5-16-2016

Transportation Asset Exposure, Adaptation Alternatives, and Infrastructure Resilience: Steering Committee Project Appraisal

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The Economic Impacts of Sea-Level Rise in Hampton Roads: Transportation Asset Exposure, Adaptation Alternatives, and Infrastructure Resilience

Steering Committee Project Appraisal

Bahar Barami, Ph.D., May 18, 2016

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U.S. Department of Transportation
Office of the Secretary of Transportation
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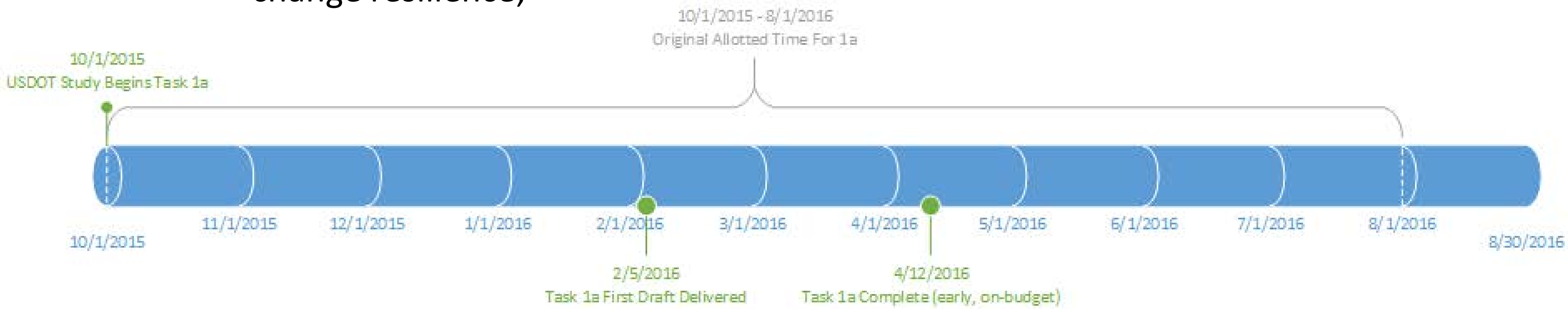
USDOT/Volpe Overall Scope and Timeline

- **Quantifying** scale/scope of climate change risks
- **Inventory** data sources and baseline conditions
  - Estimates the value of the transportation infrastructure assets at risk of damage from sea-level-rise (SLR) and flooding;
- **Evaluating** conventional models and tools
  - Regional economic impacts of SLR and flooding
- **Identifying** infrastructure adaptation measures
  - Cost-effective reduction of SLR/flooding vulnerabilities, and ultimately climate-change resilience;



Task 1a Scoping Paper (distributed to stakeholders outside USDOT and available for others):

- Existing transportation asset information, including condition, gaps, vulnerabilities, geographic attributes, resistance to climate stressors, exposure to damage and overall system impacts

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Approach

Analyzes Infrastructure Resilience as a function of a region's ability to:

- **Identify vulnerabilities** to climate risks and prepare to **mitigate** them;
- **Quantify the economic impacts** of SLR and flooding;
- **Chart alternative pathways for adapting** to the risks;
- **Implement** effective and cost-beneficial **adaptation actions**;

Informative Models:

- NOAA and VIMS regional hydrological climate models;
- FEMA's HAZUS-MH database for a GIS-based inventory of the potential scale of direct loss of asset value;
- Damage-cost data from SHELDUS database on county-level property damage from flooding, hurricane, coastal surges, and severe storms, 1960-2014;
- NOAA historical weather-related data on county-level property damage;
- Economic impact estimates from Input-Output (I-O) models(e.g., REMI, RIMS !!, IMPLAN; CGE), regional planning agencies (HRPDC, HRTPO), and Sandia's REAcct I-O model.

Climate Risk Components

$$Risk = f(\boldsymbol{Hazard\ Frequency}_{event\ probability} \times \boldsymbol{Asset\ Exposure}_{assets\ at\ risk\ of\ loss} \times \boldsymbol{Vulnerability}_{asset\ sensitivity} \times \boldsymbol{Consequences}_{value\ of\ losses/severity})$$

Measured as a function of three key metrics:

- *Sea-Level Rise (centennial* SLR of 1.5 ft.; VIMS: a potential SLR of 1.5 ft. between 2032 and 2065);
- *Storm Surge and Flooding (*recurrent flooding due to low-lying topography); and
- Land *Subsidence.*

These hazards create a greater likelihood of flooded roadways, rail tracks, transit stations; damaged bridges/piers/airport runways; curtailed rail/air/barge/highway operations; and slope failure

Proximity to the sea, high-density urban development, and lack of protective structures increase exposure to hazard; Norfolk's exposure is among highest in HR, with over 10% of its infrastructure assets, valued $1.3B-$2.2B, at risk of damage from SLR and flooding

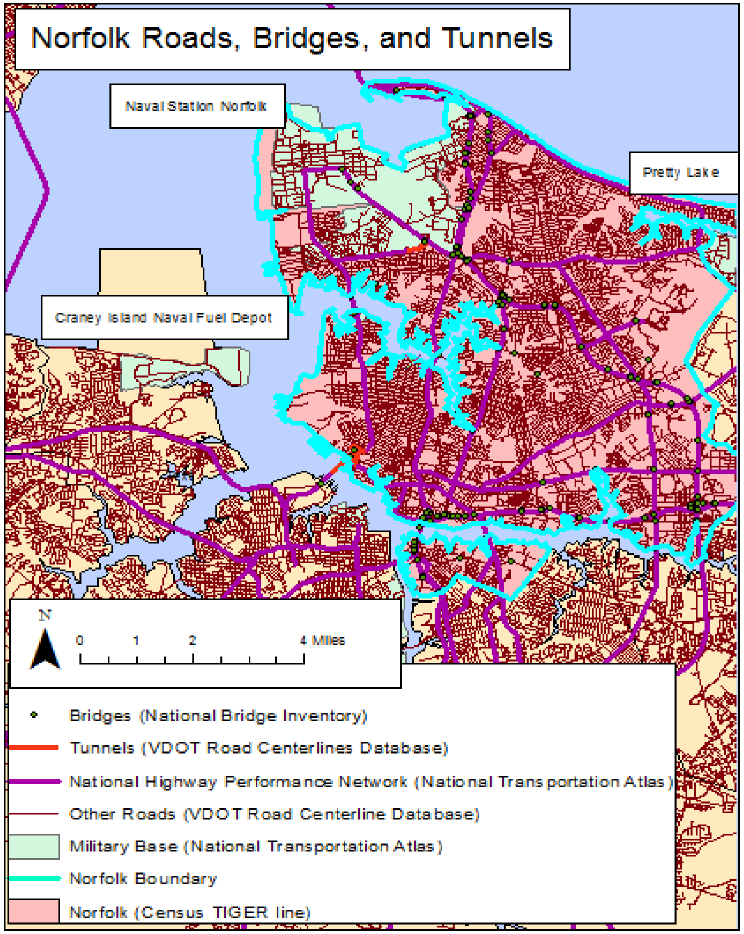
Region-wide vulnerabilities, measured as a function of asset concentration; sensitivity to damage; the number of tunnels and bridges; and reliance on port commerce

Magnitude of damage as a function of the scale and costs of physical infrastructure destruction, business interruption costs, and loss of access to jobs and transport

Norfolk Transportation Network

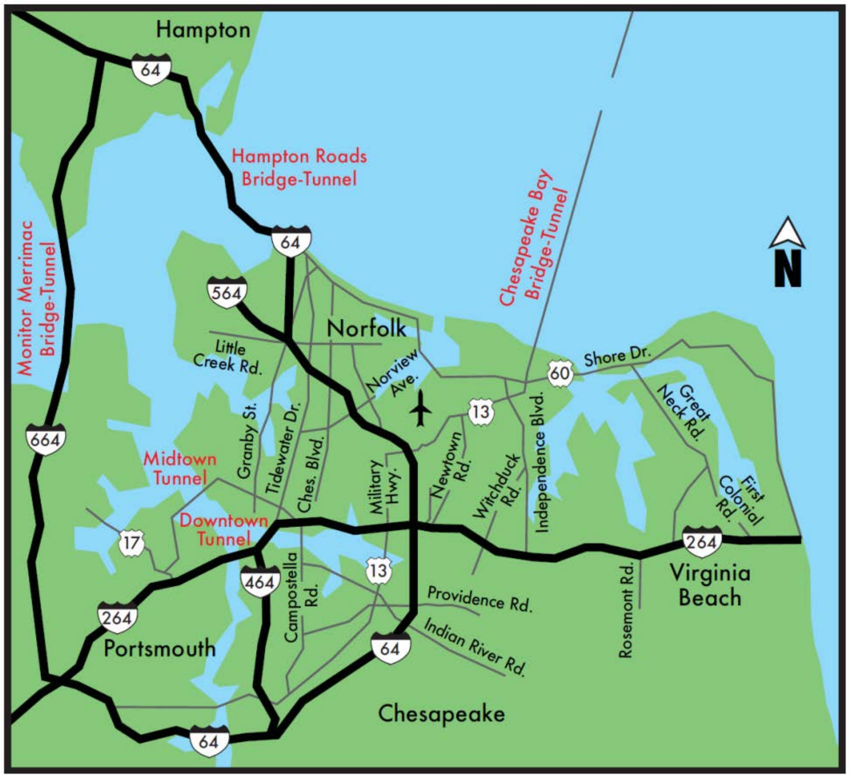
Primary Focus: Norfolk and Pretty Lake

- Roads and Bridges
  - >1,000 miles of roads; 173 highway bridges; and 5 rail bridges;
- Five major tunnels
  - HR Bridge-Tunnel, Monitor-Merrimack Bridge Tunnel, Downtown Tunnel, Midtown Tunnel, & Chesapeake Bay Bridge-Tunnel—connecting peninsula to Norfolk and Southside
- Norfolk International Terminals
  - POV's largest terminal with 1.4 million TEUs
- Norfolk's ORF Airport
  - One of the region's two primary mid-sized airports, with 1.6M annual enplanements;
- Mass Transit
  - The Tide Light Rail Transit, freight and commuter rail service, bus and ferry service, and the VNG natural gas pipeline provide the city with a full range of transport services.

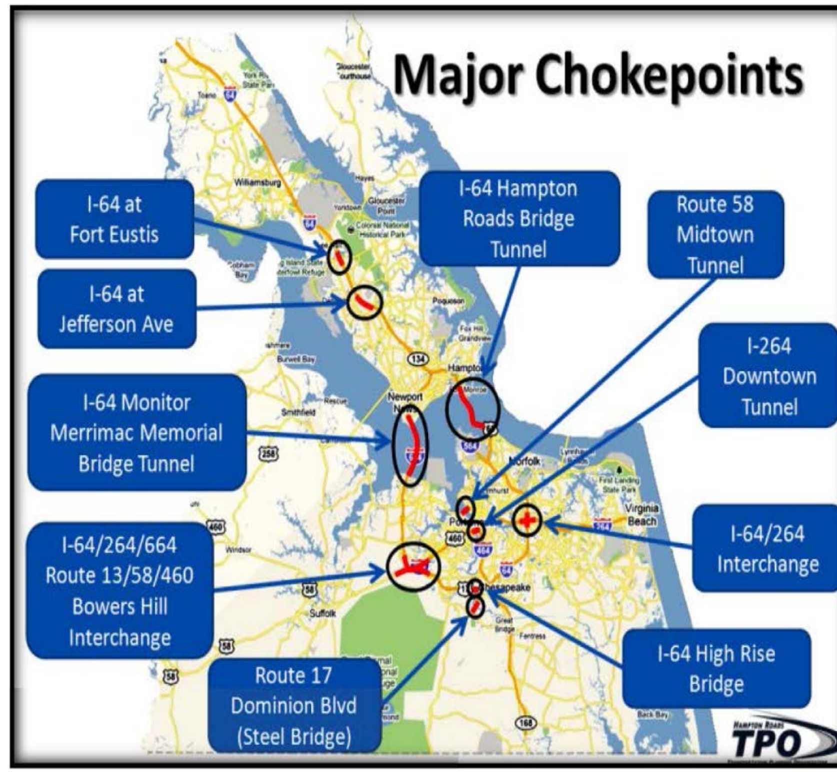


Key Features of Norfolk's Network

Bridges, Tunnels, and Major Highways Dominate the Norfolk Transportation Network



Norfolk's I-64 Intersections, Tunnels, and Bridges are Major Chokepoints in the Region



Actual and Potential Weather Damage* Estimates in Norfolk

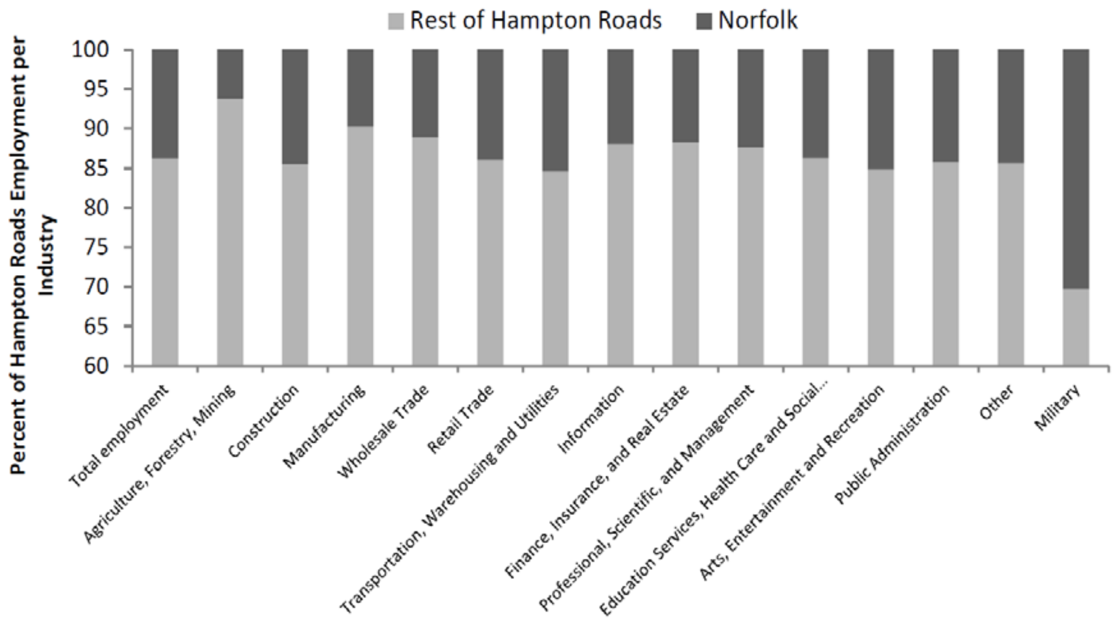
- SHELDUS: $117M, or $2.2M per year
  - Over 54 years, 1960-2014
- HAZUS-MH: $1.4B
  - For 172 miles of highway, rail bridges and tunnels
  - $321,000 for 5 rail bridges, and $628M for 173 highway bridges; (generally considered very low estimates)
- 60% of Norfolk's flood-prone assets in fully developed parcels
  - SLR risk greater than more other Hampton Roads cities
  - HRPDC: 1m SLR + midlevel storm surges→$1.3B-$2.2B (10% of parcel's improvement value)
  - HRPDC: 7% of HR's improvement value ($9B-$16.5B) carries damage risk
- Other vulnerabilities
  - Recurrent flooding + uncompensated business interruption loss
  - Lack of adequate private insurance protection

*Flooding, hurricanes, coastal surges, and storm damages

Dominant Sectors in Norfolk Economy: Potential Sources of Instability

Norfolk's high concentration of military- and port-infrastructure assets represents potential vulnerabilities to cascading economic downturns:

- Military accounts for over 32% of civilian jobs in Norfolk; the sector's economic impact on regional GDP is $16.6B, with $10.9B of it in local earnings;
- Ports/Transportation—with POV's total economic impacts of $10B—and Public Administration jobs together account for another 30% of Norfolk's employment;



- With two thirds of its jobs in three climate-sensitive sectors, Norfolk is vulnerable to severe downturns in its regional GDP, as indicated by the recent job losses and declining income levels;

Tools for Economic Impacts Analysis and Decision-Making

- BCA models
  - Commonly used for making funding decisions for transport improvement projects
  - Challenges with BCA: limited applications for longer-term regional planning: it fails to account for extensive spillover impacts of SLR damages, and positive regional co-benefits from investment in adaptation
- **I-O models**
  - Generates useful estimates of the economic impacts of climate disruption
  - Examples: REMI, RIMS-II, and IMPLAN, and EIA tools such as Sandia's Regional Economic Accounting (REAcct) tool have generated useful estimates of the economic impacts of climate disruption
- DOT Asset-Management tool, TAM
- IIA I-O model
- Multi-Criteria Decision-Making (MCDA) tools
  - Developed for the FHWA Gulf- Coast Pilot;
- NCHRP CAPTA tool
  - Determines Consequence Thresholds and selecting countermeasures for adverse climate events are among potentially effective decision-making tools.

I-O Model Estimates of the Direct and Indirect Impacts of Climate-Related Disruption

Costs of Damaged Infrastructure do not Fully Capture the Total Economic Losses from Climate Disruption

Total disruption costs → 2x to 3x costs of direct damages

A 2015 study by Sandia Laboratories estimated the potential range of direct economic losses from a 4-day storm-related disruption, modeled for three SLR scenario in Norfolk:

- Norfolk's losses ranged between $26M and $56M, depending on the storm-severity scenario; these direct costs accounted for only 38% of the total losses;
- Adding the indirect costs of losses from business interruption and loss of the means of livelihood/access to jobs would raise the total losses from direct and indirect damages by a factor of 2.6, to a range of $70M to $144.6M.

Sandia's REAcct Tool Estimates of SLR Disruption in Norfolk

	Scenario 1	Scenario 2	Scenario 3
Annual Direct Losses	$26.92 M	$39.71 M	$55.60M
Annual Indirect Losses	$43,08M	$63.49 M	$89.00 M
Total	$70.0 M	$103.2 M	$144.60 M

Frequent Flooding → Rising Social Vulnerabilities

Severe climate disruption costs

Direct damages:

Property losses, traffic disruptions, and destroyed transportation assets

Indirect losses:

Business interruption; loss of earnings; loss of insurance protection due to frequency of disruption, and amplified effects of poverty

Contributing Factors:

Frequent inundation and "nuisance flooding" (major contributor to rising economic costs of SLR).

HR City	# of Repetitive Loss Properties	Average Cost of Mitigation (000)	Total Cost of Mitigation (000)	Average FEMA Funding
Chesapeake	409	$250	$102,250	$757K
Hampton	863	$75*	$64,725	$833K
Norfolk	900	$162.5	$146,250	$778K
Portsmouth	186	$75	$13,950	$NA
Virginia Beach	561	$185	$103,785	$725K
Total HR	2,979	NA	$430,900	NA

NOAA has developed a Social Vulnerability Index (SoVI)

- Norfolk, 2009: 280 "frequently flooded" or "repetitive-loss properties"[1]
- Norfolk 2014: 900 structures (3x 2009)
- 2,979 repetitive property losses which were not compensated by private insurance or NFIP
- $431M in uncompensated costs, creating a large gap between what FEMA paid and what was needed for flood mitigation improvements.

1. Defined by NFIP as "properties that have experienced at least two paid flood losses of >$1000 each in any 10-year period since 1978;"

Adaptation: Scope and Scale of the Path to Alternative Solution

Simple ← → Complex

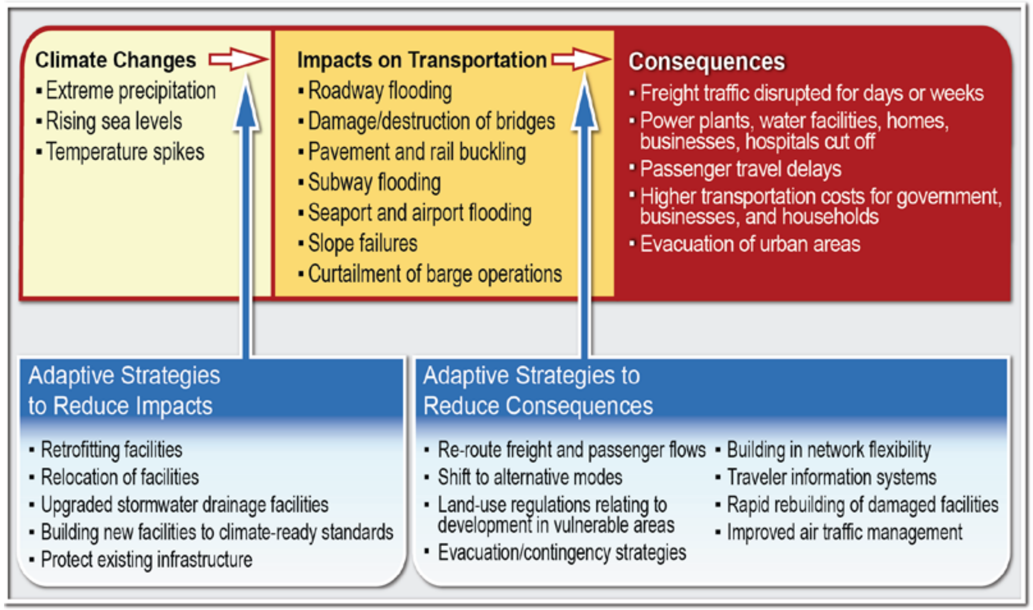
Retrofits | Facility Upgrades | Major Engineered Structures | Relocation

- e.g. Seawalls and Levees

Adaptation[1]: Integrated and iterative process of **accommodation**, **engineering protection**, and retreat

- ***Accommodation measures:***
  - *Elevated structures* (cost range:$2,000-$30,000);
  - Floatable developments (cost range: $2,000-$30,000);
  - *Drainage* improvements;
  - *Flood Proofing* existing structures;
  - *Beach Nourishment (*costs: $300-$1,000/ft.)
- ***Engineered Protection:***
  - *Storm-Surge Barriers;*
  - Closure dam or movable gates/barriers: $0.7M to $3.5M per meter (plus annual maintenance);
  - *Seawalls*: $150-$4,000 per linear ft;
  - *Levees or Dikes, at* $100-$1500 per linear foot;

Role of Adaptive Strategies in Reducing Impacts and Consequences



1. Intergovernmental Panel on Climate Change (IPCC)

Adaptation Planning Tools: MCDA Process for Priority Setting

Multi-Criteria Decision-Making (MCDA) planning tool & IIA I-O Risk Filtering model[1]:

- ❑ Assists regional planners to conduct vulnerability assessments
- ❑ Calculates scores for each candidate improvement project across several scenarios,
- ❑ Helps planners to develop a priority ranking of the LRTP projects
- ❑ Four Criteria for Prioritization
  - existing facility plans;
  - proposed LRTP and Capital Investment Plan (CIP) projects;
  - TAZ location of significant segments of the region; and
  - funding-agency multimodal policies;

Steps	MCDA Assessment Components	Output
Step 1	Define the criteria and assign max score (relative importance) for each [e.g., for each asset (highway, bridge, rail, transit, airport) aligning criteria: congestion system condition, cost effectiveness ($/VMT) safety/security;	Assigned scores and measures of criticality;
Step 2	Define the list of projects to be prioritized;	Regional CIP or equivalent project lists;
Step 3	Assign baseline ratings to projects defined in Step 2 according to criteria define in Step 1	Automatically generated ratings;
Step 4	Calculate the aggregated score of each project via built-in MCA criteria value function based on inputs from Step 1-3	Baseline project ranking
Step 5	Develop up to 5 default climate and non-climate scenario-conditions: Scenario 1: Increase in SLR+ storm surge; Scenario 2: SLR + Storm Surge + economic recession; Scenario 3: SLR + Storm Surge + increased wear & tear on public infrastructure; Scenario 4: SLR + Storm Surge + ecologic damage/species loss/infectious diseases; Scenario 5: SLR + Storm Surge + increased traffic density + population +tourism growth;	Conduct Scenario-based analysis based on the matrix of project scores and priorities in the corresponding check box (as in following matrix;

1. FHWA Gulf-Coast Pilots

Adaptation Planning Tools: CAPTool*

Asset management system for identifying critical or high-cost assets, appropriate countermeasures for their protection.

- 6-Step adaptation planning process
- Consequence Threshold → Countermeasure Opportunities

- **Threshold** beyond which the asset owner/operator/ system-user would **consider investments in countermeasures justified**, in order to prevent losses or mitigate the consequences.
- For each asset, this step determines what level of risk to the *population, property or service/mission* can be addressed in the agency's current operations;
- Determines which assets are deemed critical and require further attention:
  - *Potentially Exposed Population (PEP)*
  - *Property Loss*
  - *Mission Importance*

- Range of adaptation options that are embedded in the tool's dictionary;
- Prediction
- Intelligence gathering
- Detection
- Interdiction
- Response
- Preparedness
- Design
- Engineering structures
  - e.g., storm barriers, seawalls, berms, retrofits, easement, asset redundancy.
- For each countermeasure, relevant costs are determined by reference to a cost estimating manual, RSMeans.

*NCHRP tool – Cost Asset Protection for Transport Agencies

Challenge of Quantifying the Benefits of Adaptation Projects

- *Hague Flood Wall,* $60M
  - Protect against rainfall runoffs
  - Pump station to remove rainfall runoff when gate is closed
  - New storm culvert beneath the Navy berms
  - Peripheral wall when land surface is low around creek, street elevation, and other improvements;
- *Pretty Lake Flood Wall, $50M*
  - Tide gage
  - Pump station
  - Structure elevation
  - Flood wall
- *Mason Creek Pump Station,* $30M;

Adaptation Measure Examples (Norfolk)

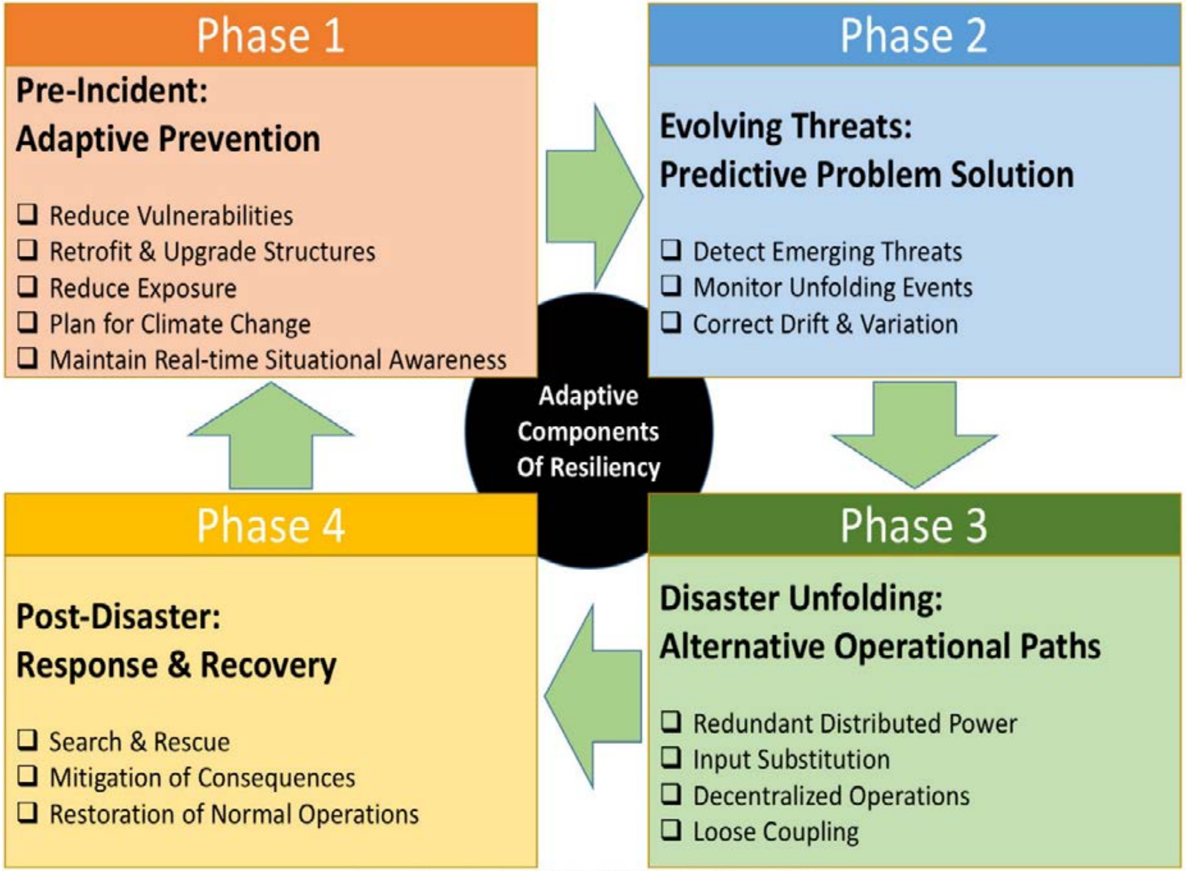
City of Norfolk Neighborhood	Proposed Adaptation and Mitigation Projects	Assessed Property Value in the Watershed	Estimated cost	Project Cost as a % of Property Value ($5B total assessed value in watershed)
The Hague	Floodwall Tide gate Pump Station Berms/Closure walls	$1,624 M	$60 M	3.7%
Pretty Lake	Floodwall Tide Gate Pump Station Structure elevation	$1,812 M	$50 M	2.8%
Mason Creek	Pump Station New storm culvert Peripheral Berms Structure elevation	$1,604 M	$30 M	1.9%
Total	NA	$5,040 M	$140M	2.8%

Next Steps: Resilience Analysis

Volpe Resilience Framework

Systematic process for improving climate change resilience due to economic, safety, security, and operational disruption:

- Prevent,
- Protect,
- Detect,
- Avoid,
- Monitor,
- Adapt, and
- Mitigate



Graphic Source: The Volpe National Transportation Systems Center

Future Tasks:

- Expand the analysis beyond the baseline condition inventory to include a broader infrastructure resilience approach.
- Conduct a full scale analysis of the Pilot region's transportation risks
- Develop proposal for cost-effective mitigation/adaptation measures
- Incorporating RM goals from NASA, DOD, DHS, USACE, EPA, Regional Planning Agencies is likely to generate significant regional benefit multiplier effects.

Next Steps: Close Data Gaps

- **Reducing the Siloes of Databases and Estimating Models.**
  - Abundant sources of data and modeling capabilities
  - Data sources view asset management, climate change, and regional economy in isolated analytical siloes
  - Fail to fully capture interconnections
  - More integrated use of EIA, TAM, and BCA tools to model regional climate resilience, and refinements to a regional CGE methodology to estimate the longer-term impact of preventive measures, and adaptation/mitigation actions
- **Integrating SLR Adaptation Approaches with Longer-Term Mitigation Solutions.**
  - NASA's R&D projects on Earth Observing Satellites (EOS) Professor Nordhaus' DICE-model estimates on carbon pricing and the impact of climate change on the GDP
- **Removing the Siloes of Transport Modes and Economic Security Strategies**
  - Recognize interlinkages between climate and disruption risks to the economy particularly in high poverty, high-exposure, frequently-flooded areas.
  - Recognize indirect impacts of frequent flooding on employment and income in
    - Transport-sensitive sectors such as tourism
    - Military,
    - Maritime commerce,
    - Technology-intensive sectors such as Profession/Scientific
    - Finance/Insurance
  - Recognize public/private regional freight and passenger railroads can enhance the region's trade & supply-chain resilience
  - Assess asset/operational vulnerabilities in the private rail industry's tracks and asset condition
  - Improve networks to provide alternate routes and modes when a particular asset is disrupted

Next Steps: Collaboration with USDOT/Volpe

- ***Interagency Integration of Analytical and Estimating Tools and Models.***
  - In-depth focus on specific tools and capabilities as needed to support the Pilot and Pilot Working Groups
    - NCHRP CAPTA/CapTool; and Sandia's REAcct tool
  - Employ more rigorous economic methods such as CGE
  - Examine economic impacts of specific scenarios on the regional economy and SLR resilience
- ***Promoting OST's Twinning Strategic Approach to Climate Resilience.***
  - US Air Force Office of Assistant Secretary for Installation, Energy, and Environment (SAF/IEE):
    - Promote energy efficiency & alternative aviation/installation fuel sources through micro-grid and solar PV;
  - NASA:
    - Climate change risk engagement
    - Research priorities and adaptation planning for DOD agencies that are directly at risk of SLR and flooding inundation in Hampton Roads.
    - CLARREO climate satellite mission
    - Climate Adaptation Science Investigator (CASI);
  - EPA:
    - CIRA climate impact tool
  - NOAA:
    - SoVI model to explore opportunities to mitigate social vulnerabilities offer
- ***Collaboration with ODU and EIAC members on Economic Impact Assessment***.
  - Improve use of economic impact methodologies such as REMI, IMPLAN, and CGE to evaluate the long-term infrastructure investment options for preventive adaptation and risk mitigation
  - Build on the ODU 2015 State of Commonwealth Report findings on the DOD/Navy strategic shifts in Home Porting and the Pacific Pivot
  - Address social vulnerabilities that arise from fluctuations in GDP growth and rising rates of income inequality
  - More effectively assess regional trend impacts on climate change disruption and infrastructure resilience