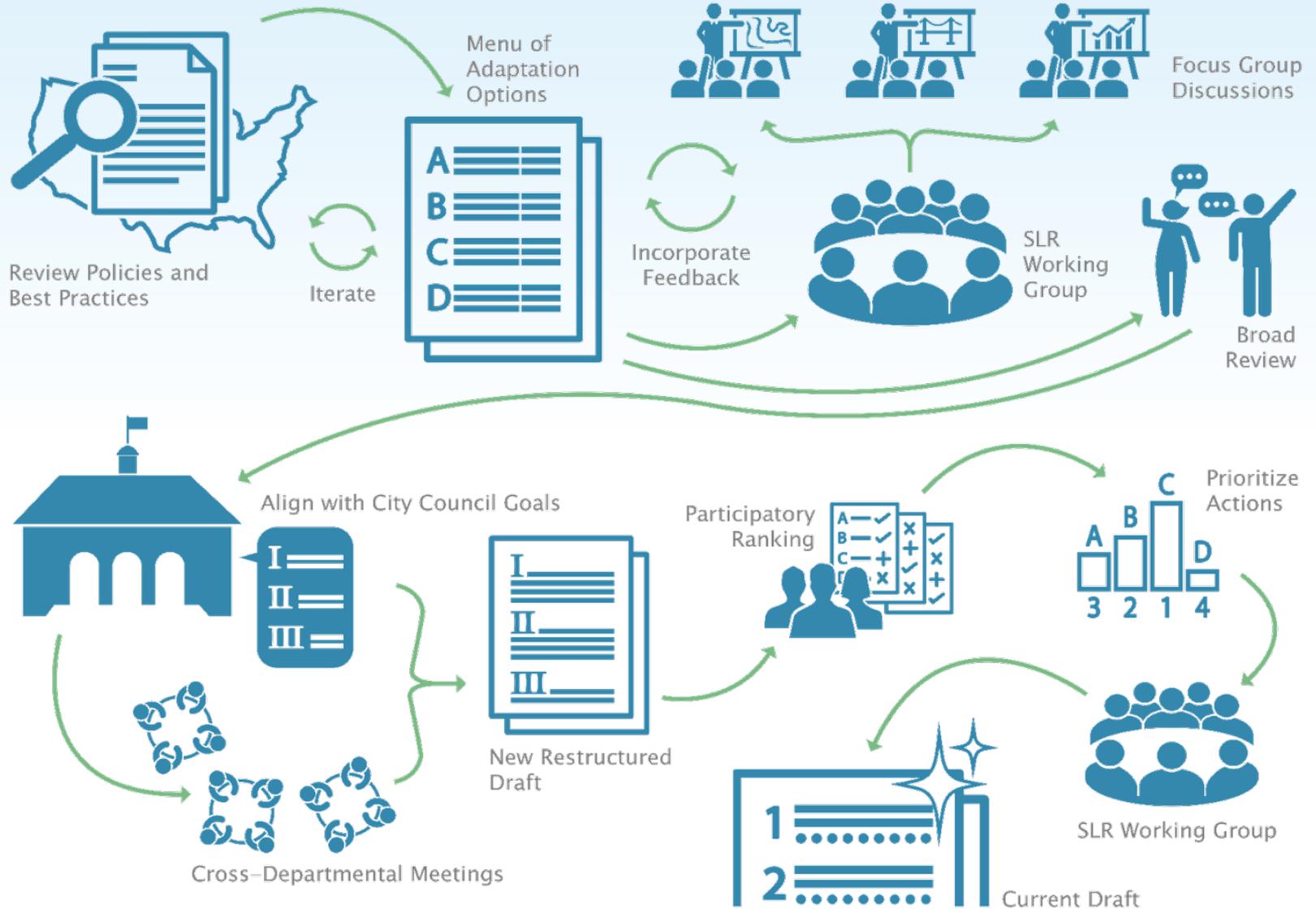
Adaptation Strategies

Adaptation Strategies



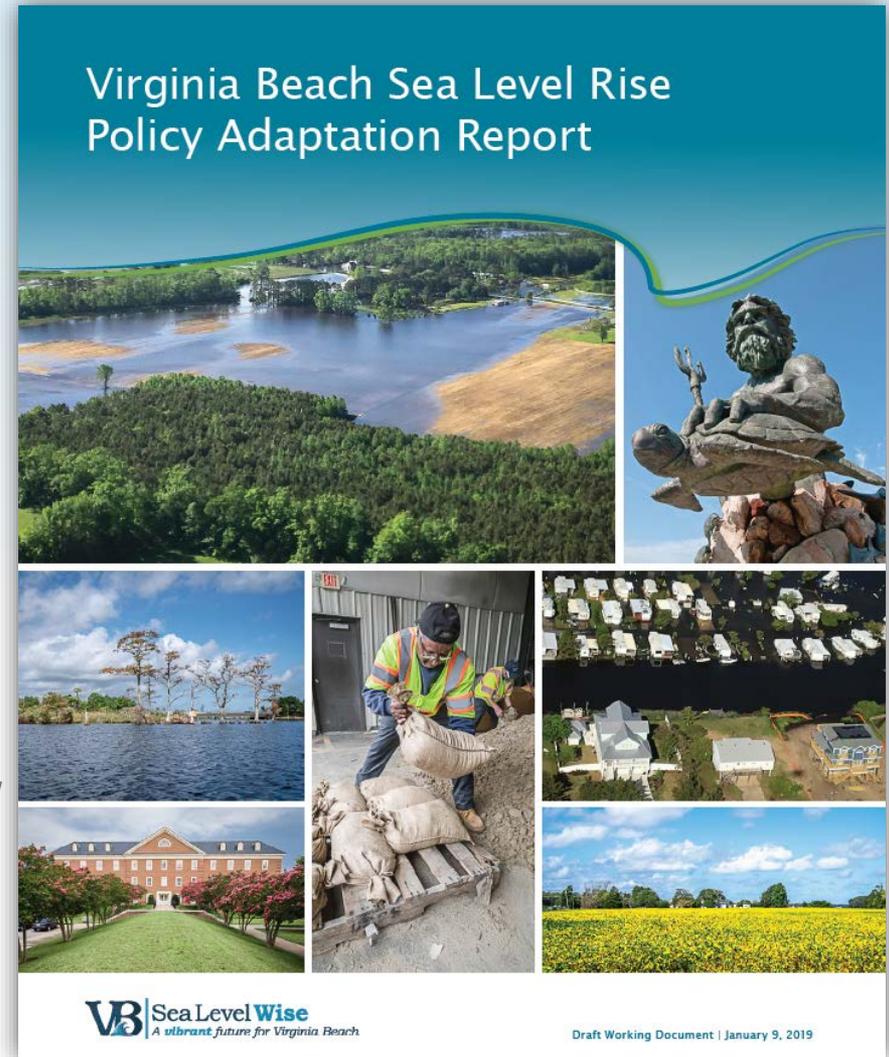
Policy Document Overview

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"



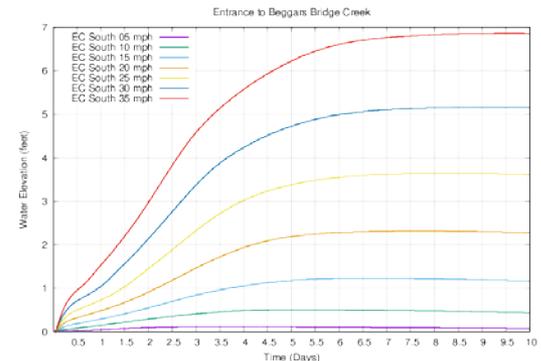
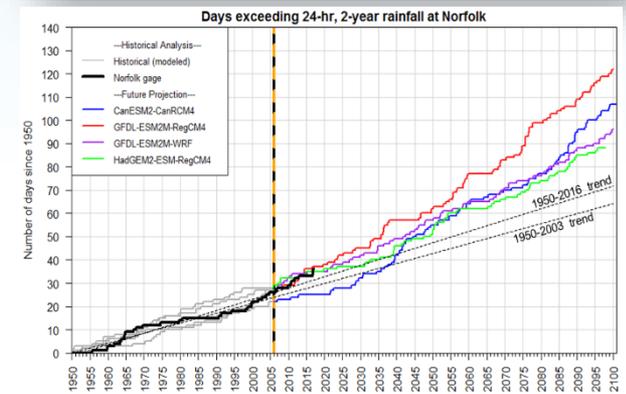
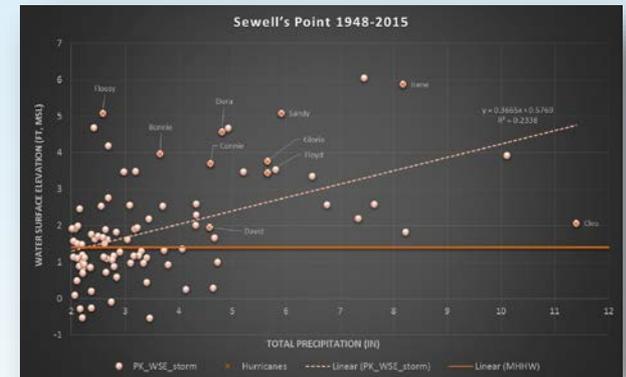
Implementation Vision

- Administered and monitored by the Deputy City Manager's 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 VIII-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:

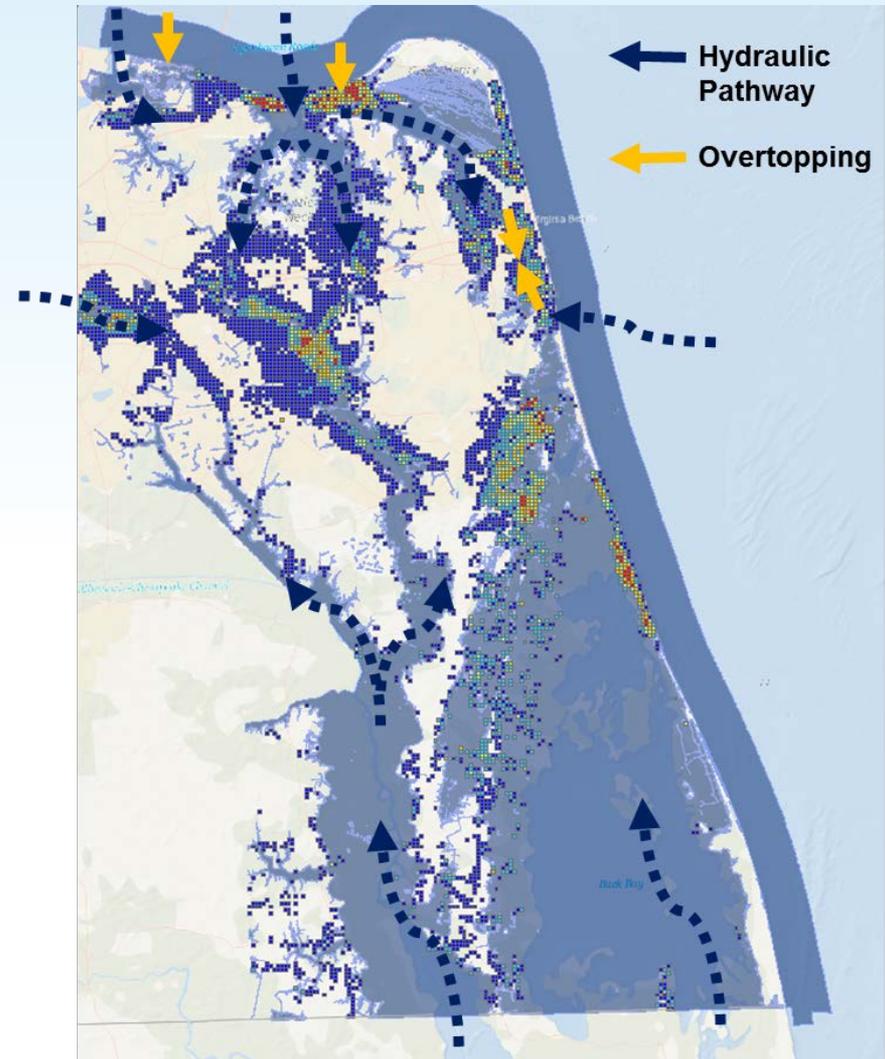
- All elevations sourced from direct sampling and statistical analysis of the distribution of water elevations in each watershed
- Lynnhaven, Elizabeth River, and Atlantic Ocean elevations were sourced from the 2015 FEMA Flood Insurance Study
- Back Bay and North Landing River elevations were sourced from CIP 7-030, PWCN-15-0014, WO2A
- The values do not represent potential wind-driven water levels in the Back Bay and North Landing River
- Back Bay and North Landing River tailwater values have been limited to return periods where tailwater elevations are above recurring wind tides.
- 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)

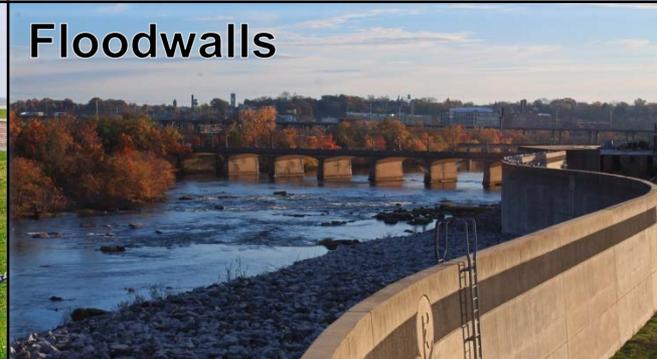
Protect High Risk Areas
Designed to Future 10- to 50-yr flood
Cost: Moderate (100s Millions)

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

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



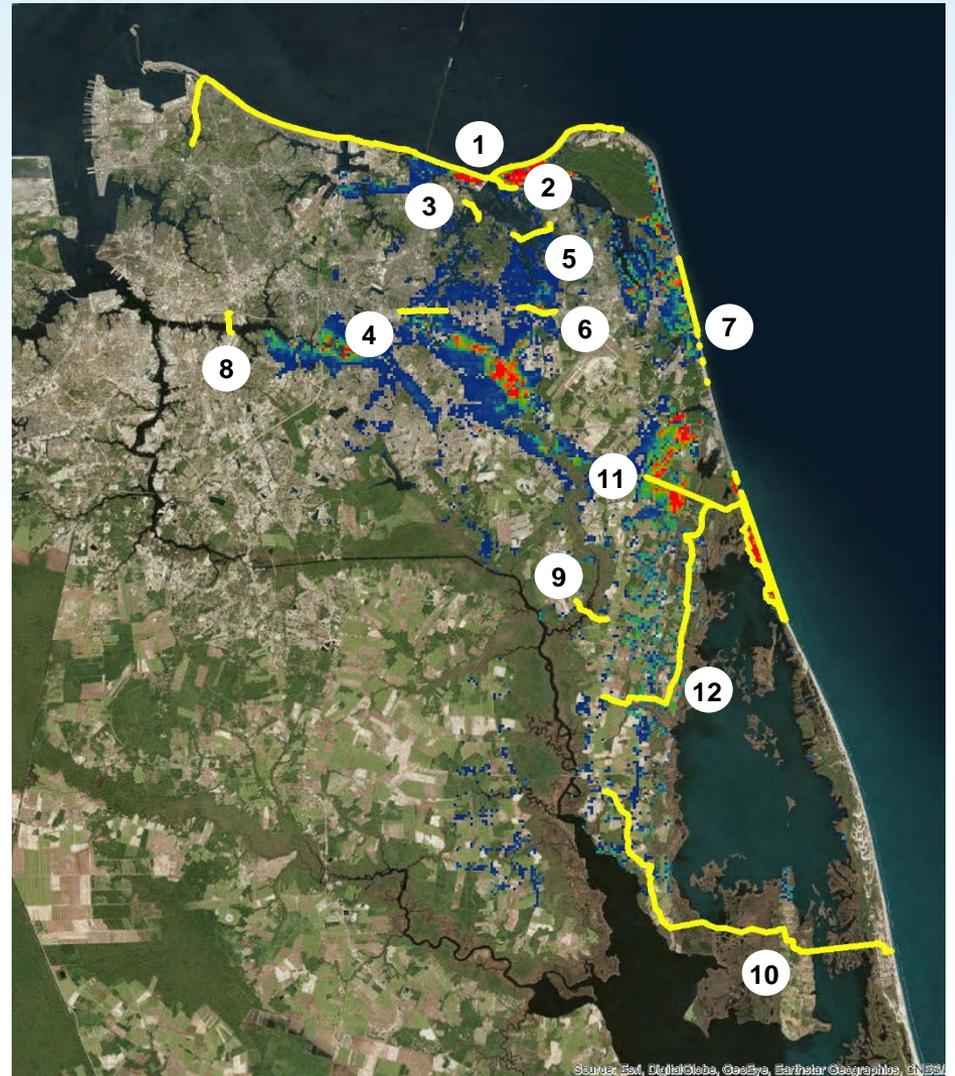
Putting the Pieces Together

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



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

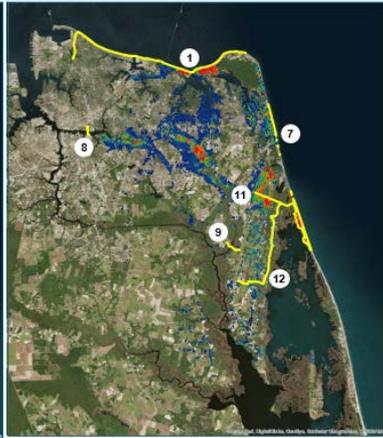


Combinations for Evaluation

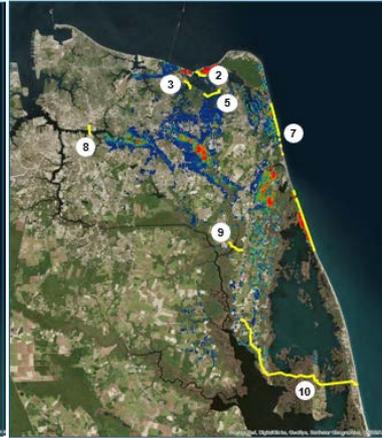
Alternative 1



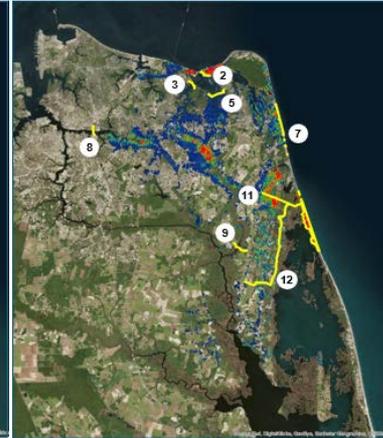
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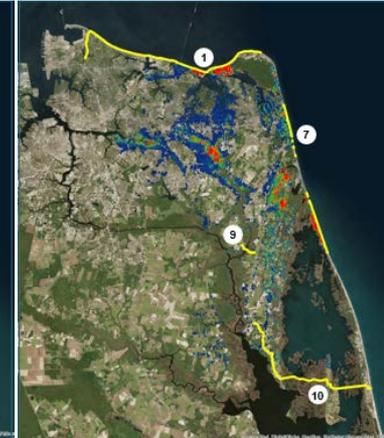
Alternative 3



Alternative 4



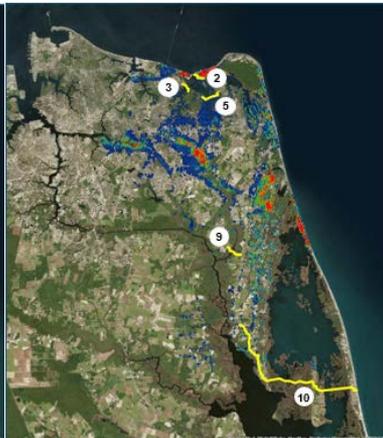
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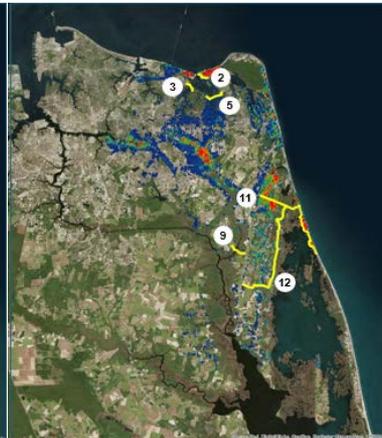
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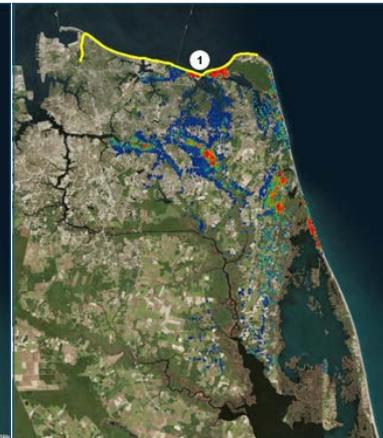
Alternative 7



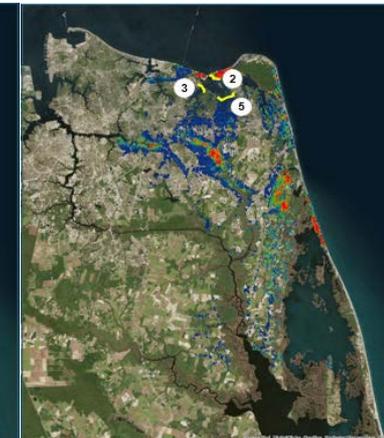
Alternative 8



Alternative 9

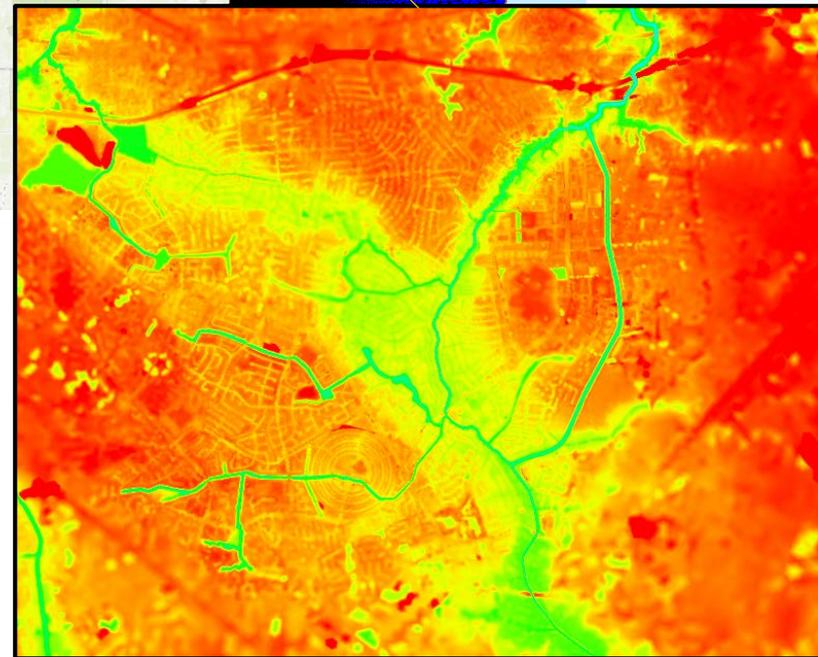
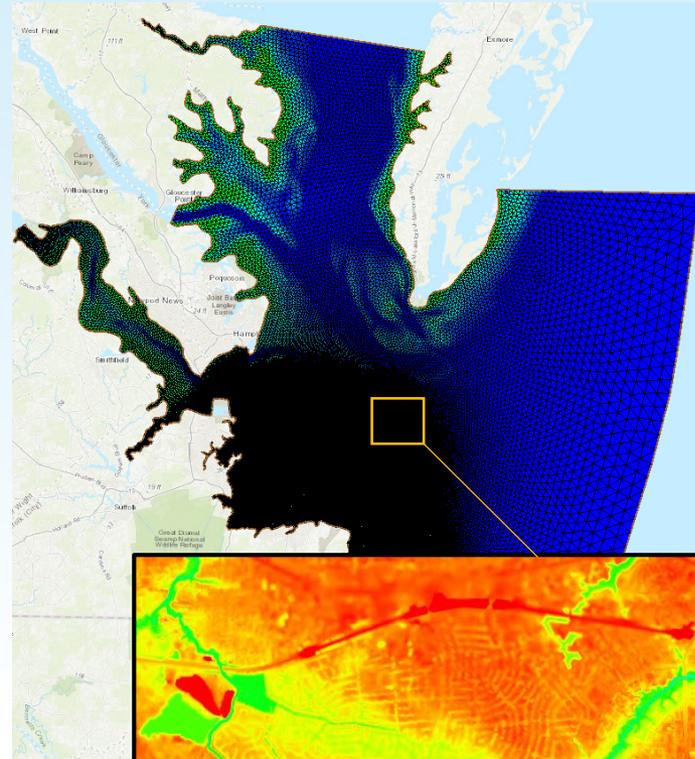


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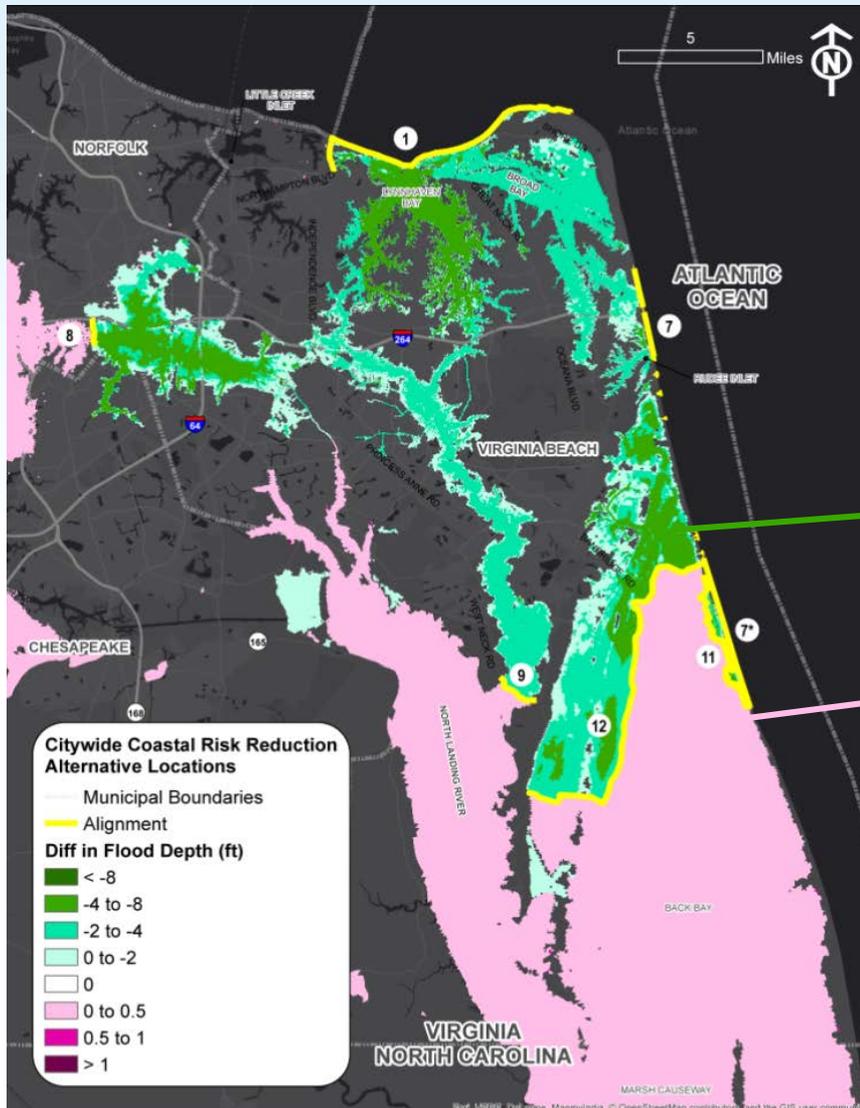


Model Evaluation

- 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



Model Evaluation Benefits and Impacts



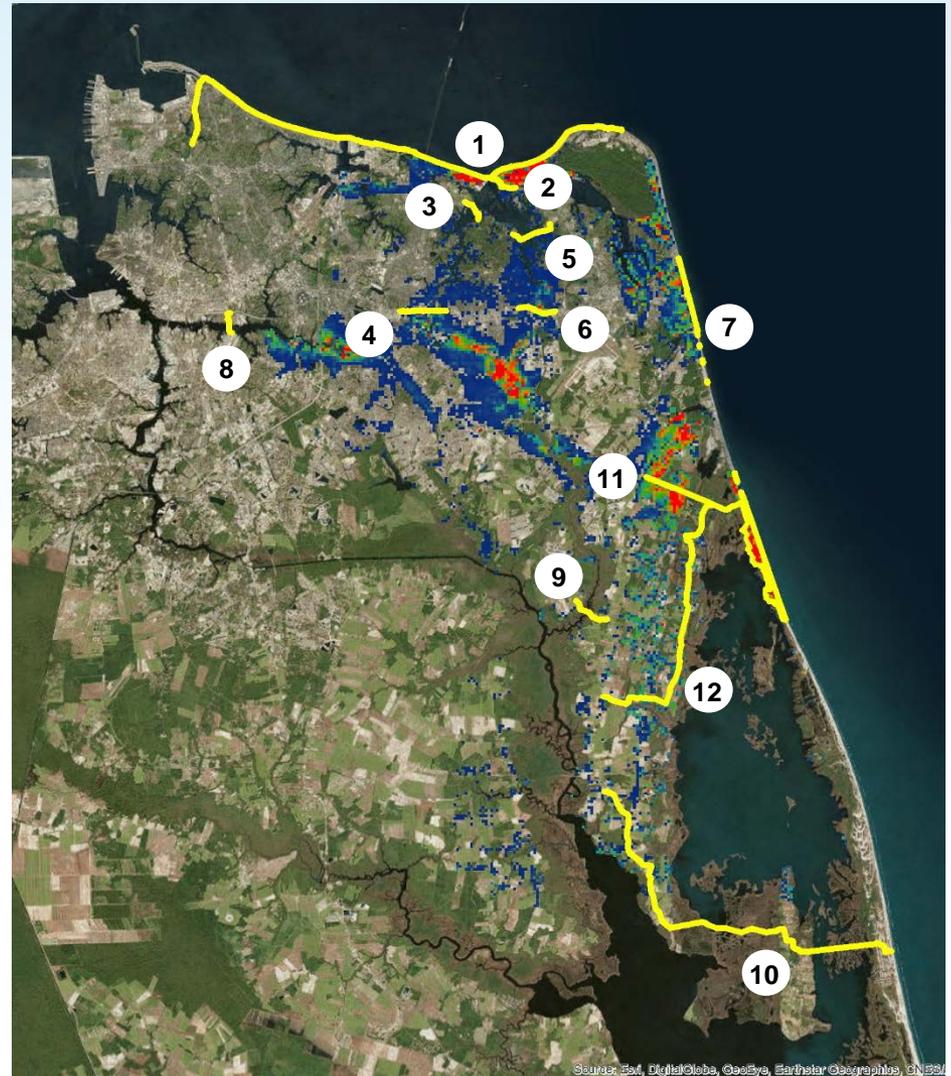
Areas of Benefit
(reduced flood depth)

Areas of Adverse Impact
(increased flood depth)

FOR INFORMATIONAL PURPOSES
Initial values shown, currently under
refinement

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
8. Elizabeth River
9. West Neck Creek Bridge
- ~~10. Knotts Island~~
11. Sandbridge Road
12. Muddy Creek Road



Down-selection of Alternatives

Alternative 1



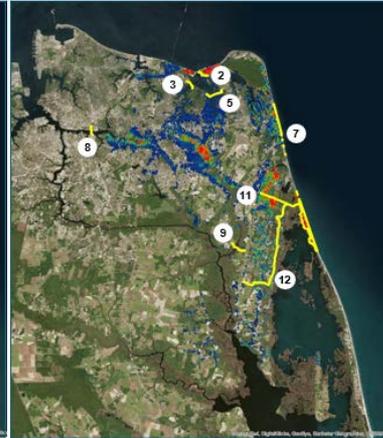
Alternative 2



Alternative 3



Alternative 4



Alternative 5



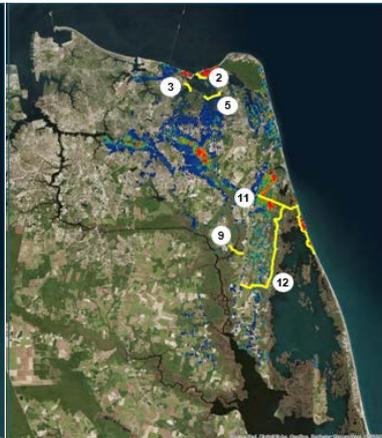
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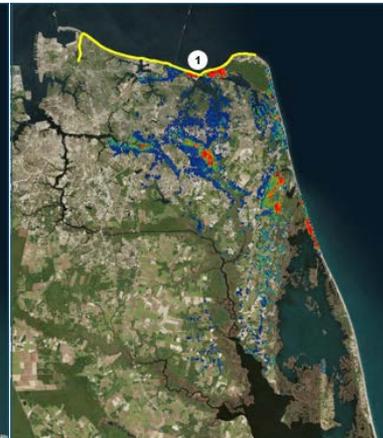
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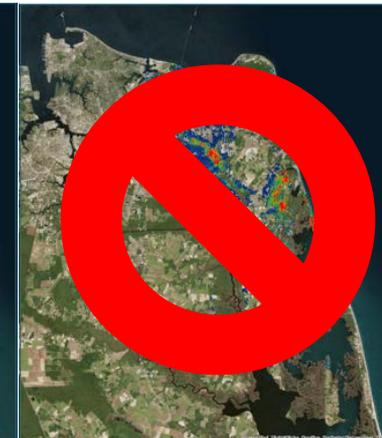
Alternative 8



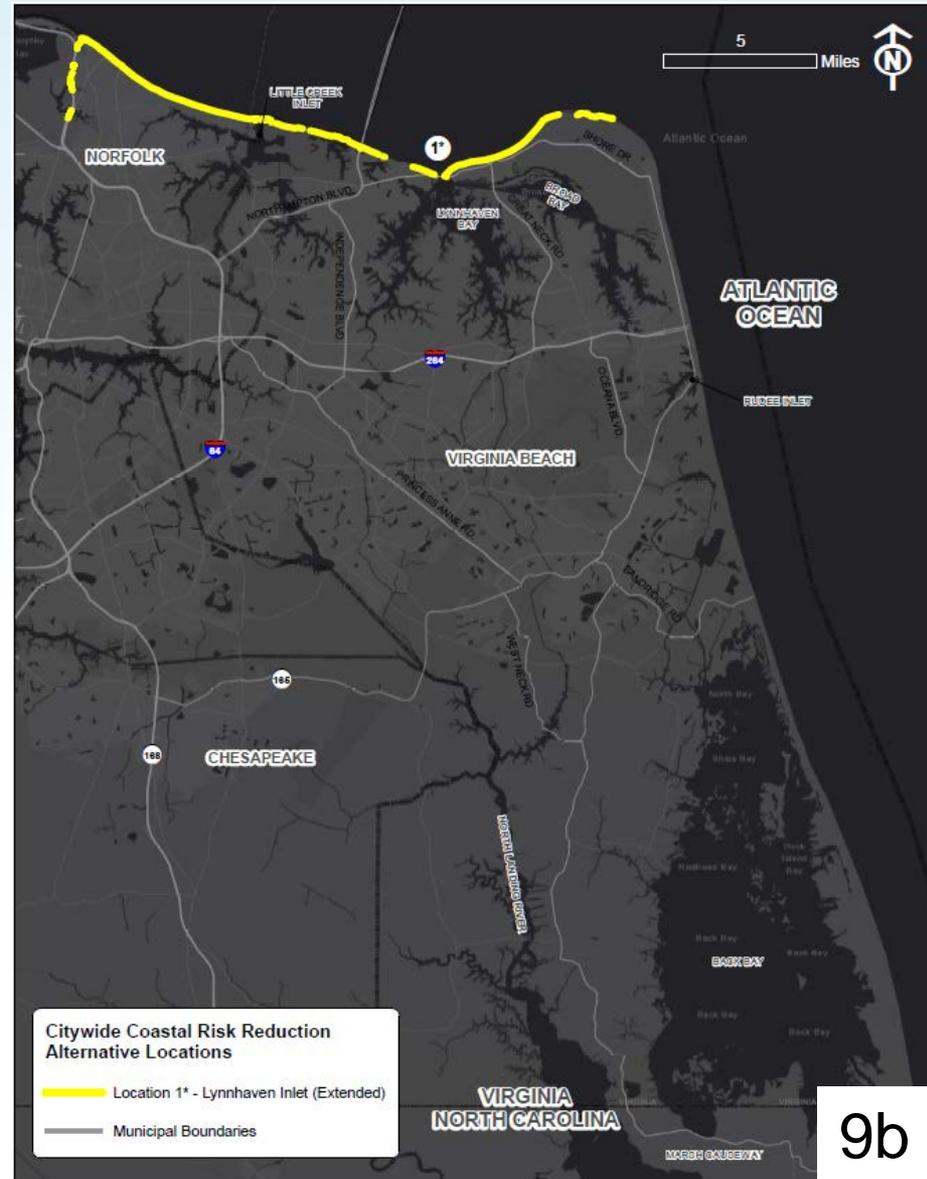
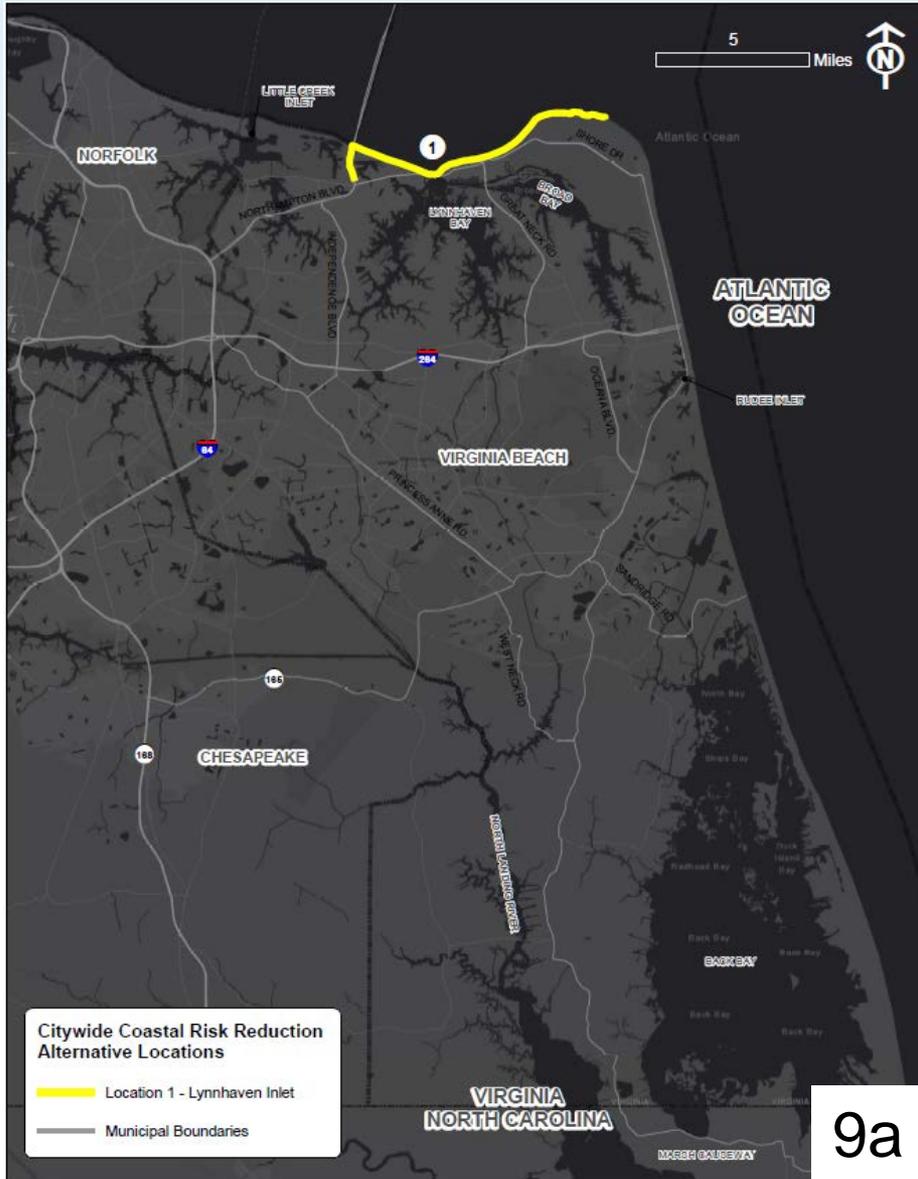
Alternative 9



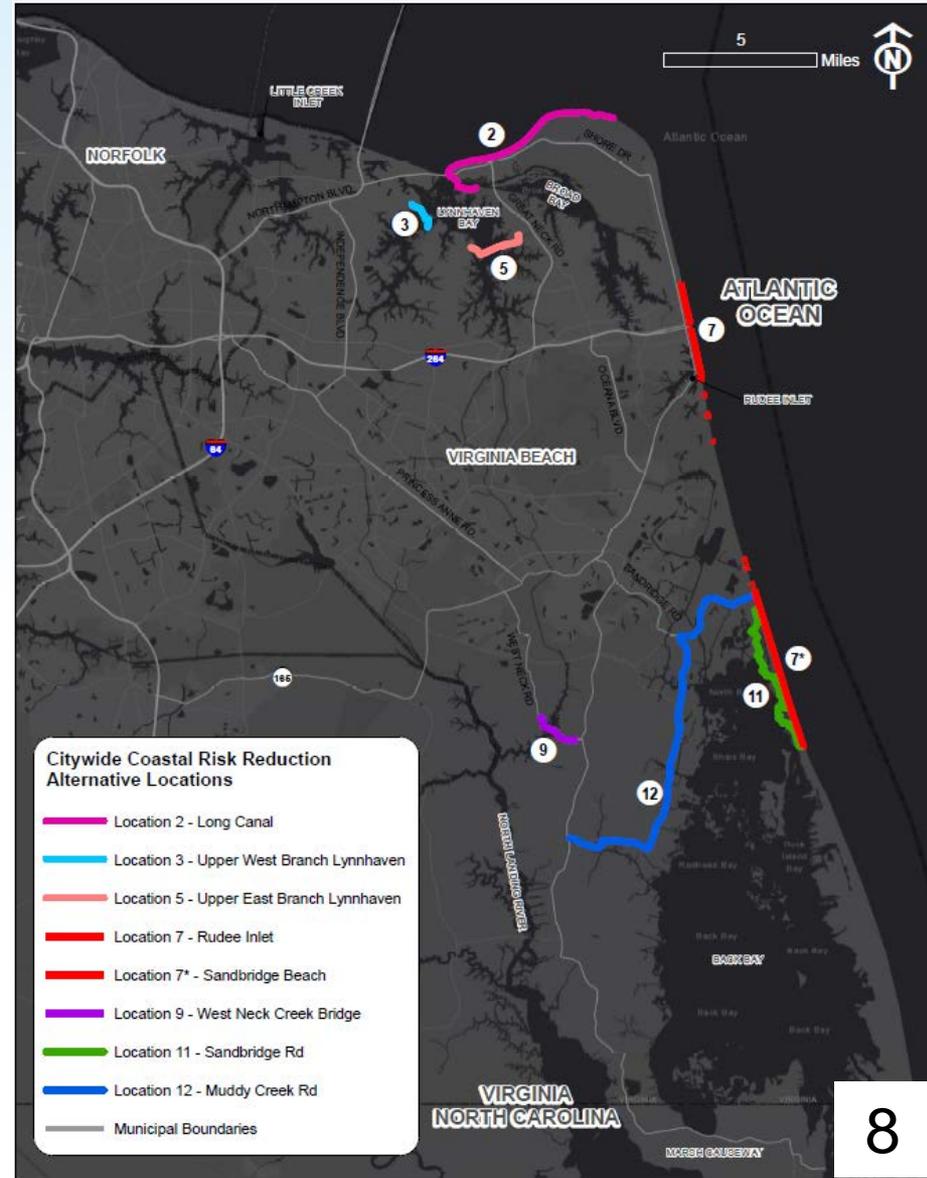
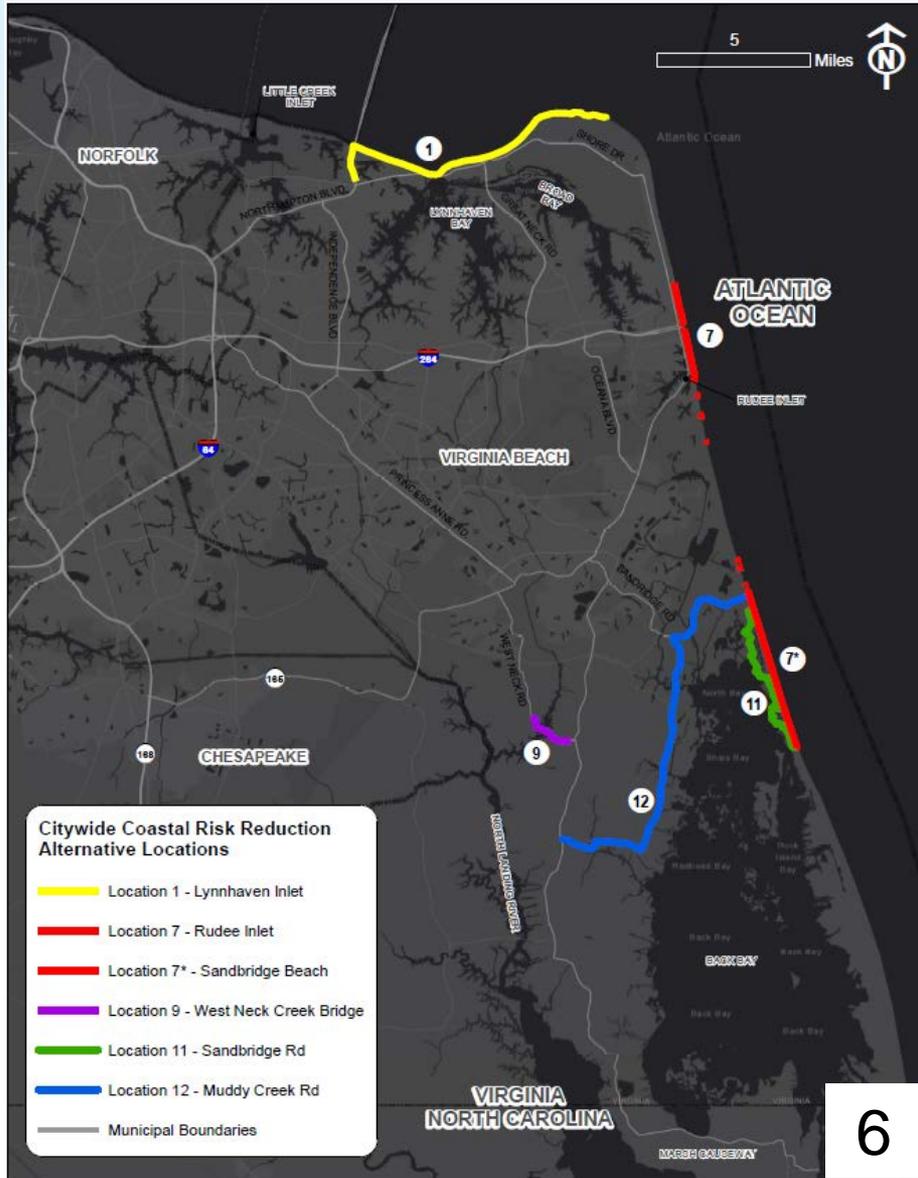
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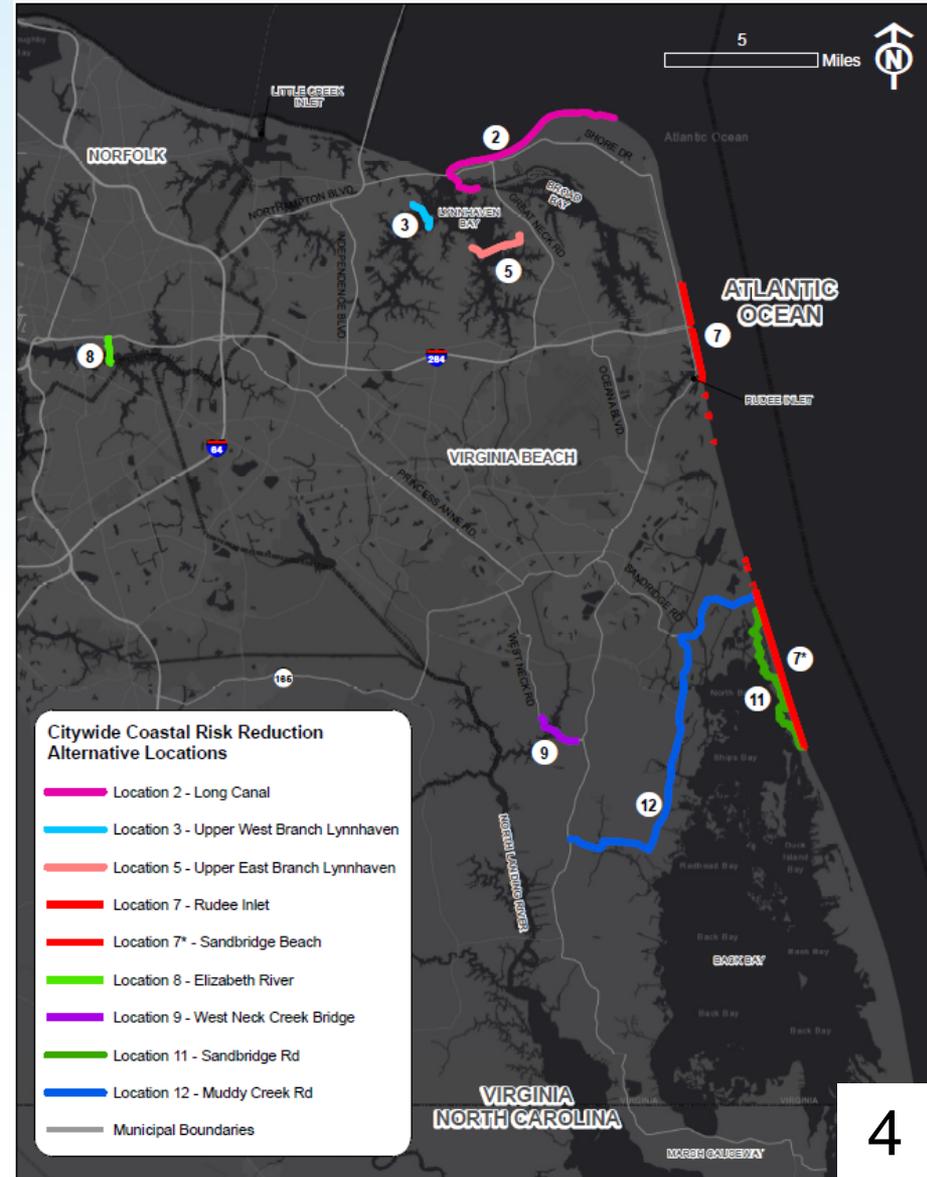
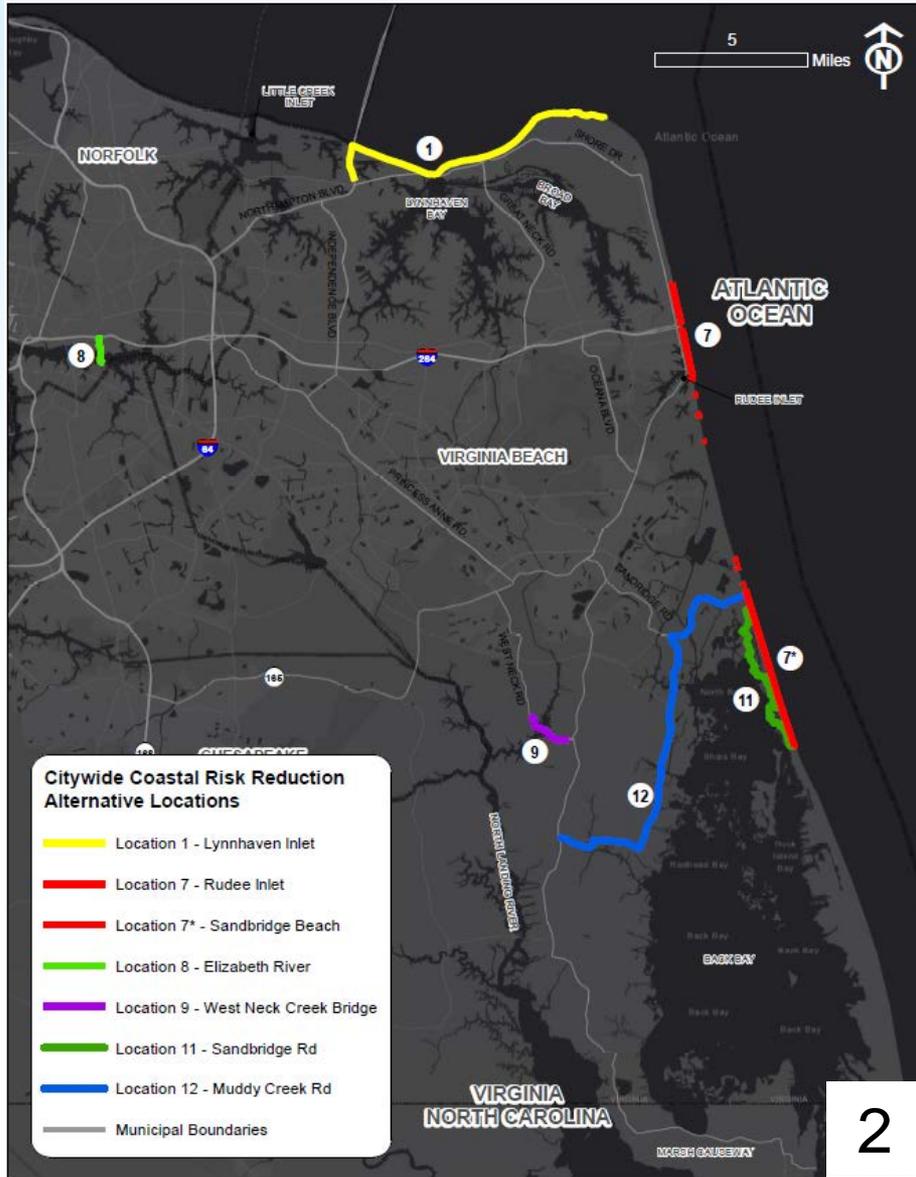
Down-selected Alternatives



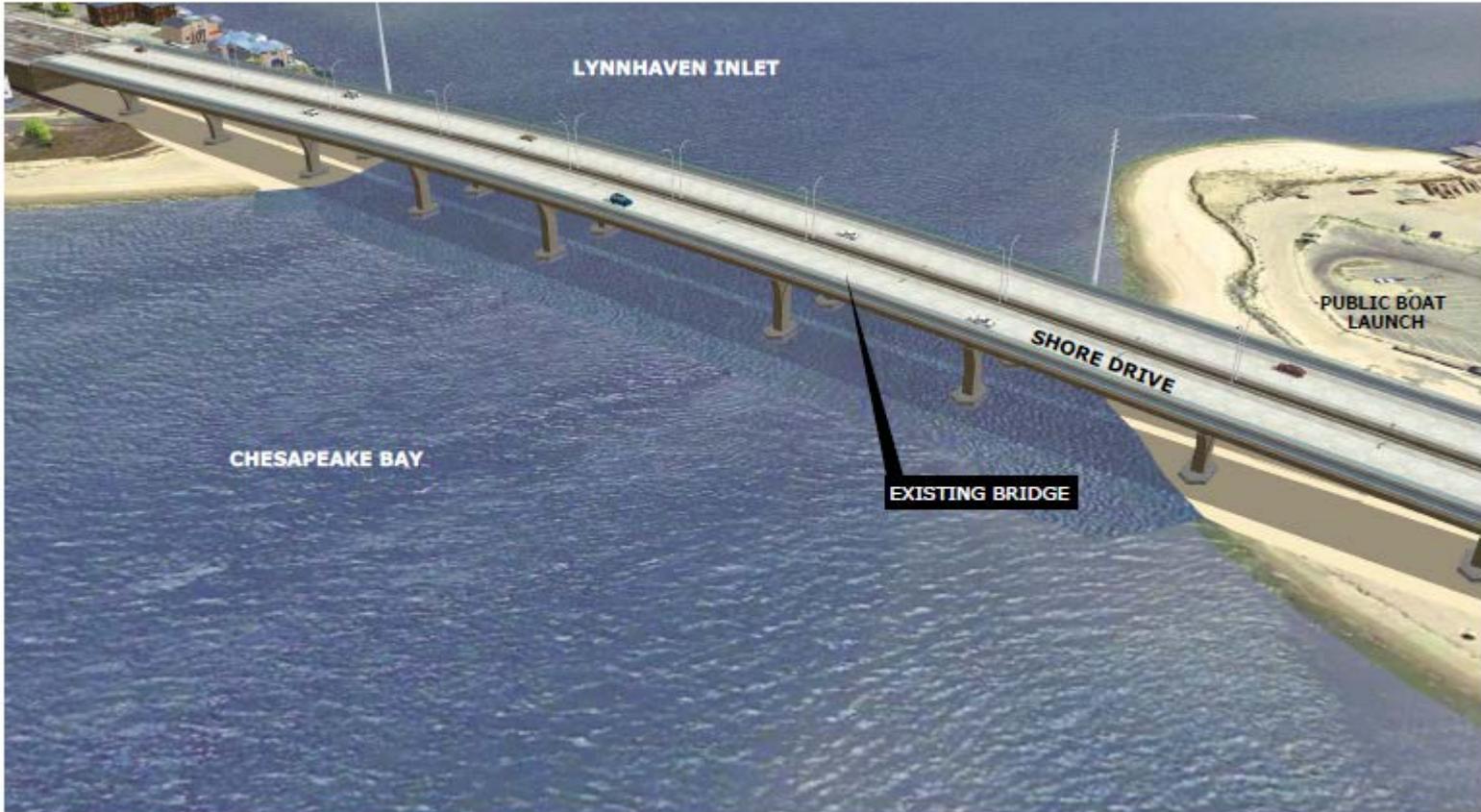
Down-selected Alternatives



Down-selected Alternatives



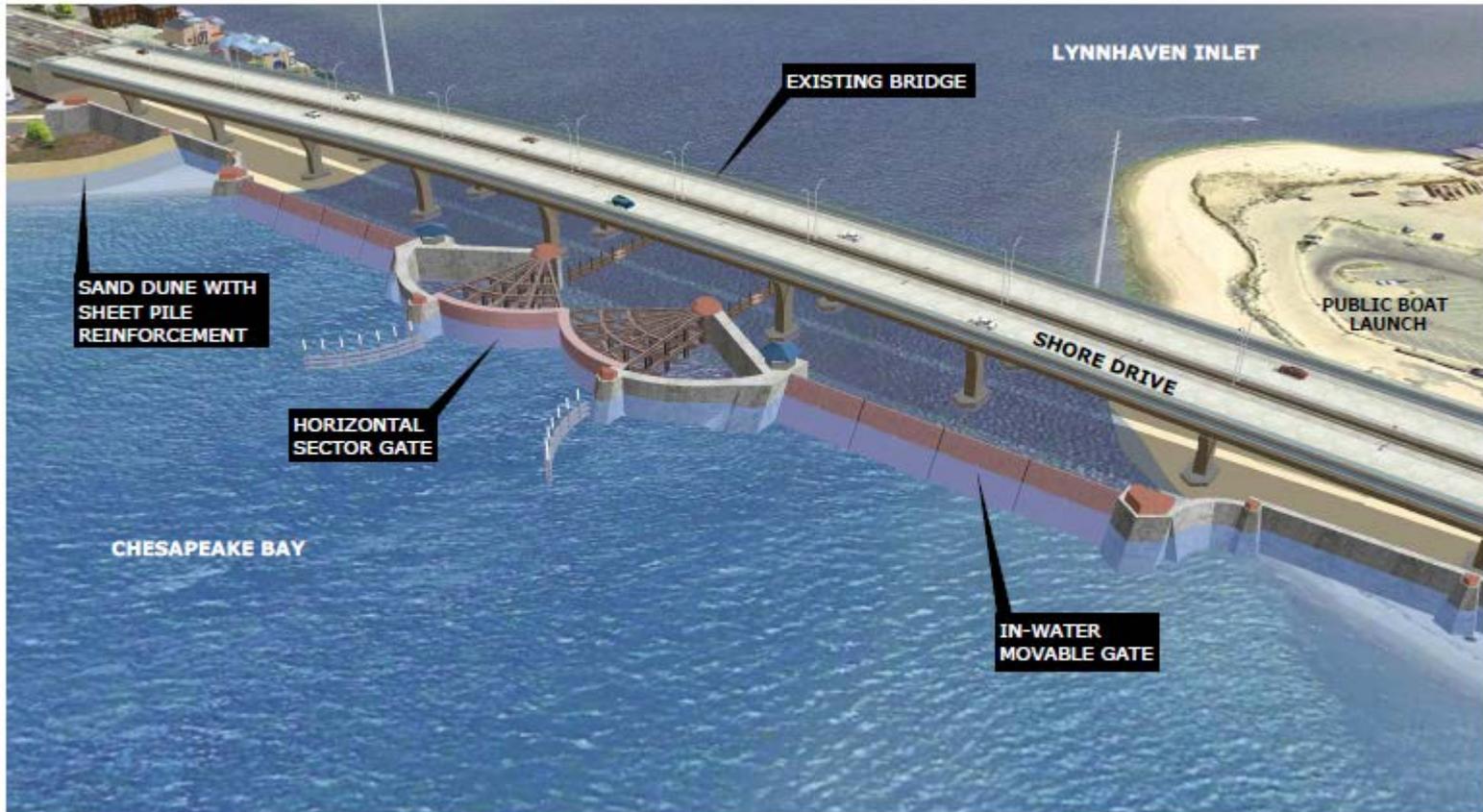
Renderings – Lynnhaven Inlet



EXISTING CONDITIONS (ENLARGED)

LYNNHAVEN INLET

Renderings – Lynnhaven Inlet



COMBINATION GATE SOLUTION (ENLARGED)

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

Total Length (feet): 18,638.0
Total Capital Cost: \$187,881,115.13
Average Annual O&M Cost: \$2,796,795.06

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

Alignment Option: 1 2

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 Elevation (ft. NAVD)	Avg. Structure Height (ft)	Acquisitions	Segment Cost	Avg. Annual O&M Cost
14.5	668+05.36	745+20.24	Earthen Levee	7,713.3			4.6	9.0		\$ 13,079,117.90	\$ 668,258.48
14.5	772+14.13	854+12.89	Earthen Levee	8,244.7			3.8	8.7		\$ 12,279,965.97	\$ 705,746.32
10.5	0+00.00	7+19.70	Floodwall	719.7			8.1	1.4		\$ 571,399.62	\$ 184,818.96
10.5	7+19.70	7+80.96	Deployable Floodwall	61.3			8.7	1.8		\$ 108,225.13	\$ 36,897.75
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		\$ 102,150.90	\$ 27,195.12
10.5	14+95.75	15+26.50	Deployable Floodwall	30.8			5.5	5		\$ 351,048.33	\$ 8,295.00
10.5	15+26.50	18+38.64	Floodwall	312.1			5.4	5.1		\$ 902,658.78	\$ 88,147.28
10.5	18+38.64	20+79.94	Sector Gate	241.3		189,586.7	-17.3	37.8		\$ 159,111,666.40	\$ 957,616.63
10.5	20+79.94	23+65.49	Floodwall	503.0			5.4	5.1		\$ 1,454,761.63	\$ 129,176.40

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 (including O&M)
Inlet	10'	36,900	\$1,422,434,000	\$204,438,000.00	Design (includes field investigation, environmental assessment & mitigation)	\$142,243,355	\$40,364,700.65	\$2,233,005,000.00
West Beachfront	10'				Environmental assessment & mitigation	\$213,374,032		
East Beachfront	10'				Drainage improvements	\$39,574,548		
Inland	12'				Utility relocation	\$28,443,871		
Inlet	10.0'	40,000	\$121,705,000	\$24,353,000.00	Design (includes field investigation, environmental assessment & mitigation)	\$12,176,436	\$4,940,000.70	\$197,518,000.00
Beachfront	14.0'				Environmental assessment & mitigation	\$19,264,745		
					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 investigation, environmental assessment & mitigation)	\$85,188,333	\$22,133,777.40	\$1,024,342,000.00
Inland	11.5'				Environmental assessment & mitigation	\$37,675,483		
					Drainage improvements	\$46,501,026		
					Utility relocation	\$13,023,359		
In-water Gate & Inland	9.0'	7,100	\$15,882,000	\$3,172,400.00	Design (includes field investigation, environmental assessment & mitigation)	\$1,586,195	\$539,306.43	\$24,967,000.00
					Environmental assessment & mitigation	\$2,379,293		
					Drainage improvements	\$1,180,237		
					Utility relocation	\$317,239		
In-water Gate & Inland	9.0'	73,300	\$267,286,000	\$53,441,200.00	Design (includes field investigation, environmental assessment & mitigation)	\$26,720,582	\$9,084,937.79	\$420,582,000.00
					Environmental assessment & mitigation	\$40,080,873		
					Drainage improvements	\$16,194,407		
					Utility relocation	\$5,344,188		
						\$842,688,711	\$64,268,871.13	\$3,897,014,000.00

Citywide Alternatives Comparison

Escalation: 3.0%

Construction Year Costs

Citywide Alternative	2018 Total Costs (Hard + Soft)	Future Year	Difference
		2040	(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

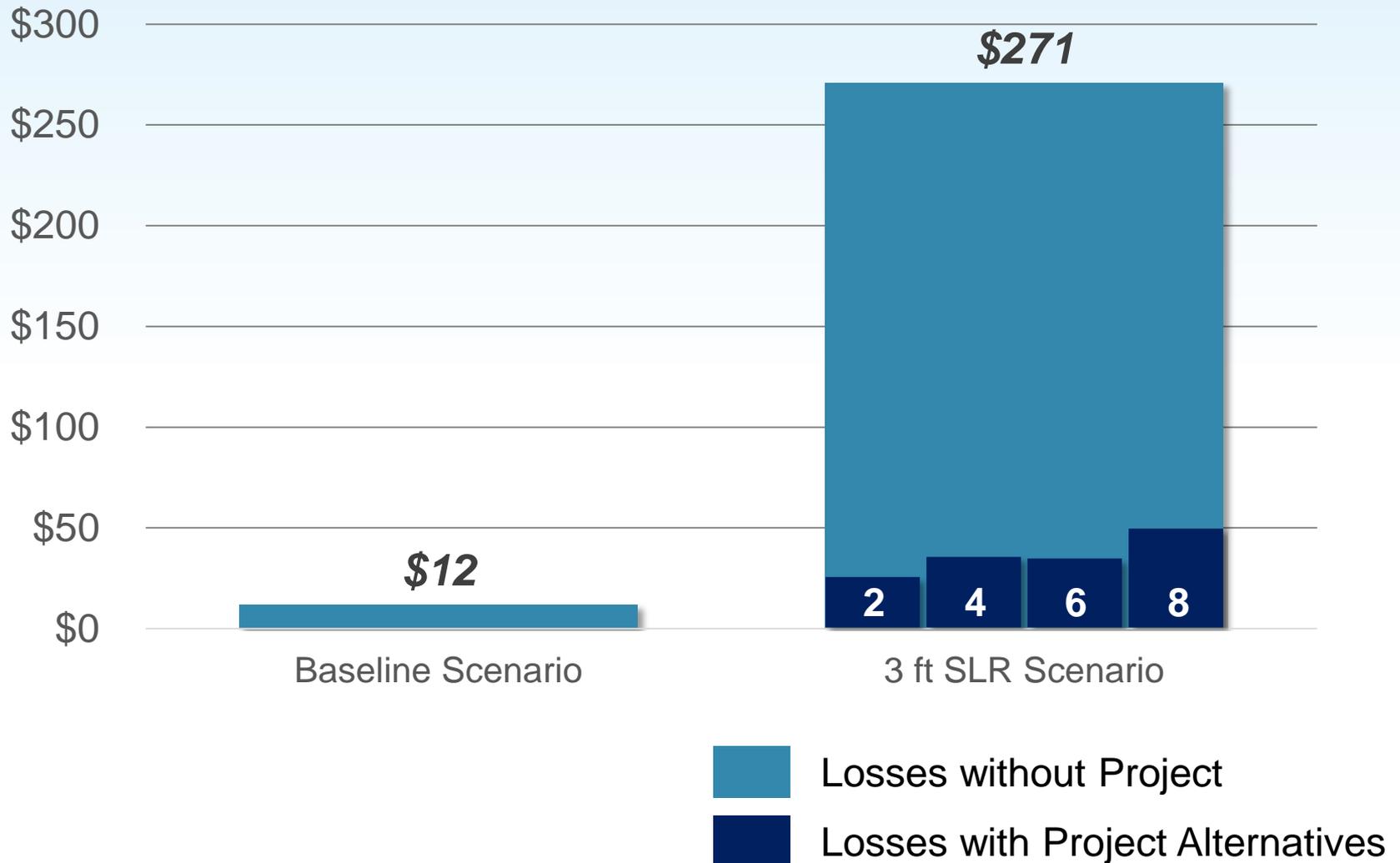
*Values subject to change pending final modeling and cost adjustments for gate types

**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

Annualized Losses (Millions)



Next Steps



Discussion

