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Making a difference, together

Anne Arundel County Roadway Vulnerability Assessment

Project Overview and Findings

March 12, 2025

General Housekeeping for Virtual Meetings

- Please use the Q & A to ask questions
- You can see your questions and answers, but not those from other participants
- Technical problems with the presentation will be addressed immediately
- Project-related questions will be answered at the end of the presentation
- Meeting is being recorded
- Recording, slides for meeting, and other materials will be shared on the project website

https://www.aacounty.org/public-works/highways/roadway-vulnerability-assessment

Project Team & Project Stakeholders

Core Project Team

DPW - Highways

- Alexander Baquie
- Blake Lightcap
- Scott Clement

McCormick Taylor

- Joe Knieriem
- Sean Doig
- Katherine Weber

DPW - BWPR

- Erik Michelsen
- Brenda Morgan

DPW - Director's Office

- Matt Diehl

Office of Transportation

- Brian Ulrich

Emergency Management

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Resilience Authority/CE Office

- Matthew Fleming

Planning and Zoning

- Michael Stringer

Inspections and Permits

- Raghu Badami

Today's Agenda

- Study Scope and Objectives
- Modeling Inundation
- Road Methodology and Results
- Bridge Methodology and Results
- Adaptation Measures
- Conclusion and Public Comment
- Questions

Study Scope

DPW awarded FEMA Building Resilient Infrastructure and Communities (BRIC) Grant to assess vulnerability of county-maintained roads and bridges to 3 climate stressors:

- Sea Level Rise
- Storm Surge
- Precipitation Change

Evaluate

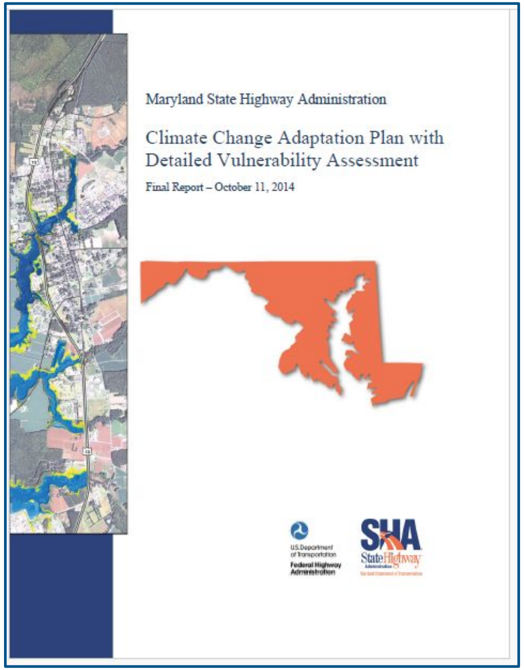
- ~1800 miles of county-maintained roads
- 86 National Bridge Inspection Standards (NBIS) bridges

Project Objectives

- Build on previous studies
  - 2014 and 2019 MDOT SHA climate change studies
  - 2023 Anne Arundel Sea Level Rise Strategic Plan
- Tailor the methodologies to meet the county's specific needs and available data
- Identify vulnerable County roads and bridges
- Identify adaptation measures and develop an analysis of adaptation options framework
- Engage internal stakeholders and the public
- Summarize findings in comprehensive report

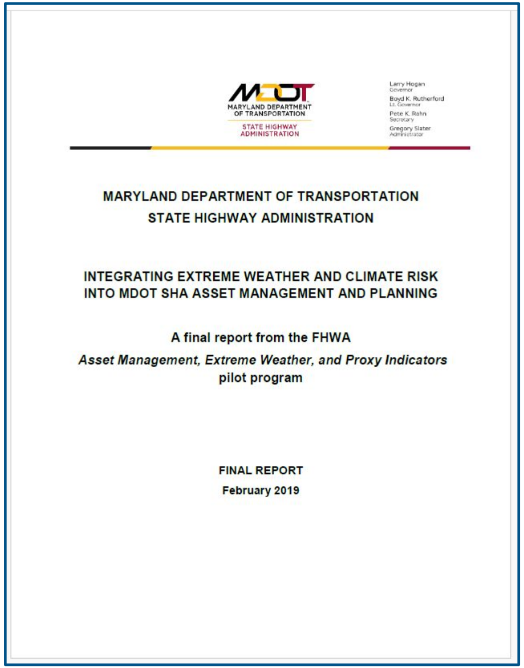
Previous Studies - 2014

- Climate Change Adaptation Plan with Detailed Vulnerability Assessment
  - Maryland State Highways Administration (SHA)
  - Final Report dated October 11, 2014
  - Pilot study limited to state maintained roads and bridges within Anne Arundel and Somerset Counties
  - Hazard Vulnerability Index (HVI) for state roads
  - Vulnerability Assessment Scoring Tool (VAST) to assess bridges & large culverts
  - Looked at sea level rise, storm surge, and precipitation change
  - 2 points in time—2050 & 2100



Previous Studies - 2019

- Integrating Extreme Weather and Climate Risk into MDOT SHA Asset Management and Planning
    - Maryland SHA
    - Final Report dated February 2019
    - Statewide study
    - VAST used for assessment of bridges and large culverts only
    - Studied sea level rise, storm surge, and precipitation change
    - 2050 only


MDOT
MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

INTEGRATING EXTREME WEATHER AND CLIMATE RISK INTO MDOT SHA ASSET MANAGEMENT AND PLANNING

A final report from the FHWA
Asset Management, Extreme Weather, and Proxy Indicators pilot program

FINAL REPORT
February 2019

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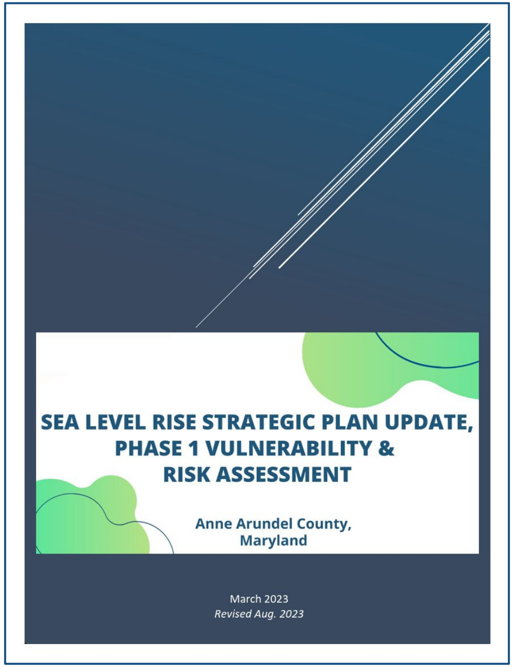
Previous Studies - 2023

- Sea Level Rise Strategic Plan Update, Phase 1 Vulnerability & Risk Assessment
  - Anne Arundel County
  - Revised August 2023
  - Countywide study
  - Studied sea level rise only
  - Evaluates impacts to privately owned land, public utility infrastructure, well/septic systems, and other resources and industries
  - 2050, 2065, and 2100 time horizons

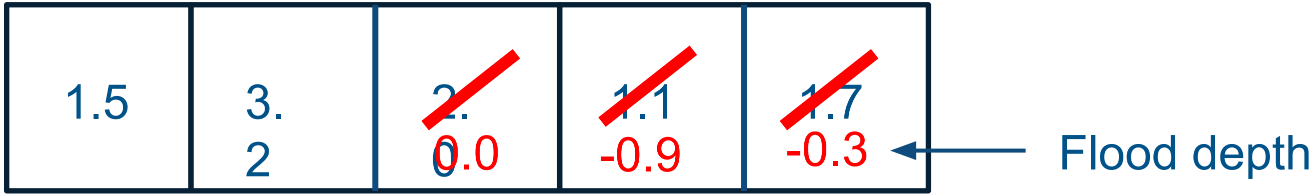


Modeling Inundation

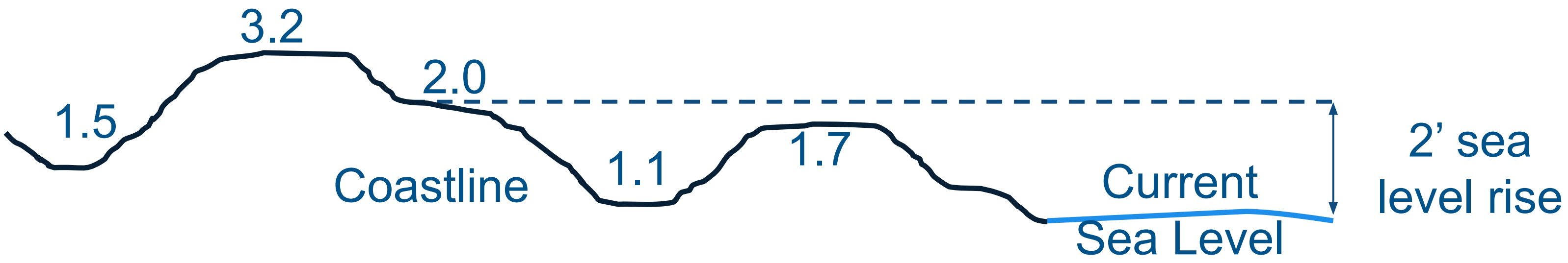
Sea Level Rise Inundation Steps

1. **Create an elevation model for the ground surface**
   - Called a "Digital Elevation Model" or DEM
2. **Model the existing water surface elevation**
   - Typically built using NOAA gauge data
3. **Model the future water surface elevation**
   - Based on current climate change science
4. **"Flood" the ground model based on:**
   - Future water surface elevation
   - Hydrologic connection

- Picture a checkerboard where every square is an elevation



- Now rotate that 2D model to represent the 3D topography of an area

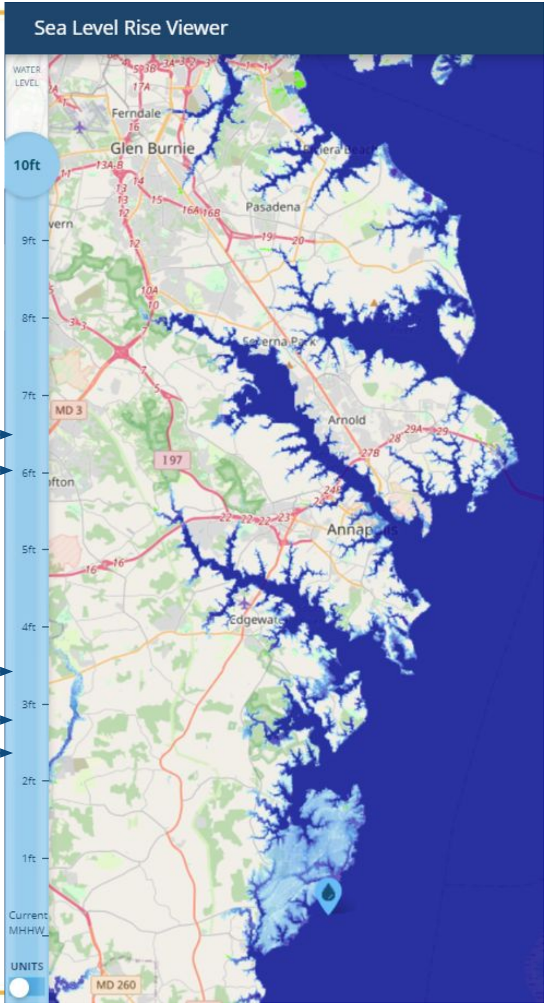


- And add the sea level rise scenario
  - Hydrologically connected areas below the new sea level will be inundated.
  - Flood depth in a given location will be the original elevation less the sea level rise elevation

Current Study’s Inundation Model

- NOAA SLR Viewer – provides data in 1-foot increments up to 10 feet
- Model all 10 scenarios
- Evaluated 1-, 2-, 3-foot increments as permanent inundation
- Additional increments evaluated as potential storm surge

2014 Study 2100 (6.41-ft)
2023 Study 2100 (6.02-ft)
2023 Study 2065 (3.21-ft)
2014 & 2019 Study 2050 (2.79-ft)
2023 Study 2050 (2.31-ft)



Road Methodology and Results

2014 MDOT SHA Study Road Methodology

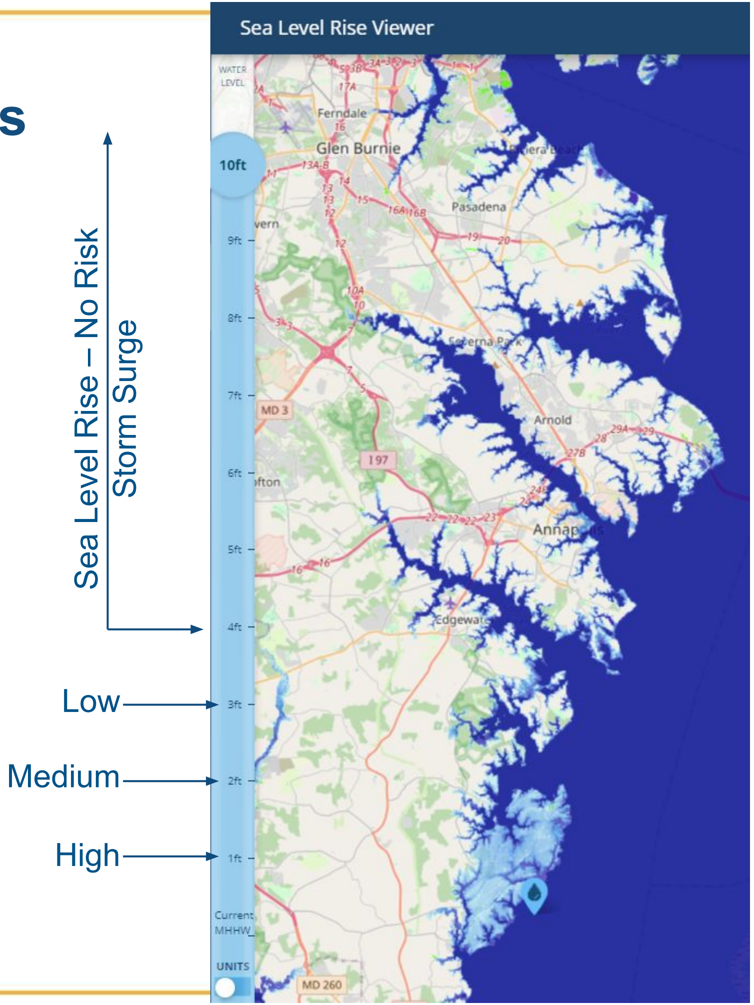
- Only 2014 study assessed roads and it was state roads only
- Evaluated
  - Sea Level Rise (SLR)
  - Storm Surge – 100-year storm event
- 3 components
  - What is the flood depth?
  - Is it an evacuation route?
  - What is the functional classification? (Local, Collector, Arterial, Interstate)

Current Study Road Methodology

- County-maintained Roads
- Evaluated
  - Sea Level Rise (SLR)
  - Storm Surge
  - Precipitation
- Each road segment evaluated as High/Medium/Low for:
  - *Likelihood* of inundation for each climate stressor
  - *Impact on the larger system* if inundation occurs
- Result is a 2D “risk matrix”

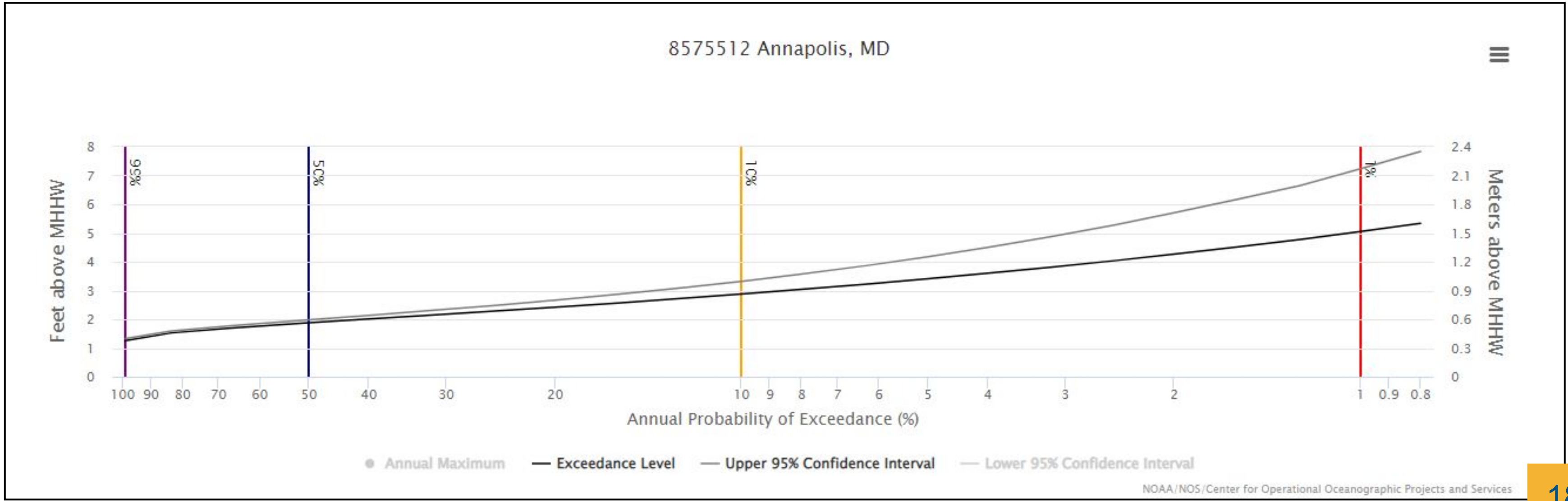
Sea Level Rise Likelihood Analysis

- NOAA SLR Viewer – provides data in 1-foot increments up to 10 feet
- Inundation at 1-foot = High Risk
- Inundation at 2-feet SLR = Medium Risk
- Inundation at 3-feet SLR = Low Risk



Storm Surge – Likelihood Analysis

- Used Naval Academy Sea Level data back to 1930s
- Percent annual chance of a particular water elevation increase occurring



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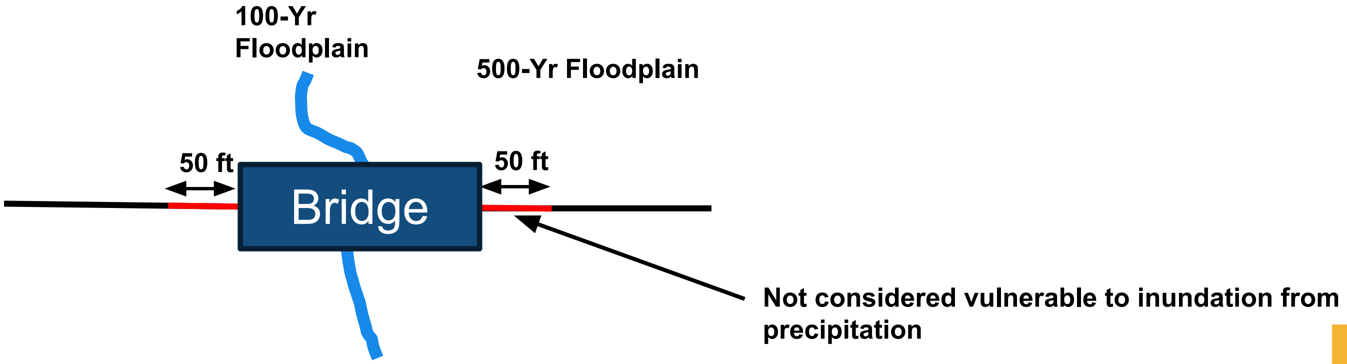
Storm Surge – Likelihood Breakdown

Elev Above SL	% Annual Likelihood Exceedance	% Annual Likelihood Upper 95% Confidence Interval	Score Category
1	99.0%	99.0%	High
2	50.0%	50.0%	High
3	8.0%	12.5%	Medium
4	2.5%	5.0%	Medium
5	1.0%	2.5%	Low
6	0.2%	1.5%	Low
7		1.0%	Low
8		0.2%	Low
9			Low
10			Low

- No Inundation = No Risk

Precipitation – Likelihood Analysis

- High risk = within 100-feet of a confirmed flood location
- Medium risk = within the FEMA 100-Year Floodplain
- Low risk = within the FEMA 500-Year Floodplain
- Excluded sections of road associated with bridges within 50 foot of the bridge – design criteria should place the road elevation above the floodplain

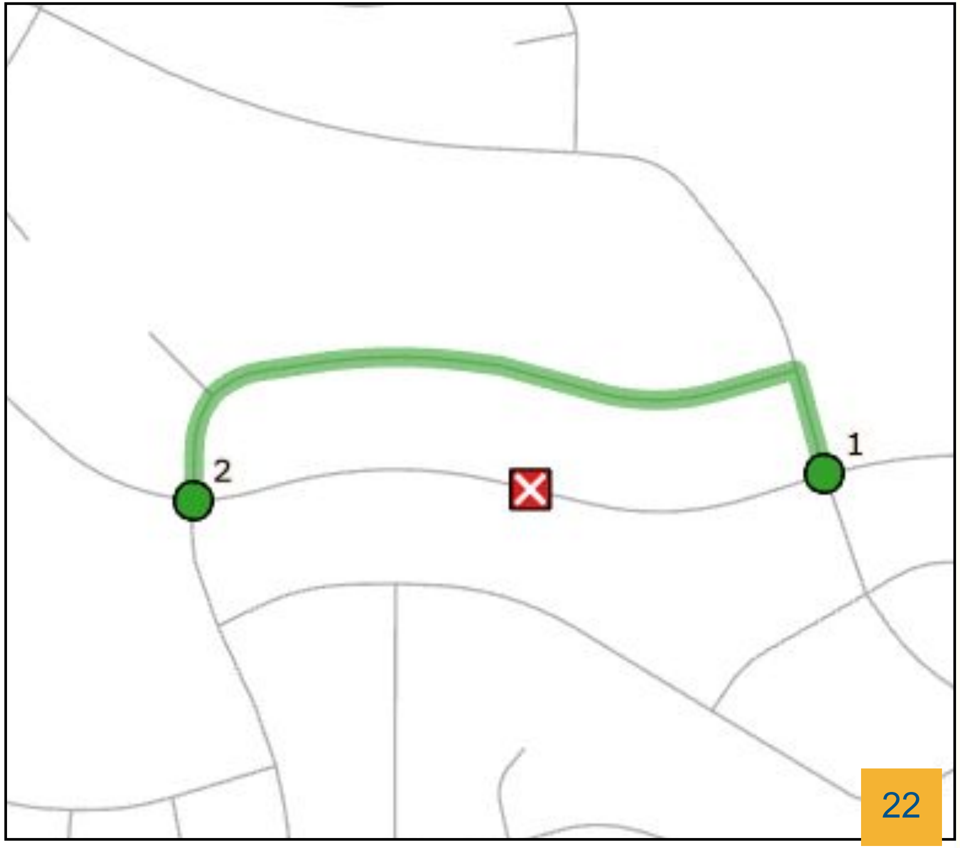


Impact

- Effect on the larger system if inundation occurs
- One score per road regardless of climate stressor
- Contributing Factors:
  - Detour 1 – how much longer is the drive if a road is closed?
  - Detour 2 – what's the cumulative traffic flow through the closed road?
- Approach differs from MDOT SHA studies
  - Evacuation route
  - Functional classification

Detour 1 Analysis

1. Captures how much <u>additional travel distance</u> is required if a road is closed
2. If no alternative route is available, detour 1 receives a higher score.



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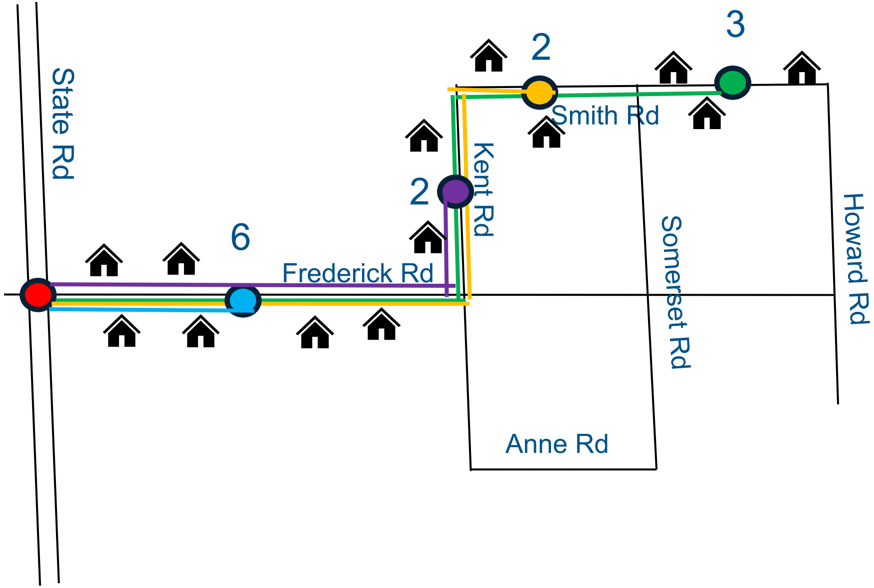
Detour 2 Analysis – Estimating Impact

1. For all county roads, determine the route to the nearest state road for a given block.
2. Determine the number of addresses on that block.
3. If any portion of the route is closed then that is the number of addresses from this block that are impacted.
4. Replicate this analysis for every block. Use the routes to calculate number of impacted addresses if a specific block is closed.



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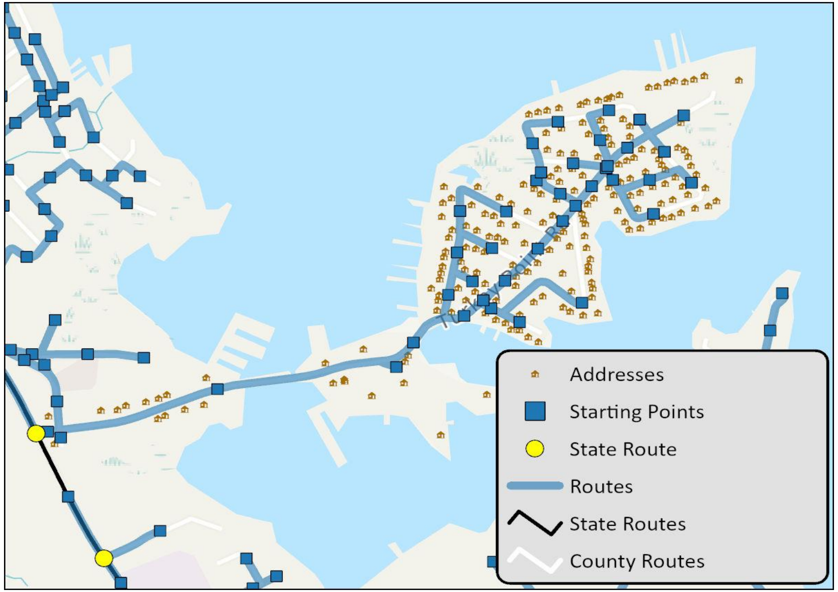
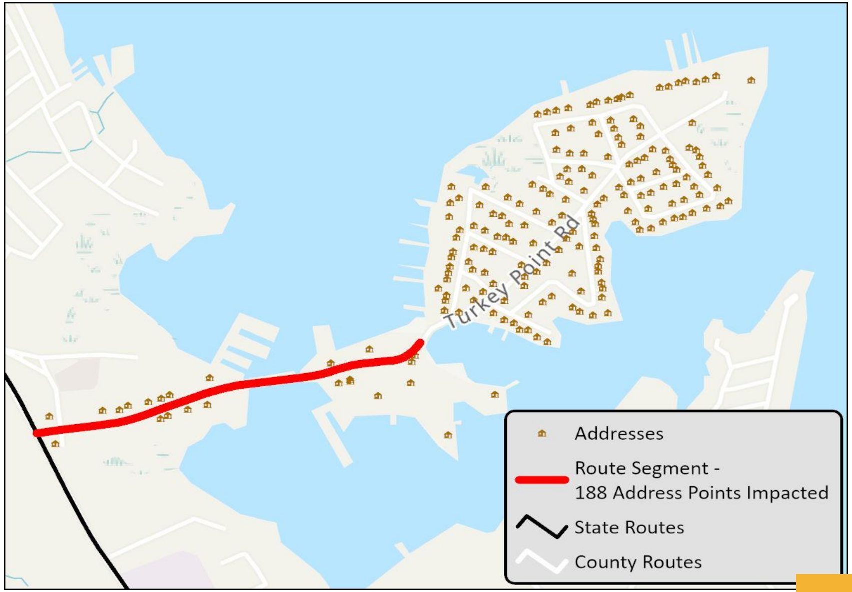
Detour 2 Analysis – Real World Example





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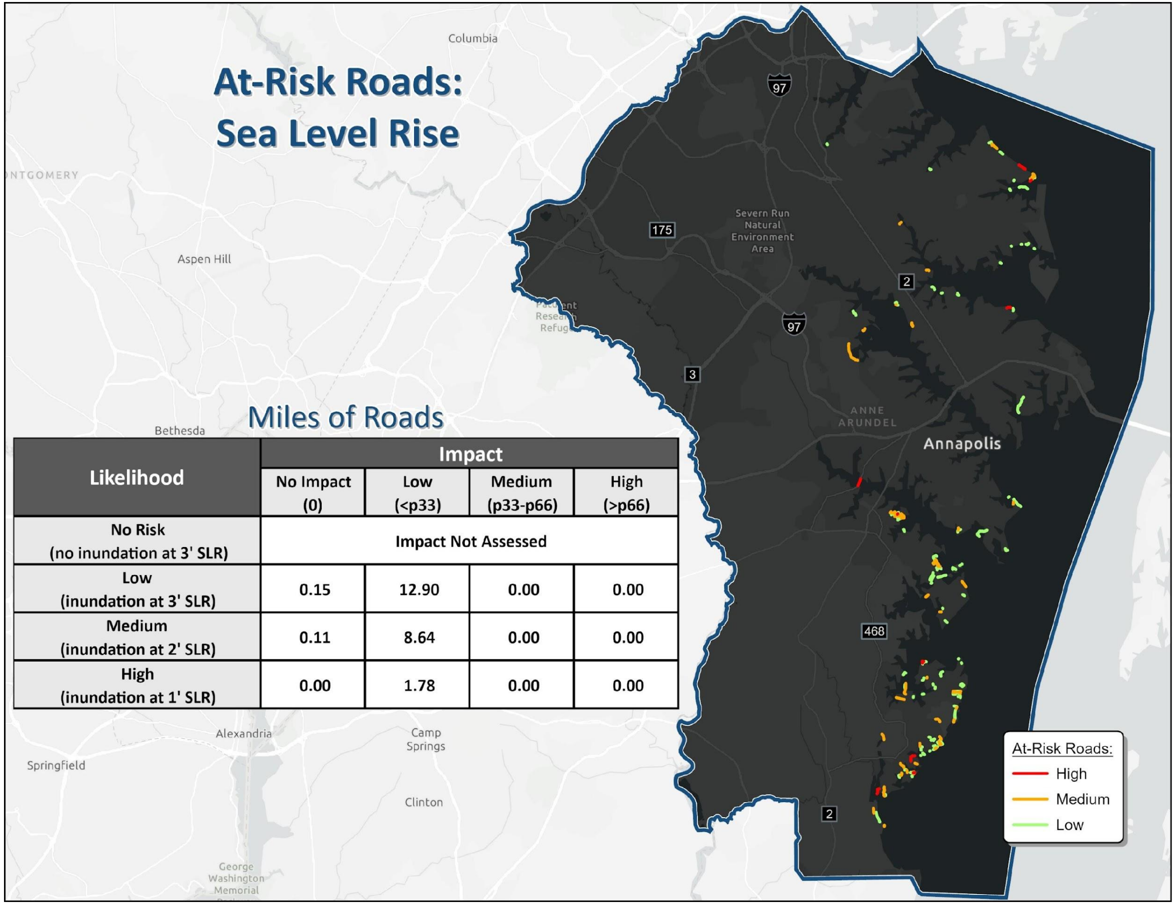
Final Road Assessment Scoring

	Indicator	Scoring
Like liho od	**Sea Level Rise**	High = Inundated at 1’ SLR Medium = Inundated at 2’ SLR Low = Inundated at 3’ SLR
	Storm Surge	High = Inundated at 1’– 2’ SLR Medium = Inundated at 3’– 4’ SLR Low = Inundated at 5’– 10’ SLR
	Precipitation	High = Within 100’ of Confirmed Flooding Medium = Within FEMA 100-Yr Floodplain Low = Within FEMA 500-Yr Floodplain
Imp act	**Travel Cost (Detour 1) x Volume (Detour 2)**	High = > 17,277 Medium = <17,277 – 8,138 Low = <8,138

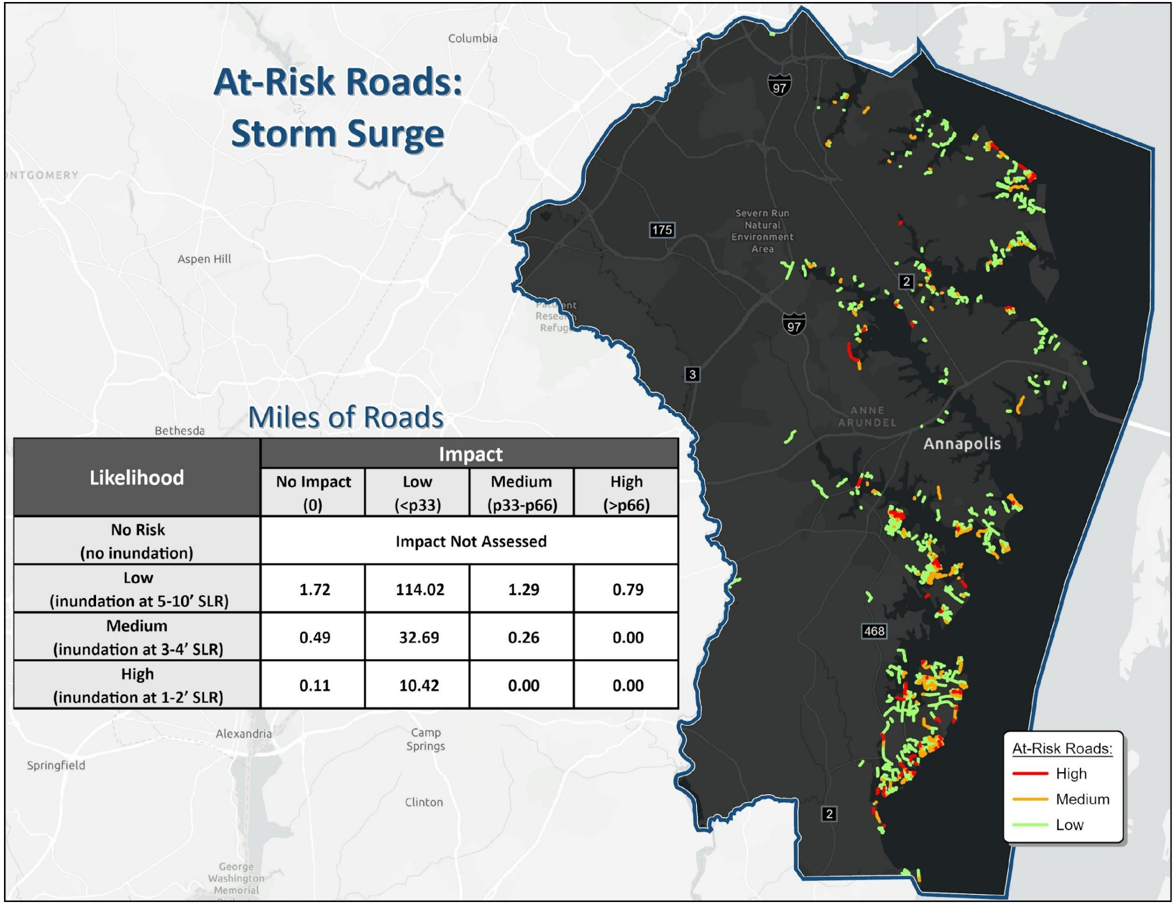
At-Risk Roads: Sea Level Rise



Miles of Roads

Likelihood	Impact			
	No Impact (0)	Low (<p33)	Medium (p33-p66)	High (>p66)
No Risk (no inundation at 3' SLR)	Impact Not Assessed			
Low (inundation at 3' SLR)	0.15	12.90	0.00	0.00
Medium (inundation at 2' SLR)	0.11	8.64	0.00	0.00
High (inundation at 1' SLR)	0.00	1.78	0.00	0.00

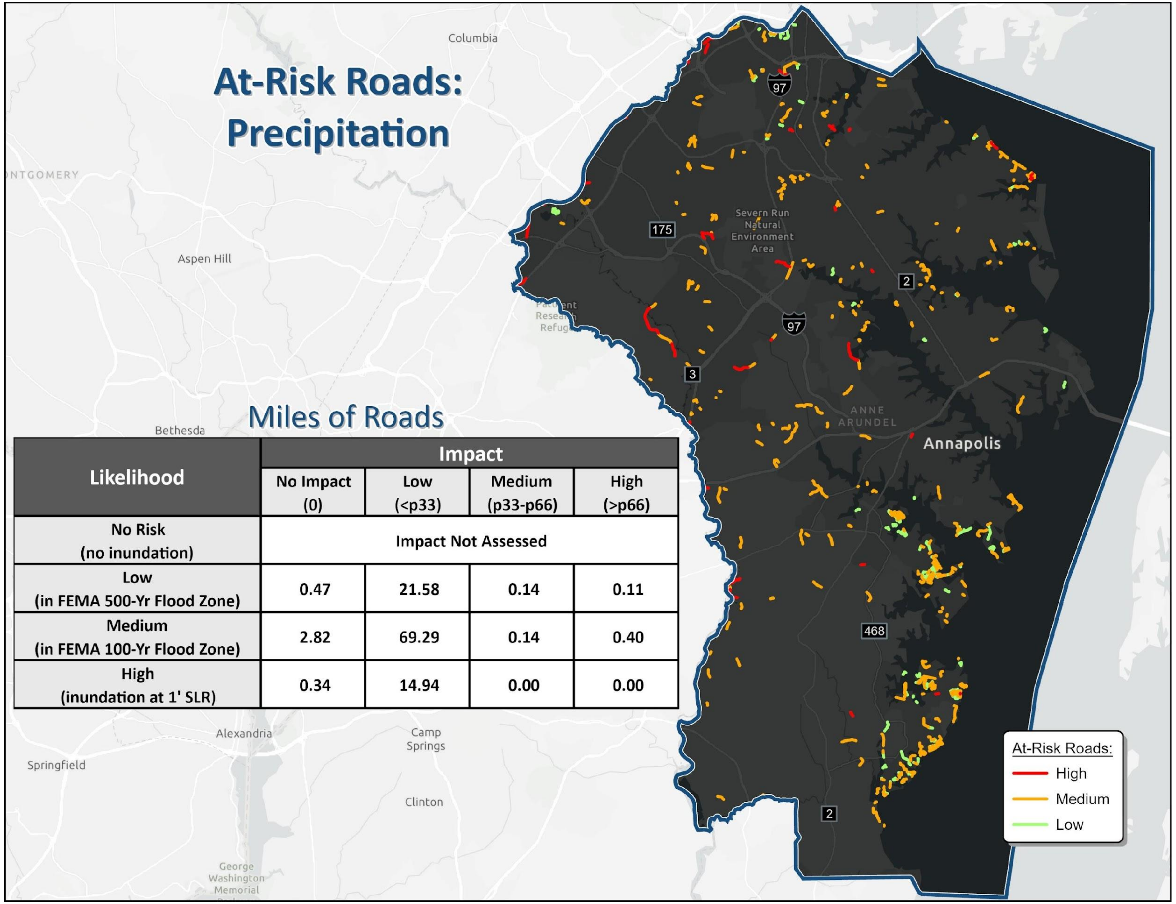
At-Risk Roads: Storm Surge



Miles of Roads

Likelihood	Impact: No Impact (0)	Low (<p33)	Medium (p33-p66)	High (>p66)
No Risk (no inundation)	Impact Not Assessed			
Low (inundation at 5-10' SLR)	1.72	114.02	1.29	0.79
Medium (inundation at 3-4' SLR)	0.49	32.69	0.26	0.00
High (inundation at 1-2' SLR)	0.11	10.42	0.00	0.00

At-Risk Roads: Precipitation

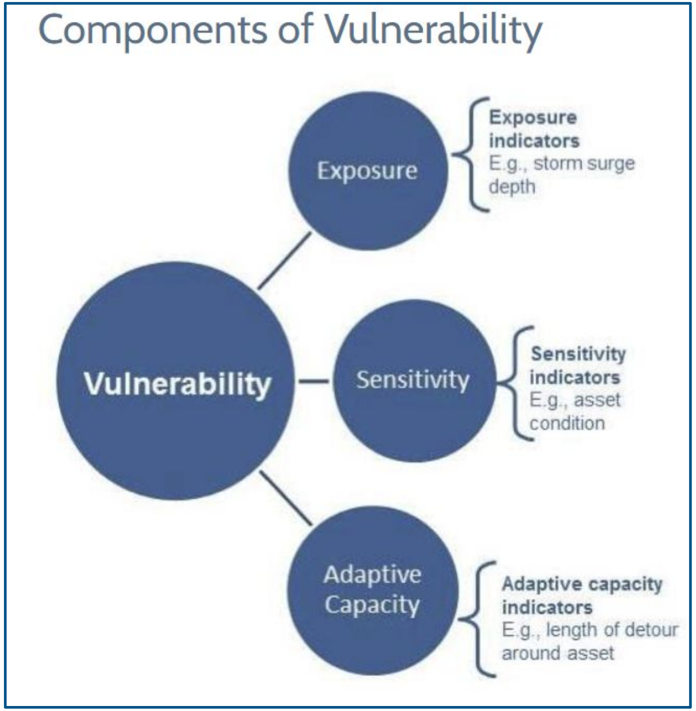


Miles of Roads

Likelihood	Impact			
	No Impact (0)	Low (<p33)	Medium (p33-p66)	High (>p66)
No Risk (no inundation)	Impact Not Assessed			
Low (in FEMA 500-Yr Flood Zone)	0.47	21.58	0.14	0.11
Medium (in FEMA 100-Yr Flood Zone)	2.82	69.29	0.14	0.40
High (inundation at 1' SLR)	0.34	14.94	0.00	0.00

Bridge Methodology and Results

MDOT SHA Bridge Methodology



- Used the USDOT Vulnerability Assessment Scoring Tool (VAST)
- Indicators for each component
- Climate Stressors considered:
  - Sea Level Rise (SLR)
  - Storm Surge (SS)
  - Precipitation Change (PC)
- Each Stressor produces a unique vulnerability score

Current Study Bridge Methodology

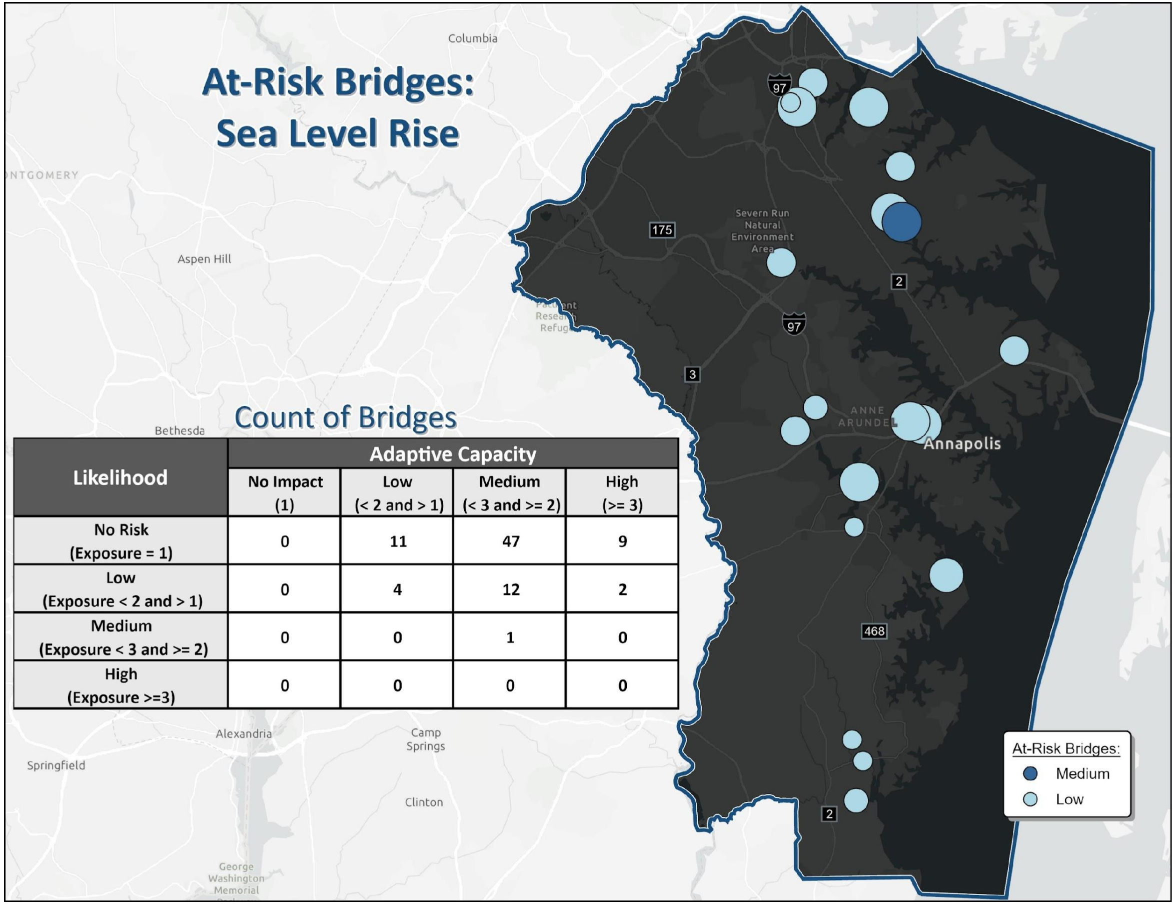
- Used the VAST
- County-maintained bridges
- VAST output is a score between 1-4
- Converted these scores to a 2D high/medium/low "risk matrix"
  - Combined Exposure and Sensitivity to represent "likelihood"
  - "Impact" captured by VAST's Adaptive Capacity

Score	Category
>= 3	High
<3 and >= 2	Medium
<2 and > 1	Low
1	No Likelihood/Impact

Current Study Bridge Data Sources

- Used the same inundation data as for the roads
  - NOAA
  - FEMA
  - County road flood locations
- Sensitivity indicators came from the bridge dataset
  - Structure condition
  - Height above waterway
  - Age
- Adaptive Capacity
  - Detour 1
  - Functional Classification – from bridge dataset
  - Average Daily Traffic (ADT) – from bridge dataset

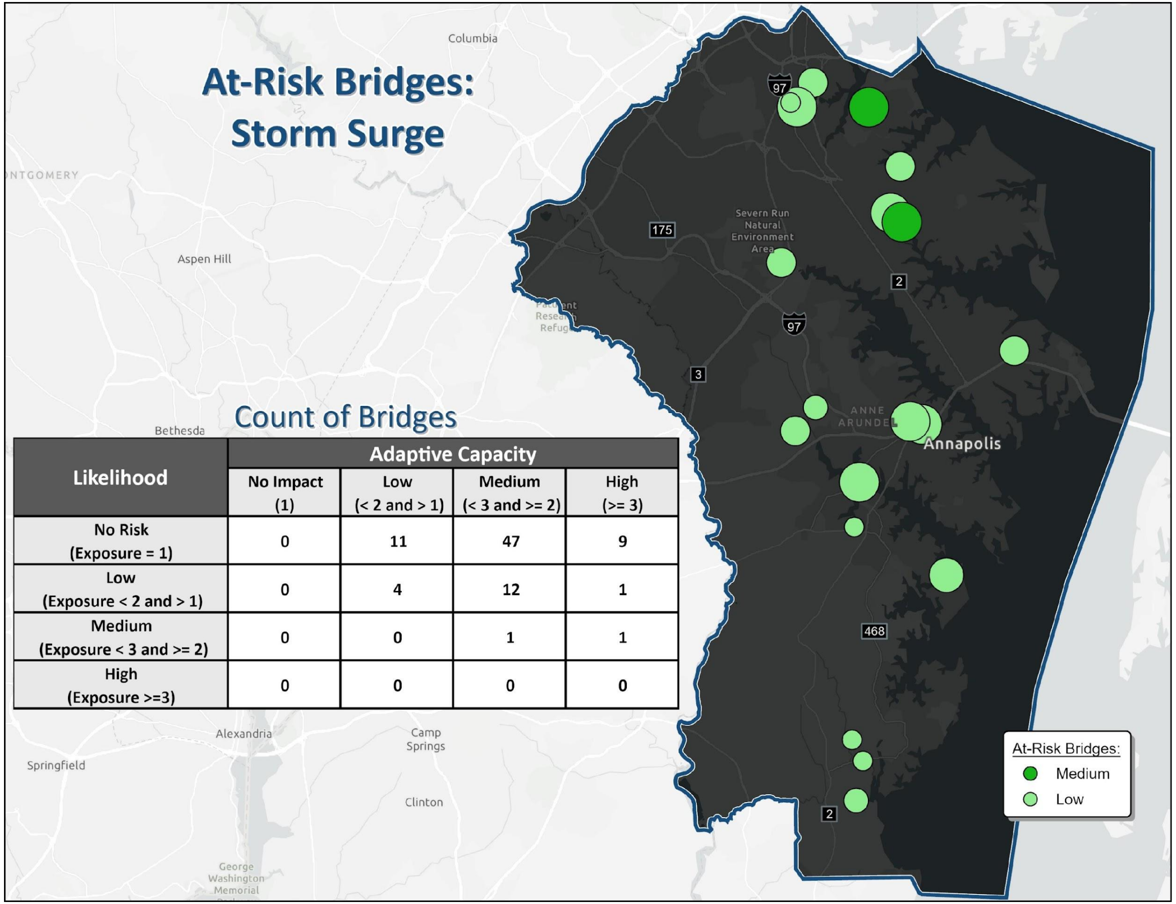
At-Risk Bridges: Sea Level Rise



Count of Bridges

Likelihood	Adaptive Capacity			
	No Impact (1)	Low (< 2 and > 1)	Medium (< 3 and >= 2)	High (>= 3)
No Risk (Exposure = 1)	0	11	47	9
Low (Exposure < 2 and > 1)	0	4	12	2
Medium (Exposure < 3 and >= 2)	0	0	1	0
High (Exposure >=3)	0	0	0	0

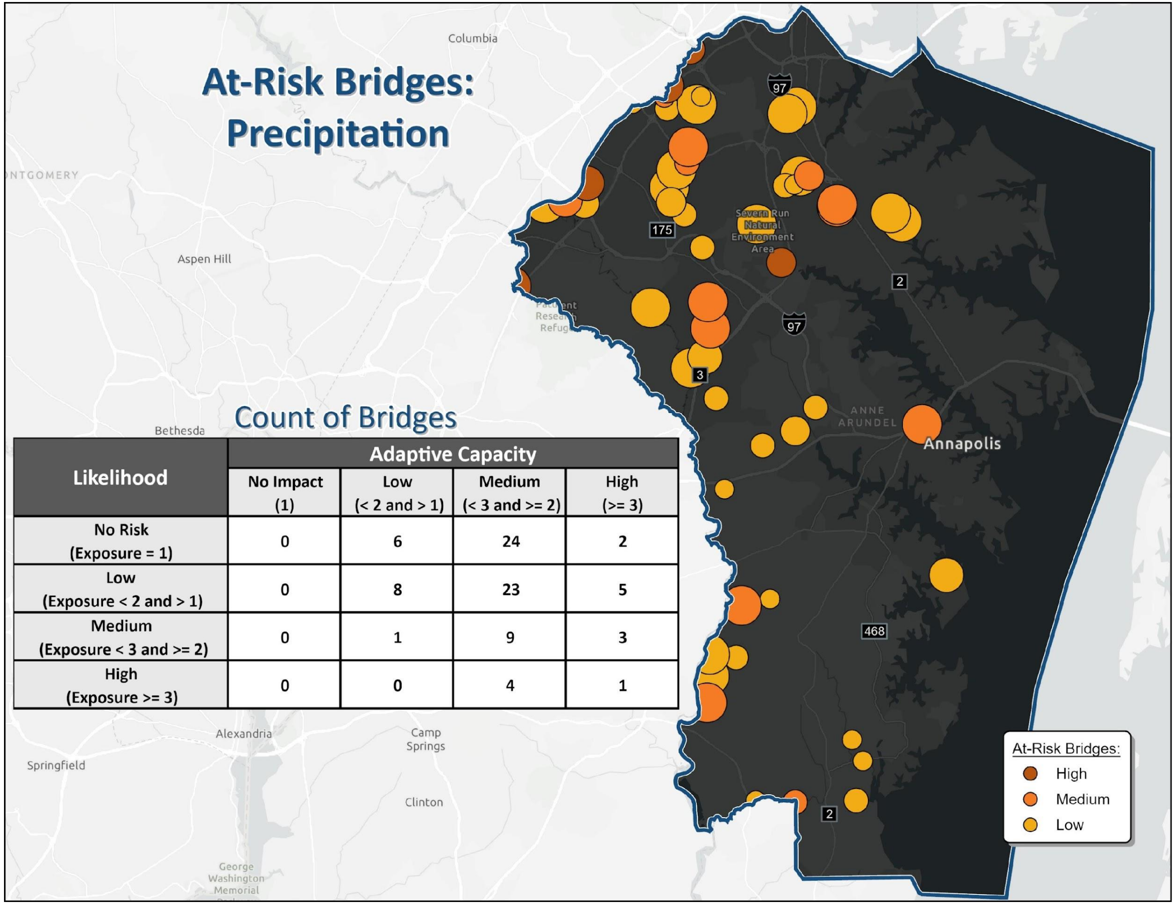
At-Risk Bridges: Storm Surge



Count of Bridges

Likelihood	Adaptive Capacity			
	No Impact (1)	Low (< 2 and > 1)	Medium (< 3 and >= 2)	High (>= 3)
No Risk (Exposure = 1)	0	11	47	9
Low (Exposure < 2 and > 1)	0	4	12	1
Medium (Exposure < 3 and >= 2)	0	0	1	1
High (Exposure >=3)	0	0	0	0

At-Risk Bridges: Precipitation



Count of Bridges

Likelihood	Adaptive Capacity			
	No Impact (1)	Low (< 2 and > 1)	Medium (< 3 and >= 2)	High (>= 3)
No Risk (Exposure = 1)	0	6	24	2
Low (Exposure < 2 and > 1)	0	8	23	5
Medium (Exposure < 3 and >= 2)	0	1	9	3
High (Exposure >= 3)	0	0	4	1

Adaptation Measures

Adaptation Measures Matrix

- Intergovernmental Panel on Climate Change (IPCC) defines Adaptation as the *adjustment in natural or human systems in response to actual or expected climatic stimuli or their affects, which moderates harm or exploits beneficial opportunities.*
- Focused on adaptation measures appropriate to inundation vulnerability for roads/bridges
- Synthesized adaptation measures from prior efforts and available resources
- Developed a tool or resource to identify adaptation measures appropriate to address specific observed or anticipated vulnerabilities

Adaptation Measures Matrix

- Organized by asset type, stressor, and vulnerability
  - Includes questions to help identify vulnerability
- Focuses on vulnerability and not impact
- Requires desktop and on-site investigation
  - Questions to identify vulnerability
  - Primary inspection element
- Provides potential engineering and operations & maintenance adaptations
- Provides resource information

Road Matrix

ROAD VULNERABILITY AND ADAPTATION MATRIX

Index	SLR	SS	PC	RR	Vulnerability	Questions to identify vulnerability	Primary inspection element	Decision	Engineering Adaptation	Operations & Maintenance Adaptation	Resources
1	SLR	SS	PC	RR	Approaches, embankments, and retaining structure undermining or washout	Unvegetated shoulders or embankments? Evidence of rills or mass soil failures? Exposure to SLR? SS? PC? RR?	scour/erosion at embankments and/or around retaining structures	Now Future No	Elevate approaches; provide extended wing walls; retrofit/improve roadside drainage systems	Add armoring (rip rap) to side slopes and embankments; increase frequency of inspections; consider continuous monitoring for high-risk, critical routes	Maryland Highway Drainage Manual; MDE Model Soil Erosion and sediment Control Ordinance (2018)
2	SLR	SS	PC	RR	Deterioriation of pavement and subgrades due to inundation	Observed cracking or failure of pavement course? Exposure to SLR? SS? PC? RR?	pavement and subgrade condition (structural)	Now Future No	Elevate the pavement structure; increase design standards to withstand inundation/saturation	-	MDOT SHA Pavement Design Guide
3	SLR	SS	PC	RR	Sinkholes caused by subgrade inundation	Standing water in drainage conveyances? High water table? Exposure to SLR? SS? PC? RR?	standing water in drainage conveyances	Now Future No	Reevaluate geotechnical analysis to evaluate cause; consider additional geotechnical explorations; provide ground improvements where warranted	Consider groundwater monitoring in high-risk areas; apply grouting, geogrid reinforcement, underdrains, or improved subgrade	MDOT SHA Standard Specifications for Subsurface Explorations; FHWA NHI-16-072
4	SLR	SS	PC	RR	Deteriorating roadside vegetation (salt exposure, inundation, drought)	Sparsely vegetated or unvegetated roadsides? Tidal exposure? Drought exposure? Exposure to SLR? SS? PC? RR?	vegetative cover of roadside	Now Future No	Consider alternative stabilizations (e.g., rip rap) within roadside conveyances	Retrofit with salt- and inundation-resistant vegetation; consider retrofittig with channel liners	Section 3.3.4 in Maryland Highway Drainage manual, Design channel linings following FHWA HEC 15: Design of Roadside channels with Flexible Lining
5	SLR	SS	PC		Debris accumulation on roadways and clear zones	Expected high water elevation with respect to road elevation? Exposure to SLR? SS? PC?	observed debris	Now Future No	-	Station equipment for rapid debris removable	MDOT SHA Stormwater Management Facility Routine Maintenance Manual; MDOT SHA Highway Design Manual
6	SLR	SS			Salt impact to concrete pavement	Concrete composition? Expected high water elevation with respect to road elevation? Exposure to SLR? SS?	pavement structural condition	Now Future No	Increase rebar cover thickness	Apply protective coating; increase frequency of inspections/monitoring	MDOT SHA Standard Specifications for Construction Materials; MDOT SHA Pavement Design Guide
7	SLR		PC		Inundation of adjacent sag curves where previously flooding was not present	Expected high water elevation at adjacent sag curves? Maximum roadside ground elevation at crest between sags? Exposure to SLR? PC?	rills and/or flow pathways between adjacent culverts	Now Future No	Reevaluate hydraulic analysis; increase primary or adjacent culvert crossing sizes/capacities; improve roadside conveyances between crossings	Ensure culverts and ditches remain clear of debris, deterioriation, and sedimentation	Maryland Highway Drainage Manual

Sea Level Rise
Storm Surge
Precipitation Change
Rainfall Runoff

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Bridge Matrix – Part 1

BRIDGE VULNERABILITY AND ADAPTATION MATRIX

Index	SLR	SS	PC	RR	Vulnerability	How to identify vulnerability	Primary inspection element	Decision	Engineering Adaptation	Operations & Maintenance Adaptation	Resources
1	SLR	SS	PC		Roadway uplift due to soil saturation and roadway overtopping	Observed cracking in pavement of approaches and deck? End bents anchored? High water table? Exposure to SLR? SS? PC?	Standing water in drainage conveyances, pavement condition	Now Future No	Raise roadway if possible; install diversion and conveyance structures; improve roadway/pavement design; increased monitoring of infrastructure and conditions; consider asphalt/concrete mixtures that withstand flood conditions	Install diversion and conveyance structures	Issues would be accounted for in design. Maryland 2018 pavement design guide
2	SLR	SS			Steel/concrete corrosion from nearer saltwater	Type of substructure material? Exposure to SLR? SS?	High water marks, substructure condition	Now Future No	-	Change coating type or apply coating; utilize more rebar cover and exclude material types susceptible to corrosion(e.g., weathering steel); increased monitoring of infrastructure and conditions	MDOT SHA Standards Specifications for Construction and Materials; FHWA-HRT-24-127: Best Practicies for Corrosion Control and Mitgation
3	SLR	SS			Structural instability due to buoyancy	Freeboard below substructure to expected high-water elevation? Exposure to SLR? SS?	High water marks	Now Future No	Anchor superstructure to abutments and piers	Temporary placement of mass on superstructure	Various Maryland SHA details can be found at the online, including guidance on anchoring bridge superstructure to piers (See 03-09 for Bearings) FHWA-HRT-09-028: Hydrodynamic Forces on Inundated Bridge Decks
4	SLR	SS			Mechanical systems of moveable structures (e.g., drawbridges) damaged by water	Elevation of mechanical system with respect to expected high-water elevation? Exposure to SLR? SS?	High water marks, mechanical system/vault condition	Now Future No	Flood proofing	Install pumps and/or backup power	Mechanical systems mentioned in recent version of the Manual on Uniform Traffic Control Devices (MUTCD), but no mention of mechanical systems placement in case of flooding Hazards can be addressed using FEMA utility requirements for structures
5	SLR	SS			Damage or failure of utilities attached to bridges	Elevation of attached utilities with respect to expected high-water elevation? Casing type/material? Exposure to SLR? SS?	High water marks, condition of utility casings	Now Future No	-	Raise the utility above the anticipated SLR and/or design SS elevation where applicable	Hazards can be addressed using FEMA utility requirements for structures
6	SLR				Expansion of tidal range leading to tidal erosion where previously there was none.	Exposure to SLR but not currently tidally influenced? Scour protection countermeasures present?	Scour/erosion on banks and/or channel bed	Now Future No	Scour protection; increase bridge opening;	Increased monitoring of infrastructure and conditions	Site dependent based on a hydraulic analysis. FHWA National Bridge Inspection Standards for inspections. FHWA Hydraulic Engineering Circular 18 Evaluating Scour at Bridges.
7	SLR				Raising tailwater leading to less stormwater conveyance capacity	Exposure to SLR but nt currently tidally influenced?	Observed water elevation, standing water in drainage conveyances	Now Future No	Install backflow preventers on closed systems; reevaluate stormwater conveyance systems, upgrade if warranted	-	Tailwater discussed in the Highway Drainage Manual (HDM) but backflow preventers are not included. FHWA-HIF-24-006: Urban Drainage Desig contains information on flap gates.
8		SS	PC	RR	High velocity flows beyond design level of service causing scour	Scour protection countermeasures present? Type of countermeasures? Exposure to SS? PC? RR?	Scour/erosion near bents	Now Future No	Reevaluate the scour analysis and add additional counter measures as warranted	Increase monitoring/inspection of critical structures on emergency routes; provide enhanced scour protection; retrofit/replace bridges as required for new scour conditions	Site dependent based on a hydraulic analysis. FHWA National Bridge Inspection Standards for inspections. FHWA Hydraulic Engineering Circular 18 Evaluating Scour at Bridges.

Bridge Matrix – Part 2

BRIDGE VULNERABILITY AND ADAPTATION MATRIX

Index	SLR	SS	PC	RR	Vulnerability	How to identify vulnerability	Primary inspection element	Decision	Engineering Adaptation	Operations & Maintenance Adaptation	Resources
9		SS	PC		Floating debris damages	Debris reported/observed? Exposure to SS? PC?	Observed debris at bents and substructure	Now Future No	Depends on the hydraulic analysis. Evaluate likelihood of upstream debris; if replacement/rebuild needed, elevate the bottom of the bridge (aka the "low chord") during design phase to provide additional freeboard.Consider changes to design standards.	Station equipment for rapid debris removal	MDOT SHA Stormwater Management Facility Routine Maintenance Manual; MDOT SHA Highway Design Manual FHWA HEC-09 Debris-Control Structures; TRB NCHRP Report 653: Effects of Debris on Bridge Pier Scour
10		SS	PC		Debris settling on roadways with subsiding floodwater	Expect high water elevation with respect to bridge deck and approaches? Exposure to SS? PC?	Observed debris accumulation on approaches or roadside	Now Future No	Provide open parapets for debris flow-through; if bridge needs to be replaced/rebuilt increase the bottom of the bridge (aka "low chord") elevation in design phase. Consider changes to design standards.	Station equipment for rapid debris removable	MDOT SHA Stormwater Management Facility Routine Maintenance Manual; MDOT SHA Highway Design Manual FHWA HEC-09 Debris-Control Structures; TRB NCHRP Report 653: Effects of Debris on Bridge Pier Scour
11		SS			Increased structural loading due to wind and/or waves	Exposure to SS?	Substructure and/or superstructure cracking at bent connections	Now Future No	Reevaluate structural design of inland bridges. Retrofit or replace as warranted.	-	MDOT SHA Office of Structures Guidelines and Procedures Memorandums;Several FHWA guidelines (e.g., FHWA-NHI-15-044: Enginering for Structural Stability in Bridge Construction)
12			PC		Scour due to increases in peak discharges and volumes	Scour countermeasures present? Type of countermeasures? Exposure to PC?	Observed scour/erosion at drainage conveyance outfalls and/or channel banks and bottom	Now Future No	Reevaluate hydraulic analysis for changes to hydrology and sediment supply; provide countermeasures if scour potential increases	-	FHWA Hydraulic Engineering Circular 18 Evaluating Scour at Bridges.
13			PC		Increase in stormwater peak due to upstream land use changes	Increase in upland impervious land cover? Exposure to PC?	High water marks, erosion/scour	Now Future No	Reevaluate hydrologic analysis; ensure bridge opening is still sufficient; increase hydraulic opening if needed	-	FHWA Hydraulic Engineering Circular 18 Evaluating Scour at Bridges.
14				RR	Runoff from approach roadway eroding embankments	Vegetated embankments on approaches? Stabilization measures on embankments? Exposure to RR?	Erosion/scour on embankments, rills forming on embankments	Now Future No	Consider retrofit with closed drainage system around the structure	Add robust slope protection such as matting, riprap armoring, or vegetation	Issues would be accounted for in design. Maryland Highway Drainage Manual
15				RR	Scupper capacity exceeded from high intensity rainfall	Scuppers present? Spacing of scuppers? Exposure to RR?	Water ponding on bridge during rain events, sediment/debris accumulation at scuppers	Now Future No	Add additional scuppers; upgrade bridge deck and drainage systems	Clean debris from existing scuppers; monitor drainage system during extreme precipitation events	Site dependent based on a hydraulic analysis. FHWA HEC-21 Design of Bridge Deck Drains

Sea Level Rise
Storm Surge
Precipitation Change
Rainfall Runoff

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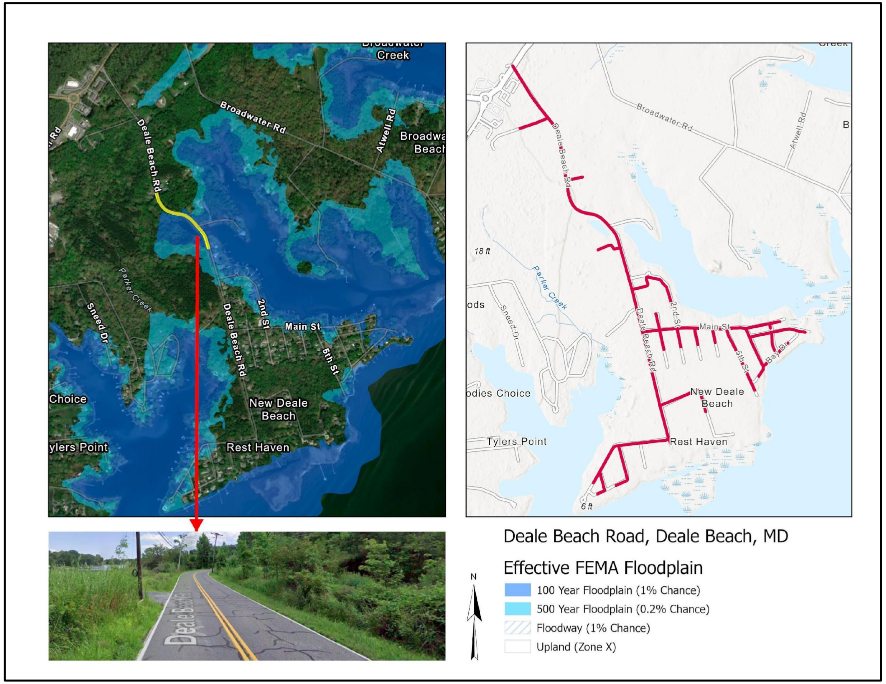
Analysis of Adaptation Options

Implemented as a multi-step process for each identified vulnerable asset:

- Step 1 – perform desktop and field investigations to determine applicability of individual specific vulnerabilities, either observed or anticipated
- Step 2 – evaluate possible adaptation measures against all applicable specific vulnerabilities together to determine which are viable for further consideration
- Step 3 – objectively assess the cost of viable adaptation measures against the extent of modeled impacts to quantify benefit

Case Study: Deale Beach Road



- Adjacent to Carrs Creek
- Sits in the FEMA 100-year floodplain
- Provides access to the rest of the County for about 241 households
- Modeling shows it will be inundated at 2 feet of inundations (SLR or SS)
- Output:
  - Sea Level Rise: Medium risk of inundation
  - Storm surge: High risk of inundation
  - Precipitation: Medium risk of inundation
  - Impact: Low

Step 1 - Evaluating Specific Vulnerabilities

- Conduct a desktop and site investigation to identify specific vulnerabilities observed
- Consult maintenance history records and inspection reports for supplemental information

Index	Vulnerability	Questions to identify vulnerability	Primary inspection element	Decision	Deale Beach Rd
1	Approaches, embankments, and retaining structure undermining or washout	Unvegetated shoulders or embankments? Evidence of rills or mass soil failures? Exposure to SLR? SS? PC? RR?	scour/erosion at embankments and/or around retaining structures	Not visible. Now Future No Site visit needed.	Y/N/Maybe? no known retaining structures nor noticeable erosion along embankments
2	Deterioration of pavement and subgrades due to inundation	Observed cracking or failure of pavement course? Exposure to SLR? SS? PC? RR?	pavement and subgrade condition (structural)	Now Future No	[redacted]
3	Sinkholes caused by subgrade inundation	Standing water in drainage conveyances? High water table? Exposure to SLR? SS? PC? RR?	standing water in drainage conveyances	Now Future No	[redacted]
4	Deteriorating roadside vegetation (salt exposure, inundation, drought)	Sparsely vegetated or unvegetated roadsides? Tidal exposure? Drought exposure? Exposure to SLR? SS? PC? RR?	vegetative cover of roadside	Now Future No	[redacted]

Step 2 - Evaluating Adaptation Options

- The goal of this step is to evaluate all potential adaptation measures as a whole against all applicable specific vulnerabilities to determine which are actually viable options worth considering and which should be ruled out

Index	Vulnerability	Decision	Deale Beach Rd	Engineering Adaptation	Operations & Maintenance Adaptation
2	Deterioration of pavement and subgrades due to inundation	Now Future No	Y - the roadway has visible cracks that have been patched/repaired over time	Elevate the pavement structure; increase design standards to withstand inundation/saturation	-
4	Deteriorating roadside vegetation (salt exposure, inundation, drought)	Now Future No	Maybe - since part of road falls within the FEMA 100-yr floodplain and modeling results show its SLR likelihood score is at "Medium" and Storm Surge likelihood score is "High"	Consider alternative stabilizations (e.g., rip rap) within roadside conveyances	Retrofit with salt- and inundation-resistant vegetation; consider retrofitting with channel liners
7	Inundation of adjacent sag curves where previously flooding was not present	Now Future No	Maybe - SLR likelihood score is "Medium" and Storm Surge likelihood score is "High" (saltwater will likely inundate road), unknown if flooding is expected to occur at places where it usually doesn't, since its in the 100yr floodplain previous flooding is assumed likely	Reevaluate hydraulic analysis; increase primary or adjacent culvert crossing sizes/capacities; improve roadside conveyances between crossings	Ensure culverts and ditches remain clear of debris, deterioration, and sedimentation

Step 3 - Prioritizing Adaptation Options

- Accounting for modeled impact
- Questions to answer:
  - How to objectively compare viable options for a given asset?
  - How to objectively compare the selected option for each of multiple assets?
  - How to prioritize investment of limited resources?
- No one size fits all approach, but possible considerations include:
  - Accounting for frequency of inundation
  - Accounting for duration of impact
    - SLR = permanent
    - SS/PC = temporary

Step 3 - Prioritizing Adaptation Options

- Possible considerations continued:
  - Leveraging FEMA Benefit Cost Analysis Toolkit
    - $ invested per # households benefited
    - $ invested per additional mile of detour avoided
  - Benefit to critical facilities like Fire/EMS stations and service routes
  - Benefit to public utilities (water, sewer, electric, gas, communications)
  - Timing of adaptation projects around end of life replacement of assets
- Recommend using multiple factor prioritization when evaluating potential projects rather than just a single method to quantify benefit and compare potential projects

Conclusion & Public Comment Period

Conclusion

- Developed methodology to assess vulnerability of roads and bridges to 3 climate stressors
- Identified and categorized vulnerable road and bridge assets
- Presented the results in tabular and graphical format
- Developed Adaptation Measures Matrix to identify specific vulnerabilities
- Developed an Analysis of Adaptation Options process framework to apply to identified assets
- Results of this study will inform future candidate project identification and evaluation

Public Comment Period

- Recording of presentation, slides, and adaptation matrices will be posted to project webpage:

https://www.aacounty.org/public-works/highways/roadway-vulnerability-assessment

- Request for public comments submitted via the project webpage will open soon
- Methodology and results summarized in technical report to follow

Questions?

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Roadway Vulnerability Assessment Project Website

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