Florida Sea Level Scenario Sketch Planning Tool Extension for Custom Analysis

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Disclaimer

SI* (Modern Metric) Conversion Factors

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
in^2	Square inches	645.2	square millimeters	mm^2
ft^2	Square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised Marh 2033).

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16. Abstract

In this project, the University of Florida GeoPlan Center (“the team”) developed an online screening tool (the “Resilience Report”) to systematically and rapidly conduct flood vulnerability assessments for transportation projects. The Resilience Report summarizes and displays analyses of current and future flood exposure for a user-specified area of interest in the State of Florida, with a focus on coastal flooding. This tool will assist FDOT and its partners with streamlined access to resilience and flooding data for better screening of potential impacts. This project had three objectives: (1) build a geospatial framework to support project level analysis of multiple flood datasets; (2) identify and test existing flood risk data sources; and (3) pilot test the tool with user groups. The design of the Resilience Report and geospatial framework was informed by robust research on existing data and tools for assessing infrastructure vulnerability to climate change. This research revealed data gaps and led to the selection of the following data for the initial Resilience Report: sea level rise, high tide flooding, storm surge, and flood hazard areas. Because climate data are still emerging, this project focused on designing a framework for storing, analyzing, and displaying results with the flexibility to rapidly ingest new data. Two virtual training webinars were offered, and 129 people attended. In the first two weeks after launching the tool, 17 resilience reports were requested across seven organizations, indicating high interest. The research team will continue enhancing the Resilience Report with additional data, functionality, and partnerships.

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Executive Summary

The nation's transportation systems are facing significant threats from the impacts of climate change, in particular from increasing heat, coastal flooding and sea level rise (SLR), and heavy precipitation (Jacobs et al., 2018). To protect against the most severe impacts of climate change, data regarding future conditions and climate extremes must be incorporated into the transportation planning, design, and construction process. The goal of this project was to build a tool to mainstream such data and information into the transportation planning process.

In this project, the University of Florida GeoPlan Center ("the research team") developed an online screening tool (the "Resilience Report") to systematically and rapidly conduct flood vulnerability assessments for transportation projects. The Resilience Report summarizes and displays analyses of current and future flood exposure for a user-specified area of interest (AOI) anywhere in the State of Florida, though the majority of the current data are coastal flooding. This new tool will assist the Florida Department of Transportation (FDOT) and its local and regional partners as they prepare the transportation system for the impacts of climate change.

Specifically, the project had three objectives:

1. Design and build a geospatial framework and infrastructure (hardware and software) to support project level analysis of multiple flood datasets;
2. Identify and test existing flood risk data sources;
3. Pilot test the new tool with user groups.

This project builds off two ongoing collaborative projects of the research team and FDOT. The Environmental Screening Tool (EST) is a Web application that facilitates the evaluation of potential impacts to human, natural, and cultural resources from proposed transportation projects. The research team assisted with the initial EST development in the early 2000s and has continued to maintain and update the geospatial data, databases, and servers to support the EST. In 2013, the research team launched the Sea Level Scenario Sketch Planning Tool ("Sketch Tool"), an online geospatial tool for evaluating transportation asset exposure to current flooding and future SLR. The Sketch Tool provides planning-level analyses, but does not allow for project-level scoping and has only limited datasets.

This project sought to leverage the strengths of these two tools (EST and Sketch Tool) to facilitate project level screening for flood exposure and assist transportation professionals with resilience decision making. During the early phases of this project, it was determined that the products developed herein would be incorporated into the EST to leverage the existing user base and computing infrastructure (instead of deploying the Resilience Report from the Sketch Tool mapping application). Specifically, the EST's Area of Interest (AOI) Tool was used as a model for triggering and running the Resilience Report.

This research project was completed under five major tasks:

1. Review of tools for assessing vulnerability of infrastructure to climate change.
2. Identification and assessment of existing flood data sources.
3. Development of hardware and software infrastructure.

4. Pilot testing of the new tool.
5. Technology transfer: developing user guides and conducting technical training.

The development of the Resilience Report was informed by robust research on existing and emerging data and tools for assessing infrastructure vulnerability to climate change (Tasks 1 and 2). The review of tools revealed the common characteristics of similar tools, including climate stressors and data, tool functionality, and data visualizations. This review narrowed the focus for assessing data sources (Task 2, Chapter 3) and identified visualization features and tool functionality to pursue (Task 3, Chapter 4). The majority of tools reviewed were developed to visualize and communicate the results of climate vulnerability assessments and did not offer project level analysis, which this project aims to do.

The assessment of existing data sources (Task 2, Chapter 3) revealed the common data sources available for vulnerability assessments and the lack of widespread spatial data representing future inland flood risks and future storm surge. The research team curated a pilot list of available datasets, though not all were included in the Resilience Report. The final Resilience Report includes four types of flood data, some with multiple datasets:

- Sea Level Rise (SLR):
    - National Oceanic and Atmospheric Administration (NOAA) 2022 SLR scenarios
    - National Oceanic and Atmospheric Administration (NOAA) 2017 SLR scenarios
- High Tide Flooding (HTF):
    - Three datasets showing spatial extent of minor, moderate, and major HTF
    - One dataset indicating the number of projected days of annual minor HTF under future SLR scenarios
- Storm Surge: Outputs for hurricane categories 1-5 from the Sea, Lakes, and Overland Surges from Hurricanes (SLOSH) model.
- Flood Hazard Areas: Federal Emergency Management Agency (FEMA) special and moderate flood hazard areas from the national flood hazard layer.

The data assessment (Task 2, Chapter 3) also revealed that future climate data is still emerging. Hence, the research team focused on designing and developing a framework for storing, analyzing, and displaying analysis results with the flexibility to rapidly ingest new data (according to minimum specifications and standards discussed in Chapter 3). Additionally, the research team sought to create data visualizations (e.g., interactive charts, graphs) to summarize the analyses for quick interpretation.

The Resilience Report leverages the EST's enterprise database software (Oracle), database server, and application servers as the foundation for the geospatial framework and technical infrastructure. Additional components were developed to support the new data and geospatial analyses in the tool. A software not used in the EST, Oracle Application Express (APEX), is used to display the results of the resilience overlay analyses. This software was chosen due to its tight integration with the Oracle database, powerful visualization capabilities (charts, tables, and maps), and its ease of rapid deployment of new analyses.

The Resilience Report is requested through the EST Map Viewer's AOI Tool, which requires users to have an EST account with AOI access. Once logged into the EST, a user can draw on the map their desired area for analysis (either point, line, or polygon) using the AOI Tool. After submitting basic information and drawing one or more alternatives (features), the user can request a "Resilience Report." Once requested, automated database processes run spatial overlays of each flood layer with the AOI, which takes approximately 1-3 minutes. After the analyses are complete, the AOI Tool will display a link to the results page.

The beta version of the Resilience Report was demonstrated for a few user groups. In total, the beta version was presented to approximately 35 people, some of whom tested the tool and provided feedback and comments. Many of the comments were addressed within this project, while others will be considered for future enhancements. After launching the production version of the Resilience Report, the research team developed user guides and technical training materials to build capacity (Task 5, Chapter 6). Two training webinars were offered virtually, where 129 people attended. In the first two weeks since the training webinars, resilience reports were submitted for 16 AOIs across six FDOT districts and one additional organization, indicating high initial interest.

The benefits of this project include streamlined access to resilience and flooding data for better screening of potential impacts and better project scoping. The Resilience Report can assist in data gathering for PD&E and/or corridor studies and can provide resilience screening for LRTP projects. The Resilience Report could also be used to identify areas in need of more refined analysis (e.g., engineering-level studies). This project supports FDOT's Resiliency Policy 000-525-053 by developing geospatial tools to facilitate the identification of risks related to SLR, flooding, and storms and assessment of potential impacts. Additionally, this project supports the FTP 2045 Goal of Agile, Resilient, and Quality Transportation Infrastructure.

The research team considers the Resilience Report developed in this project as "Version 1" and plans to continue enhancing the tool with additional data and functionality, as funding and agency priorities permit. New data and analyses to be considered include updated SLR inundation depth grids, updated elevation data, exposure and criticality data, and other climate stressors. New functionality to be considered includes developing a summary report, adding support for ranking and project prioritization, adding guidance for choosing scenarios, and adding identification of tipping points to support adaptation pathways. Increasing the functionality and utility of the Resilience Report will depend on partnerships with FDOT, regional transportation agencies, and others to use the tool in context of their needs and/or specific projects. The research team is actively pursuing partnerships to develop detailed use cases to demonstrate how to use the Resilience Report and incorporate future flood information into the planning and design process.

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List of Abbreviations and Acronyms

AEP	Annual Exceedance Probability
AGOL	ArcGIS Online
APEX	Application Express (Oracle)
AOI	Area of Interest
CF	Change Factor
CHS	Coastal Hazards System
DEM	Digital Elevation Model
DOT	Department of Transportation
ESRI	Environmental Systems Research Institute
EST	Environmental Screening Tool
ETDM	Efficient Transportation Decision Making
EWL	Extreme Water Levels
FBC	Florida Building Commission
FDEM	Florida Department of Emergency Management
FDEP	Florida Department of Environmental Protection
FDOT	Florida Department of Transportation
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIU	Florida International University
GCM	Global Climate Model
GIS	Geographic Information Systems
HTF	High Tide Flooding
IPCC	International Panel on Climate Change
MHHW	Mean Higher High Water
MPO	Metropolitan Planning Organization
MSL	Mean Sea Level
NAVD88	North American Vertical Datum of 1988
NTDE	National Tidal Datum Epoch
NOAA	National Oceanic and Atmospheric Administration
OEM	Office of Environmental Management
RAP	Resilience Action Plan
SACS	South Atlantic Coastal Study
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SLR	Sea Level Rise
SFWMD	South Florida Water Management District
USACE	United States Army Corps of Engineer
USGS	United States Geological Survey

1 Introduction

In this project, the University of Florida GeoPlan Center (the “research team”) developed an online geospatial tool (the “Resilience Report”) that summarizes and displays analyses of flood exposure for a user-defined area of interest. The Resilience Report extends the functionality of two existing tools: Sea Level Scenario Sketch Planning Tool (“Sketch Tool”) and Environmental Screening Tool (EST) Area of Interest (AOI) Tool. This Resilience Report produces “on-demand” analyses of custom areas and flood data for the Florida Department of Transportation (FDOT) and its local and regional partners as they prepare the transportation system for the impacts of climate change.

The nation’s transportation systems are facing significant current and future threats from the impacts of climate change, in particular from increasing heat, coastal flooding and sea level rise (SLR), and heavy precipitation (Jacobs et al., 2018). Heat waves and increased summer temperatures can damage road and rail infrastructure and pose health risks to construction and maintenance workers and the general public. Warming winters also change freeze-thaw cycles and increase road maintenance. Coastal flooding, from high-tide flooding and storm surge, are being exacerbated by SLR, and cause direct damage to vehicles, roads, bridges, airports, ports, tunnels, and public transit. Heavier precipitation events increase stormwater runoff, which puts roads at risk of washout and erosion. Increased riverine flooding can damage pavement and increase bridge scour. Damaged, flooded, and inaccessible transportation facilities cause disruptions and delays to commerce, travel, and evacuations.

In North and Central America, future temperatures and relative sea level rise are expected to continue to increase (IPCC, 2021), meaning that these impacts will likely worsen. Climate-related impacts are projected to increase the costs for maintaining, repairing, and replacing infrastructure. Under the worst case climate scenario (RCP8.5), yearly damages to paved roads nationwide from temperature and precipitation stressors are projected to be nearly $20 billion by 2090 (Jacobs et al., 2018). These impacts threaten transportation network performance, reliability, and safety. In addition, these stressors magnify cascading impacts to our nation’s economy, environment, mobility, and quality of life, especially for vulnerable communities and urban infrastructure (Jacobs et al., 2018).

To protect against the most severe impacts of climate change, data regarding future conditions and climate extremes must be incorporated into the transportation planning, design, and construction process. A common way to address these impacts is using a *systems resilience approach*. The Federal Highway Administration (FHWA) defines resilience as “the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions” (FHWA, 2014). Geospatial and decision support tools offer a way to streamline climate data and considerations into the transportation planning, design, and construction process. But these tools are one component of an overall systems approach to guide decision making regarding resilient infrastructure.

For over two decades, the research team has worked in partnership with FDOT to develop geospatial data and decision support tools to facilitate environmental review of proposed transportation projects. The Environmental Screening Tool (EST) is a web application developed in the early 2000s to facilitate the Efficient Transportation Decision Making (ETDM) process. ETDM is Florida's process for evaluating the potential impacts to human, natural, and cultural resources from proposed transportation projects. The research team assisted with the initial development of the EST and has continued to maintain and update the geospatial data, enterprise databases, and servers to support the EST.

In 2013, the research team launched the Sketch Tool, an online geospatial tool for evaluating the potential impacts of current flood risk and future SLR on Florida's transportation system. While the Sketch Tool has been useful for long-range planning, there are some noted limitations. First, it does not include episodic, temporary flood events (such as high tide flooding, future storm surge, and future heavy and extreme precipitation), which are exacerbated by SLR and will impact the transportation system before permanent inundation due to SLR occurs. Next, the Sketch Tool provides pre-analyzed data, which does not allow for project-level scoping without further geo-processing (clipping and summarizing data). Addressing these limitations could result in better project scoping through identification of problem areas in need of avoidance, mitigation, or adaptation strategies.

The goal of this project was to build a tool ("the Resilience Report") to support project level analysis of potential flood impacts to proposed transportation projects. During the initial phase of this project, it was determined that the data and reporting products developed herein would be incorporated into the EST to leverage the existing user base and computing infrastructure. In particular, the EST's Area of Interest (AOI) Tool was used as a model for triggering and running the report.

This project had three objectives:

4. Design and build a geospatial framework and infrastructure (hardware and software) to support project level analysis of multiple flood datasets;
5. Identify and test existing flood risk data sources;
6. Pilot test the new tool with user groups.

This project was completed in five main tasks (1) Review of Tools; (2) Data Assessment; (3) Development of Hardware and Software; (4) Pilot Testing; and (5) Technology Transfer. Each major task is described in detail in the following chapters.

This project and resulting tool supports FDOT's goals of increasing transportation resilience by developing geospatial tools to facilitate vulnerability assessment of infrastructure to flooding and help identify risks. Specifically, this project supports FDOT's Resiliency Policy 000-525-053 through the identification of risks related to SLR, flooding, and storms and assessment of potential impacts. Additionally, this project supports the FTP 2045 Goal of Agile, Resilient, and Quality Transportation Infrastructure.

2 Review of Tools

To inform the development of the geospatial tool described in Chapter 1 (“Resilience Report”), the research team first reviewed geospatial and decision support tools and approaches used to assess future climate risks to the transportation system and infrastructure at large (Task 1). This review sought to identify relevant data and features that could be adopted as models for FDOT and its partners. This review also sought to assess best practices for combining climate data of varying geographic extent, data scale, resolution, and accuracy. Before the review of tools is a discussion of the how tools are used to assess climate impacts to transportation infrastructure, including the vulnerability assessment process, and approaches to integrating into decision making.

2.1 Tools Supporting Climate Change Vulnerability & Risk Assessments

A multitude of geospatial and non-geospatial tools exist to support the assessment of vulnerable areas and populations to the impacts of climate change. For the purposes of this project, the research team defines a tool as a software based program, run online or through a desktop computer, spatially enabled or not, that facilitates said assessment. This review focused on online geospatial tools, since analysis using geographic information systems (GIS) software is one of the most common methods for assessing vulnerability and communicating results. The results of vulnerability assessments are often displayed through online map viewers, with varying levels of sophistication. Even simple, “out of the box” (i.e., non-customized) map viewers are an effective tool for visual communication of identified vulnerable infrastructure, flood risk areas, and other climate stressors. If configured appropriately, these map viewers can also offer data download to support dissemination of the underlying datasets. The 2nd Round of FHWA Resilience Pilots highlighted the use of maps and visualization tools to engage stakeholders in the vulnerability assessment process, “finding them to be a straightforward way to convey data-heavy analyses and findings” (FHWA, 2016, p. 17).

Aside from online map viewers used to display vulnerability assessment results, more robust decision-support tools, which offer the ability to explore scenarios based on future conditions and policy choices, are not as common. Even less common are decision support tools that integrate data and analyses into the business processes. Some of these tools take the form of a spreadsheet that guides decision making and assessment (“infrastructure checklists”), generally in accordance with adopted guidance and/or requirements for evaluation of future conditions under climate change stressors. Other tools have been developed to aid in project prioritization, screening of projects for potential impacts, identification of potential solutions (adaptation and/or mitigation strategies), and facilitation of cost-benefit analyses for evaluating adaptation strategies.

2.2 Assessing Vulnerability

This section includes the FHWA definitions for the components of vulnerability (exposure, sensitivity, and adaptive capacity) and FHWA Vulnerability Assessment and Adaptation Framework (FHWA, 2017). These terms are important to define before discussion of the tools, as they are central to the tools reviewed.

- *Vulnerability*: "The degree to which a system is susceptible to, or unable to cope with adverse effects of climate change or extreme weather events. In the transportation context, climate change vulnerability is a function of a transportation system's exposure to climate effects, sensitivity to climate effects, and adaptive capacity" (FHWA, 2017, p. 82).
- *Exposure*: "Refers to whether an asset or system is located in an area experiencing direct effects of climate variability and extreme weather events. Exposure is a prerequisite for vulnerability*"* (FHWA, 2017, p. 81).
- *Sensitivity*: "Refers to how an asset or system responds to, or is affected by, exposure to a climate change stressor. A highly sensitive asset will experience a large degree of impact if the climate varies even a small amount, where as a less sensitive asset could withstand high levels of climate variation before exhibiting any response" (FHWA, 2017, p. 82).
- *Adaptive capacity*: "Refers to the ability of a transportation asset or system to adjust, repair, or flexibly respond to damage caused by climate variability or extreme weather." (FHWA, 2017, p. 81)

Additionally, the concept of *criticality* is important for vulnerability assessments and tools for assessing climate impacts. A criticality index or measure is often applied to categorize the importance of assets included in a vulnerability assessment. Approaches to determining criticality vary depending on the asset types and data available, geography, and stakeholder input. Some quantitative measures include annual average daily traffic, evacuation routes, linkages to critical facilities such as hospitals and fire stations; while qualitative measures can include cultural value based on community input.

The FHWA Vulnerability Assessment and Adaptation Framework (FHWA, 2017) articulates a robust framework for assessing vulnerability of transportation systems to climate impacts and integrating into decision-making processes. The Framework is comprised of six primary steps:

1. *Articulating Objectives and Defining Study Scope*. This step includes articulating objectives, defining the study scope, identifying key climate variables, and selecting the assets to be evaluated (could be asset-specific or focused on a geographic area).
2. *Obtaining Asset Data for the Vulnerability Assessment*. Data gathering based on the assets selected in Step 1.
3. *Obtaining Climate Data for the Vulnerability Assessment*. Data gathering based on the climate variables identified in Step 1.
4. *Assessing Vulnerability*. Involves determining the selected assets or system's exposure to climate impacts, sensitivity to climate impacts, and adaptive capacity. At this step, there should also be a consideration of risk, which is a measure that includes the probability that an asset will experience impact and the consequence or severity of that impact. Assessments can be quantitative, qualitative, or a combination.

5. *Identify, Analyzing, and Prioritizing Adaptation Options*. Engaging stakeholders to identify adaptation options to address the vulnerabilities. This could include multi-criteria analysis to compare adaptation options and economic or cost-benefit analysis.
6. *Incorporating Assessment Results into Decision-making*. Incorporating vulnerability assessments results into decision making processes such as long range transportation plans; project development and environmental review; project level design and engineering; asset management; transportation systems management and operations, maintenance, and emergency management.

The Framework is meant to be an iterative process that includes regular monitoring and evaluation to keep pace with changing conditions and assess the success of implemented adaptation strategies and initiatives. Geospatial tools have been a common way to primarily support Steps 2, 3, and 4 (obtaining asset and climate data and assessing vulnerability), but less so with Steps 5 & 6 to date. Developing tools to assist with Steps 5 & 6 could help facilitate the entirety of the framework.

2.3 Approaches for Integrating into Decision Making

Common approaches to incorporating resilience into transportation planning include development of statewide climate vulnerability assessments, adaptation plans, and resiliency frameworks. These guiding documents are often created as part of a multi-agency effort, motivated by gubernatorial directives. The development of tools to support assessment and implementation is also a common practice.

Climate Vulnerability Assessments: Vulnerability assessments are a common starting point for agencies, offering a high-level understanding of vulnerabilities to climate stressors and highlighting geographic areas and assets for further study. Regional level vulnerability assessments allow for more focus on local and regional assets potentially impacted by climate stressors. Some statewide assessments are focused solely on transportation and others are multi-agency. FHWA's Climate Change Resilience Pilot Program has been critical for facilitating assessments for State Department of Transportations (DOTs) and metropolitan planning organizations (MPOs) and providing resources to navigate the complexity of climate planning.

Resilience Frameworks: After an initial vulnerability assessment, some state and regional agencies choose to develop frameworks to guide their adaptation planning and implementation. These frameworks can offer a roadmap for interagency coordination and institutionalizing resiliency across state agencies. Virginia's Coastal Resilience Master Planning Framework serves as a foundation for local coastal resiliency planning by articulating the state's values, objectives, and strategies for planning and establishes a roadmap and process by which the state will later implement a Coastal Resilience Master Plan. The Climate Framework for Delaware offered broad recommendations for adaptation, mitigation, and flood avoidance, with 19 recommendations assigned to DelDOT.

Climate Adaptation Plans and Resilience Master Plans: Climate Adaptation Plans and Resilience Master Plans are sometimes developed at the State level to incorporate resilience into planning processes. In general, these plans outline more refined, specific activities, based on results from vulnerability assessments and/or guidance and recommendations from resilience frameworks. DelDOT's Strategic Implementation Plan was created in response to the State's Climate Framework and includes prioritized recommendations with an implementation timeline. In 2020, MassDOT began development of a climate adaptation plan, with the goal of leveraging information from a more refined vulnerability assessment focusing on future inland flooding risks and extreme heat events. Virginia's Coastal Resilience Master Plan is expected to include specific resiliency policies to address the transportation vulnerabilities and prioritize specific projects by region to meet the identified objectives in the Framework.

Incorporating Climate Information into Project Development and Environmental Review: Some State DOTs (Washington, California, and Maryland) have begun incorporating climate data and/or vulnerability assessment results into the project development and environmental review process. Mainstreaming or integrating climate information into the project development process ensures that climate change impacts and adaptation options can be considered early in the process (before design and engineering). While not always supported by tools, examples from other states offer potential models for Florida's integration with the ETDM/ EST process.

2.4 Tool Matrix

Countless geospatial and non-geospatial tools exist, and this review of tools was not meant to be exhaustive. The research team looked for: (1) tools that aid in the assessment and visualization of future climate risks to the transportation system or infrastructure at large; (2) tools that offer unique or noteworthy methods of visualizing and/or scoring risk and vulnerability due to a variety of climate stressors; and (3) tools that feature user-friendly interfaces and design features. Additionally, the research team focused mostly on state-level tools, with a few exceptions.

Tools were identified through a variety of sources, including review of relevant literature, reports, conference presentations, Transportation Research Board's TRID database, FHWA Climate Resilience Pilot Program website, utilization of the Gulf TREE Tool, and the authors' knowledge of existing tools. Publicly available tools allowed for a deeper review and direct testing, while non-publicly accessible tools (such as Volpe RDR and Pinellas County Capital Planning Tool), were either discussed with tool developers or pilot users. Some of the tools reviewed are not specific to transportation, but offer features or functionality that could be adopted to support FDOT's resiliency goals.

The research team compiled a matrix of publicly available tools to guide the tool assessment process. The matrix (see Appendix A) tracked the following variables for each tool:

- Tool Name and Hosting organization.
- Tool Description/ purpose.
- URL/ web link for accessing the tool.

- Climate stressors included or assessed.
- Geographic Extent/ Area covered by the tool.
- Tool Category: Resiliency Screening & Visualization, Decision Support, or Resiliency Scoring and Measurement Tools (see below for more details).
- Tool focus: primary focus of the tool (e.g., transportation, critical infrastructure, etc).
- User Interface: technical components of the web map viewer and hosting platform.
- Any noteworthy features, functions, or data.

The research team grouped the tools into three categories, described below:

1. **Resiliency Screening & Visualization Tools:** These tools typically display areas exposed to climate stressors and usually provide some level of analysis or screening of the potential impacts from these stressors (such as flood exposure by segment of roadway or highlighting specific assets exposed to wildfires). These tools are often used to display the results from a vulnerability assessment, offering the public and decision makers access to explore the data and results. These tools are typically presented as interactive web mapping applications with varying levels of sophistication and functionality, although static maps occasionally provide snapshots of vulnerable areas.
2. **Decision Support Tools:** These tools typically offer screening of climate impacts, but also help provide information to guide solutions or next steps, such as adaptation or mitigation strategies and cost-benefit analyses. Sometimes these tools help to explore "what-if" scenarios of future conditions based on climate change factors and/or policy and management decisions (GulfTREE, nd). Decision support tools are less common than the visualization and screening tools.
3. **Resiliency Scoring and Measurement:** These tools support the process of identifying and prioritizing vulnerable infrastructure and performing cost-benefit analyses. Most of these tools are Excel-based spreadsheets (non-spatial tools), but are included in this review to highlight their importance in the overall process of building resilient transportation systems. Additionally, some of these tools could be candidates for migration to a web-based form that could integrate with geospatial systems to offer more robust decision support.

Not all tools fall neatly into one category, as some tools offer both screening and visualization as well as decision support. The vast majority of existing tools available are resiliency screening and visualization tools. The research team offers these categories to bound our own and other reviewers' expectations of the utility and functionality of the tools, based on the overall purpose of the tool. Additionally, the level of sophistication varies across all types of tools, reflecting the range of expertise and capacity to develop and implement the tools.

2.5 Tool Examples

A subset of tools was selected from the Tools Matrix and provided here are narrative descriptions of their evaluations. Tools were chosen based on their relevancy to informing FDOT's transportation resiliency efforts. Specifically, tools were chosen based on the following criteria: user-friendliness of the interface; climate data (other than SLR) and methods (potential for replicability); tool organization; and noteworthy features and/or functionality.

2.5.1 FHWA Tools

Through multiple rounds of climate resilience pilot programs, FHWA, along with state and regional partners, have developed methods and tools to guide other organizations in replicating the vulnerability assessment process. Examples include:

- **CMIP Processing Tool:** Processes downscaled climate projections into relevant statistics, such as changes in temperature and extreme precipitation, for transportation planners.
- **Sensitivity Matrix:** Documents the sensitivity of roads, bridges, airports, ports, pipelines, and rail to climate impacts;
- **Vulnerability Assessment Scoring Tool (VAST):** Uses an indicator based approach to quantitatively score the vulnerability of transportation assets.

All tools accessible at: https://www.fhwa.dot.gov/environment/sustainability/resilience/tools/

2.5.2 Regional and County Tools

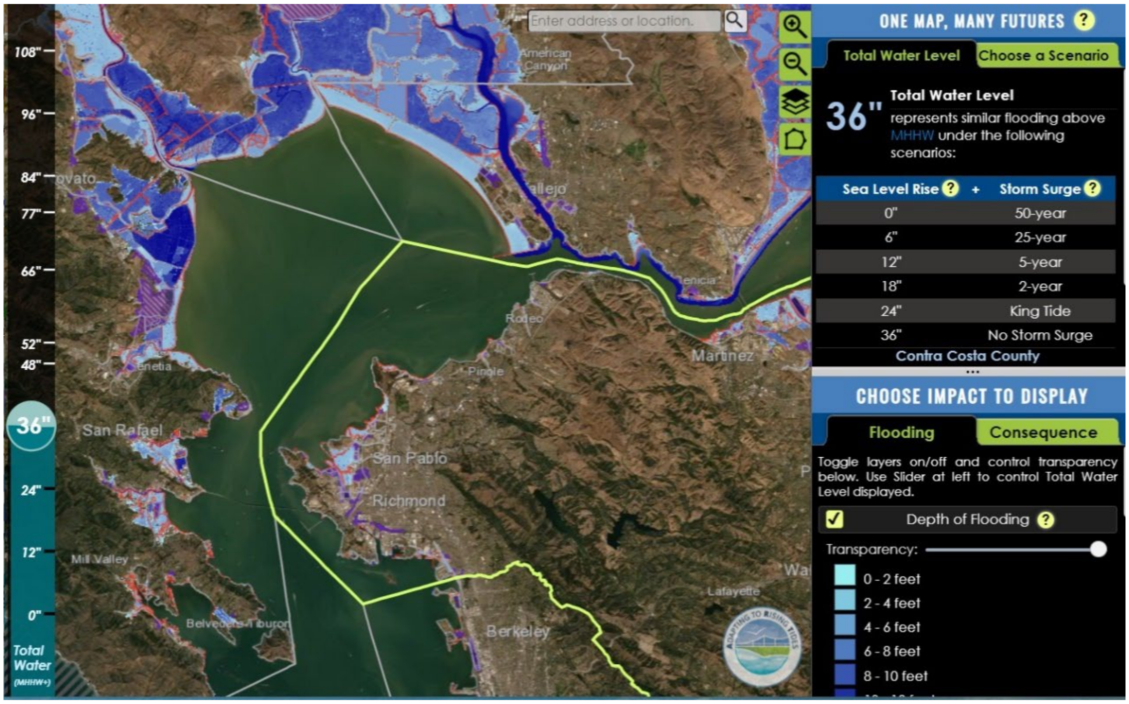
2.5.2.1 ART Bay Shoreline Flood Explorer

The ART Bay Shoreline Flood Explorer tool (see Figure 2-1) is not specific to transportation, but is noteworthy for its use of Total Water Levels (TWL) as a method for representing a multitude of flood events (see Figure 2-2). This is presented as an example of an adaptive framework that is temporally-independent. As such, flood hazards can be visualized independently (e.g., storm surge) or in combination (e.g., SLR + surge) independent of a specified time frame or planning scenario. The tool was created as part of the project, *Adapting to Rising Tides: Bay Area Sea Level Rise Analysis and Mapping Project*, which was funded by the Bay Area Tool Authority. Tool Website: https://explorer.adaptingtorisingtides.org/about

2.5.2.2 Houston Galveston Resilience Dashboard

The Regional Resilience Tool was developed by the Houston-Galveston Area Council (H-GAC) to visualize the results of their 2018 FHWA Resilience and Durability to Extreme Weather pilot project. The project examined the criticality and vulnerability of regional transportation assets (major roads and bridges) to flood hazards such as extreme flood events, storm surge, and SLR. This user-friendly, dashboard-style tool features “Resilience Street Profiles” (see Figure 2-3), which detail the criticality and vulnerability scores for each road segment, which are color-coded on the interactive map.

The tool also features a control panel, where users can easily filter the road segments based on their functional classification, criticality score, vulnerability score, and combined matrix, which overlays criticality and vulnerability. This matrix allows for highlighting road segments that are both highly vulnerable to flood risk and highly critical to the regional transportation network. The tool also includes regional resilience data layers, such as SLR and Hurricane Harvey damage, and allows users to add their own data through ArcGIS Online. The tool and data can be used to assist in prioritization of at-risk facilities and development of mitigation strategies. Tool URL: https://datalab.h-gac.com/resilience/



36" **Total Water Level** represents similar flooding above MHHW under the following scenarios:

Sea Level Rise	Storm Surge
0"	50-year
6"	25-year
12"	5-year
18"	2-year
24"	King Tide
36"	No Storm Surge

Contra Costa County

Toggle layers on/off and control transparency below. Use Slider at left to control Total Water Level displayed.

☑ Depth of Flooding

Transparency:

- 0 - 2 feet
- 2 - 4 feet
- 4 - 6 feet
- 6 - 8 feet
- 8 - 10 feet

Figure 2-1. Screenshot of ART Bay Shoreline Flood Explorer

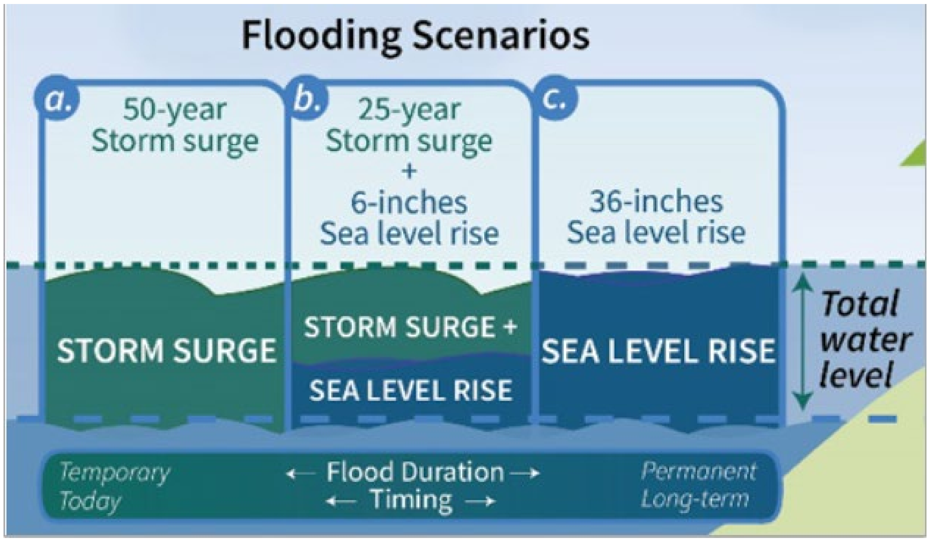
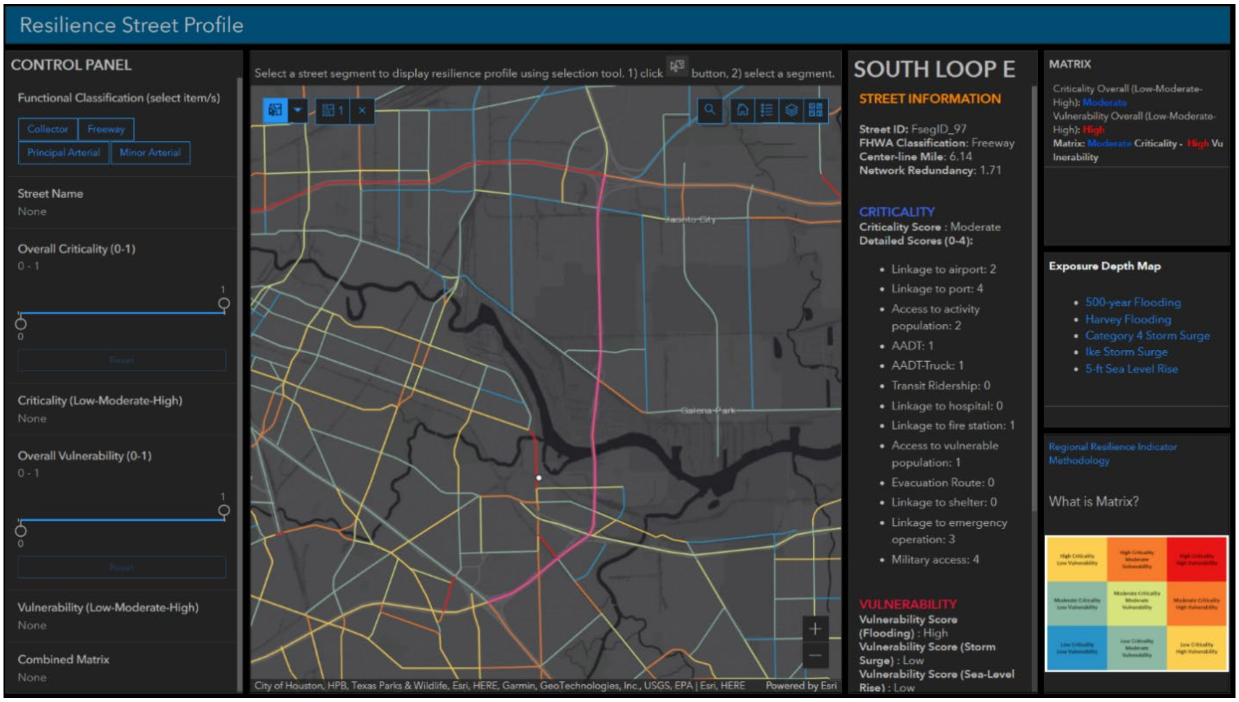


Figure 2-2. Total Water Level Conceptual Diagram (ART Bay Shoreline Flood Explorer, n.d.)



Functional Classification (select item/s)

Street Name
None

Overall Criticality (0-1)
0 - 1

Criticality (Low-Moderate-High)
None

Overall Vulnerability (0-1)
0 - 1

Vulnerability (Low-Moderate-High)
None

Combined Matrix
None

Select a street segment to display resilience profile using selection tool. 1) click button, 2) select a segment.

SOUTH LOOP E

STREET INFORMATION

Street ID: FsegID_97
FHWA Classification: Freeway
Center-line Mile: 6.14
Network Redundancy: 1.71

CRITICALITY
Criticality Score : Moderate
Detailed Scores (0-4):

- Linkage to airport: 2
- Linkage to port: 4
- Access to activity population: 2
- AADT: 1
- AADT-Truck: 1
- Transit Ridership: 0
- Linkage to hospital: 0
- Linkage to fire station: 1
- Access to vulnerable population: 1
- Evacuation Route: 0
- Linkage to shelter: 0
- Linkage to emergency operation: 3
- Military access: 4

VULNERABILITY
Vulnerability Score (Flooding) : High
Vulnerability Score (Storm Surge) : Low
Vulnerability Score (Sea-Level Rise) : Low

Criticality Overall (Low-Moderate-High): Moderate
Vulnerability Overall (Low-Moderate-High): High
Matrix: Moderate **Criticality -** High **Vulnerability**

- 500-year Flooding
- Harvey Flooding
- Category 4 Storm Surge
- Ike Storm Surge
- 5-ft Sea Level Rise

Figure 2-3. H-GAC Regional Resilience Tool

2.5.2.3 Pinellas County – Incorporating Sea Level Rise into Capital Planning

This web-based tool facilitates the requirement for flood-risk screening of infrastructure projects in Pinellas County. As of 2019, the screening is required for infrastructure projects costing over $1 million and for all critical infrastructure. The tool facilitates the key steps outlined in the County's "Guidance for Incorporating Sea Level Rise into Capital Planning". The tool requires project details to be submitted, such as the project location, functional lifespan, and planning horizon. Then the tool queries against publicly available data (web map services) to determine if the project is located within flood risk zones and low-lying areas susceptible to inundation from SLR. The tool guides the user through development of a vulnerability score, qualitative evaluations of the project's sensitivity and adaptive capacity, and exposure to flood-exposure areas. Additionally, the tool helps the user develop a risk assessment score that evaluates the anticipated damage from flood-related risks, associated disruptions in service, and costs to repair.

The tool includes an interactive map, with data layers such as vulnerability zones (from the County's vulnerability assessment), Federal Emergency Management Agency (FEMA) flood hazard areas, storm surge zones, parcels, the coastal construction line, and a shared municipal infrastructure layer that the local municipalities have each contributed data towards. Additionally, the tool leverages the newly released Florida Department of Environmental Protection (FDEP) Sea-Level Impact Projection (SLIP) Tool, by displaying adaptation strategies to improve the project's resilience to flood impacts. Expected to go live for county use in spring 2022, the tool is only applicable for Pinellas County, but it offers a great model for facilitating flood-risk screening.

2.5.3 State DOT Tools

2.5.3.1 CalTrans Climate Change Vulnerability Assessment Maps

In 2019, CalTrans conducted regional vulnerability assessments of transportation infrastructure for each of its 12 planning districts. The results of each district's assessment are displayed in an interactive map viewer, along with supporting documentation. The user interface (UI) of the map viewer is relatively basic, but the maps include up to six robust climate-change hazards, including intensifying storms, increased precipitation, rising sea levels, more frequent wildfires, higher temperatures, and cliff retreat (hazards depends on the district's geography). A geospatial database including the locations of current and future natural hazards and impacts to roadways was developed for the assessments.

The following climate-change hazards were included in the regional Vulnerability Assessments:

- *Storm Surge*: 100-year storm plus SLR. Different models used depending on the region.
- *Increased precipitation*: Downscaled climate models generated by Scripts to show change in 100-Year Storm Precipitation Depth for horizons of 2025, 2055, 2085. Used RCP 8.5, 50th Percentile (Climate Model for CA (HadGEM2-CC). Scale of Data: 15 sq miles, 38 sq km
- *Sea Level Rise:* Increments of SLR: 0.5m, 0,75m, 1m, 1.25m, 1.5m, 1.75m, 2m, 5m. Uses data from Coastal Storm Modeling System (CoSMoS) developed by U.S. Geological Survey (USGS).
- *Wildfires:* Wildfire Exposure at 2025, 2055, and 2085 using RCP 4.5 and RCP 8.5.
- *Temperatures*: Average Minimum Temperature, Average 7-day Maximum Temp for time periods 2025, 2055, and 2085.
- *Cliff Retreat:* Different methods used depending on region. One method used CoSMoS data to estimate erosion and cliff retreat, in addition to SLR and storm surge effects. Then calculated highway centerline miles exposed to cliff retreat at various increments of SLR between 0.5m and 5m.

Project Website: https://dot.ca.gov/programs/transportation-planning/division-of-transportation-planning/air-quality-and-climate-change/2019-climate-change-vulnerability-assessments

2.5.3.2 Colorado DOT Risk and Resiliency Tools

The State of Colorado has developed multiple resilience tools, both spatial and non-spatial. The State prioritized resilience efforts after a major flood event in 2013 caused serious damage to their road network, impacting nearly 500 miles of road and 50 bridges, totaling over $700 million in repairs. In 2017, CDOT completed a FHWA pilot project entitled "I-70 Risk and Resiliency Pilot", which developed a standardized approach for calculating risk and resiliency on the state's transportation system.

In 2018, CDOT adopted Policy Directive 1905 "Building Resilience into Transportation Infrastructure and Operations". This directive established CDOT's Resiliency Program and directed CDOT staff to incorporate resilience thinking into daily business operations. The tools below resulted from the pilot project and the state policy directive. Collectively, the mapping application and excel-based tools offer a comprehensive framework for screening, scoring, and assessing risks. Tools can be found at CDOT's Resilience Program website: https://www.codot.gov/programs/planning/cdot-resilience-program

- CDOT Asset Resiliency Mapping Application (ArcGIS Online): This interactive map (see Figure 2-4) allows users to visualize and assess risks from various geohazards, explore criticality on different routes, and find information on individual hazard events (such as landslides or fires). The mapping application includes various geospatial data layers from state and federal agencies, such as floodplains, landslides and geohazards, drought risk, wildfire risk, CDOT's list of statewide planned projects, and a roadway criticality index (developed in 2018 FHWA Risk and Resilience Pilot). The criticality index includes measures such as population type (rural or urban), functional classification, annual average daily traffic index, truck traffic percentage, VMT, route speed, AASHTO index, freight index, social vulnerability index, redundancy index, and tourism index.
- Risk and Resilience (R & R) Tool: This is an Excel-based spreadsheet tool to assist with cost-benefit analysis of assets based on hazard type, the likelihood of an event occurring, and the consequence or severity of the hazard's impact. The tool provides a quantitative risk assessment to estimate of the potential loss to the asset from a given hazard and helps calculate risk reduction from mitigation measures. Hazard calculations include bridge scour, rockfalls, and floods on various asset types (e.g., roads, bridges, culverts). The tool requires asset data and project information to be entered, such as asset replacement costs, asset vulnerability, and user costs and consequences from disruption (data can be generated from the Detour Identifier Tool).
- Detour Identifier Tool: This is an Excel-based spreadsheet tool and an application of the statewide travel demand model to identify optimal detour routes. The spreadsheet identifies the amount of time and distance associated with the detour route. These figures can then be put into the R&R tool.
- Project Scoring Tool for Resilience: This is an Excel-based spreadsheet tool to assist with project scoring and encourage the adoption of resilience strategies in planned projects to increase prioritization score. Research on past projects in Colorado determined that 10% is an appropriate amount to elevate a project from a low priority to a moderate priority, where it will have a better chance of getting funded. The scoring tool considers the project's eligibility for funding, criticality of the asset, whether the asset has been screened for risks and threats, and whether upgraded specifications for the project increase or incorporate resiliency (reflecting whether the project has adopted a "resiliency mindset"). The scoring tool also includes a risk mitigation assessment, which considers the project's exposure to various threats, the levels of risk from each threat, and the degree to which the risks have been mitigated.

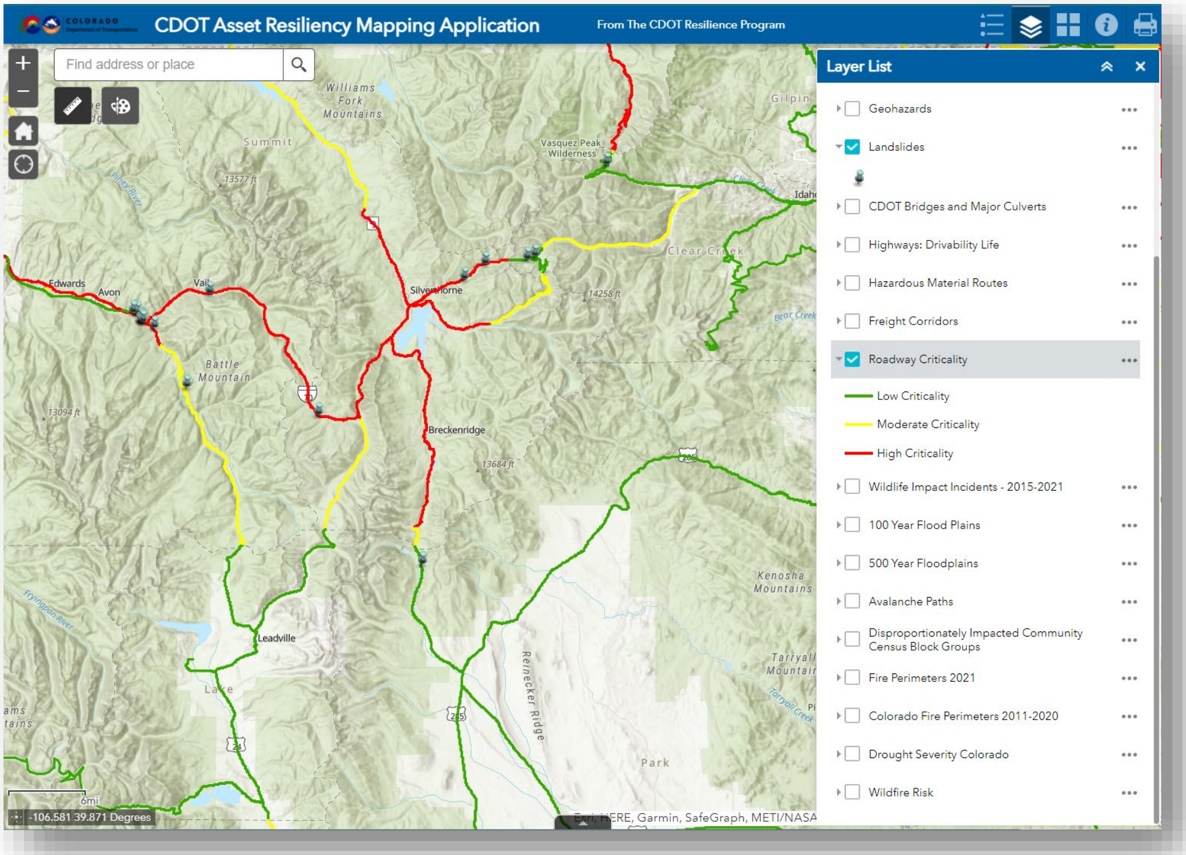


Figure 2-4. Screenshot of CDOT Asset Resiliency Mapping Application

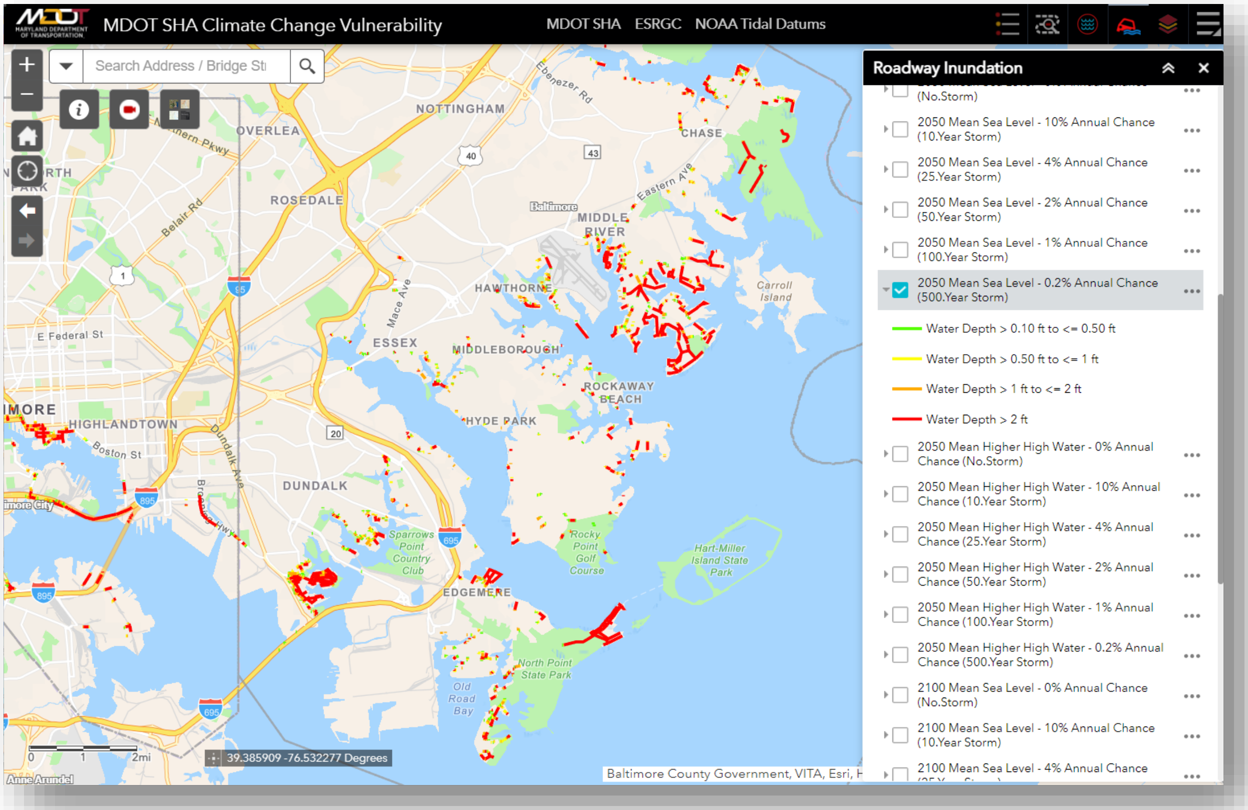
2.5.3.3 Maryland Climate Change Vulnerability Viewer

The Maryland DOT (MDOT) State Highway Administration (SHA) Climate Change Vulnerability Viewer(CCVV) is an ArcGIS Online (AGOL) web application which highlights geospatial data of climate change stressors and potential impacts to Maryland's transportation infrastructure (see Figure 2-5). The application was developed to support MDOT SHA Senior Management, Leadership & Planning in their efforts to mainstream resilience throughout the infrastructure life cycle (ESRI, n.d.). The viewer is a collaboration between MDOT, FHWA, Maryland Department of Information Technology, Salisbury University, Eastern Shore Regional Cooperative, and National Oceanic and Atmospheric Administration (NOAA). Tool Website: https://www.arcgis.com/home/item.html?id=86b5933d2d3e45ee8b9d8a5f03a7030c

The CCVV displays the analyses completed as part of a statewide road vulnerability assessment for all state-owned roads, which included a Hazard Vulnerability Index Analysis. Data layers of climate stressors focus on flood hazards, including nuisance flooding, future storm event scenarios, and hurricane storm surge. Specifically, the following data is included:

- Nuisance Tidal Inundation at years 2020, 2050, 2100 0% Annual Chance Event (No Storm Event)

- Storm Event Scenarios and Associated Roadway Inundation at years: 2015, 2050, and 2100 for the following annual chance events: 10%, 4%, 2%, 1%, 0.2% (respectively 10-, 25-, 50-, 100-, and 500-year events). These scenarios were modeled using FEMA HAZUS-MH Level 1 Coastal Only flood analysis and a SLR-adjusted digital elevation model (DEM) to represent future conditions at each time period (2015, 2050, 2100).
- Hurricane Florence Models of roadway inundation, inundated parcels, and flood depth.



(No.Storm)

☐ 2050 Mean Sea Level - 10% Annual Chance (10.Year Storm)

☐ 2050 Mean Sea Level - 4% Annual Chance (25.Year Storm)

☐ 2050 Mean Sea Level - 2% Annual Chance (50.Year Storm)

☐ 2050 Mean Sea Level - 1% Annual Chance (100.Year Storm)

☑ 2050 Mean Sea Level - 0.2% Annual Chance (500.Year Storm)

- 🟩 Water Depth > 0.10 ft to <= 0.50 ft
- 🟨 Water Depth > 0.50 ft to <= 1 ft
- 🟧 Water Depth > 1 ft to <= 2 ft
- 🟥 Water Depth > 2 ft

☐ 2050 Mean Higher High Water - 0% Annual Chance (No.Storm)

☐ 2050 Mean Higher High Water - 10% Annual Chance (10.Year Storm)

☐ 2050 Mean Higher High Water - 4% Annual Chance (25.Year Storm)

☐ 2050 Mean Higher High Water - 2% Annual Chance (50.Year Storm)

☐ 2050 Mean Higher High Water - 1% Annual Chance (100.Year Storm)

☐ 2050 Mean Higher High Water - 0.2% Annual Chance (500.Year Storm)

☐ 2100 Mean Sea Level - 0% Annual Chance (No.Storm)

☐ 2100 Mean Sea Level - 10% Annual Chance (10.Year Storm)

☐ 2100 Mean Sea Level - 4% Annual Chance

Figure 2-5. Screenshot of Maryland DOT Climate Change Vulnerability Viewer

2.5.3.4 Massachusetts DOT

Massachusetts DOT (MassDOT) has several tools to assist with climate resiliency efforts. In 2020, the MassDOT began conducting a Statewide Climate Change Adaptation Plan, where they are assessing the State's transportation infrastructure vulnerability to future inland flooding risks and extreme heat.

- **Climate Projection Viewer:** Displays downscaled climate projections for the State developed as part of the MassDOT Climate Adaptation Vulnerability Assessment. Includes three emissions scenarios (RCPs 4.5., 6.0, and 8.5) for four time periods (2030, 2050, 2070, and 2100) to analyze the changes in the duration and depth of precipitation events (1% annual exceedance probability 24-hour precipitation) and changes in temperature (projected annual consecutive days > 95°F). Tool Website: https://gis.massdot.state.ma.us/cpws/

- **Massachusetts Project Intake Tool (MaPIT):** MaPIT is a web-based screening tool to help state and municipalities map, create, and initiate roadway projects. Similar to Florida's Environmental Screening Tool, this tool helps to identify potential environmental issues with proposed transportation projects and aids in early identification of environmental permitting requirements. MaPIT is part of standard operating procedure across MassDOT and would be a logical place for screening of refined data from the statewide adaptation plan. The tool is built using ArcGIS Online and requires a login to view it, hence further information about the climate data included is limited.

- **Mapping Our Vulnerable Infrastructure Tool (MOVIT):** This internal MDOT tool maps and tracks locations of repeated flooding, erosion, and infrastructure damage due to storms. This is a partnership between MassDOT's departments of Environment, GIS, District Operations and Maintenance. The tool gathers institutional knowledge of maintenance engineers and others to provide data on vulnerable assets for project review and prioritization.

2.5.3.5 Vermont Agency of Transportation (VTrans)

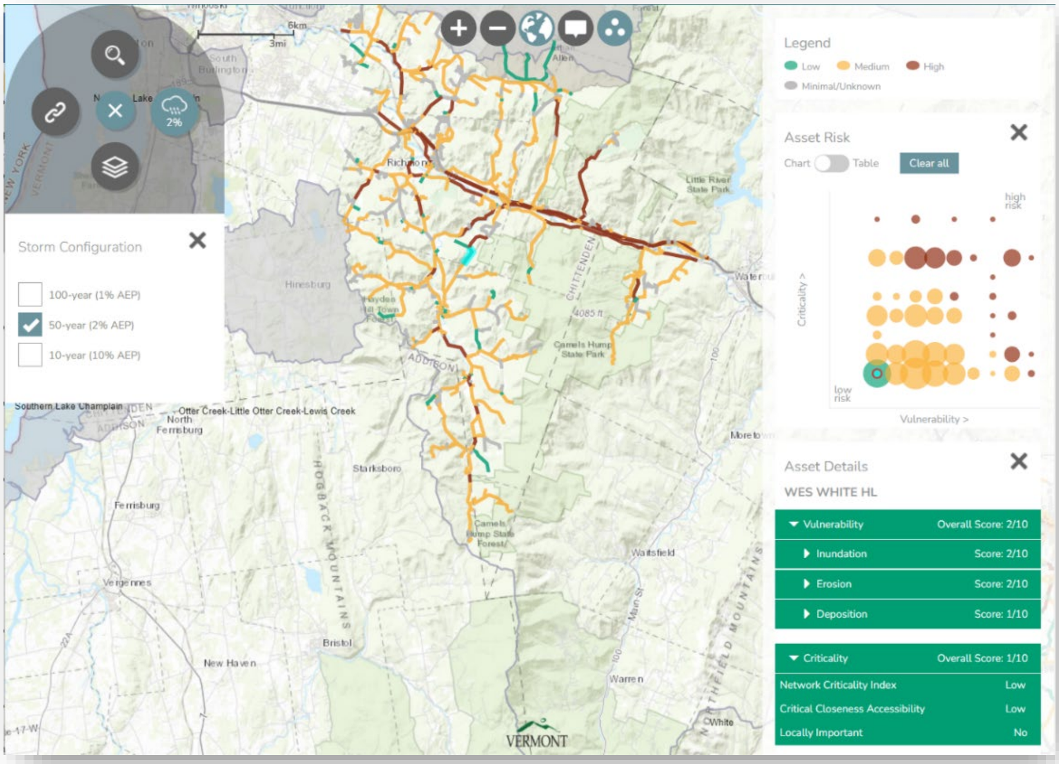
In August 2011, Tropical Storm Irene caused widespread damage to state and local roadways, spurring the state to become better prepared for floods and avoid/ minimize their future impacts. Consequently, the state embarked on a project to develop methods and tools to identify and reduce flood and erosion risk to the State's roads.

Vermont Agency of Transportation Resilience Planning Tool (TRPT): TRPT is a web-based tool to help identify transportation assets most vulnerable to damage from floods and erosion, estimate risk levels, and identify potential mitigation strategies (see Figure 2-6). The tool integrates river science, hydraulics, and transportation planning methods, applied at the watershed scale (Schiff et al., 2018). The tool includes (1) exposure analysis for roads, bridges, and culverts to flood inundation, erosion, and deposition hazards; (2) criticality index of assets to represent the asset's relative importance; (3) risk index, or the combination of vulnerability and criticality; and (4) mitigation strategies to reduce hazards to roads, bridges, and culverts. This effort was led by VTrans and funded through multiple sources, included FEMA Hazard Mitigation Grant, federal funds via VTrans State Planning and Research work program, and matching funds from state transportation dollars.

The map viewer features a user-friendly and intuitive design, with helpful and interactive charts and tables. The charts allow for quick identification of high-risk assets within the current map view and facilitates display of asset-level scores for risk, vulnerability, and criticality. Users can also toggle through various symbology options to highlight different scores and display assets of interest (roads, bridges, or culverts). Tool Website: https://roadfloodresilience.vermont.gov/#/map

Vermont Statewide Highway Flood Vulnerability and Risk Map: This online map displays the results of Vermont's statewide vulnerability assessment. This is a coarser scale of analysis than the watershed scale completed for the TRPT, but is still reliable for planning efforts such as emergency preparedness, capital planning, and hazard mitigation. For roads, bridges, and culverts, the map displays a flood risk score, which combines a flood vulnerability score with a criticality score.

The analysis looked at two asset types (1) roads and (2) bridges/culverts; three types of flood vulnerability: inundation, erosion, and deposition. These results were used to develop a state-scale prioritization and screening method, based on documented past damages, length of road segment ROW in the river corridor, length of road segment ROW in the 100-year floodplain, specific stream power, valley slope, structure width versus bankfull channel width, and bridge source criticality (Milone & MacBroom, 2018). Based on these variables, a vulnerability score for inundation, erosion, and deposition was calculated for culverts, bridges, and road embankments, and then converted to a 10-point scale. The project also included a criticality score for assets to represent the relative importance of the transportation asset. Tool Website: https://vtrans.maps.arcgis.com/apps/MapSeries/index.html?appid=f8a6527cf53e45a8896b494848b21e4f



Storm Configuration

☐ 100-year (1% AEP)
☑ 50-year (2% AEP)
☐ 10-year (10% AEP)

Asset Details

WES WHITE HL

Vulnerability	Overall Score: 2/10
Inundation	Score: 2/10
Erosion	Score: 2/10
Deposition	Score: 1/10
Criticality	Overall Score: 1/10
Network Criticality Index	Low
Critical Closeness Accessibility	Low
Locally Important	No

Figure 2-6. Vermont Agency of Transportation Resilience Planning Tool

2.5.4 Other Tools

2.5.4.1 Sea Level Impact Projection (SLIP) Study Tool

This interactive mapping tool was developed to facilitate vulnerability assessment requirements in accordance with Florida Statutes (Section 161.551, F.S). The statute requires that publicly financed projects located within the coastal building zone must conduct and publicly submit a SLIP (Sea Level Impact Projection) Study before any publicly financed construction begins. Contractors must assess the risks and vulnerabilities relating to stormwater, SLR, flooding, land subsidence, wave damage, and environmental hazards during the project's expected life cycle or 50 years (whichever is less). SLIP studies are required to be published on FDEP's website for at least 30 days prior to approval and 10 years after.

The tool is publicly available, but does require a login to run a study. There is a public-facing map viewer that displays the coastal layers used in the SLIP Study Report. The tool allows a user to choose any location for which to run the SLIP Study. The SLIP Study Report analyzes the project's location in reference to a pre-defined hazard and other layers (SLR, FEMA flood zones, hide tide flooding, wind zones, wildlife index, and elevation). The tool generates a PDF report, with assessment results and a list of potential adaptation strategies, based on the project type and location. Tool Website: https://www.floridadep-slip.org/

2.5.4.2 U.S. DOT Volpe Center Risk and Disaster Recovery Tool Suite

The U.S. DOT Volpe Center's Resilience and Disaster Recovery (RDR) Tool Suite (still being piloted) was developed to aid transportation agencies in estimating the return on investment (ROI) of resilient infrastructure across multiple future hazards. The RDR will support various hazards and allow for quick comparison of scenarios that integrate multiple variables, such as growth and development patterns, SLR, and other flooding events. The information generated from the tool suite can assess the network effects of hazards, assess resilient asset investment costs and benefits, communicate resilience costs and benefits, assess relative performance of resiliency investment options, and inform project prioritization. This set of tools is location agnostic and geospatially explicit and results are visualized through Tableau. This is not yet a publicly accessible tool and still being piloted, so information is limited.

2.6 Best Practices for Data Integration

One objective of this project was to develop geospatial functionality for project-level screening and assessment of climate impacts. Core to this objective is developing guidelines for combining or utilizing multiple datasets from different sources and with varying resolution (scale), accuracy, map projections, and uncertainty. Consideration of these variables is important when integrating disparate data to inform planning and project level decisions. Much of the data that is available may only be appropriate for screening and planning level, and not for engineering/ design level. However, coarser data is still important for broadly identifying geographic areas that would trigger the need for more refined analysis.

Integrating data from a variety of sources requires consideration of standardization and scale, with the latter being the most important factor (Rapacciuolo & Blois, 2019). Standardization of coordinate systems (projection and units) and data attributes are primary considerations (Rapacciuolo & Blois, 2019) and routine steps in GIS data processing. When merging data layers of different scales and geographic extents, interpolation procedures are often utilized. Often a hybrid approach is needed that combines multiple types of interpolation routines to account for edges, discontinuous surfaces, and edges, while creating a continuous surface with consistent values. Scale, in both geographic and temporal terms, determines the analytical capabilities and limitations of data. Process trends and relationships between these processes may vary with scale, and are yet another consideration (Qiu, et al., 2018).

Relevant to this project, is the scale of readily accessible climate data, particularly precipitation and high-water data in time series, which can be used to determine flood hazard exposure of inland areas and infrastructure. The majority of relevant and accessible climate data is derived from global climate models (GCM), at scales ranging from 800-meter (moderate resolution) to 300-kilometer cell sizes in a gridded interpolation format (Wang et al., 2016). The coarseness of GCMs do not allow for local trends affected by variables such as topography, vegetation, soils, and urbanization. For example, a future temperature projection may not include the temperature gradient between coastal and inland areas if that area was covered by the same GCM grid cell (Hayhoe & Stoner, 2022). The coarseness of GCMs can more often lead to underestimation, known as a "Type 2" error. Wang et al. (2016) present a methodology and a publicly accessible North American data set that illustrates one methodology for downscaling GCM results and combining them with elevation data to refine interpolations. Their efforts have also resulted in the development of software to streamline the integration and downscaling effort (Climate NA, http://climatena.ca/).

Along with the coarseness of GCMs, another important consideration is understanding the uncertainty in the models. Hayhoe & Stoner (2022) provide guidelines on uncertainty and time frames of analyses when on utilizing climate projections for resiliency planning. They recommend the use of observed trends for short term planning (years to a decade), due to natural variability being the largest source of uncertainty. For planning past a decade or two, they recommend use of GCMs, and multiple GCMs to reduce uncertainty within those models. Additionally, they recommend use of Representative Concentration Pathway (RCP) 8.5 for midcentury planning efforts, as global carbon emissions over the past two decades are consistent with that pathway (Hayhoe & Stoner, 2022).

2.7 Discussion on Tools Review

This chapter included a focused review of primarily geospatial tools and approaches used to assess future climate risks to the transportation system and infrastructure. The research team sought to reveal best practices and common approaches used by other transportation agencies (primarily State DOTs) to inform the development of the Resilience Report tool features and user interface design.

2.7.1 Tool Purpose and Category

The majority of tools reviewed were developed to visualize and communicate the results of climate vulnerability assessments and often created in response to policy directives or goals. Hence, the research team categorized most of these as Resiliency Screening and Visualization Tools. While the tools have varying levels of sophistication, overall most are effective for centralization and dissemination of vulnerability information for a range of stakeholders. A few tools (VTrans, SLIP, Pinellas County) offer adaptation or mitigation strategies based on the asset type, vulnerability, and geography, but these are not common yet. This could be a reflection on the state of practice, as states are at different stages in the process of planning and implementing transportation resiliency strategies.

The non-geospatial tools reviewed were largely categorized as "Resiliency Scoring and Measurement". These were mostly desktop, Excel-based spreadsheet tools to aid in the identification and prioritization of vulnerable infrastructure and conducting cost-benefit analyses. Colorado DOT has a thoughtful suite of tools, which are designed to work together, for detour identification, cost benefit analysis, and project scoring. These tools play important roles in building resilient transportation systems and some could be migrated to a web-based form that could integrate with geospatial systems to offer more robust decision support.

2.7.2 Climate Stressors and Data

Almost all tools reviewed assess some type of flood risk. The tools commonly included some combination of: SLR inundation under multiple future scenarios, hurricane storm surge, and FEMA flood hazards zones. The tools review revealed the following common practices:

- To visualize and analyze SLR impacts, the use of SLR increments (e.g., showing 0-3 meters of SLR) was more common than a specific set of projections (e.g., NOAA Intermediate High). Some tools indicate where a specific projection falls along the range of increments mapped.
- FEMA Flood Hazard Zones are commonly used to represent current inland and coastal flood risks.
- Future flood risk areas (such as inland flooding, nuisance flooding, and storm surge) are not commonly available. Only a few states (Maryland, CalTrans) have developed and modeled future flood levels and even less have included depth or duration of flooding. Coastal Virginia (which is included in the Tools Matrix but not in the narrative) has modeled duration of nuisance flooding under future SLR scenarios.
- To model increased precipitation, change in precipitation depth for the 100-year storm event (or 1% annual exceedance probability [AEP]) or was modeled by CalTrans for three time periods (2025, 2055, 2085). Similarly, MassDOT provides downscaled climate projections, including the projected percent change of 1% AEP 24-hour precipitation and projected 1% AEP 24-hour precipitation depth.

While not as common, some states included non-flooding climate stressors. Colorado DOT assess current wildfire, drought risk, geohazards, and landslides. CalTrans assesses wildfire risk, increased temperatures, and cliff retreat along coastal areas. CalTrans provides a good framework for standardized regional vulnerability assessments using multiple climate stressors.

Assessing Vulnerability
These findings relate to how vulnerability and its components (exposure, sensitivity, and adaptive capacity) are measured and displayed in the tools reviewed. Also included here is a discussion of criticality and risk indices.

- Exposure to climate stressors or hazards was the most common method in the reviewed map viewers.
- The use of a criticality Index has become a more common feature (Colorado DOT, V Trans, Houston-Galveston). A criticality index is helpful for narrowing the focus of assessments to the most critical assets. In addition to quantitative measures (e.g., average annual daily traffic, evacuation routes), qualitative measures are also important to determine community value.
- VTrans combines a criticality index and a vulnerability index to create a risk index of assets. This is helpful for identifying the assets with the highest potential for climate impacts that are also the most critical for the transportation network.
- Indices or measurements for adaptive capacity and sensitivity were scarce. Two Excel-based tools were the exception. The FHWA sensitivity matrix offers measurements for sensitivity. Colorado's Detour Tool offers a measure of adaptive capacity, based on detour length and time.

User Interface & Design of Web Mapping Applications
Many of the mapping applications reviewed offer basic functionality (but often data rich) and most are built using ArcGIS Online (AGOL). Tools that offer scenario comparison and adaptation/ mitigation solutions require more project-level input data and customization of the user interface.

Key takeaways from the technical review of user interface and web map design are as follows:

- Many of the tools reviewed are "out of the box" mapping applications, meaning they use pre-defined templates and are not customized applications. These templates are relatively quick and easy to set up and can offer straightforward communication of climate stressors and vulnerable areas. However, if many climate scenarios and data layers are included in the map viewer, it can be confusing to navigate.
- AGOL is one of the most common web mapping frameworks in use today and is a product of the Environmental Systems Research Institute (ESRI), the industry leader in GIS software. This cloud-based service is popular due to its simplicity in deploying web applications. The Web App Builder contains templates for creating web applications with little to no software programming required. If customization is desired, ESRI's JavaScript API can be used. Additionally, ESRI has dominated the desktop GIS market for decades, and has developed tools that integrate between desktop and web, making it

easy publish data from the desktop to the web. The limitations of AGOL are the lack of custom functionality in the basic applications/ templates and the high cost of licensing.

- The strengths of many of the tools reviewed is their underlying data, which serves not only transportation but other agencies and public sectors. The availability of already downscaled climate projections, modeled scenarios of future conditions, and potential impacts to assets is a huge, and not to be understated, benefit.
- Many, but not all, mapping applications reviewed offer data download. When possible, a public data download option should be available – either as GIS file downloads or as a Web Feature Service (WFS), a type of web map service that allows for access to the actual spatial data.
- Some tools reviewed had noteworthy visualization features – such as interactive charts, slider bars, and PDF generation for reports. These are helpful for visualization and interacting with data-heavy map viewers. The ART Bay Shoreline Flood Explorer tool includes a slider bar to change the total water level. As the slider is moved, the information boxes display the corresponding flood events that would occur at that water level. The VTrans Resilience Tool has a dynamic charting feature, which is linked to the map and helpful for visualization of the vulnerability and risk index. The Sea Level Rise & Storm Surge Impact Tool for the City of Coral Gables (included in matrix in Appendix A) includes dynamic charting and PDF generation.

Next Steps and Recommendations

This tools review served to assess the state of practice and narrow down the types of climate stressors and data that are commonly used to assess transportation system vulnerability to climate change. The technical review also served to assess what types of user interface features could be leveraged for this project’s tool development. Considerations from this review led the research team to further explore sources of future flood data and/or methods, including but not limited to future nuisance flooding, precipitation, future storm surge, and updated SLR scenarios (described in the next chapter). Additionally, the research team explored the uses of various charts for data visualization.

3 Assessment of Data Sources

This chapter describes the efforts to identify and assess flood risk data sources that are not currently represented in the Sketch Tool (Task 2 of this project). This review was not meant to be exhaustive, but rather the research team sought to identify readily available datasets to be piloted as part of this project. The Sketch Tool currently includes SLR scenarios from NOAA (Sweet et al., 2017) and U.S. Army Corps of Engineers (USACE, 2013) to assess future flood risk for decades between 2040 and 2100. The Sketch Tool also includes FEMA Floodplains (100-year and 500-year) to assess current inland and coastal flood risk, and Storm Surge Zones to assess current surge risk. The Sketch Tool does not include minor coastal flood events (such as high tide flooding), projections of future inland flooding, and future storm surge under SLR conditions.

To identify flood risk data sources, the research team first reviewed a multitude of relevant geospatial and decision support tools developed to assess climate impacts to infrastructure (see Chapter 2). The tools review highlighted flooding events and data sources used within and outside of Florida by state, regional, and local agencies engaged in resiliency planning efforts. Major flood event types reviewed in this chapter include coastal flooding events (SLR, nuisance flooding, storm surge) and inland flooding (precipitation). While SLR scenarios are already included in the Sketch Tool, this report includes the updated NOAA 2022 SLR scenarios, which were released in February 2022 and have not yet been added to the Sketch Tool.

Data sources identified through the tools review were further investigated during this task and described in this chapter. Additional data sources were identified by the research team, through review of relevant literature, knowledge and participation with completed and ongoing research projects, and engagement with subject matter experts in climate science, hydrology, engineering, and planning. Data sources include both spatial data layers, tabular data, and various tools for data integration and analysis. The focus here was on publicly accessible and readily available data.

The team also considered recently enacted state legislation, House Bill 7053: “Statewide Flooding and Sea Level Rise Resilience” (s. 14.2031, F.S.), which became effective July 1, 2022, and includes data requirements for FDOT’s Resilience Action Plan (RAP) and local vulnerability assessments funded through the Resilient Florida Grant Program. For the RAP, FDOT is directed to evaluate vulnerabilities to the State Highway System under current conditions and future forecasted events, including tidal, rainfall, the combination of tidal and rainfall, storm surge flooding, and future sea level rise using the NOAA 2022 scenarios. Though the Resilience Report tool developed for this project is not required to meet statutory guidelines, consideration of these standards will help keep consistency with other local and statewide efforts. After identifying an initial list of data sources, the research team developed a data matrix (see Appendix B) to organize and evaluate data characteristics.

3.1 Data Sources

The data evaluation process focused on the following flood types:

- High Tide Flooding (current and future)
- Updated scenarios of Sea Level Rise (NOAA 2022) and associated coastal flood risk datasets from the NOAA 2022 Technical Report
- Storm Surge (current and future)
- Inland Flooding, including Extreme Rainfall

Each of these data types are described in more detail in the following subsections, along with a subset of the data sources evaluated. The complete list of data sources evaluated is included in Appendix B.

3.1.1 High Tide Flooding

Recurrent flooding that occurs during high tides is referred to as high tide flooding (HTF) and also called “nuisance”, “sunny day” and “recurrent tidal” flooding. Currently, these are minor disruptive flooding events and typically do not cause significant damage. However, along much of the U.S. coast, nuisance flood events are increasing in frequency, depth, and extent due to rising mean sea levels (Sweet et al., 2014, Sweet et al., 2018). Cumulative impacts from recurrent high tide floods include reduced stormwater drainage, temporary street closures, and corrosion of infrastructure from repeated flooding and saltwater exposure (Sweet et al., 2014).

Nationwide, NOAA estimated an average of 3-7 days of minor HTF in 2021. By 2030, the annual HTF rate is expected to increase 2-3 times (7-15 days), and by 2050, an increase of 5-15 times (25-75 days) (NOAA, 2021). Depending on the location of these HTF events in relation to coastal transportation assets, a doubling or tripling of event frequency could involve significant impacts to mobility, infrastructure, and communities. Along the Southeast Atlantic Coast, annual frequencies of HTF are accelerating, which is problematic for Florida’s low-lying coastal communities. Along the Southeast Atlantic and Gulf Coasts, HTF is generally highest during the fall (September–November), with a secondary peak in early summer (June-July).

NOAA delineates and maps (see Figure 3-1) three HTF levels: minor, moderate, and high, using standard thresholds above the daily high tide, known as mean higher high water (MHHW). Minor HTF includes when tides exceed approximately 0.55 m (1.8 ft), moderate HTF when tides exceed 0.85 m (2.8 ft), and major HTF when tides exceed 1.2m (3.9 ft). NOAA provides GIS data showing the spatial extent of these three HTF thresholds, along with the observed and projected number of minor HTF days. Data can be obtained from the NOAA CO-OPS Derived Product API v0.1: https://api.tidesandcurrents.noaa.gov/dpapi/prod/.

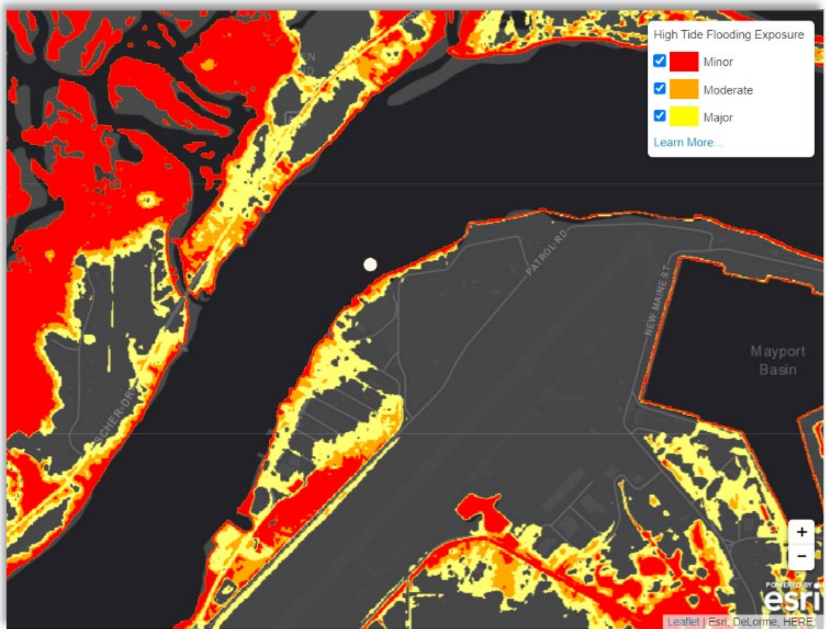


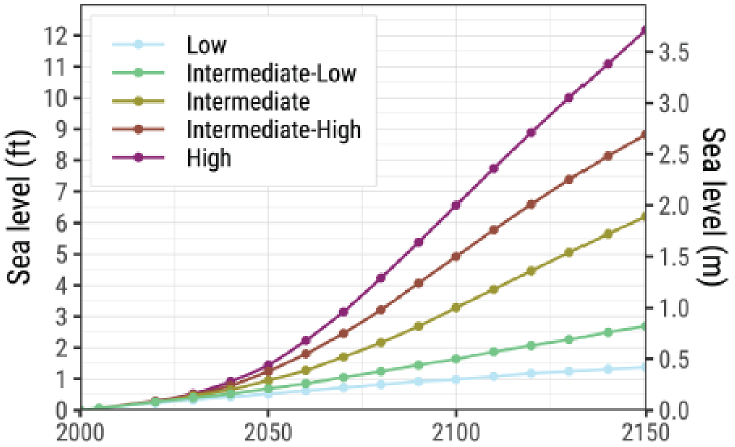
Figure 3-1. Spatial Extent of Minor, Moderate, and Major High Tide Flooding

3.1.2 NOAA/ Interagency 2022 SLR Report

Updated SLR information for the U.S. was released in February 2022 and documented in *Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines* ("NOAA 2022 Technical Report", Sweet et al., 2022). The report was developed by the U.S. Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force ("Task Force") and builds on the 2017 Task Force Report (Sweet et al., 2017). The report includes three types of SLR information: (1) updated Global, Regional, and Local SLR scenarios out to 2150, (2) observation-based extrapolations, and (3) extreme water level probabilities out to 2050. The 2022 report reflects the most current available science on SLR and is a key input for the Fifth National Climate Assessment.

3.1.2.1 2022 Global, Regional, and Local SLR Scenarios

The 2022 SLR Scenarios are an update to the 2017 Scenarios (Sweet et al., 2017). This update includes a set of five SLR scenarios (Low, Intermediate-Low, Intermediate, Intermediate-High, High), representing a range of plausible SLR out to 2150 (see Figure 3-2). These updated scenarios reflect the most current available science about global processes (such as glacier and ice sheet melt, mass redistribution), resulting in a higher certainty about the projections and a narrower range of SLR in the near-term (from now until 2050). The 2017 and 2022 scenarios ultimately arrive at the same global mean sea level values by 2100, but the 2022 scenarios follow a slower acceleration of SLR through 2050 and greater acceleration after 2050. Global, regional, and local processes, such as vertical land motion, are reflected in regional and local SLR scenarios, providing for more appropriate regional applications.



	Year		
Scenario	**2050**	**2100**	**2150**
Low	0.5	1.0	1.4
Intermediate-Low	0.7	1.6	2.7
Intermediate	1.0	3.3	6.2
Intermediate-High	1.2	4.9	8.8
High	1.4	6.6	12.2

Units in feet relative to year 2000

Figure 3-2. 2022 Global SLR Scenarios (Collini et al., 2022)

NOAA provides the 2022 SLR scenarios (1) by tide station (those with adequate data record for calculating sea level trends) for local scale use and (2) by a 1-degree gridded area to be used for regional projections. Data can be downloaded or accessed through NOAA's API. These projections should be included in the Resilience Report, as they reflect the latest climate science. However, one primary limitation is that the data does not delineate the spatial extent of inundation under these scenarios.

3.1.2.2 Observation-Based Extrapolations

The second type of SLR information included in the 2022 Report are regional extrapolations of SLR based on tide gauge observations from 1970 to 2020. These extrapolations serve as a near-term (2020-2050) comparison to the five SLR scenarios and can be viewed as "trajectories" of current SLR. Figure 3-3 shows the regional SLR scenarios in relation to the observation-based extrapolation (median [bold dash] and 17th/83rd percentile confidence limits [light dash]), and average annual water levels from tide gauges through the Southeast region (Collini et al., 2022). The report notes that these extrapolations are not meant to replace the SLR scenarios, but instead offer another line of evidence for planning for near-term SLR. The report provides a detailed account of how these extrapolations were calculated, along with their likely ranges (confidence limits).

These observation-based extrapolations were compared against regionalized 2022 SLR scenarios to assess how near-term (out to 2050) SLR is tracking along the five scenarios. For the Southeast region, the median observation-based extrapolation is bounded by the intermediate and intermediate-high scenarios in the year 2050. For the Eastern Gulf region, the median observation-based extrapolation is bounded by the intermediate-high and high scenarios in the year 2050. These comparisons can assist in choosing SLR scenarios for near-term planning efforts (out to year 2050) by showing how sea levels are tracking with SLR scenarios.

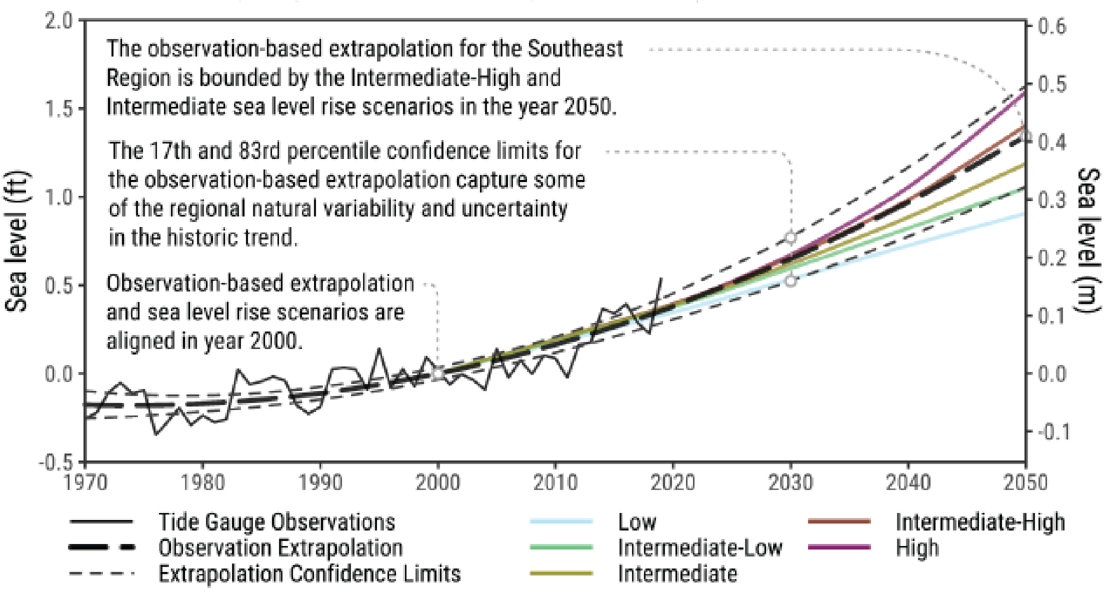


Figure 3-3. Observation-based Extrapolations for Southeast Tide Gauges (Collini et al., 2022)

3.1.2.3 Extreme Water Level Probabilities

The third type of SLR information included in the 2022 Technical Report is Extreme Water Level (EWL) probabilities, which estimate how coastal flood frequency and magnitude will change with SLR. The report's analysis of EWLs indicate that damaging floods will occur much more frequently as sea levels continue to rise over the next 30 years (Sweet et al., 2022). The report includes a new national 1-degree gridded data set of EWL probabilities that estimate the change in frequency of NOAA minor, moderate, and major high tide flooding (HTF) events out to the year 2050. The gridded EWL dataset was developed with a regional frequency analysis of tide gauge data to estimate the likelihood of infrequently occurring EWLS that bring damaging impacts. The EWL data are also provided by tide gauge, but the report states that the gridded approach results in a better assessment of EWL probabilities from a regional outlook, when compared to a single-gauge assessment.

Additionally, the gridded dataset can provide information where no tide gauges exists. The water levels assessed include specific flood thresholds that reflect critical frequencies (such as 1%, 10%, etc) or impacts (minor, moderate, or major high tide flooding). Note, the 1% annual chance water levels or 100-year flood in this analysis are not the same as the FEMA Flood Insurance Rate Maps (FIRM) regulatory products. The FIRMs do not account for SLR but do account for wave effects. The EWL probabilities in the report do include SLR but do not include wave effects. The SLR included in the EWL reflect the upper-bounding sea level scenario identified by the regional observation-based extrapolations. The report recommends the inclusion of wave effects for future assessments of coastlines, as wave effects can contribute 25-90% of EWLs (Sweet et al., 2022, Collini et al., 2022).

The EWLs can be used to help communities plan for the impacts of increasing coastal flooding by estimating the change in frequency of EWL events and the time frame of occurrence.

Understanding the probability of higher-frequency, lower-impact events and when these events may shift from minor to moderate or major impacts brings additional critical data points for coastal planners to assess flood risks. In the example below (see Figure 3-4) from the Application Guide (Collini et al., 2022), the EWL analyses indicate that moderate floods in Portland, Maine may occur 18 times more frequently in 2050 than in 1992. This analysis uses the supplemental EWL tables from the NOAA 2022 Technical Report that account for future SLR (Collini et al., 2022).

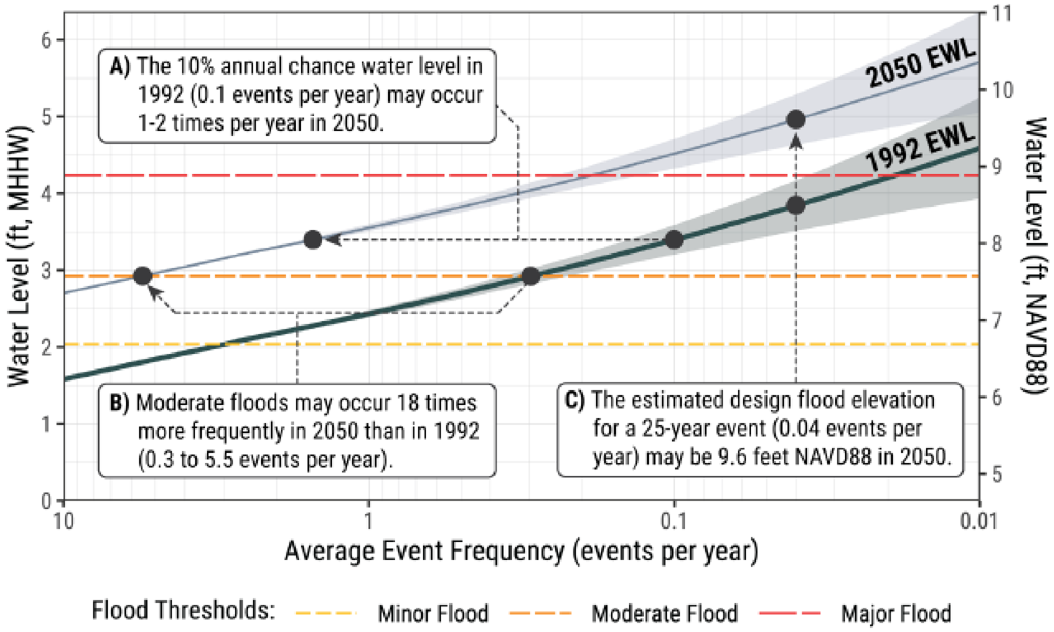


Figure 3-4. Changes in Frequency and Magnitude of Extreme Water Level Events (Collini et al., 2022)

3.1.3 Storm Surge

3.1.3.1 Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Model

The Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, which was developed by the National Weather Service, is commonly used to generate GIS data on the depth and extent of current hurricane storm surge. Storm surge composites include the Maximum Envelopes of Water (MEOWs) and Maximum of MEOWs (MOMs), which are created to assess and visualize storm surge risk under varying conditions. These models predict surge by running tens of thousands of climatology-based hypothetical tropical cyclone simulations.

In 2021, the Florida Division of Emergency Management (FDEM) and the Regional Planning Councils partnered to update the SLOSH models for the Statewide Regional Evacuation Studies. The result is a more refined product for the State. The outputs represent the extent of flooding for MOMs by storm category (1-5) and do not include future SLR conditions. The Sketch Tool currently includes these outputs, with exposed assets classified by the percentage of the asset exposed to each storm surge category. One enhancement that could be explored within this project is to also evaluate the depth of flooding values by storm category for a particular AOI. However, the depth grids are pending release of the 3DEP Peninsular Florida LiDAR collection.

3.1.3.2 Coastal Hazards System v2.0

The Engineer Research and Development Center (ERDC) and Coastal & Hydraulics Lab (CHL) of the U.S. Army Corps of Engineers (USACE) developed the Coastal Hazards System (CHS) v2.0. The CHS results provide projections of storm surge inundation depth compounded by SLR. To support the South Atlantic Coastal Study (SACS), the USACE created depth grids to represent various Annual Exceedance Probability Events for three SLR scenarios: (1) existing conditions, (2) SLR of 2.73 feet, and (3) SLR of 7.35 ft. Annual Exceedance Probability events include the 10-, 50-, 100-, and 500- year. The models included a variety of input topographic and bathymetric data sources, but all sources were resampled to a 5-meter grid cell. The resulting depth grid cell sizes are approximately 10 meters x 10 meters.

In the context of this project, the CHS depth grids could be used to report on potential flood risk within an area of interest (AOI). For example, the presence or absence of inundation within an AOI and the depth of flooding within an AOI could be reported. The primary limitation of using these data is that only two USACE SLR scenarios are used, making it difficult to compare across scenarios. Additionally, this data is still considered “experimental” and has not yet been widely adopted by practitioners. Benefits of using these data is that hydrodynamic (ADCIRC) modeling was used to create these future surge scenarios across the entire state, which is difficult to find. Coastal Hazards System, V2.0: https://chs.erdc.dren.mil/.

3.1.3.3 USACE South Atlantic Coastal Study (SACS)

The USACE South Atlantic Coastal Study (SACS) is a coastal risk study aimed at advancing coastal resilience in the southeastern U.S. using a three-tiered approach at multiple scales (USACE, 2021a). The SACS Tier 1 Risk Assessment is a regional analysis using national-level datasets to identify areas of potential risk to coastal flood events under both existing and future conditions. The SACS Tier 2 assessment is a state-level analysis and offers refinement of the Tier 1 results through addition of locally-specific data. A Tier 3 analysis, which is forthcoming, will be conducted at a local level, based on the Tier 2 results. The SACS study area includes approximately 65,000 miles of tidally influenced shoreline from North Carolina to Mississippi.

SACS Tier 1 analysis resulted in several indices-based layers of exposure, hazards, and risk:

- *Composite Risk Index*: This is the primary output of the Tier 1 Risk Assessment, which is the Composite Exposure Index x Hazard Index: Defined risk as function of probability of hazard occurrences and exposure.
- *Composite Exposure Index (CEI).* Weighted aggregate of exposure datasets related to population, infrastructure, social vulnerability, environmental, and cultural resources.
- *Combined Hazard Surface*: Composite surface represents three water levels with varying probabilities of occurrence: (1) 10% AEP water levels (areas with a 10% or greater chance of being flooded in any given year); (2) 1% AEP water levels (imported from the National Flood Hazard Layer); and (3) Hurricane Category 5 MOM from NOAA’s SLOSH model (Jelesnianski et al. 1992), represented as a .001 probability of occurrence.

The resulting surface includes raster pixels which are coded with the maximum annual exceedance probability of the flood event that could occur at that location (USACE, 2021b).

- *Combined Hazard Plus SLR Layer:* Three feet of SLR was added to the 1% and 10% AEP flood hazard layers to simulate future flooding under these events.

From these SACs outputs, three layers could be candidates for this project: combined hazard layer, combined hazard plus SLR, and composite risk indices. The combined hazard layer includes high probability events (10% AEP) and the combined hazard plus SLR layer includes the 1% and 10% AEP events with SLR, all of which are not in the Sketch Tool. These layers can potentially provide high-level screening for flood risks and social and environmental vulnerability. The main limitation is that only one amount of SLR (3-ft) has been included.

3.1.4 Inland Flooding

3.1.4.1 Extreme Rainfall Projections

Climate change is driving changes in the frequency, intensity, and geographic distribution of storms, floods, and droughts (Hayhoe et al., 2018). Across the southeastern U.S., the number of heavy rainfall events is increasing. The 1990s, 2000s, and 2010s rank as the top three decades with the highest number of heavy precipitation events and this trend is projected to continue as global temperatures rise (Carter et al., 2018). Heavy and extreme rainfall events impact transportation assets across all modes (Jacobs, 2018), hence estimating the change in extreme rainfall events has been the focus of multiple research efforts across the nation.

Transportation planners and engineers need to project how these more frequent and intense precipitation events will impact spatiotemporal flooding patterns. Modeling of future climate change impacts is complicated by the concept of non-stationarity, meaning that patterns or trends of the past may no longer be representative of the future and not valid for analyzing future trends. FHWA HEC-17 (Highways in the River Environment – Floodplains, Extreme Events, Risk, and Resilience) suggests consideration of two non-stationarity sources in the riverine environment which can modify patterns of flooding: climate change and land use/ land cover changes. Land use/land cover changes include physical changes in the watershed like urban and agricultural development and addition or removal of flood control structures.

Florida International University (FIU) Extreme Rainfall Projections

In Florida, Florida International University (FIU), South Florida Water Management District (SFWMD), and U.S. Geological Survey (USGS) have been collaborating on research and methods to develop extreme rainfall projections under future climate conditions. In 2021, FIU developed a series of statewide extreme rainfall projections (Obeysekera et al., 2021) for the Florida Building Commission (FBC). The FIU study leveraged a related study conducted by the USGS and SFWMD for the district’s geographic area (Irizarry-Ortiz and Stamm, 2022). The Rainfall Working Group, convened by the University of South Florida’s Flood Hub, is expected to continue to expand the SFWMD/USGS work to the entire state.

Central to the rainfall projections are "change factors" (CFs), which are multipliers that can be applied to current Depth-Duration Frequency (DDF)/ Intensity Duration Frequency (IDF) Curves to calculate a future rainfall amount for a given duration and return period (probability of occurrence). The IDF/DDF curves are commonly used in calculating runoff conveyance for stormwater design, but typically do not include consideration of climate change. The application of CFs is one method for projecting changes in future rain events under a changing climate. Typically, CFs greater than 1.0 represent an increase in future rainfall, while CFs less than 1.0 represent a decrease. For example, a CF of 1.2 represents a 20% increase in rainfall. The CFs in the FIU study generally ranged from 1.0 to 1.6 across the state, indicating an increase in future extreme rainfall from Atlas 14 DDF values (Obeysekera et al., 2021).

The FIU CFs were aggregated into five climate divisions across the state and results are available by:

- Global Climate Model (GCM) Datasets: Coordinated Regional Downscaling Experiment (CORDEX); Local Constructed Analogs (LOCA); and Multivariate Adaptive Constructed Analogs (MACA).
- Two future periods of analysis: NEAR: 2030-2069 and FAR: 2060-2099
- Return Period**:** 5-,10-, 25-, 50-, 100-, and 200 years
- Rainfall durations: 1-, 3-, 7-, 10 days and confidence limits: 17th, 50th, 83rd percentile
- Geographic area: Statewide

SFWMD Future Extreme Rainfall Change Factors

The resiliency strategy of the SFWMD includes assessment of its flood control structures and adaptation strategies needed to ensure flood protection under current and future climate conditions (SFWMD, 2022). To evaluate future climate conditions, the District is adding future extreme rainfall projections and SLR scenarios into consideration of flood hazards. In addition to developing CFs to estimate future rainfall, the SFWMD/USGS also developed application guidance, example case studies, and products (such as an interactive map for identifying CFs). SFWMD is adopting the extreme rainfall CFs developed and published under this effort (Irizarry-Ortiz and Stamm, 2022), as part of its flood resiliency planning efforts.

The SFWMD adopted CFs results are available by:

- 50th percentile (median) confidence limit for the 1-, 3-, and 7-day duration
- 5-, 10-, 25-, 50-, 100-, and 200-year return frequency events
- Ensemble of all GCM results for medium-low and high future emissions scenarios
- Future projected climate for the period 2050–2089 (centered in 2070) and historical (retrospective) conditions for 1966–2005.
- Geographic area: 16 counties and 14 rainfall areas (SFWMD boundaries plus Everglades National Park rainfall area, Florida Keys, Biscayne Bay).

Use of the FIU/ FBC rainfall data requires input from experts in hydrologic modeling and climate modeling for choosing the appropriate CFs, GCMs, and confidence limits. The SFWMD/ USGS extreme rainfall CF results are provided as an ensemble of all GCM results, using the median confidence limit, and aggregated by county. This delivery of the CFs resolves some of the difficulty in choosing appropriate parameters, providing for streamlined use of the CFs. Some practitioners, however, may wish to use the more granular results from the FIU/ FBC study.

Applications of the Florida Extreme Rainfall Projections

Potential applications of the extreme rainfall CFs include flood vulnerability assessments which attempt to assess the changing nature of rainfall driven flood risks and/or compound flood risks (for example from rainfall and storm surge or rainfall and river discharge). However, there are currently no widely available, spatially explicit models of these CFs showing the extent of future flooding. The projections need to be input into hydraulic modeling software for flood simulation. Several of Florida's Regional Planning Councils (RPCs) are currently working on a project supported by FEMA's CDGB-MIT program, which aims to develop a framework and GIS tool to model future extreme rainfall for regional-level analysis. As these datasets become available, they can be piloted for inclusion in the Resilience Report.

In the context of the Resilience Report, the ability to see CFs in the context of proposed transportation projects could allow for high-level screening of assets and could narrow the focus towards smaller areas in need of more refined, spatially explicit models of future extreme rainfall. Per HEC17 guidelines, the level of analysis should be paired with the plan/project requirements, such as the design life and criticality of the asset. For projects warranting a deeper level of analysis, FDOT and other agencies could consider hydraulic modeling for smaller geographic areas that provide spatially explicit future flood models using CFs. It should also be noted that capacity building and training will be needed for integrating precipitation CFs, as these are not currently widely adopted.

3.1.5 First Street Foundation Flood Model

The First Street Foundation Flood Model (FSF-FM) is a unique product that offers spatially explicit, high resolution models of future flooding from multiple flood types over the next 30 years. The FSF-FM model is a "nationwide probabilistic flood model that shows the risk of flooding at any location in the contiguous 48 states due to rainfall (pluvial), riverine flooding (fluvial), and coastal surge flooding." (FSF, 2020). The model also incorporates grey and green adaptation measures to localize and more accurately represent flood risks. The FSF-FM incorporates future flood risks by using the International Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP) 4.5 trajectory (mid-range scenario) and 21 global climate models (GCMs) from CMIP5.

The FSF-FM includes inland flood modeling (riverine/fluvial and rainfall/ pluvial), as well as coastal flood modeling (surge and extreme tides). Fluvial (riverine) flooding is based on the Fathom-US model, a peer-reviewed hydraulic model that allows for representation of river and stream channels of varying sizes/ widths. The Fathom-US model uses regionalized flood-frequency analysis of river gauge records for flood risk calculation (as opposed to a rainfall-driven hydrological model). For ungauged catchments, the model uses characteristics of similar gauged catchments to estimate flood risk. Pluvial flooding is modeled by applying rainfall data to a DEM and then modeling surface runoff, while considering factors such as land cover and impervious surfaces. The model uses data from NOAA's Atlas 14 to represent current rainfall. Coastal flood models include flood risk from surge and extreme high tides. The three flood hazard types (surge, fluvial, and pluvial) were modeled separately and together in various combinations to capture joint effects.

Property-level flood data for one state costs $35,721 for a single use and an annual fee of $44,651 for ongoing use. For non-commercial use, the data is aggregated at the census tract, zip code, county, congressional district, and state levels. Unfortunately, these aggregated levels are too coarse to be of use for this project's objectives.

3.2 Discussion and Recommended Datasets

In this chapter, the research team reviewed flood data sources for potential inclusion in the Resilience Report. This section describes the pilot datasets (Table 3-1) recommended for testing in the Resilience Report. This is an initial recommended list and all datasets listed may not be successfully piloted and included in the Resilience Report. Feedback from FDOT and end-users will assist in determination of the final layers.

For the coastal flood data sources, the research team recommends piloting the three types of data (SLR scenarios, observation-based extrapolations, and EWL probabilities) released in the NOAA 2022 Technical Report. This data represents nationally standardized sources of future flood exposure information and reflect the latest climate science. Each data type adds to our understanding of coastal flood risk, particularly in the near-term (now til 2050). The updated SLR scenarios reflect a narrower range of plausible SLR and the observation-based extrapolations offer another line of evidence in choosing SLR scenarios for near-term planning. The EWLs refine the existing knowledge about the frequency and magnitude of flood events and the nuisance flooding map layers provide the spatial extent of the three HTF thresholds.

Although not spatially explicit flood models, the extreme precipitation projections from FIU/ FBC and SFWMD/USGS represent the best available data in the State regarding how extreme rainfall events are likely to change under future climate conditions and should be piloted for this project. CFs aggregated at a county scale could be used to screen for areas and rain events with a high magnitude of change (large CFs). Reporting CFs in the context of proposed transportation projects would allow for high-level screening of assets and could narrow the focus towards smaller areas in need of more refined, spatially explicit models of future extreme rainfall. Furthermore, the partners involved in these rainfall efforts are working with the USF Flood Hub to recommend a statewide approach to future rainfall.

Adding these datasets can aid in a more comprehensive assessment of the potential damage over an asset's life cycle. In regards to the storm surge data with SLR, the research team is not recommending any additional data be piloted, as the data is limited in consideration of future SLR scenarios. A future version of the Resilience Report may include the USACE CHS surge data. Although it includes limited SLR scenarios, it is the best available, high resolution surge model with SLR conditions that covers the state. Use of the existing Storm Surge zones data from FDEM is recommended for now. Additionally, the research team did not find spatially explicit (GIS) models showing the extent and/or depth of future inland flood depth. As datasets become available, they will be prioritized for inclusion in the Resilience Report.

Table 3-1. Datasets to Pilot

Data Type, Source	Temporal	Climate Scenario	Description	Format, Geography
Nuisance Flooding, NOAA	Current (2022) Future (2050)	NOAA 2022 SLR - Five Scenarios	Projected number of HTF days, above mean higher high water. Data layers show spatial extent of HTF	Tabular data by tide station. Accessed through API. Spatial layers showing extent of flooding.
Sea Level Rise Scenarios (2022), NOAA 2022 Tech Report	2000 - 2150	NOAA 2022 SLR – Five Scenarios (Low to High) IPCC AR6 Projection methods	A set of five SLR scenarios out to 2150, using 2005 as baseline. Scenarios represent the most current climate science and an update to NOAA 2017.	Table of SLR values (1) by tide station. Inundation layers in 1-ft increments (NOAA).
Observation-Based Extrapolations, NOAA 2022 Tech Report	2020 - 2050	No climate scenario, not projections	Trajectories of current SLR, based on tide gauge observations. Near-term (2020-2050) comparison to SLR scenarios.	netCDF files, and csvs by tide station.
Extreme Water Levels Probabilities, NOAA 2022 Tech Report	2050	NOAA 2022 SLR Scenarios (based on tracking of observation-based extrapolations)	Estimate how coastal flood frequency and magnitude will change with SLR. Forecasted to 2050 by adding local SLR associated with the upper-bounding SLR scenario in regional observation-based extrapolations.	Table of EWLs (1) by tide station and (2) 1-degree gridded dataset for regional analysis. 1-degree gridded dataset estimates the change in frequency of HTF events out to the year 2050.
Extreme precipitation, FIU and SFWMD/ USGS	FIU: 2030-2069 & 2060-2099 SFWMD: 2050–2089	GCMs: LOCA, MACA CORDEX IPCC RCP 4.5, 8.5	Extreme rainfall change factors and projected event rain amounts for a set of rain events and frequencies, based on AOI's location.	Tabular data of change factors by climate division (FIU) and by county (SFWMD/ USGS).

3.2.1 Interoperability Standards

Because this project looks at future conditions, it is important to consider specific attributes of the data to ensure alignment and comparison of multiple datasets where appropriate. At minimum, we define the following interoperability standards (Table 3-2 below) to be documented with the data to assist in the proper organization, display, and application of the data. As much as possible, the Resiliency Report should contain data with consistent parameters to facilitate comparison and evaluation of potential vulnerabilities. For example, if evaluating potential future flooding conditions for a particular AOI, the report could display multiple data sources corresponding to a similar timeframe (planning horizon) and climate scenario (as close as possible). Alternatively, the report could include display multiple timeframes and scenarios; however, these common attributes need to be identified and displayed for each data source.

Consideration of resolution and accuracy of individual datasets is important when determining the scale of applicability (e.g., planning, project, or design scale). The use of global climate models includes various types of uncertainty because the impacts of climate change cannot be predicted with 100% certainty. There are three main sources of uncertainty with SLR scenarios:

- *Process uncertainty* includes how well the causes of SLR are understood and used to model future changes. Process uncertainty is represented by the confidence limits around the SLR scenarios and shown graphically in the NOAA 2022 Technical Report by the shading above and below the median values for each scenario.
- *Emissions uncertainty* includes how human behavior will change future greenhouse gas emissions and warming. Emissions uncertainty is represented by the five scenarios, ranging from Low (low future emissions) and to High (high future emissions).
- *Low confidence processes* include areas of emerging science, such as rapid ice melt, for which there is no scientific consensus. The potential for rapid ice sheet melt is considered in the Intermediate, Intermediate-High, and High 2022 SLR scenarios (Collini et al., 2022).

Identifying and understanding the sources of uncertainty and associated accuracy measurements within the data are an important data use consideration. For the purposes of this project, the research team seeks to highlight these data characteristics, where possible, to inform robust decision making. It is also best practice to consider multiple scenarios, where available, for assessment of a range of possible futures, rather than one determined future scenario.

Table 3-2. Draft Interoperability Criteria for Datasets

Standard	**Description**
Time Horizon	Date: indicating the approximate year or year range that the data represents. Could be current or future conditions.
Climate Scenario	Data should have clearly defined climate scenario (e.g., NOAA 2022 Sea level rise scenario, IPCC RCP 8.5, etc.) for which the data aligns.
Geography	At minimum, the data needs to have an associated point location (e.g., latitude/ longitude). Polygon datasets are preferred, as they can represent areas of interest or boundary conditions under which the climate phenomenon is occurring.
File format	GIS vector (shapefile, file geodatabase, web map service, web feature service). GIS raster (ESRI file geodatabase, tiff). Tabular with point locations: comma-separated file (csv), Excel spreadsheet.
Spatial Resolution	Size of the smallest measurement unit observed or recorded for an object, where available. For example, a digital elevation model could have a spatial resolution of 1-foot grid cells, representing a 1-foot by 1-foot square area.
Accuracy	Positional or attribute accuracy of the data, or how close the observations are to true values. This can include any information on error margins or confidence intervals, where available. For example, SLR Scenarios could include reporting of the median values along with the entire confidence limit range. Or elevation data could indicate a vertical accuracy of +/- 6 inches.

4 Development of Hardware and Software

This chapter describes Task 3 of this project, which included the technical development process for creating the Resilience Report, an online report that summarizes and displays analyses of flood exposure for a user-specified area of interest. Development of the Resilience Report required configuration of hardware and software infrastructure to support analysis and display of summary statistics and exposure information. Hardware infrastructure configured included database servers and application servers to support analysis and display of data and results. Software infrastructure configured included database objects and geospatial algorithms for data storage and automated analysis and development of user interfaces to display results.

The design and content of the Resilience Report was informed by robust research on existing and emerging data and tools for assessing infrastructure vulnerability to climate change (detailed in Chapters 2 and 3). From the tools review (Task 1, Chapter 2), the research team sought to create a user-friendly and intuitive interface with data visualizations (in the form of various interactive charts and tables) to summarize the analyses for quick interpretation. The data assessment (Task 2, Chapter 3) revealed the common data types currently used in vulnerability assessment tools and the lack of widespread spatial data representing future flood risks (e.g., future surge, inland/ precipitation). Because much of this data is still emerging, the research team focused on designing and developing a framework for storing, analyzing, and displaying analysis results with the flexibility to rapidly ingest new data (according to minimum specifications and standards discussed in Chapter 3).

4.1 Technology Stack

To create the Resilience Report, the Team configured hardware and software to support the computing and visualization infrastructure needed to support the Resilience Report. This included the configuration of database server components (for storage, management, and retrieval of data); configuration of map servers (for display of spatial data and maps), and development of needed geo-processing algorithms (for conducting automated spatial analyses).

During the initial phase of this project, it was determined that the data and reporting products developed herein would be incorporated into FDOT's Environmental Screening Tool, leveraging the existing user base and computing infrastructure. In particular, the EST's Area of Interest (AOI) Tool was used as a model for triggering and running the report. The Resilience Report uses some of the EST's hardware and software infrastructure (technology stack) but also uses additional software. The Report utilizes the same enterprise database software, database server, and application servers as the EST, with additional configuration needed to support new data and geospatial analyses. For display of the actual Resilience Report, a new software, Oracle Application Express (APEX), was used.

Below is a description of the primary software components developed and modified:

- **Oracle Database** is used as the enterprise relational database that stores and provides access to data (both spatial and non-spatial) and project information input by users. Database Objects including schemas, views and tables were developed and configured to store, access, and analyze new data for the Resilience Report. Database triggers and procedures were used to automate actions, such as the overlay analyses of the user-specified AOI with the specific data in the report.

- **ESRI ArcSDE** is used to store enterprise level geospatial data within the Oracle database, which can be accessed through web map services and other GIS applications. Spatial data evaluated from Task 2 was loaded and stored into ArcSDE for display and analysis.
- **ESRI ArcGIS Server** is used as the map server. A Resilience Report map service was developed and deployed to display the spatial data layers included in the report.
- **Oracle Application Express (APEX)** was used to develop the Resilience Report application, which is deployed from a webpage. Oracle APEX is a low-code application platform that facilitates the building of enterprise applications. Because the EST already uses Oracle database, Oracle APEX was chosen for its integration with the database, powerful visualization capabilities (charts, tables, maps) and ease of rapidly creating high quality applications.
- **Programming Languages:** For the back-end (database), the primary language used by Oracle and Oracle APEX is Structured Query Language (SQL) and Procedural Language for SQL) PL/ SQL to access and manipulate data. For the front-end (web user interfaces), Oracle APEX uses HTML, CSS, and JavaScript to configure and format tables and charts.

4.2 Resilience Report

The Resilience Report is accessed through a webpage, from which the user can view the results. The report must first be requested through the EST Map Viewer, using the AOI Tool to draw the area desired for analysis. After drawing an area of interest, the user can request the Resilience Report, which triggers a series of overlay analyses to be run in the database. When completed a link to the report is provided in the EST Map Viewer (see Figure 4-1 for the workflow).

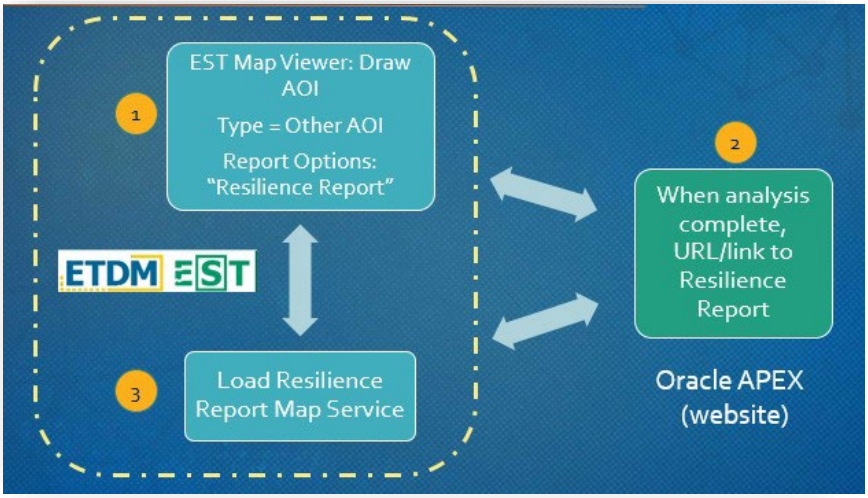


Figure 4-1. Workflow for Requesting and Accessing the Resilience Report

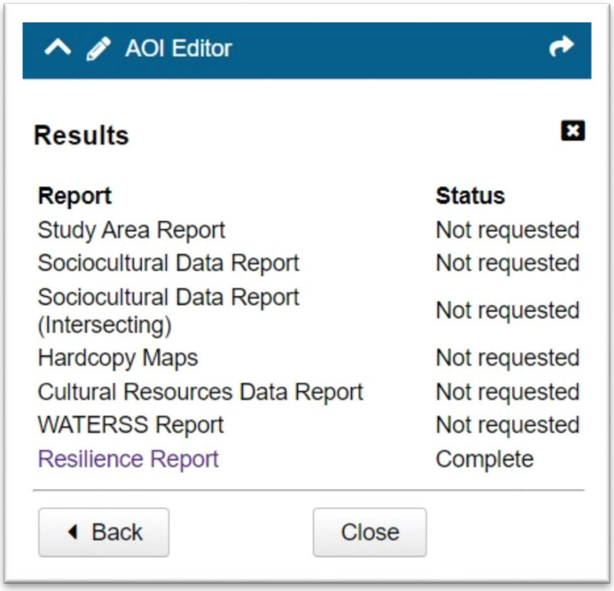
4.3 Requesting the Resilience Report

Below are the basic steps for requesting a resilience report through the EST Map Viewer.

1. **User logs into the EST website:** https://www.fla-etat.org/est/secure/
   Open the Map Viewer using the map icon in the header bar.
2. **Open AOI Editor widget > choose "Create" to draw a new AOI.**
3. **Enter the basic project** information: project name, type, description, and keep until (date indicating how long to save the results).
   a. For Type, choose "Other Area of Interest"
4. **Draw Feature(s).** Click "Add Feature" to begin drawing the desired area (feature) to be analyzed. The feature is drawn on the map.
   a. The editors allow for a point, line, or polygon to be drawn, along with an optional buffer amount around each feature.
   b. For points, users can click a point on the map or enter an address, latitude/ longitude, or roadway milepost. For lines, users can draw a line on the map, or select an RCI segment for analysis. For polygons, users can draw a polygon on the map.
   c. One or more features can be drawn. Each features will be analyzed separately.
   d. Note: coastal counties will produce more results but all areas statewide can be tested.
5. **Request Resilience Report.** When done drawing, under the "Report Options", select the checkbox for "Resilience Report" and then choose "Run" (see Figure 3).
6. **Wait for the Results.** The analyses for the report will be running in the database, which takes approximately 1-3 minutes, depending on the number and size of features drawn and any concurrent analyses being requested. Features covering larger geographic areas will take longer to run, while features covering smaller geographic areas will be quicker to run.

4.4 Accessing the Report

When the analyses are completed, the AOI Editor widget will indicate the "Status" = "Complete" and the Resilience Report will contain a hyperlink to the results (webpage) for their drawn AOI (see Figure 4-2).



Results

Report	Status
Study Area Report	Not requested
Sociocultural Data Report	Not requested
Sociocultural Data Report (Intersecting)	Not requested
Hardcopy Maps	Not requested
Cultural Resources Data Report	Not requested
WATERSS Report	Not requested
Resilience Report	Complete

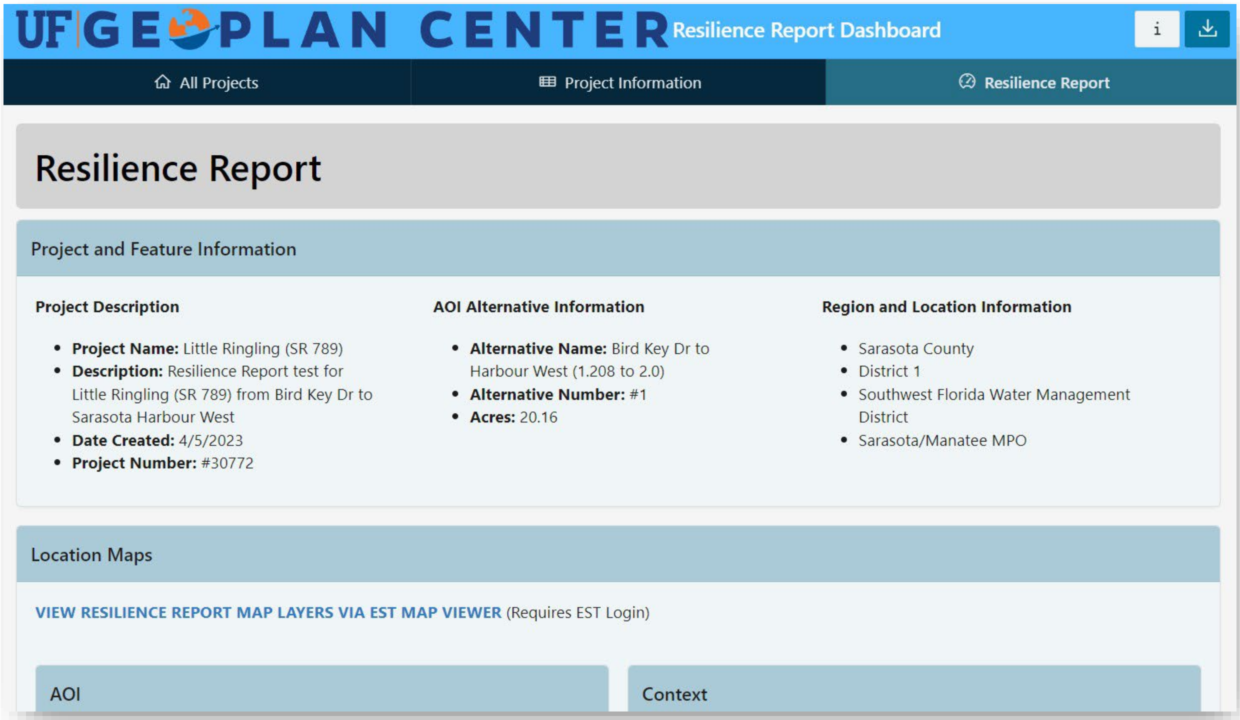
Figure 4-2. Area of Interest Editor – Completed Results with Resilience Report Link

4.5 Using the Report

4.5.1 Report Pages

There are three main pages in the Resilience Report website, described below:

- **Projects List Page:** This page includes a list of all projects for your organization that have requested a resilience report. A link to this page is available from the Resilience Report page. There is a search function to find the project of interest.
- **Project Information Page:** This is the landing page the user will see when clicking on the link from the EST Map viewer. This page includes information the user submitted about the project (Project Name, Description), the date the project was created, and an internal Project ID. This page also includes a list of alternatives (features) associated with this project. In many cases, there will only be one alternative, but the EST Map viewer allows for multiple alternatives to be drawn.
- **Resilience Report Page:** This is the primary page the users will interact with and contains the results of the overlay analyses for the alternative(s) drawn in the EST Map Viewer (see Figure 4-3). The resilience report page will only show the results for one alternative at a time (unless the alternatives are grouped together into a single analysis area).



Resilience Report

Project and Feature Information

Project Description

- **Project Name:** Little Ringling (SR 789)
- **Description:** Resilience Report test for Little Ringling (SR 789) from Bird Key Dr to Sarasota Harbour West
- **Date Created:** 4/5/2023
- **Project Number:** #30772

AOI Alternative Information

- **Alternative Name:** Bird Key Dr to Harbour West (1.208 to 2.0)
- **Alternative Number:** #1
- **Acres:** 20.16

Region and Location Information

- Sarasota County
- District 1
- Southwest Florida Water Management District
- Sarasota/Manatee MPO

Location Maps

VIEW RESILIENCE REPORT MAP LAYERS VIA EST MAP VIEWER (Requires EST Login)

Figure 4-3. Resilience Report – Results Page

4.5.2 Resilience Report Page: Sections & Data

This is the page that contains the results of the overlay analyses for the AOIs. In the top right corner of the page, there are two buttons. The button with an “i” (info icon) opens an information window with resources and links to the user guides. The button with a download icon allows the user to save the report page as a PDF. After clicking the button, it will first create a “PDF Preview” (which may take up to 10-30 seconds). Then the user has the option to save and download a PDF version of the Resilience Report page.

Currently, there are 12 sections in the Resilience Report, with each section focusing on a different dataset. Below each section and corresponding data is described.

1. <u>Project and Feature Information:</u> This section includes project information input by the user in the AOI Editor (Project Name, Description, and Alternative name). Also includes the date the project was created, an internal Project Number, number of acres in the AOI, and the county, MPO, WMD, and FDOT District in which the project is located.
2. <u>Location Maps:</u> This section contains an embedded map zoomed into the feature and a context map showing the overview location of the feature. This section also contains a link back to the EST Map Viewer, where the user can view and interact with the Resilience Report layers. If the user if not already logged into the EST or if their session timed out, they will be prompted to log in.

3. Coastal Region Information: This section includes the number of linear feet intersecting with the Coastal Construction Line (CCCL) and the number of acres located within the Coastal Building Zone (CBZ). If the feature does not intersect with either, then a message will be displayed to the user: e.g., "Feature is not located in the CBZ." For projects with features in the CBZ, a Sea Level Impact Projection (SLIP) Study may be required.
4. Sea Level Rise – Tide Station Information: This section includes the closest tide station located to the AOI. This station is used to derive the SLR values in the next sections.
5. Sea Level Rise Scenarios: This section contains sea level rise values from two sources (below) and provides links to the source documentation for each.
    - **NOAA 2022 SLR Scenarios – Feet (NAVD88) by Decade.** Displays table of SLR values, representing future mean sea level (MSL) in feet (referenced to the North American Vertical Datum of 1988 "NAVD88") for each decade between 2040 and 2100 and for each of the five NOAA 2022 SLR scenarios (Low, Intermediate-Low, Intermediate, Intermediate-High, and High). Baseline year is 1992.

      Data obtained from NOAA in spreadsheet format, with SLR scenario values listed by tide station, relative SLR amount in centimeters (cm), and baseline year 2005. The Team converted the values from cm to feet and added the two offsets provided by NOAA to align the values with the midpoint (1992) of the National Tidal Datum Epoch (NTDE) 1983–2001. The Team used the median SLR values from NOAA. Data obtained from NOAA at: https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-data.html.

      For full documentation of the NOAA 2022 SLR Scenarios, see: https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html
    - **NOAA 2017 SLR Values – Feet (NAVD88) by Decade.** Displays table of SLR values, representing future MSL in feet (referenced to NAVD88) for each decade between 2040 and 2100 and for each of the six NOAA 2017 SLR scenarios (Low, Intermediate-Low, Intermediate, Intermediate-High, High, and Extreme). Baseline year is 1992.

      Data obtained from the U.S. Army Corps of Engineers Sea Level Change Calculator: https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html. Values were downloaded by tide station relative to local MSL and adjusted to baseline year 1992 (midpoint of NTDE 83-01). The Team applied a datum conversion to NAVD88 (sourced from NOAA).

      For full documentation of the NOAA 2017 SLR Scenarios, see: https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

Note: The Resilience Report includes both the NOAA 2017 SLR scenarios and the updated NOAA 2022 SLR scenarios for multiple purposes. The NOAA 2017 scenarios have been widely used and are currently still in use by many communities, MPOs, and

FDOT partners in the state. Next, HB7053: “Statewide Flooding and Sea Level Rise Resilience” (s. 14.2031, F.S.), which became effective July 1, 2022, includes data requirements for FDOT’s Resilience Action Plan (RAP) and local vulnerability assessments funded through the Resilient Florida Grant Program. FDOT is directed to use the NOAA 2022 scenarios for the Resilience Action Plan (in progress). Local vulnerability assessments funded through the Resilient Florida grant program are still required to use the NOAA 2017 scenarios. Both sets of projections are included in the report to accommodate these various use cases.

6. Sea Level Rise Scenarios (Charts): This section provides a visual representation in chart format (see Figure 4-4) of the SLR values shown in the prior section. The NOAA 2022 SLR Scenarios (feet by decade) are shown on the left, while the NOAA 2017 SLR Scenarios (feet by decade) are shown on the right.

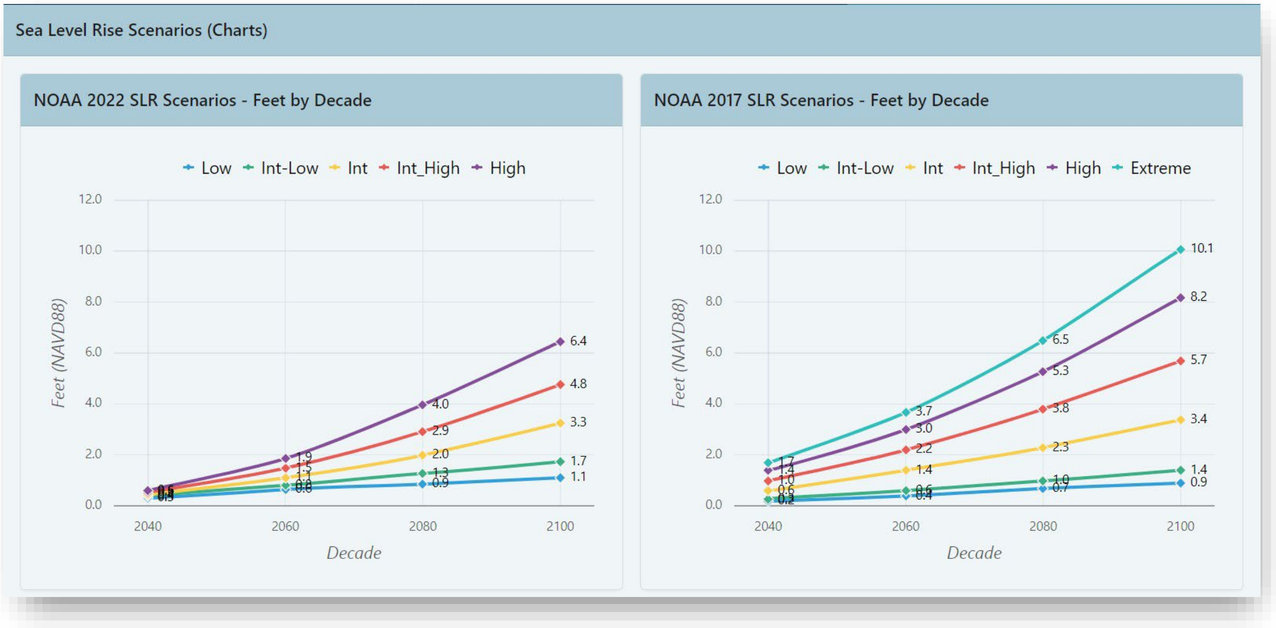


Figure 4-4. Charts of Sea Level Rise Scenarios

7. Sea Level Rise Exposure analysis (NOAA 2017 only): This section includes an exposure analysis using the NOAA 2017 SLR inundation layers from the Sea Level Scenario Sketch Planning Tool (https://sls.geoplan.ufl.edu). A table includes the acres and percentage of the feature exposed to SLR inundation under three scenarios and time frames.
    - NOAA2017 Intermediate-Low: 2040, 2070, 2100
    - NOAA2017 Intermediate: 2040, 2070, 2100
    - NOAA 2017 Intermediate-High: 2040, 2070, 2100

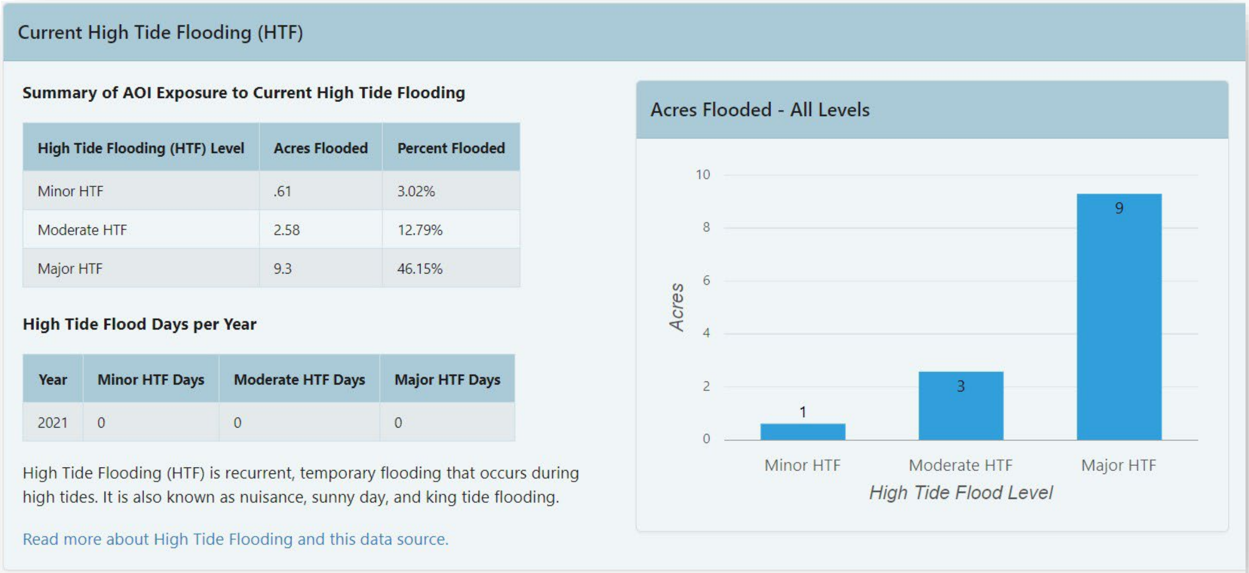
   Below the table are three charts showing the depth analysis for the intermediate-high scenario at 2040, 2070, and 2100. These charts represent the depth of permanent flooding that would occur under each of these scenarios.

Note: Only the NOAA 2017 scenarios are included here because that is the most current inundation depth data available in the Sketch Tool. In the future, this section will likely be updated with new inundation layers from NOAA, whom are in the process of developing ½ foot inundation depth layers with the updated Lidar-based DEMs in Florida. When completed, the research team will evaluate adding these new layers under the direction from the FDOT Project Manager.

8. Current High Tide Flooding: This section contains data on high tide flooding (HTF), also known as nuisance flooding, tidal flooding, and sunny-day flooding. NOAA delineates and maps three HTF levels: minor, moderate, and major, using standard thresholds above the daily average high tide (mean higher high water).
    - Minor HTF includes when tides exceed approximately 0.55 m (1.8 ft)
    - Moderate HTF when tides exceed 0.85 m (2.8 ft)
    - Major HTF when tides exceed 1.2 m (3.9 ft).

   This section includes the acres flooded and percent of each feature flooded under each of the three HTF thresholds (see Figure 4-5). Raster data layers for each threshold were downloaded from NOAA and used in the overlay analysis: https://coast.noaa.gov/htdata/Inundation/NOS_Mapping/NOS_HTF_2022.zip

   This section also includes the observed number of HTF days from the previous meteorological year, sourced from the NOAA CO-OPS Derived Product API v0.1, querying the “High Tide Flooding – Met Year Flood Count”: https://api.tidesandcurrents.noaa.gov/dpapi/prod/.



Current High Tide Flooding (HTF)

Summary of AOI Exposure to Current High Tide Flooding

High Tide Flooding (HTF) Level	Acres Flooded	Percent Flooded
Minor HTF	.61	3.02%
Moderate HTF	2.58	12.79%
Major HTF	9.3	46.15%

High Tide Flood Days per Year

Year	Minor HTF Days	Moderate HTF Days	Major HTF Days
2021	0	0	0

High Tide Flooding (HTF) is recurrent, temporary flooding that occurs during high tides. It is also known as nuisance, sunny day, and king tide flooding.

Read more about High Tide Flooding and this data source.

Figure 4-5. Current High Tide Flooding Information

9. <u>Percent of Area Impacted by Current High Tide Flooding:</u> Displays three pie charts with the percentage of the AOI alternative exposed to each HTF threshold. This corresponds to the "Percent Flooded" column in the table above: "Summary of AOI Exposure to Current High Tide Flooding." The percent flooded is shown in blue and percent not flooded is shown in green. Open the EST Map Viewer link (in the "Location Maps" section) to see where the AOI alternative will be impacted by each HTF threshold.

10. <u>Projected Annual Days of Minor High Tide Flooding by Decade and NOAA 2022 SLR Scenario:</u> This section contains data on projected annual days of high tide flooding per decade and under each of the five NOAA 2022 SLR scenarios. This data can be used to understand how SLR will increase the frequency of tidal flooding events. This data was downloaded from the NOAA CO-OPS Derived Product API v0.1, querying the "High Tide Flooding – Decadal Projections": https://api.tidesandcurrents.noaa.gov/dpapi/prod/.

11. <u>Storm Surge Zones:</u> This section contains an overlay analysis of storm surge zones by hurricane category 1-5. Zones were obtained from the Florida Division of Emergency Management and were developed by Florida's Regional Planning Councils as part of the Florida Statewide Regional Evacuation Update Study. The data was derived from National Hurricane Center SLOSH model runs throughout the state.

12. <u>FEMA Flood Zones:</u> Results of an overlay analysis of the 1% annual chance flood event ("100-year") and 0.2% annual chance flood event ("500-year"), as defined by the Federal Emergency Management Agency (FEMA). Data sourced from FEMA's National Flood Hazard Layer and downloaded from the Florida Geographic Data Library (www.fgdl.org). *Note*: this data represents current flood hazard areas and does not account for future climate conditions or changing precipitation patterns.

5 Pilot Testing

One of the three objectives of this research project was to pilot test the Resilience Report with potential end-user groups. This chapter details the pilot testing process conducted by the research team. The end-users involved in testing provided feedback on the data in the report, design and configuration of the user interface, and functionality of the new report. During and after the pilot testing, some changes were addressed based on the feedback.

5.1 Testing Process

The core testing group was an existing EST users group that FDOT's Office of Environmental Management (OEM) meets with monthly. The group has varying levels of experience with the EST and has different backgrounds (planners, PD&E, consultants). With consultation from OEM, it was determined that this was an appropriate group to test and offer feedback. The research team met with this EST users group three times over the course of the project and corresponded via email about feedback.

The research team also met with small groups of other potential end users and interested parties, as identified by the FDOT Project Manager and the PI, to demonstrate the functionality and content of the new tool. This group consisted of staff from FDOT central office and various districts. Additionally, the research team met with the Technical Advisory Committee (TAC) convened currently for this research project and Dr. Obeysekera's research project on nonstationarity (BDV29 977-67). The TAC consisted of a mix of internal FDOT staff (Central office and District offices), consultants, and MPOs. The research team demonstrated the Resilience Report to the TAC and received comments and feedback. In total, the research team met with approximately 35 people, some multiple times, to obtain feedback and comments.

The testing was done statewide, due to the availability of several statewide datasets, allowing for users to test the tool anywhere in the state. End-users that provided feedback and participated in testing were from a variety of geographic regions, including but not limited to FDOT Districts 1, 4, and 6, and Hillsborough MPO.

5.2 Feedback

Below are the major feedback and comments received from the testing process. The comments are grouped into three categories: general comments (Table 5-1), data comments (Table 5-2), and technical questions and issues (Table 5-3). The comments and feedback are listed in the left column of the tables and the corresponding actions taken or recommended to be taken are listed in the right column. Not all comments were able to be addressed within the scope of this project, but all comments were documented for consideration for future changes.

Table 5-1. General Comments

Comment/ Feedback	Actions to Address
How do we turn all these data points and into information?	Ongoing technical training and capacity building is needed. We can explore development of recommendations and streamlined reports that narrow down the information based on the specific project analyzed.
Case studies would be helpful.	Over time, we can develop case studies for use in training workshops. May need help identifying real-world projects to use as example cases.
How to ensure continuity of data and information throughout the transportation planning, design, and construction process, so analysis is available from previous step?	Because this information is saved in a database, it could be recalled at each successive stage in the process.
This report is very helpful. Thank you for all of the time and effort you have put into this Tool.	
How can we avoid duplication with the FDEP SLIP (Sea-Level Impact Projection) tool? Perhaps run reports for same location and compare the results to evaluate any differences/ discrepancies.	Each tool has a different purpose. SLIP is designed to meet a specific legislative purpose and is only required for state-funded projects within the coastal building zone (CBZ). The Resilience Report is a broader tool to evaluate future climate impacts statewide. The Resilience Report analyzes an entire area for impacts, while the SLIP Tool works off of a single point location. An FDOT staff gave two SLIP Study reports ran for a project and the research team compared results and have noted the differences.
Does this tool account for current adaptation or mitigation strategies implemented on the roadways?	Not currently, but could explore for a future version of the Resilience Report.
Is there a summary level view of projects that could facilitate a prioritization (based on some chosen metrics)?	Not currently, as projects as analyzed one by one. A prioritization could be developed for a set of projects, for example, a set of LRTP projects.
Would be helpful to have resilience guidance for project managers regarding how to use the data and tool.	Agreed. The training workshops will address use of the data and tool. A future project could explore more in-depth guidance.
I would like to follow-up with you and consider using the tool for a system wide analysis.	Contacted and set up follow up meeting.

Table 5-1. General Comments (continued)

Comment/ Feedback	Actions to Address
Is there some consideration of adding heat as a stressor or will the focus be on flooding stressors?	The first draft of this tool is focused on flooding, but the tool was designed to accommodate a variety of climate stressors.
Is there a way to include standard construction cost into the tool?	Not currently, but could explore for a future version of the Resilience Report.

Table 5-2. Comments about Data

Comment/ Feedback	Actions to Address
Comments about High Tide Flooding	
Need more explanation of HTF data.	Addressed in tool and will cover in training.
Delineate between permanent flooding (SLR) and intermittent flooding (HTF, surge, etc)	Will be addressed in the training workshops.
Remove 2020 from “Projected days…” since we are past this year.	Addressed
Swap colors (blue for flooded, green for not flooded).	Addressed
HTF Maps (minor, moderate, and major). What year is this information?	Represents current tidal flooding, data was created in 2016. The date is in the metadata.
HTF Maps (minor, moderate, and major). How can I print a map (from EST viewer)?	Use the Print widget in the Map Viewer. Over time, we may embed static screenshots directly in the Resilience Report.
Comments about Sea Level Rise	
Provide a disclaimer explaining why both the NOAA 2017 and 2022 Scenarios are displayed	Addressed
NOAA2017 Exposure Table - add % AOI exposed	Addressed
Are you recommending a set of SLR scenarios to evaluate? It would be helpful to have guidance on choosing scenarios.	Can add to guidance on choosing SLR scenarios to training workshops. In future versions of Resilience Report, the Team could look into including a method for selecting scenarios using a risk-based approach.
In the map viewer - would be nice to see what roads are inundated, even if the roads are flooded - would want to see flooding on connecting roads	Can address in future version of Resilience Report. Need to first re-run roads exposure analysis with new NOAA ½ foot inundation layers (forthcoming).
Depth of flooding - re-word to indicate permanent flooding	Addressed

Table 5-2. Comments about Data (continued)

Comment/ Feedback	Actions to Address
Storm Surge	
indicate that each category is separate but should be additive (Each category includes the lower Cat)	Addressed
What about the SACS data? They have depth grids - 10/50/100/500 yr storms.	The Team reviewed this data in Task 2. Currently, the data is listed as “experimental” and only 2 SLR scenarios are used. But we are open to testing the data.
Other Data Related Comments	
FEMA Floodplains – change wording to 1% annual chance of flooding	Addressed.
Coastal Building Zone – Add link to SLIP study website for projects in the Coastal Building Zone	Addressed, added.
Can we include local data? Pilot local data from Broward	Yes, can look into this.

Table 5-3. Technical Questions and Issues

Comment/ Feedback	Actions to Address
SLR Charts – not displaying for newly drawn AOI.	Addressed, fixed.
Depth of flooding - 2040 NOAA2017 High - chart looks incorrect for Project 16240 – Flagler Ave	Addressed: This was a scaling issue with the chart. Tweaked chart value parameters to include decimal places, set y-axis value to be a minimum of 0.1. These changes helped for areas with small amounts of flooding.
Can we add CAD files/ upload shapefiles (instead of drawing a feature)?	Not currently, but you can email us and we’ll run the analysis
The Resilience Reports are not available in the EST AOI Dashboard.	Addressed.

6 Technology Transfer

This chapter describes the technology transfer activities conducted for the Resilience Report Tool to support end-users' understanding and utilization of the data. The research team developed user guides and offered two virtual training webinars to inform potential end-users about the data sources included and demonstrate how end-users can request, access, and navigate the Resilience Report. This chapter provides a brief summary report of the two training webinars and links to the two User Guides.

6.1 User Guides

Two user guides were developed: (1) User Guide which includes detailed background and data documentation and (2) A shorter "quick guide". Both are available from the Resilience Report info button (top right corner of webpage).

6.2 Summary of Training Webinars

Two training webinars were held on March 29, 2023 and April 6, 2023. The training announcement and invitation was sent out to over 300 FDOT and MPO staff and consultants. The announcement included a description of the training webinar, target audience, learning objectives, agenda, and registration information.

A total of 165 people registered for the two training webinars, of which 129 people attended, resulting in an overall attendance rate of 78%. For the first webinar, held on March 29, 2023, 77 people registered and 64 attended, resulting in an attendance rate of 83%. For the second webinar, held on April 6, 2023, 88 people registered and 65 attended, resulting in an attendance rate of 74%.

Figure 6-1 below shows the attendees by organization type, with over half of the attendees representing private consulting firms, 18% from FDOT (central office and districts), 18% from MPOs, 2% from regional planning councils, 2% from academia, and 2% from other agencies. Figure 6-2 below shows the percentage of attendees who are current Environmental Screening Tool (EST) users (62% are current users and 38% are not). Figure 6-3 shows the percentage of attendees who have used the EST Area of Interest (AOI) Tool (56% used the tool, 44% have not).

Both webinars were held from 10:00 am – 11:30 am and followed the agenda listed below:

Agenda

- 10:00 – 10:15 am: Background and Project Objectives
- 10:15 – 10:50 am: Data Sources in the Resilience Report
- 10:50 – 11:20 am: Demo: Requesting, Accessing, and Interpreting the Report
- 11:20 – 11:30 am: Q & A, Wrap-up.

A recording of the first training webinar is available here:

https://www.gotostage.com/channel/22b88b2683d647b4907e8b2457d8b350/recording/0ee5e5dee38f4562b122e1fddf8ab0ef/watch

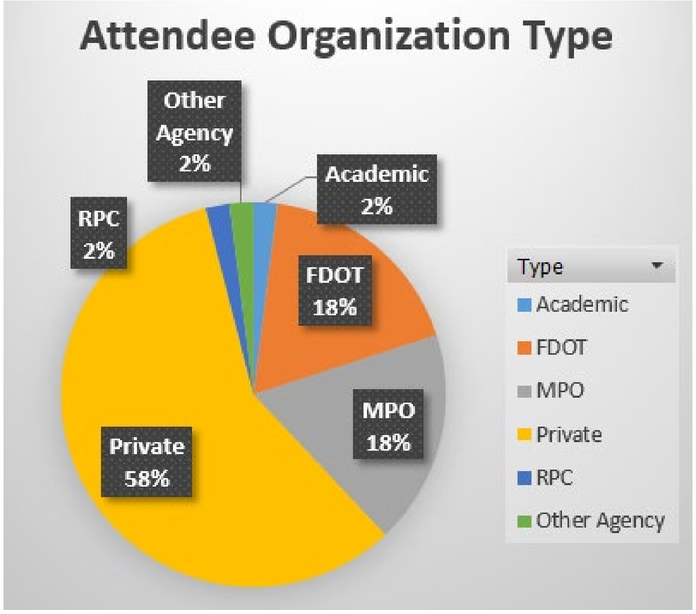


Figure 6-1. Organization Type of Attendees

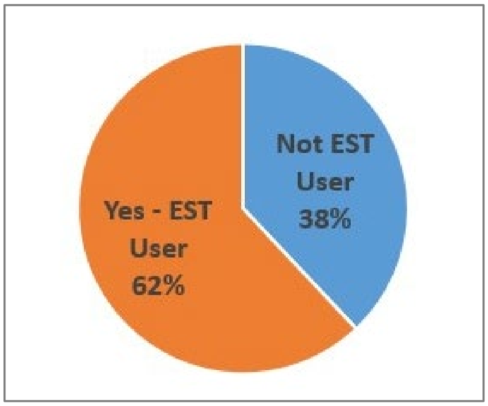


Figure 6-2. EST User Status of Attendees

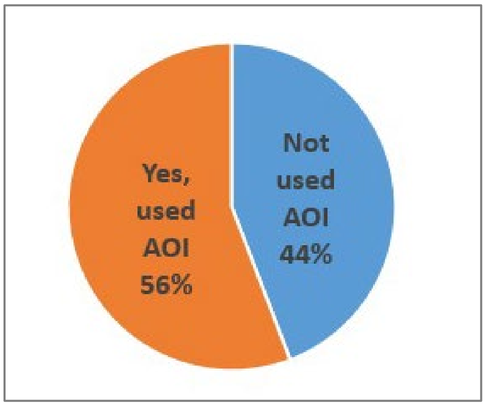


Figure 6-3. AOI Tool Status of Attendees

6.3 Questions and Comments Received

The following questions and comments (listed in italics) were received during the two webinars. Responses are noted where applicable.

- *It's important to note that the existing MHW elevations from the NOAA gauge stations are based on the 1983-2001 tidal epoch. One would need to add 20+ years of SLR to these values to get the current MHW, etc. NOAA will not be updating the tidal epoch until 2025.*
    - Response: Once the updated tidal epoch is released, we will update the tool.
- *The example showed the NOAA 2017 data. Is the NOAA 2022 inundation model available and if not when?*
    - Responded: Not currently, but we expect that NOAA will be releasing ½ foot inundation depth grids, which we plan to use in the Resilience Report.
- *Can you review the low/intermediate/high likelihood again? Also, is the 2022 NOAA data available yet to MPOs to use?*
    - Responded: Went over the slide and information again.
- *Do the resilience reports account for the disproportionate distribution of SLR (e.g., higher on gulf coast than east coast) in the assessments?*
    - Responded: Yes, these are accounted for in the SLR projections, which account for rates of SLR and vertical land motion by tide station
- *Great presentation! Thank you so much for this information*
- *You may have mentioned this point already, but what is the existing elevation data based on and what is the general vertical accuracy?*
    - Response: For the last LiDAR collection (not the most current that just was released) about 10" but depends on where you're at in the state. The newer version has higher vertical accuracy and we'll be incorporating that into the Resilience report.
- *You mentioned updated LiDAR data that the state is releasing. Can you give us more info on this topic and if this data is available? Also, excellent presentation!*
    - Response: gave more information and where to access the data.
- *Thank you!!!*
- *Does the tool take into account (or plan to take into account in later versions) king tides? I know that data can be tricky to incorporate*
    - The tool accounts for three High Tide Flooding levels, which should cover king tide flood events.
- *very informative! Thanks*
- *Just wanted to thank you for this detailed training. It has been really helpful. I thought the background on the data sources was especially helpful.*
- *Great presentation! Was it recorded by chance?*
- *Great Presentation!*
- *Great enhancement of the AOI tool. Will be very useful. Thank you!*

6.4 Poll Questions

Five polls were launched in the first webinar and four launched in the second webinar to gather information about data used, engage participation, and assess webinar satisfaction. Poll results from the first webinar yielded a 67% response rate, indicating high engagement. Poll results from the second webinar yielded a 58% response rate, indicating moderate engagement. Poll questions and results from the first webinar are shown Table 6-1 and from the second webinar in Table 6-2.

Table 6-1. Webinar 1 Poll Questions and Results

1. How familiar are you with the Environmental Screening Tool (EST) Area of Interest (AOI) Tool?		
50 of 64 Attendees responded		
I use it frequently	32%	16 Responses
Have an account, but rarely use it	24%	12 Responses
Have EST account, but never used AOI Tool	6%	3 Responses
Never used EST or AOI Tool	26%	13 Responses
Never heard of it	12%	6 Responses
2. Which of the following SLR tools have you used? (check all that apply)		
43 of 64 Attendees responded		
NOAA Sea Level Rise Viewer or Coastal Flood Exposure Mapper	72%	31 Responses
UF Sea Level Scenario Sketch Planning Tool	35%	15 Responses
U.S. Army Corps of Engineers Sea Level Curve Calculator	23%	10 Responses
Climate Central Surging Seas	14%	6 Responses
Other (not listed)	28%	12 Responses
3. What SLR scenarios do you use in your planning? (check all that apply)		
44 of 64 Attendees responded		
NOAA 2017	30%	13 Responses
NOAA 2022	30%	13 Responses
USACE	14%	6 Responses
Other (not listed)	11%	5 Responses
None	41%	18 Responses
4. What types of flooding are you currently evaluating in your planning or design processes? (check all that apply)		
38 of 64 Attendees responded		
Storm surge flooding	61%	23 Responses
Sea level rise	55%	21 Responses
High tide flooding/tidal flooding	26%	10 Responses
Current or future flood hazard zones/floodplains	74%	28 Responses
Extreme or heavy precipitation events	47%	18 Responses
5. How did we do?		
38 of 64 Attendees responded		
I am confident that my comments or questions will be considered	26%	10 Responses
I am not confident that my comments or questions will be considered	5%	2 Responses
I do not have comments or questions.	68%	26 Responses

Table 6-2. Webinar 2 Poll Questions and Results

1. How familiar are you with the Environmental Screening Tool (EST) Area of Interest (AOI) Tool?		
45 of 65 Attendees responded		
I use it frequently	40%	18 Responses
I have an account, but rarely use it	24%	11 Responses
I have an EST account, but have never used the AOI Tool	7%	3 Responses
I have never used the EST or AOI Tool	20%	9 Responses
Never heard of it before this webinar	9%	4 Responses
2. Which of the following SLR tools have you used? (Check all that apply)		
37 of 65 Attendees responded		
NOAA Sea Level Rise Viewer or Coastal Flood Exposure Mapper	59%	22 Responses
UF Sea Level Scenario Sketch Planning Tool	35%	13 Responses
U.S. Army Corps of Engineers Sea Level Curve Calculator	8%	3 Responses
Other (not listed)	35%	13 Responses
3. What SLR scenarios do you use in your planning? (Check all that apply)		
34 of 65 Attendees responded		
NOAA 2017	29%	10 Responses
NOAA 2022	26%	9 Responses
USACE	12%	4 Responses
Other (not listed)	3%	1 Responses
None	53%	18 Responses
4. What types of flooding are you currently evaluating in your planning or design processes? (check all that apply)		
36 of 65 Attendees responded		
Storm surge flooding	56%	20 Responses
Sea level rise	53%	19 Responses
High tide flooding/tidal flooding	22%	8 Responses
Current or future flood hazard zones/floodplains	72%	26 Responses
Extreme or heavy precipitation events	33%	12 Responses

7 Conclusion

In this project, the research team developed an online, geospatial tool called the Resilience Report, which serves as a screening tool to systematically and rapidly conduct flood assessments for a user-specified area of interest. The tool summarizes and displays analyses of flood exposure anywhere in the State of Florida, though currently the majority of the data included focuses on coastal areas.

The design and content of the Resilience Report was informed by robust research on existing and emerging data and tools for assessing infrastructure vulnerability to climate change. The review of tools (Task 1, Chapter 2) led the research team to focus on creating a user-friendly and intuitive interface with data visualizations (various interactive charts and tables) to summarize the analyses for quick interpretation. The data assessment (Task 2, Chapter 3) revealed the common data types currently used in vulnerability assessment tools and the lack of widespread spatial data representing future flood risks (e.g., future surge, inland flooding, and precipitation). Because much of these data are still emerging, the research team focused on designing and developing a framework for storing, analyzing, and displaying analysis results with the flexibility to rapidly ingest new data (according to minimum specifications and standards discussed in Chapter 3).

The Resilience Report leverages the EST's enterprise database software, database server, and application servers as the foundation for the geospatial framework and technical infrastructure. Additional components were developed to support the new data and geospatial analyses in the tool. The Resilience Report uses Oracle APEX to display the results of the resilience overlay analyses. This software was chosen due to its tight integration with the Oracle database, powerful visualization capabilities (charts, tables, and maps), and its ease of rapid deployment of new analyses.

The beta version of the Resilience Report was demonstrated for a few user groups (Task 4, Chapter 5). In total, the research team presented the beta version to approximately 35 people, some of whom tested the tool and provided comments and feedback. Many of the comments were addressed within this project, but not all were able to be addressed in the timeline. These comments will be considered for future enhancements to the Resilience Report.

After launching the production version of the Resilience Report, the research team developed user guides and technical training materials to build capacity (Task 5, Chapter 6). Two training webinars were offered virtually, where 129 people attended. In the first two weeks since the training webinars, resilience reports were submitted for 16 AOIs across six FDOT districts and one additional organization, indicating high initial interest.

7.1 Next Steps

The research team considers the Resilience Report developed in this project as "Version 1" and plans to continue enhancing the tool with additional data and functionality, as funding and agency priorities permit. The research team has limited funding to continue evaluation of the

Resilience Report with FDOT and its partners to scope and determine the next steps for increasing the utility of the tool. This section briefly describes some potential next steps the research team could pursue, organized into three categories: (1) data; (2) functionality; and (3) partnerships/ use cases.

7.1.1 Data

Tools are only as good as their underlying data and most data sources require periodic updates to reflect current or changing conditions. This is particularly true of climate data, which forecasts future conditions based on GCMs, which are continually refined to incorporate improved knowledge of global processes. As additional data layers and analyses become available, they can be tested and incorporated into the Resilience Report. It should be noted that some new data will also require capacity building and technical training to ensure appropriate use of the data. Below is a list of potential datasets and analyses for consideration and scoping in the next version of the Resilience Report.

Datasets and analyses for consideration:

- Updated SLR inundation depth grids: NOAA is currently developing ½-foot inundation layers using the latest peninsular LiDAR collection in Florida. Once completed, the SLR exposure and depth analysis in the Resilience Report can be updated with these new depth grids.
- Elevation profile: The Florida Peninsular LiDAR collection was completed in late 2022, resulting in a hugely beneficial, high-resolution dataset for Florida. The research team can pursue building an analysis which gathers elevations at various points along a roadway (center and/or edges) and/or across a roadway to identify low-lying areas.
- FDOT Statewide RAP analysis: Analyses conducted for the Statewide RAP has produced GIS layers of ranked vulnerable areas and roads. At the time of this report, the RAP and these GIS layers are still in draft format. Once published, these layers can be added to the Resilience Report for assessment of already identified vulnerable areas and roads that are connecting, adjacent, or close to a user's AOI.
- Exposure data: Data regarding social vulnerability or asset-level vulnerability (in addition to RAP layers). These data could come from various sources developed regionally or locally. Adding exposure datasets can aid in understanding the context of vulnerability for which a particular project is located.
- Criticality Index: A criticality index is helpful for narrowing the focus of vulnerability assessments to the most critical assets. The tools review (Chapter 2) revealed these indices emerging as more common feature for transportation tools (Colorado DOT, V Trans, Houston-Galveston). A criticality index could be developed for state assets (e.g., SIS) and at the local level for regionally significant assets.
- Extreme Precipitation Projections: These projections, which have been developed by numerous collaborative stakeholders in Florida (see Chapter 3), were not released in this version of Resilience Report due to multiple concurrent efforts in progress to

update the data. These projections should be included in the Resilience Report after the USF Flood Hub's precipitation working group has released their recommendations.

- Additional NOAA 2022 Technical Report data: EWL data and observation-based extrapolations (discussed in Chapter 3) offer additional information about SLR trajectories and changing flood regimes in the near-term (now until 2050). After the USF Flood Hub has released their SLR working group recommendations, these additional data sources should be considered. These would require additional technical training for end-users.
- Other climate stressors: As spatially explicit datasets on extreme heat, wildfires, future precipitation and other climate stressors are developed, they can be assessed for inclusion in the Resilience Report. Some existing data to explore include the Union of Concerned Scientists "Killer Heat" dataset of projected extreme heat days for four heat index thresholds (available by city and county) and the FEMA National Risk Index datasets on heat waves and wildfires. These are readily available datasets at coarse scales, but could provide some screening-level information.
- Updated flood data as available: As the existing data sources used in the Resilience Report are updated, then can be incorporated.

7.1.2 Functionality

Currently, the functionality of the Resilience Report is limited, but the framework under which it was designed and built can be expanded upon. Below are a few ideas for enhancing functionality:

- Develop summary report: Currently, the Resilience Report presents a lot of information for multiple scenarios. A summary report could be developed based on the asset information to provide a more streamlined assessment of the vulnerability. For example, other tools require the user to input more information about the asset, such as expected or operational lifespan, asset type, risk tolerance, and critical elevations. These additional attributes could help refine the results and only show a limited range of scenarios and analyses matched to the asset characteristics and lifespan.
- Comparison of alternatives: The EST AOI Tool allows for multiple alternatives (features) to be submitted for analysis. Functionality could be developed to compare alternatives and show analysis results side-by-side for easier comparison.
- Ranking and prioritization: User feedback suggested the addition of a summary level view of multiple projects to facilitate ranking and prioritizing projects.
- Choosing SLR Scenarios: Feedback from users indicated that guidance is needed on choosing SLR scenarios. Functionality could be developed that guides users through a selection process using a risk based approach that uses the project/ asset type, lifespan, risk tolerance, and location to match scenarios.
- Adaptation Pathways Support: Adaptation pathways is an adaptive planning approach where planners and decision makers map out a sequence of adaptation strategies in

response to SLR and flooding. The approach uses tipping points to trigger different levels of adaptation strategies and investments. Functionality could be developed to identify these tipping points and aid in determining the appropriate level of adaptation investment and strategy.

- Toolbox for adaptation and mitigation strategies: Based on the asset type and location, strategies for adaptation or mitigation could be presented.
- Analysis of adaptation and mitigation strategies: Adding current adaptation or mitigation strategies implemented on the roadways to analyze how these strategies will reduce flooding.
- Identifying Opportunities and Co-Benefits: This idea moves beyond standard adaptation and mitigations strategies to reduce vulnerabilities and looks towards identifying co-benefits between resiliency and other goals (e.g., multimodal, conservation, safety, etc) for FDOT and their partners. For example, this could include areas proposed for land conservation also being used as green infrastructure to reduce road flooding or the addition of bike lanes for multimodal enhancements and to provide buffering from extreme flooding events.

7.1.3 Partnerships/ Use Cases

Increasing the functionality and utility of the Resilience Report will depend on partnerships with FDOT, MPOs, and others to use the tool in context of their needs and/or specific projects. Developing detailed use cases with different partners would further demonstrate how to use the Resilience Report and incorporate future flood information into the planning and design process. The research team is interested and will pursue partnerships to develop such use cases. Examples include: data gathering for PD&E or resilience/ corridor studies and working with an MPO to analyze and prioritize LRTPs.

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Appendix A. Tools Matrix

Tool Name & Organization	URL	Description	Climate Stressors	Category	Geography	Focus	Noteworthy Features
AdaptVA Interactive Map, Virginia Institute of Marine Science (VIMS)	http://cmap2.vims.edu/AdaptVA/adaptVA_viewer.html	Viewer showing water levels, social vulnerability, physical vulnerability, infrastructure and natural capital. Includes natural resource layer such as: shoreline management; natural resources; Protection/ restoration opportunities. Esri services.	SLR (NOAA 2017 Low, Intermediate, Int-High, Extreme) decadal from 2020 - 2100 FEMA Flood Hazard Zones Storm surge (Categories 1-4)	Resiliency Screening & Visualization	Virginia	Natural capital, infrastructure	SLR time slider; Novel integration of physical vulnerability and risk with natural capital
ART Bay Shoreline Flood Explorer, San Francisco Bay Conservation and Development Commission (BCDC).	https://explorer.adaptingtorisingtides.org/explorer	The flooding maps and associated analyses provide a regional-scale illustration of coastal flooding due to specific SLR and storm surge scenarios, and are intended to improve SLR awareness and preparedness. Uses ESRI basemap services, Jquery 3.3.1, Custom js	Flooding at 10 Total Water Levels (above MHHW): 12", 24", 36", 48", 52", 66", 77", 84", 96", 108". TWL are then matched to events (SLR, surge, king tides). At the regional scale, these scenarios present avg water levels that are representative of what could occur along the entire Bay shoreline. The mapped scenarios are based on binning the water levels with a tolerance of ±3 inches.	Resiliency Screening & Visualization	San Francisco Bay Area, CA	Flooding	Use of total water levels as a framework to display and analyze multitude of flooding scenarios
CalTrans Regional Climate Change Vulnerability Assessment Maps, CalTrans	https://dot.ca.gov/programs/transportation-planning/division-of-transportation-planning/air-quality-and-climate-change/2019-climate-change-vulnerability-assessments	Interactive maps showing the results of potential climate change impacts in each of Caltrans' 12 districts. ArcGIS Online	**Storm Surge:** 100-year storm plus SLR **Precipitation**: Change in 100-Year Storm Precipitation Depth for 2025, 2055, 2085. **SLR**: Increments 0.5 m, 0.75 m, 1 m, 1.25 m, 1.5 m, 1.75 m, 2 m, 5 m. Data from CoSMoS -USGS. **Wildfires:** Exposure at 2025, 2055, and 2085 using RCP 4.5 and RCP 8.5 **Temperatures:** Avg Min Temp, Avg 7-day Max Temp for 2025, 2055, 2085. **Cliff Retreat:** Highway exposure to cliff retreat under SLR scenarios	Resiliency Screening & Visualization	California	Transportation	Multiple climate stressors and scenarios modeled

Tool Name & Organization	URL	Description	Climate Stressors	Category	Geography	Focus	Noteworthy Features
Climate Central Surging Seas, Climate Central	https://sealevel.climatecentral.org/	Many tools 1) Coastal Risk Screening Tool: Ice Sheet Contributions to SLR: 2) Coastal Risk Screening Tool: Map By Year: 3) Coastal Risk Screening Tool: Map By Water Level: water levels representing combinations of SLR, tides, and storm surge. 4) Coastal Risk Screening Tool: Map By Elevation Data. 5) Risk Zone Map: Global interactive map; 6) Mapping Choices: split screen for comparing scenarios. Mapbox, Google Maps, API	SLR, storm surge	Resiliency Screening & Visualization	U.S.	Flood exposure, Real Estate, Affordable Housing	Local factsheets & reports for download. Various "windows" into SLR data by year, by water level, by human choices, etc; scenario comparisons split screen
CMIP Climate Data Processing Tool v2 FHWA	https://www.fhwa.dot.gov/environment/sustainability/resilience/tools/	Processes downscaled climate projections into relevant statistics, such as changes in temperature and extreme precipitation, for transportation planners.	Temperature, Precipitation	Other	U.S.	Transportation	Downscales global climate models
Coastal Virginia Road Accessibility & Flooding, Virginia Institute of Marine Science (VIMS)	https://cmap2.vims.edu/VAroads/	ArcGIS Online Interactive map for incorporating current and future road flooding into locality planning efforts. Analyses of Inaccessible roads and duration of flooding, social vulnerability, FEMA flood hazard zones. Dashboard of road impacts, and downloadable Road Flooding Summaries (showing length of each road flooded at 0.1 m increment).	FEMA Flood zones; SLR increments: 0.5 m – 3 m; Flood duration: current (2020) and future (2050, 2100). To project flooding durations for 2050 and 2100, used NOAA SLR projections recommended by Commonwealth of Virginia for planning.	Resiliency Screening & Visualization	Coastal Virginia	Transportation	Tailored reports/ impacts for localities. PDF download with detailed summary of inaccessible roads
Colorado DOT - Asset Resiliency Mapping Application, Colorado DOT	https://cdot.maps.arcgis.com/apps/webappviewer/index.html?id=193b5f40075642a49350c6bdf130b15a	ArcGIS Online map that overlays the state's planned transportation projects with climate threats	Floodplains (Current 100-year and 500-year), Drought risk, Wildfire risks, Geohazards; Landslides	Multiple	Colorado	Transportation	Includes multitude of hazards and roadway criticality index

Tool Name & Organization	URL	Description	Climate Stressors	Category	Geography	Focus	Noteworthy Features/ Data
Colorado DOT Detour Identifier Tool, Colorado DOT	https://www.codot.gov/programs/planning/cdot-resilience-program	Excel-based spreadsheet tool, which is an application of the statewide travel demand model to identify optimal detour routes. Identifies the amount of time and distance associated with the detour route. These figures are needed for the R&R tool.	N/A	Resiliency Scoring & Measurement	Colorado	Transportation	Identifies the amount of time and distance associated with a detour route.
Colorado DOT Project Scoring Tool for Resilience, Colorado DOT	https://www.codot.gov/programs/planning/cdot-resilience-program	Excel-based spreadsheet tool for project scoring and to encourage adoption of resilience strategies in planned projects to increase prioritization score. The scoring tool considers the project's eligibility for funding, criticality of asset, whether the asset has been screened for risks, and whether upgraded project specifications increase or incorporate resiliency. Also includes a risk mitigation assessment.	Floodplains (Current 100-year and 500-year); Drought; Rockfall/ Geohazards; Avalanche; Man-made	Resiliency Scoring & Measurement	Colorado	Transportation	Considers a multitude of factors to aid project prioritization (including funding, criticality, exposure, likelihood and severity of impacts)
Colorado DOT Risk and Resiliency Tool, Colorado DOT	https://www.codot.gov/programs/planning/cdot-resilience-program	Excel-based spreadsheet tool to assist with cost-benefit analysis of assets based on hazard type, the likelihood of an event occurring, and the consequence or severity of the hazard's impact. Provides a quantitative risk assessment to estimate of the potential loss to the asset from a given hazard and helps calculate risk reduction from mitigation measures.	Rockfall on PTCS (post-tension concrete slabs), bridge, or roadway Flood on roadway, bridge, bridge approach, minor culvert, and major culvert Scour on bridge	Resiliency Scoring & Measurement	Colorado	Transportation	Assists w/ cost-benefit analysis based on various factors

Tool Name & Organization	URL	Description	Climate Stressors	Category	Geography	Focus	Noteworthy Features/ Functions/ Data
Houston-Galveston Regional Resilience Tool (Dashboard), Houston-Galveston Area Council (HGAC)	https://datalab.h-gac.com/resilience/	ArcGIS online tool developed as part of FHWA pilot study to display the criticality and vulnerability of road segments. Includes the modeled flood exposure depth grid data, which identifies specific parts of road segment that are vulnerable to flooding. Useful in planning road improvements and developing mitigation strategies.	**Inland Flooding:** 100-year and 500-year flooding (FEMA floodplain maps); Hurricane Harvey flooding (NHC) **Coastal Storm Surge:** Categories 1-5 hurricane storm (NOAA); Hurricane Ike Storm Surge (NHC) **SLR:** 4-foot SLR, 5-foot SLR (NOAA)	Resiliency Screening & Visualization	Houston-Galveston region, Texas	Transportation	Nice dashboard, query filters
Maryland DOT - Climate Change Vulnerability Viewer, Maryland DOT	https://www.arcgis.com/home/item.html?id=86b5933d2d3e45ee8b9d8a5f03a7030c	ArcGIS Online web application which highlights SLR and potential impacts on Maryland's roadway assets & infrastructure. Tool supports MDOT SHA Senior Management, Leadership & Planning as they make efforts to avert and mitigate potential impacts of sea level rise that result from global climate change.	Storm Event Scenarios (depth grids) and Associated Roadway Inundation at years: 2015, 2050, and 2100 for the following annual chance events: 10%, 4%, 2%, 1%, 0.2% (respectively 10-, 25-, 50-, 100-, and 500-year events). Scenarios are modeled using MSL and MHHW/ Layers on Hurricane Florence flooding	Resiliency Screening & Visualization	Statewide - Maryland	Transportation	Modeling of multiple flooding scenarios (various events and future time periods)
Massachusetts Ocean Resource Information System - Mass Mapper, Mass Office of Coastal Zone Management	https://www.mass.gov/service-details/massachusetts-ocean-resource-information-system-moris	Mapping application that provides access to MassGIS map layers and associated information, which can be displayed and queried. Users can quickly create and share maps and download data. ESRI custom JS.	SLR 1-6 feet increments FEMA Flood Hazard Areas Hurricane Storm Surge	Data Visualization & Download	Massachusetts	Multiple (more of a data library)	Add layer from service

Tool Name & Organization	URL	Description	Climate Stressors	Category	Geography	Focus	Noteworthy Features/ Functions/ Data
Massachusetts Project Intake Tool (MapIT), MassDOT	https://gis.massdot.state.ma.us/mapit/	ArcGIS Online screening tool to help identify projects that overlap environmental GIS layers and indicate areas of sensitivity or significance.	Environmental layers, Flood hazards		Statewide - Massachusetts	Transportation	Not publicly accessible
Massachusetts Vulnerable Infrastructure Tool (MOVIT), MassDOT	Internal Tool	The purpose of this tool is to map and track locations of repeated flooding, erosion, and infrastructure damage due to storms.	Historic and current hazard areas due to flooding, erosion, storm damage	N/A	Statewide - Massachusetts	Transportation	Tracking known damage locations
MassDOT Climate Projection Viewer, MassDOT	https://gis.massdot.state.ma.us/cpws/	The Climate Projection Viewer displays downscaled climate projections for the State developed as part of the MassDOT Climate Adaptation Vulnerability Assessment. Downscaled climate projections include three emissions scenarios (RCPs 4.5., 6.0, and 8.5) for four time periods (2030, 2050, 2070, and 2100).	• Projected percent change of 1% annual exceedance probability (AEP) 24-hour precipitation • Projected 1% AEP (Annual exceedance probability) 24-hour precipitation depth • Projected annual maximum number of consecutive days > 95°F • Projected number of days > 95°F in summer month	Visualization	Statewide - Massachusetts	Climate Scenarios	Downscaled climate projections for temperature and precipitation
NOAA Coastal Flood Exposure Mapper, National Ocean and Atmospheric Adminstration (NOAA)	https://coast.noaa.gov/digitalcoast/tools/flood-exposure.html	This online visualization tool supports communities that are assessing their coastal hazard risks and vulnerabilities. The tool creates a collection of user-defined maps that show the people, places, and natural resources exposed to coastal flooding. The maps can be saved, downloaded, or shared to communicate flood exposure and potential impacts. Custom UI, AGOL services	SLR Flood Frequency FEMA Flood hazard areas	Resiliency Screening & Visualization	U.S. East Coast, West Coast, Gulf of Mexico, and islands in the Pacific and Caribbean.	Coastal Flooding Exposure	Create, save, and share user-defined maps of flood risks. User-friendly interface. REST Map services publicly available.

Tool Name & Organization	URL	Description	Climate Stressors	Category	Geography	Focus	Noteworthy Features/ Functions/ Data
NOAA Sea Level Rise Viewer, National Ocean and Atmospheric Administration (NOAA)	https://coast.noaa.gov/digitalcoast/tools/slr.html	Web mapping tool to visualize community-level impacts from coastal flooding or sea level rise. Photo simulations of how future flooding might impact local landmarks are also provided, as well as data related to water depth, connectivity, flood frequency, socioeconomic vulnerability, wetland loss and migration, and mapping confidence. Custom UI with Underscore.jsAGOL services	SLR: 1- 10 feet increments; High Tide Flooding	Resiliency Screening & Visualization	U.S.	SLR Impacts	Nationwide coverage, easy to use slider, local SLR scenarios, user-friendly interface. Map services publicly available through REST endpoint.
Pinellas County Capital Planning Tool, Pinellas County	Internal Tool	ArcGIS Online Web-based tool to facilitate the required flood-risk screening of infrastructure projects in Pinellas County. As of 2019, screening is required for infrastructure projects over $1 million and for all critical infrastructure. The tool facilitates key steps outlined in the County's "Guidance for Incorporating SLR into Capital Planning": (1) Communication of current climate science and local SLR projections, (2) Vulnerability Assessment; (3) Risk assessment; and (4) adaptation measures.	SLR (projections in accordance with Tampa Bay Climate Science Advisory Panel) FEMA Flood zones	Resiliency Screening & Visualization	Pinellas County	Infrastructure/ Capital Planning	Web-based that is also geospatially enabled. Links to geospatial data showing vulnerability. Enterprise level, crossing multiple departments and centralization of asset evaluations.

Tool Name & Organization	URL	Description	Climate Stressors	Category	Geography	Focus	Noteworthy Features/ Functions/ Data
Sea Level Impact Projection Study Tool (SLIP), FDEP	https://www.floridadep-slip.org/	This interactive mapping tool developed to facilitate vulnerability assessment requirements of Florida Statutes (Section 161.551, F.S). Requires that publicly financed projects located within coastal building zone must conduct and publicly submit a SLIP (Sea Level Impact Projection) Study before any publicly financed construction begins. Front-end: leaflet.js, esri-leaflet.js, popper.js, jQuery, datatables.jsBackend: turf.js, AGOL basemap services via esri-leaflet	SLR (1-10 feet) FEMA Flood zones High tide flooding Wind zones	Resiliency Screening & Visualization; Decision Support	Florida Coastal Building Zone (but adaptable to entire state where data available)	Infrastructure/ Capital Planning	Easy to use, user-friendly reporting format
Transportation Climate Change Sensitivity Matrix, FHWA	https://www.fhwa.dot.gov/environment/sustainability/resilience/tools/	Excel-based spreadsheet tool which documents the sensitivity of roads, bridges, airports, ports, pipelines, and rail to climate impacts;	11 Climate Impacts: Precipitation-Driven Inland Flooding, Increased Temperatures and Extreme Heat, SLR/ Extreme High Tides, Storm Surge, Wind, Drought, Dust Storms, Wildfires, Winter Storms, Changes in Freeze/ Thaw, and Permafrost Thaw	Resiliency Scoring & Measurement	Applicable anywhere	Transportation	One of only tools for assessing sensitivity of transportation assets to climate impacts.

Tool Name & Organization	URL	Description	Climate Stressors	Category	Geography	Focus	Noteworthy Features/ Functions/ Data
Vermont Transportation Flood Resilience Planning Tool, Vermont Agency of Transportation (VTrans)	https://roadfloodresilience.vermont.gov/	Planning tool to evaluate exposure, criticality, risk, and mitigation strategies. Includes road, bridge, and culvert exposure to flood inundation, erosion, and deposition hazards; (2) Criticality index of assets - importance to transportation network function and access to essential facilities; (3) Risk index, or the combination of vulnerability and criticality; and (4) Mitigation strategies to reduce hazards to roads, bridges, and culverts. Esri basemap services, Front-end Framework: Angular.js, ArcGIS API for JavaScript 3.21	Flood inundation exposure to: 100-year (1% AEP) 50-year (2% AEP) 10-year (10% AEP) Erosion Deposition hazards	Resiliency Screening & Visualization; Decision Support	Vermont	Transportation	Nice user-interface, with interactive charts of criticality/ risk indices linked to the map; Includes strategies for mitigation/ adaptation based on asset
Volpe Risk and Disaster Recovery Tool, U.S. DOT Volpe Center	https://www.volpe.dot.gov/our-work/resilience-and-disaster-recovery-tool-suite	Suite of tools developed to aid transportation agencies in estimating the return on investment (ROI) of resilient infrastructure across multiple future hazards. Multiple models. Python and Tableau	Intended to be hazard agnostic	Multiple	Applicable anywhere	Transportation	Aids in return on investment, cost-benefit analysis
Vulnerability Assessment Scoring Tool (VAST), FHWA	https://www.fhwa.dot.gov/environment/sustainability/resilience/tools/	Excel-based spreadsheet tool Uses an indicator based approach to quantitatively score the vulnerability of transportation assets.	N/A	Resiliency Scoring & Measurement	Applicable anywhere	Transportation	Quantitative vulnerability scoring for transportation

Appendix B. Data Matrix

Name	Source	Climate Variables	Description	Geography	Spatial Resolution	URL	Time Period
Flood Frequency/ Nuisance Flooding	NOAA	High Tide Flooding	The red layer in the map represents areas currently subject to tidal flooding, often called “recurrent or nuisance flooding.”	National/ coastal	Tide gauges	https://tidesandcurrents.noaa.gov/HighTideFlooding_AnnualOutlook.html	2021, 2022, 2050
Flooding Days Projection Tool	UH Sea Level Center and NASA	High Tide Flooding	Allows decision makers to assess how SLR and other factors will affect the frequency of high-tide flooding (HTF) in coming decades on a location-specific basis. Provides probablistic projections of flood frequency in the future that provide the full range of possibilities for a given year, including the potential for the occasional severe years. Rather than producing a single, most-likely number of flooding days for a future year, these projections are probabilistic.	National and island territories	90 Cities and associated tide gauges	https://sealevel.nasa.gov/data_tools/15 https://sealevel.nasa.gov/	2018
National Risk Index (NRI) for Natural Hazards	FEMA	Multiple: Coastal Flooding, Drought, Hail, Heat Wave, Hurricane, Lightning, Riverine Flooding, Strong Wind, more	Online mapping application that identifies communities most at risk to 18 natural hazards. Visualizes natural hazard risk metrics and includes data about expected annual losses from natural hazards, social vulnerability and community resilience. Multiple hazards included: Avalanche, Coastal Flooding, Cold Wave, Drought, Earthquake, Hail, Heat Wave, Hurricane, Ice Storm, Landslide, Lightning, Riverine Flooding, Strong Wind, Tornado, Tsunami, Volcanic Activity, Wildfire, Winter Weather	Nationwide	County and Census Tract	https://www.fema.gov/flood-maps/products-tools/national-risk-index	2021
Coastal Inundation Dashboard	NOAA	NWS flood data, tropical storms, surge, coastal flooding, sea level rise	This tool brings together real-time water levels, 48-hour forecasts of water levels, and historic flooding information into one online tool to help decision makers and coastal residents understand both short-term risks—such as an approaching hurricane or nor’easter—as well as longer-term risks, such as high-tide flooding and SLR	Nationwide (coastal)	Tide stations (coastal)	https://tidesandcurrents.noaa.gov/inundationdb/	Current

Name	Source	Climate Variables	Description	Geography	Spatial Resolution	URL	Time Period
Projected Intensity-Duration-Frequency (IDF) Curve Data Tool for the Chesapeake Bay Watershed and Virginia	Carnegie Mellon, Northeast Regional Climate Center, RAND Corp	Precipitation (Future)	Updated intensity-duration-frequency (IDF) curves to reflect future climate changes. The updated IDF curves are generated from the best-available science and publicly available in an interactive online tool. Using the online tool, the updated IDF curves can be easily integrated and used across the Chesapeake Bay Watershed and Virginia to plan, design, and build infrastructure assets to be more resilient to climate change.	Virginia	County aggregation	https://midatlantic-idf.rcc-acis.org/	2021
NY IDF Viewer	Northeast Regional Climate Center (NRCC) & New York State Energy Research & Development Authority (NYSERDA)	Precipitation (Future)	Extreme precipitation projections developed for incorporation into climate change adaptation planning for NY State. Publicly available products include: 1) historical and future downscaled IDF curves for each station, 2) gridded maps illustrating projected changes in return period precipitation amounts, and 3) gridded maps illustrating projected changes in the recurrence intervals of historical precipitation thresholds.	NY State	0.5 degree x 0.5 degree grid cells	http://ny-idf-projections.nrcc.cornell.edu/index.html	Time periods: (1970–1999) (2010–2039) (2040–2069) (2070–2099)
Prism Climate Data	Oregon State Univ	Precipitation, Temperature, dew point, vapor pressure	Estimates of six basic climate elements: precipitation (ppt), min temperature (tmin), max temperature (tmax), mean dew point (tdmean), min vapor pressure deficit (vpdmin), max vapor pressure deficit (vpdmax). Two derived variables, mean temperature (tmean) and vapor pressure (vpr), are sometimes included.	Nationwide	native grid resolution of 800 m, but filtered to 4km for download and use on website.	https://prism.oregonstate.edu/	Historical data and 30-year Normals
Precipitation Frequency Data Server (PFDS) for NOAA Atlas 14	NWS	Precipitation	The Precipitation Frequency Data Server (PFDS) is a point-and-click interface developed to deliver NOAA Atlas 14 precipitation frequency estimates and associated information.	Nationwide	NOAA Stations	https://hdsc.nws.noaa.gov/hdsc/pfds/	Historical data

Name	Source	Climate Variables	Description	Geography	Spatial Resolution	URL	Time Period
First Street Foundation Flood Factor	First Street Foundation	Rainfall (pluvial), riverine (fluvial), and coastal surge flooding.	The First Street Foundation Flood (FSF-FM) model is a probabilistic flood model that shows flood risk in the contiguous 48 states due to rainfall (pluvial), riverine flooding (fluvial), and coastal surge flooding. The model uses a consistent methodology and provides a high resolution (3-meter cell size) across the entire U.S. Provides spatially explicit projections of flood risk over the next 30 years. Incorporates future flood risks by using IPCC RCP 4.5 trajectory (mid-range scenario) and 21 GCMs from CMIP5. Paid model for full resolution ($35,000 - $45,000).	Nationwide	3-meter grid cells	https://firststreet.org/api/	2020
2022 Scenarios of Future Mean Sea Level	NOAA 2022 Interagency Report	Sea Level Rise Scenarios	This report and accompanying datasets from the U.S. Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force provide SLR scenarios to 2150 by decade that include estimates of vertical land motion. Data are available at 1-degree grids along U.S. coastline and downscaled at NOAA tide-gauge locations.	Nationwide/ coastal	Tide Gauges and 1-degree grid	https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-data.html	2022
2022 Extreme Water Levels (EWLs)	NOAA 2022 Interagency Report	Extreme Water Levels	EWL probabilities for various heights along the U.S. coastline. Data are available at 1-degree grids along U.S. coastline and downscaled at NOAA tide-gauge locations. Estimates of flood exposure are assessed using U.S. coastal flood-severity thresholds for current conditions (e.g., sea levels and infrastructure footprint) and for the next 30 years (out to year 2050), assuming no additional risk reduction measures are enacted.	Nationwide/ coastal	Tide Gauges and 1-degree grid	https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html	2022
Observation-based Extrapolations	NOAA 2022 Interagency Report	Sea Level Rise. Extrapolated SLR trends out to 2050 based on historical observations	Regional extrapolations of SLR based on tide gauge observations from 1970 to 2020. Serve as a near-term (2020-2050) comparison to five SLR scenarios and can be viewed as "trajectories" of current SLR. Extrapolations do not replace the SLR scenarios, but offer another line of evidence for planning for near-term SLR.	Nationwide/ coastal	Tide Gauges and 1-degree grid	https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html	Out to 2050

Name	Source	Climate Variables	Description	Geography	Spatial Resolution	URL	Time Period
Sea Level Projection Tool	NASA	Sea Level Rise	Allows users to visualize and download SLR projection data from IPCC 6th Assessment Report (AR6). Tool allows users to view global and regional SLR projections from 2020 to 2150, along with how these projections differ depending on future scenario. Users can click anywhere in the ocean to obtain the IPCC projection of sea level for that individual location. Contributions of different physical processes to future SLR are provided, indicating which will be the dominant drivers of future sea level for a given location.	Global	individual tide gauges	https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool https://sealevel.nasa.gov/data_tools/17	2020 - 2150
DoD Regionalized Sea Level Change & Extreme Water Level Scenarios	DoD	Sea Level Rise, Extreme Water Levels	Scenarios for screening-level vulnerability assessments for Department of Defense coastal & tidally influenced sites https://drsl.serdp-estcp.org/Docs/CARSWG_SLR.pdf	Individual facilities and surrounding tide gauges	National	https://drsl.serdp-estcp.org/	2030, 2065, 2100
ESLR-NGOM: Storm Surge Data	LSU	Storm Surge + SLR	Interactive maps to show surge data for the year 2100 under four different SLR scenarios. This surge data can be viewed on a storm-by-storm basis or maximum storm surge inundation (known as maximum of maximums storm surge (MOMs)) under each scenario. Additionally, the map shows stillwater (flood level not including wave effects) floodplains for the 1% and 0.2% annual chance storms under low and intermediate-high SLR scenarios.	Western Gulf of Mexico	10-meter cells	https://noaa.maps.arcgis.com/apps/MapJournal/index.html?appid=964181e11b4d4736ac85d7ecd33104ab	2100
Coastal Hazards System (CHS) v2.0	U.S. Army Corps of Engineers Coastal and Hydraulics Lab	Storm Surge + Sea Level Rise	The Coastal Hazards System (CHS) is a national coastal storm hazard data resource for probabilistic coastal hazard assessment (PCHA) results and statistics, storing numerical and probabilistic modeling results including storm surge, astronomical tide, waves, currents, and wind. The web tool returns point data with annual exceedance frequency AEF) base conditions, and base + sea level change, base + tides, and historic tropic storms.	National/ coastal	variable dependent on options selected	https://chs.erdc.dren.mil/	N/A

Name	Source	Climate Variables	Description	Geography	Spatial Resolution	URL	Time Period
USACE South Atlantic Coastal Study (SACS)	U.S. Army Corps of Engineers	Storm Surge + Sea Level Rise	SACS is a coastal risk study aimed at advancing coastal resilience in the southeastern U.S. using a three-tiered approach at multiple scales (USACE, 2021a). The SACS Tier 1 Risk Assessment is a regional analysis using national-level datasets to identify areas of potential risk to coastal flood events under both existing and future conditions. The SACS Tier 2 assessment is a state-level analysis and offers refinement of the Tier 1 results through addition of locally-specific data. A Tier 3 analysis, which is forthcoming, will be conducted at a local level, based on the Tier 2 results.	Approximately 65,000 miles of tidally influenced shoreline from North Carolina to Mississippi.	30-meter grid cells	https://www.sad.usace.army.mil/SACS/	2021
National Storm Surge Hazard Maps - Version 2	NOAA NHC	Storm surge Categories 1-5	This page outlines the approach to merging the SLOSH MOM products to create a seamless view of storm surge inundation and risk for Category 1-5 hurricanes.	Nationwide	625-meter SLOSH grids	https://www.nhc.noaa.gov/nationalsurge/	2021
Global Peak Surge Map	LSU	Storm surge historic data	The experimental Return Frequency Analysis Tool estimates the return period of storm surge heights in specific locations. This tool overlays historic surge envelopes, then runs stats on all surge heights within a selected distance of a specific location. This methodology enables us to estimate the 100-year storm surge return period for areas within 10 miles of Manhattan, New York, or the 50-year surge level for locations within 25 miles of Miami Beach, Florida.	Nationwide	N/A	https://surge.climate.lsu.edu/data.html	2015
Flood Event Viewer	USGS	water levels, high water marks, wave height	The Flood Event Viewer (FEV) is the public data discovery component of the USGS Short-Term Network (STN) database. The tool gives users a map interface from which they can examine data collected during flood events, such as hurricane landfalls and Nor'easters. Users can also view real-time data from a range of STN monitoring stations.	Nationwide	N/A	https://stn.wim.usgs.gov/fev/	Current