REGIONAL TRANSPORTATION INFRASTRUCTURE SEA LEVEL RISE ASSESSMENT AND ADAPTATION GUIDANCE

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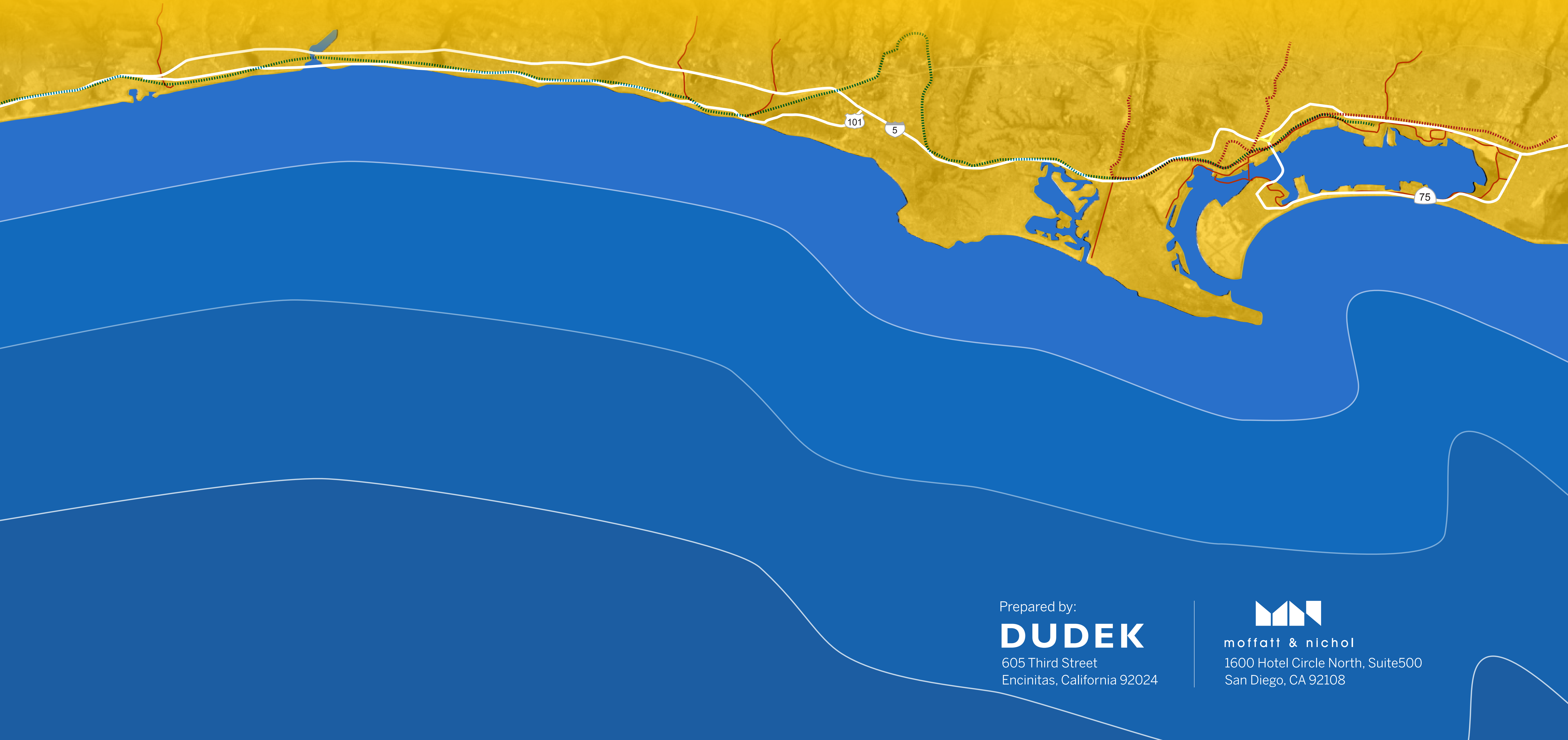

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PHOTO: SARAH RICHMOND

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TABLE OF CONTENTS

TABLE OF CONTENTS

TABLES

Acronyms and Abbreviations

Acronym/Abbreviation	Definition
AADT	annual average daily traffic
ATP	active transportation pathways
Caltrans	California Department of Transportation
CCC	California Coastal Commission
CDFW	California Department of Fish and Wildlife
CoSMoS	Coastal Storm Modeling System
CRSMP	Coastal Regional Sediment Management Plan
cy	cubic yard
GHAD	Geological Hazard Abatement District
GO	General Obligation
Hwy	Highway
I	Interstate
LCP	local coastal program
LOSSAN	Los Angeles–San Diego–San Luis Obispo
MTS	Metropolitan Transit System
NCC	North Coast Corridor
NCC Program	North Coast Corridor Public Works Plan/ Transportation and Resource Enhancement Program
RBSP	Regional Beach Sand Project
SANDAG	San Diego Association of Governments
SCOUP	Sand Compatibility and Opportunistic Use Program
SPS	Shoreline Preservation Strategy
SPWG	Shoreline Preservation Working Group
SR	State Route
SRS	Sand Retention Strategy
TIF	Tax Increment Financing
TOT	Transient Occupancy Tax
TREP	Transportation and Resource Enhancement Program
VAST	Vulnerability Assessment Scoring Tool

PHOTO: GOOGLE STREET VIEW

01

Introduction

1 Introduction

The San Diego region has more than 70 miles of coastline. The coastal region includes 10 cities, an international port and airport, more than 40% of the region's population, and more than 500,000 employees accounting for about $30 billion in wages (Kalansky et al. 2018). The San Diego Regional Climate Collaborative commissioned a regional economic vulnerability assessment that estimated sales and gross domestic product vulnerabilities ranging from tens of millions to billions of dollars under different projected sea level rise scenarios. Under the highest sea level rise scenario analyzed, over 2,600 establishments with 49,000 jobs were vulnerable to flooding (Center for the Blue Economy, 2018). A network of transportation infrastructure moves people and goods throughout the region and links them with neighborhoods, jobs, education, and recreation that are critical to the quality of life in the San Diego region.

Sea level rise will likely impact all modes of transportation located near the San Diego shoreline. Erosion, flooding, and inundation of even small segments of the interconnected transportation system can render much larger portions impassable, disrupting connectivity and access to the wider transportation network. In the foreseeable future, sea level rise is projected to rise substantially faster than in the past (about 0.6 feet over the last century). By 2050, sea level rise is projected to be approximately 1 to 2 feet and by 2100, sea level rise is projected to be approximately 3 to 7 feet, and potentially even higher (relative to a 2000 baseline sea level) (OPC 2018). Over the next several decades, the most damaging events will involve temporary erosion and flooding caused by storm surge and wave run-up that coincide with peak high tides, particularly during El Niño winters. However, increasing sea level rise will worsen these extreme events, causing larger, longer, and more damaging floods, eventually leading to daily inundation. Thus, sea level rise will reduce the period of time transportation assets are safe from coastal hazards and significantly increase the challenge for regional and local planners to ensure reliable transportation routes are available.

Planning for sea level rise is necessary to effectively minimize these potential impacts. Over the past few years, many of the region's coastal cities and agencies have initiated sea level rise planning efforts. Recent project specific sea level rise analyses have been completed for the City of Chula Vista's Restoration and Enhancement Alternatives for the Chula Vista Bayfront Harbor District Road Improvements (ESA, 2017), the Encinitas-Solana Beach Coastal Storm Damage Reduction Project (USACE 2015), and the North Coast Corridor Public Works Plan/Transportation and Resource Enhancement Program (SANDAG 2013). In addition, multiple entities have already completed vulnerability assessments, including Caltrans District 11, the Port of San Diego, San Diego County Regional Airport Authority, and Cities of Oceanside, Carlsbad, Del Mar, and Imperial Beach. Local jurisdictions are currently working on updates to their Local Coastal Programs (LCPs) to incorporate adaptation strategies. The City of San Diego is in the process of conducting a vulnerability assessment to inform the development of a resilience plan. All of these assessments indicate that transportation infrastructure is vulnerable. Because disruptions to one segment of transportation infrastructure can cause traffic delays and disruption of emergency services to the rest of the system, irrespective of jurisdictional boundaries, the San Diego Association of Governments (SANDAG) identified a need to bring together this local work and look at transportation through a regional lens.

1.1 Project Overview

PHOTO: MOFFATT & NICHOL

In this project, regional transportation infrastructure is defined as any transportation asset that crosses jurisdictional boundaries, including roadways such as Interstate 5 (I-5), Pacific Coast Highway 101 (Hwy 101), and State Route (SR) 75;[1] bikeways and trails, otherwise known as active transportation pathways (ATPs); and transit routes including a portion of the Los Angeles–San Diego–San Luis Obispo (LOSSAN) rail corridor and Metropolitan Transit System (MTS) trolley lines.[2] The focus is on regional, as opposed to local, transportation infrastructure because these assets require cross-jurisdictional collaboration to prioritize and plan for a dependable and resilient system in the face of future sea level rise.

Funded by a California Department of Transportation (Caltrans) Senate Bill (SB) 1 Adaptation Planning Grant, this guidance document examines potential sea level rise impacts to regional transportation infrastructure and presents best planning practices and a suite of adaptation measures to address these impacts. The following is a guide to the information:

Chapter 1 – Introduction: Defines regional transportation infrastructure, describes project objectives, and provides background for SANDAG's role in shoreline management.

Chapter 2 – Vulnerability Assessment: Presents analysis and mapping of sea level rise hazards for four scenarios using the Coastal Storm Modeling System (CoSMoS) 3.0 Phase 2 model and previous studies, and assesses the risk of select assets using the Federal Highway Administration (FHWA) Vulnerability Assessment Scoring Tool (VAST).

Chapter 3 – Adaptation Planning Best Practices: Synthesizes interviews with staff from coastal cities and agencies about lessons learned when conducting vulnerability assessments and updating or preparing local policies and plans to address sea level rise.

Chapter 4 – Adaptation Pathways: Lays out policies, funding mechanisms, and projects that may be considered at the regional or local level to minimize risks from hazards and maintain a functioning regional transportation system.

Chapter 5 – Conclusions: Summarizes the main findings of the project, developed in consultation with Caltrans, the North County Transit District (NCTD), MTS, and the region's coastal cities and agencies, and recommends next steps for planning and implementation of sea level rise adaptation strategies.

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[1] In this report, roadways are used as a generic term denoting a regional vehicular transportation route. The term does not take jurisdiction into account, e.g., local city or county street vs. state highway system. As this is a regional-level document, local streets and roads are not included as roadways.

[2] Based on this definition, the San Diego International Airport is not considered regional transportation infrastructure. However, a number of transportation assets that serve the airport are included in this analysis. In addition, SANDAG staff interviewed San Diego County Regional Airport Authority staff on best planning practices, and these findings have been incorporated into the report to the extent possible.

1.2 SANDAG's Role in Shoreline Management

SANDAG serves as the forum for regional decision-making, acting as the Metropolitan Planning Organization (MPO) for the San Diego region. Governed by a board of directors composed of elected officials from each of the region's 18 cities and the County of San Diego, SANDAG builds consensus, makes strategic plans, obtains and allocates resources, and provides information on a broad range of topics pertinent to the region's quality of life, including shoreline management. SANDAG is supported by a number of committees and working groups, and one of SANDAG's longest-running working groups is the Shoreline Preservation Working Group (SPWG). The San Diego region experiences chronic erosion and narrowing of its beaches due to decreased sand supply to the shoreline,[3] particularly within the northern and southern parts of the region (Figure 1-1). The SPWG was founded in the 1980s as the Shoreline Erosion Committee, and consists of elected officials from coastal jurisdictions and technical advisors throughout the region who advise SANDAG on issues related to sediment management and, more recently, sea level rise, which will exacerbate the region's erosion problem.

The SPWG played a key role in developing the four policy documents that guide the region's approach to shoreline erosion:

1. **The Shoreline Preservation Strategy for the San Diego Region (SPS; SANDAG 1993):** Outlines a long-term vision for addressing critical shoreline erosion areas in the region through an extensive beach building and maintenance program as well as sand retention structures, protective structures, and policies and regulations regarding the use of the shoreline and its development.
2. **The Sand Retention Strategy (SRS; SANDAG 2001):** Concludes that groins, breakwaters, or reefs have the potential to increase the cost effectiveness of beach nourishment activities.
3. **Sand Compatibility and Opportunistic Use Program (SCOUP) Plan (SANDAG 2006):** Presents a plan for implementing opportunistic beach nourishment (less than 150,000 cubic yards (cy)) on a regional basis.
4. **Coastal Regional Sediment Management Plan (CRSMP; SANDAG and CSMW 2009):** Aims to implement the SPS by establishing a process to address beach erosion through effective management of sediment resources throughout the region.

This policy framework set the stage for SANDAG's coordination of two Regional Beach Sand Projects (RBSP I and II, respectively) as well as smaller-scale opportunistic beach nourishment projects. These projects demonstrated the effectiveness of beach nourishment to reduce shoreline erosion and flooding, thereby enhancing the beach for public access and recreation, shoreline habitat, and protection of coastal infrastructure and property. In the face of sea level rise, beach nourishment will continue to be used to try to maintain wide beaches and their associated benefits. However, to maintain the long-term mobility provided by regional transportation infrastructure solutions beyond beach nourishment are needed. This report examines the potential of future risks through a vulnerability assessment and describes robust planning practices and various adaptation pathways to facilitate an inclusive, cost-effective, and proactive approach to addressing sea level rise impacts on regional transportation infrastructure. Potential updates to these existing SANDAG policy documents, based on the results of this study, are described in Section 4.1.1.

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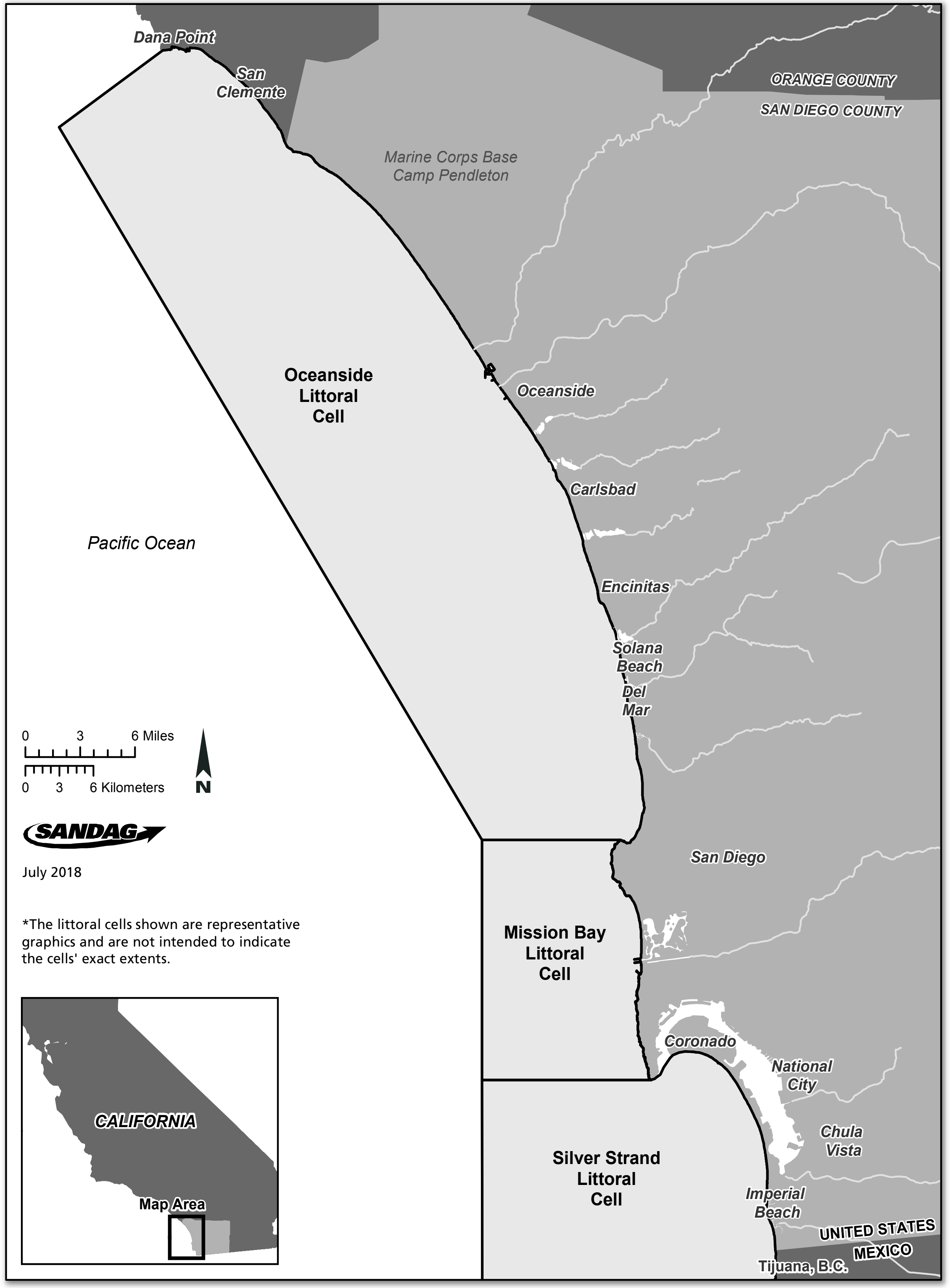
[3] Historical records indicate that the effects of Oceanside Harbor, inland flood control works, sediment detention basins, lagoon and harbor sediment trapping, urban development, and seawalls have resulted in a reduction in the supply of sediment to the shoreline by approximately 400,000 cy/year of sand (Griggs, G.B. 2005).

Figure 1-1. Coastal Cities, Littoral Cells, and Critical Erosion Areas



July 2018

*The littoral cells shown are representative graphics and are not intended to indicate the cells' exact extents.

1.3 Sea Level Rise Hazards

The California Coastal Commission (CCC) presently recommends using the Ocean Protection Council's sea level rise guidance (OPC 2018) as the best available science. OPC (2018) projects sea level rise for multiple greenhouse gas (GHG) emissions scenarios and uses a probabilistic approach based on Kopp et al. 2014. OPC (2018) identifies three "Risk Aversion" scenarios to focus the attention of planners on sea level rise scenarios based on the risk tolerance acceptable for the area in question. It should be noted that the California Natural Resources Agency recently released the Fourth Climate Change Assessment, which presented a broader, more dramatic range of sea level rise scenarios than the OPC guidance to provide a lens into possible increased sea level rise over the second half of the 21st century (CNRA 2018).

Sea level rise projections under the high emissions scenario and varying probabilities are presented in **Table 1-1**. The high emissions scenario represents a high-end, "business-as-usual" GHG emissions scenario, which assumes current global fossil fuel use continues unimpeded. The range between the probabilities increases with time, primarily due to the large uncertainty in the ice sheet's response to climate change in the second half of the century. This is especially the case for the H++ Scenario, characterized as Extreme Risk Aversion, where no probabilities are associated with the potential catastrophic ice sheet collapse and extreme sea level rise. This scenario is intended to be considered for planning of particularly critical infrastructure and other high-stakes, long-term decisions (CCC 2018).

Sea level rise scenarios employed for vulnerability assessments vary by jurisdiction. This variability is due to the unique risk tolerances of each jurisdiction. It is also due to the fact that sea level rise projections evolve as science progresses; therefore, published periods for each jurisdiction may rely on varying best available science. Sea level rise scenarios selected by each jurisdiction in the region are illustrated in **Figure 1-2.**

1.3.1 Coastal Erosion Hazards

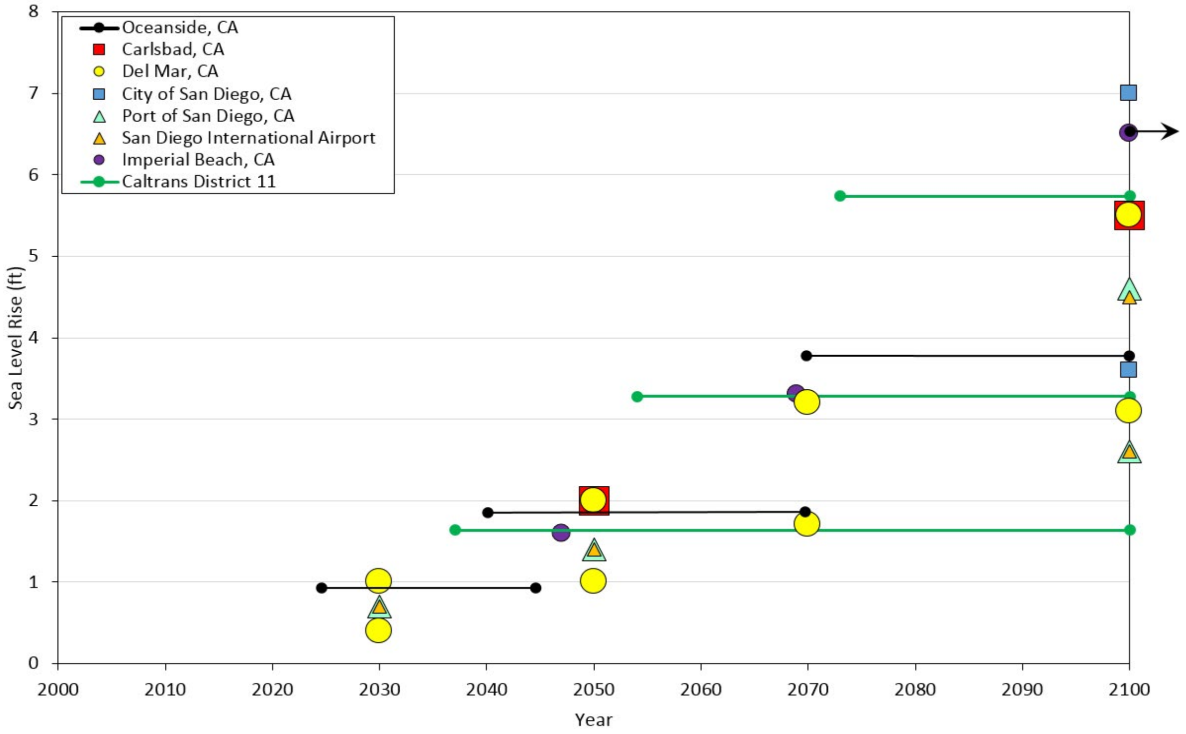
Due to the limited scope of this project, the focus of this initial sea level rise analysis solely utilizes CoSMoS storm flood hazard results and does not address other CoSMoS outputs such as cliff retreat projections or shoreline change (i.e., coastal erosion estimates). Such data can be sourced from CoSMoS should a deeper project or site specific analysis be pursued. The cliff recession model assess the impact of waves and water level variations on both soft and hard rock (i.e., loosely consolidated sediment and indurated lithologies, respectively). The shoreline change model incorporates sediment transport modeling under the impact of waves and water level variations. The shoreline change model is tuned by historical shoreline position data, as well as complimented by sediment input loads, such as deposition from rivers and streams, regional sediment supply, and long-term erosion. Management scenarios, such as assumptions of the development of shoreline armoring or beach nourishment, are available to zero-in on a case most applicable to certain areas or projects. Across the greater San Diego region, coastal jurisdictions have approached coastal erosion hazards differently. For example, the City of Oceanside directly used shoreline change and cliff retreat projections from CoSMoS (ESA 2018). The City of Carlsbad (M&N 2017a) and City of Imperial Beach (Revell Coastal, 2016) utilized preliminary CoSMoS results according to the data available at the time and supplemented with other data where applicable. The City of Del Mar considered CoSMoS cliff retreat results, and supplemented with a site-specific historic cliff retreat analysis (ESA 2016). The Port of San Diego (2019), San Diego International Airport (2019), and City of San Diego (in progress) solely utlilize flood results, as is performed in this report. In addition to modelled shoreline projections, the San Diego coastline continues to be the focus of several observational studies. Through the SANDAG Regional Beach Monitoring Program two-dimensional coastal profiles are monitored in each coastal jurisdiction (CFC, 2019). In addition, the Scripps Institution of Oceanography at UC San Diego conducts beach and bluff monitoring throughout the region to capture three-dimensional coastal evolution (Young, 2018; Ludka et al., 2018). Such studies support the understanding of regional coastal evolution, and can be utilized to help prepare for and respond to hazards such as beach erosion and bluff collapse.

Table 1-1. Sea Level Rise Projections – High Emissions Scenario – San Diego, California

Year	Probabilistic Projections (in Feet)[a, b]				
	Median	**Likely Range**	**1-in-20 Chance**	**1-in-200 Chance**	**H++ Scenario**[c]
	50% probability sea level rise meets or exceeds…	*66% probability sea level rise is between…*	*5% probability sea level rise meets or exceeds…*	*0.5% probability sea level rise meets or exceeds…*	
		Low Risk Aversion		*Medium-High Risk Aversion*	*Extreme Risk Aversion*
2050	0.9	0.7–1.2	1.4	2.0	2.8
2060	1.2	0.9–1.6	1.9	2.7	3.9
2070	1.2	1.1–2.0	2.5	3.6	5.2
2080	1.9	1.3–2.5	3.1	4.6	6.7
2090	2.2	1.6–3.0	3.7 (3.8)[d]	5.7	8.3
2100	2.6	1.8–3.6	4.5 (4.6)[d]	7.0	10.2

Source: OPC 2018.
[a] Based on Kopp et al. 2014. [b] Adapted from OPC 2018, Table 34. [c] Sweet et al. 2017. [d] Adapted from OPC 2018, Table 31 for La Jolla (illustrating very minor difference from San Diego projections).

Figure 1-2. Selected Sea Level Rise Scenario By Jurisdiction



Note: Individual sea level rise studies have been conducted for SANDAG's North Coast Corridor program, the City of Chula Vista's Bayfront development, and the U.S. Army Corps of Engineers Solana-Encinitas Shoreline Study. However, because these studies are project specific and are not included in a comprehensive jurisdiction-wide vulnerability assessment, they are not included in Figure 1-2. The City of Oceanside and Caltrans D11 SLR scenarios are depicted as a line graph to represent the fact that their Vulnerability Assessment provided a date range for discrete SLR projections.

PHOTO: SAN DIEGO UNION TRIBUNE

02

Vulnerability Assessment

PHOTO: ART WAGER

Regional transportation infrastructure is critical for goods movement both regionally and nationally as discussed in **SANDAG's 2016 Freight Gateway Study Update.** Rail freight is significantly cheaper than truck freight so investments in rail capacity have significant benefits in reducing truck volume, reducing delay on the roads, and reducing shipper costs. The connection of the railroad to the Port of San Diego allows for movement of high commodity freight, including vehicles, as well as lower-value goods, with an average of eight freight trains moving through the region per day. Passenger trains are also central to the region's transportation network, carrying 1.4 million passengers per year.

Flooding of transportation infrastructure can initiate cascading events from immediate impacts to people and travel, to the more distant, secondary impacts of impaired business, and finally more permanent impacts of damage to infrastructure and the environment. The first step in planning for sea level rise is to identify the vulnerability of regional transportation assets. This vulnerability assessment presents a region-wide sea level rise analysis to evaluate the degree to which important regional assets are susceptible to, and unable to accommodate, projected sea level rise. This assessment identifies the assets and locations that are likely to be impacted and the causes and components of each asset's vulnerability.

2.1 Technical Approach

Due to the high degree of uncertainty associated with predicting when and at what rate sea level rise will occur, planning for sea level rise must consider high and low estimates of sea level rise. Planning for a range of potential future conditions provides the San Diego region with the tools to make current and future planning decisions to adapt to changing conditions. The two scenarios chosen for this anaysis correspond approximately with the medium-high risk aversion projections (0.5% probability) for the years 2050 and 2100 (OPC 2018).[1] According to OPC (2018) state guidance, the medium-high risk aversion scenario should be utilized for projects which are more vulnerable, less adaptive, and result in severe consequences if affected by sea level rise, such as regional transportation infrastructure. Each sea level rise projection is coupled with a "no storm" and "100- year storm" condition **(Table 2-1).**

2.1.1 Coastal Storm Modeling System

The San Diego region's exposure to future rates of sea level rise and storm events was evaluated using results from the CoSMoS 3.0 Phase 2 model. CoSMoS is a numerical model developed by the U.S. Geological Survey (2019) that integrates sea level rise, dynamic water levels (i.e., high tide, storm surge, sea level anomaly, and river discharge), and shoreline change to assess coastal flood risks (O'Neill et al. 2018). Using a series of nested hydrodynamic models, meter-scale predictions of storm-induced coastal flooding and erosion are available for existing and future climate scenarios across Southern California. Small-scale features, such as vertical seawalls, may not be captured in the model due to resolution of the topographic data used. In areas where these small-scale coastal structures were not captured, coastal flooding limits are likely overstated. A more detailed analysis of this structure would be needed to more accurately define the flood hazard zone in these areas. Such small-scale features, even if captured, are assumed to "hold-the-line" if present and degree of degradation is not considered. Additionally, CoSMoS data does not incorporate flooding and erosion impacts resulting from upland runoff and ground water groundwater seepage. Topographic data utilized within CoSMoS is an aggregate of many topographic surveys between the period of 2009 and 2011, and may not accurately reflect reflect existing conditions.

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[1] As a result of limited data available in CoSMoS, the selected scenarios in this analysis do not align exactly with recommended sea level rise projects by the OPC (2018). The 2.5 feet scenario is 0.5 feet greater than the year 2050, 0.5% probability scenario; and the 6.6 feet scenario is 0.4 feet less than the year 2100, 0.5% probability scenario.

Figure 2-1 Regional Transportation Assets in North San Diego County

Table 2-1. Selected Sea Level Rise and Storm Scenarios

		Storm Scenario	
		No Storm	**100-Year Storm**
Sea Level Rise Scenario	***2.5 feet*** *(0.75 meters)*	2.5-foot sea level rise + no storm	2.5-foot sea level rise + 100year storm
	6.6 feet *(2.0 meters)*	6.6-foot sea level rise + no storm	6.6-foot sea level rise + 100year storm

Due to the regional scope of this report, no new modelling has been performed to more accurately assess uncertainties in CoSMoS results. Instead, assets identified as vulnerable according to CoSMoS results are highlighted in order to draw the attention of local planning and public agencies. CoSMoS results for 2.5 feet and 6.6 feet of sea level rise along with the no storm and 100-year storm scenario represent inundation and coastal flood areas.[2] These hazard areas are described as follows:

Inundation Hazard Zone – The CoSMoS "no storm" flood hazard zone is used to illustrate the Inundation Hazard Zone. The term inundation will be used to describe areas of daily wetting and drying associated with a spring high tide.

Flood Hazard Zone[3] – The CoSMoS 100-year storm (i.e., one percent annual chance) flood hazard is used to illustrate the Flood Hazard Zone. Storm flooding events are typically short in duration (i.e., hours) and occur episodically. To conservatively capture the flood hazard zone, CoSMoS results incorporate the influence of extreme wave events, wave setup, strong winds, storm surge, significant precipitation (i.e., fluvial discharge), and spring high tide.Coastal flooding extents represent a minimum two-minute duration of flooding. Flooding resulting from stormwater is not considered. CoSMoS flood maps differ from FEMA flood maps in that FEMA 100-year maps are based on historical wave and flood data, whereas CoSMoS flooding is determined by projected future wave and flood events combined with sea level rise.

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[2] The analysis performed in this report solely utilizes CoSMoS storm flood hazard results and does not address other CoSMoS outputs such as cliff retreat projections or shoreline projections (i.e., coastal erosion estimates).

[3] Future wave conditions are based on hindcast and future-cast data, and tides were derived from the Oregon State University TOPEX/Poseidon global tide database. Sea level anomalies were also applied in the modeling. CoSMoS coastal flooding includes the effects of waves during storm events. Flooding extents are mapped at the intersection of the maximum two-minute sustained water level and landward position of the eroded beach profile.

2.2 Regional Transportation Infrastructure Vulnerability

The following vulnerability assessment identifies regional transportation assets located within the inundation hazard zone and/or flood hazard zone for 2.5-foot sea level rise and/or 6.6-foot sea level rise scenarios. For purposes of this report, regional transportation infrastructure is defined as any transportation asset that crosses jurisdictional boundaries. While other assets may be considered regionally significant, only those that meet this definition are included here. The assessment is broken into two planning zones: North San Diego County **(Figure 2-1)** and South San Diego County **(Figure 2-6)**. Regional transportation assets are subdivided into three categories: regional coastal roadways; coastal bikeways and trails, otherwise known as ATPs; and coastal transit, which includes the regional rail system and trolley lines. ATP assets were sourced from the San Diego County Department of Parks and Recreation-maintained SanGIS Regional Data warehouse. Only ATPs that crossed jurisdictional lines and were vulnerable to the selected sea level rise scenarios are included in the following analysis. The assessment is for assets in operation as of November 2019 and does not include planned, future projects.

For the purposes of roadway and railway bridge vulnerability, the term "soffit" is used to describe the underside of a bridge. Soffit wetting depth is used to describe the depth of water that is in contact with a bridge. Site photos of identified vulnerable assets are provided in **Appendix A**. A summary of jurisdictional vulnerability assessment results for transportation and their relationship to the below results is provided in **Appendix B.**

2.2.1 North San Diego County

For the purposes of this study, North San Diego County (North County) spans the coastal reach from the Santa Margarita River just north of the city of Oceanside to the Los Peñasquitos Lagoon in the city of San Diego. Inundation and flood hazard maps of 2.5-foot and 6.6-foot sea level rise scenarios are provided from Oceanside to Encinitas in **Figure 2-2** and **Figure 2-3,** and from Encinitas to La Jolla in **Figure 2-4** and **Figure 2-5.** Each figure calls out specific assets and locations of vulnerabilities that correspond to a summary table in the sections that follow. All assets that are determined to be vulnerable are numbered from 1 to 28, beginning with the most northern asset; however, because not all assets are vulnerable to 2.5 feet of sea level rise, **Figure 2-2** and **Figure 2-4** show numbers out of sequence.

The following links provide an animation of the information included in Figures 2-2 through 2-5:

Figure 2-2. Inundation and Flood Hazards – Oceanside to Encinitas – 2.5 ft SLR

Figure 2-3. Inundation and Flood Hazards – Oceanside to Encinitas – 6.6 ft SLR

Figure 2-4. Inundation and Flood Hazards – Encinitas to San Diego – 2.5 ft SLR

Figure 2-5. Inundation and Flood Hazards – Encinitas to San Diego – 6.6 ft SLR

2.2.1.1 Roadways

Two major regional roadways occupy the coastal zone of North San Diego County: I-5 and Hwy 101. I-5 is the main north–south transportation route within San Diego County. It provides the most efficient roadway connection between coastal jurisdictions. Hwy 101 is a vital north–south transportation route along the coast of San Diego County. In many communities, it is the roadway located closest to the coast and, therefore, it provides views and access to the Pacific Ocean, local beaches, and surf spots. Roadway vulnerability to sea level rise is depicted in **Figures 2-2 to 2-5** and was included in previous analyses by Moffatt & Nichol (2013); these results are summarized in **Table 2-2.**

SOURCE: MOFFATT & NICHOL, 2019

Both I-5 and Hwy 101 are highly sensitive to flood hazards, as even minor amounts of flooding on roads can cause significant traffic delays and potentially disrupt emergency service vehicles and evacuation routes. Flooding of roadways and bridges increases the likelihood and costs of maintenance and repair. When the soffit of a bridge gets wet when water levels are high, bridge components become exposed to submersion by brackish water (freshwater/saltwater mix), potentially reaching and corroding reinforced steel. This can cause cracking and spalling of concrete and reduce the tension strength of the reinforced steel. When a bridge is subjected to flooding that is more extreme than it was designed for, it is likely that bridge abutment protection (e.g., rock revetments) will be submerged. This means that stormwater flows could erode loose fill material and structurally undermine the bridge and adjacent roadway. Most importantly, when the soffit is flooded, a bridge will begin to act like a dam and take on the horizontal loads (i.e., force) of downstream flows, as well as debris, which begins to amass on the upstream face. When water surface elevations reach the soffit, it is necessary to temporarily close the bridge. According to a recent study (Moffatt & Nichol 2013), bridges throughout the San Diego region vary in elevation, as do 100-year flood levels at individual lagoons; therefore, each bridge needs to be assessed for flooding vulnerabilities on an individual basis.

A total of three locations along I-5 were identified in North County as vulnerable to flood hazards. All vulnerable locations are associated with bridges over lagoons or creeks. Vulnerabilities identified generally included soffit flooding, which threatens the structural integrity of bridges. As previously stated, when the soffit is flooded, bridge closures may be necessary for public safety. Storm flooding events typically occur on the order of hours, which could lead to closures and significant delays on I-5. Few efficient detours are available to bypass I-5, with the nearest available roadway being Hwy 101, which is also anticipated to flood in many locations during similar storm conditions.

A total of eight locations along Hwy 101 in North County were identified as vulnerable. Similar to I-5, all vulnerable locations are associated with bridges over lagoons or creeks. Several areas were identified to experience soffit flooding at a minimum, threatening the structural capacity of the bridge and potentially causing roadway closures. Under both 2.5 feet of sea level rise and 6.6 feet of sea level rise, a 100-year storm could flood the Hwy 101 bridge decks at Loma Alta Creek, Buena Vista Lagoon, and San Dieguito Lagoon. Additionally, the roadway on both sides of the San Elijo Lagoon Bridge is also vulnerable to these scenarios. Flooding could cause travel delays, limit coastal access, and impair business districts located along Hwy 101.

Under 6.6 feet of sea level rise Agua Hedionda Lagoon becomes vulnerable to flooding. A more severe threat than short-term flooding would be daily inundation on Hwy 101 at Buena Vista Lagoon, Las Encinas Creek, and San Dieguito Lagoon. Daily inundation would cause near-permanent disruption to local coastal traffic and would have widespread effects on coastal access.

CLICK HERE to see animation of Inundation and Flood Hazards below

Figure 2-2. Inundation and Flood Hazards – Oceanside to Encinitas – 2.5 ft SLR

Note: Under 2.5 feet of sea level rise, CoSMoS flood results are not depicted in San Luis Rey River. However, flooding should be anticipated in this area so the maps were modified based on local knowledge to show a minimum anticipated flood extent equivalent to that of inundation. A site-specific analysis would be necessary to more accurately predict flooding in this area. Flooding is depicted in yellow on this map to clearly show the difference between flooding and daily inundation. In the animation, flooding is shown in blue.

Figure 2-3. Inundation and Flood Hazards – Oceanside to Encinitas – 6.6 ft SLR

CLICK HERE to see animation of Inundation and Flood Hazards below

Note: Although inundation/flooding is shown throughout creeks and lagoons, transportation asset water crossings are not necessarily vulnerable. See the report for a discussion of crossing elevations and water levels.

Note: Flooding is depicted in yellow on this map to clearly show the difference between flooding and daily inundation. In the animation, flooding is shown in blue.

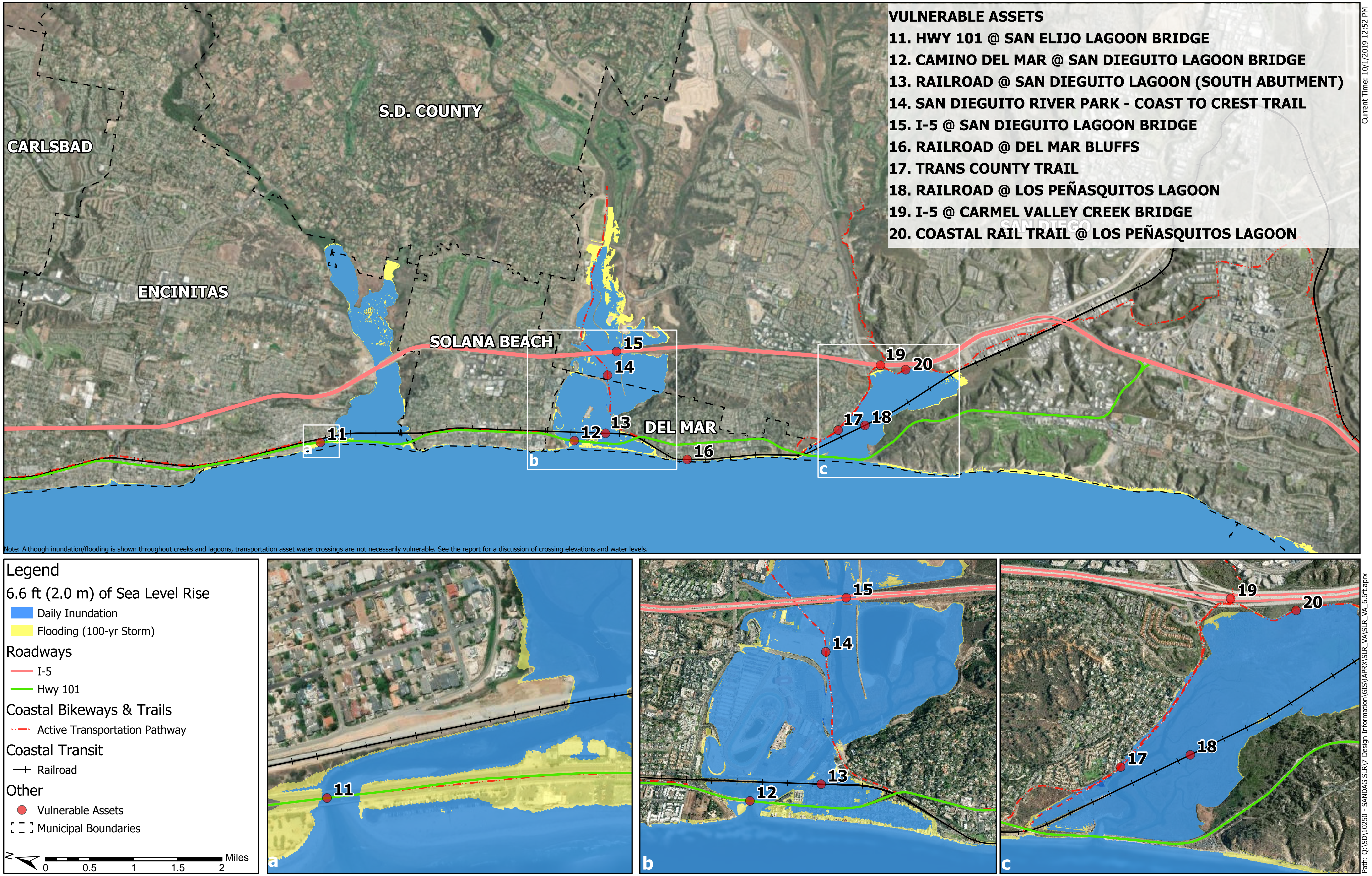
CLICK HERE to see animation of Inundation and Flood Hazards below

Figure 2-4. Inundation and Flood Hazards – Encinitas to San Diego – 2.5 ft SLR

Note: Flooding is depicted in yellow on this map to clearly show the difference between flooding and daily inundation. In the animation, flooding is shown in blue.

Figure 2-5. Inundation and Flood Hazards – Encinitas to San Diego – 6.6 ft SLR

CLICK HERE to see animation of Inundation and Flood Hazards below



Note: Flooding is depicted in yellow on this map to clearly show the difference between flooding and daily inundation. In the animation, flooding is shown in blue.

Table 2-2. North County – Roadway Asset Vulnerability

No.	Roadway Asset (North to South)	SLR Scenario (ft)	Hazard Type	Distance Impacted (lf)	Soffit Wetting Depth (ft)	Hazard Impacts
1	Hwy 101 @ San Luis Rey River	2.5	No hazard	0	0	No impact.
		6.6	Flooding	500	1.9	Soffit wetting would necessitate temporary highway closure, impacting local traffic and coastal access at Oceanside Harbor. Flooding, and wetting and drying, will threaten the bridge's structural integrity.
3	Hwy 101 @ Loma Alta Creek	2.5	Flooding	80[a]	5.8	It should be noted that this reach is currently vulnerable to 3.3 ft of soffit flooding during a 100-year storm. Soffit wetting would necessitate temporary highway closure, impacting local traffic and coastal access. Wetting, and wetting and drying, will threaten the bridge's structural integrity.
		6.6	Flooding	325	9.9	100-year storm flooding will temporarily close Hwy 101. Detour will route through I-5 and could create congestion for a short period (i.e., hours). Flooding, and wetting and drying, will threaten the bridge's structural integrity.
5	I-5 @ Buena Vista Lagoon Bridge	2.5	No hazard	0	0	No impact.
		6.6	Flooding	100	2.7	Soffit wetting would necessitate temporary highway closure, impacting regional traffic. Soffit wetting and drying will threaten the bridge's structural integrity.
6	Carlsbad Blvd @ Buena Vista Lagoon Bridge	2.5	No hazard	35[a]	5.4	It should be noted that this reach is currently vulnerable to 2.9 ft of soffit wetting during a 100-year storm. Soffit wetting would necessitate temporary roadway closure, impacting local traffic and coastal access. Soffit wetting and drying will threaten the bridge's structural integrity.
		6.6	Flooding and inundation	1,530	9.5	Daily inundation will cause regular lane closures and potentially permanent closure. The nearest detour is I-5. Flooding, and wetting and drying, will threaten the bridge's structural integrity.
8	Carlsbad Blvd @ Agua Hedionda Lagoon	2.5	No hazard	0	0	No impact
		6.6	Flooding	1,200	—[b]	Southbound and northbound roadway will be vulnerable to large wave events, temporarily interrupting the coastal
9	Carlsbad Blvd @ Las Encinas Creek	2.5	Flooding	50	—[b]	Southbound lane closures expected during storm conditions. Access to North Ponto Beach of South Carlsbad State Beach would be made difficult.
		6.6	Flooding and inundation	1,000	—[b]	Southbound roadway will be vulnerable to large wave events and potentially will experience daily wetting and drying. Northbound roadway is not vulnerable. Flooding, and wetting and drying, will threaten the bridge's structural integrity.
10	Carlsbad Blvd @ Batiquitos Lagoon Bridge	2.5	Flooding	0	0	No impact
		6.6	Flooding and inundation	350	4.5	Daily wetting and drying will limit access to South Carlsbad State Beach and the coastal roadway connection between Encinitas and Carlsbad. Nearest detour is I-5. Flooding, and wetting and drying, will threaten the bridge's structural integrity.
11	Hwy 101 @ San Elijo Lagoon Bridge	2.5	Flooding	190	—[c]	Temporary lane closure during high water level events anticipated for Hwy 101 northbound just south of Hwy 101 bridge.
		6.6	Flooding	1,700	3.9	Extensive flooding during high wave events anticipated north of the Hwy 101 bridge and south of the bridge in vicinity of all businesses. Soffit wetting would potentially necessitate bridge closure and limit access to Restaurant Row and Cardiff Beach State Park. Flooding, and wetting and drying, will threaten the bridge's structural integrity.
15	I-5 @ San Dieguito Lagoon Bridge	2.5	Flooding	600	1.8	Soffit wetting would necessitate temporary highway closure, impacting regional traffic. Soffit wetting and drying will threaten the bridge's structural integrity. Roadway closure would limit access to the City of Solana Beach.
		6.6	Flooding	600	5.9	Soffit wetting would necessitate temporary highway closure, impacting regional traffic. Soffit wetting and drying will threaten the bridge's structural integrity.
12	Camino Del Mar @ San Dieguito Lagoon Bridge	2.5	Flooding	40	9.3	100-year storm flooding threatens the roadway at the bridge and bridge entrance abutments, necessitating roadway closure. It should be noted that this reach is currently vulnerable to 6.8 ft of soffit wetting during a 100-year storm. Flooding, and wetting and drying, will threaten the bridge's structural integrity. Roadway closure would limit access to the City of Solana Beach.
		6.6	Flooding and inundation	2,240	13.4	Daily inundation and storm flooding threaten bridge abutments and Camino Del Mar throughout the residential neighborhood. Regular disruption of transportation between Solana Beach and Del Mar. Soffit wetting and drying will threaten the bridge's structural integrity.
19	I-5 @ Carmel Valley Creek Bridge	2.5	Flooding	—[b]	3.0	Soffit wetting would necessitate temporary highway closure, impacting regional traffic. Flooding, and wetting and drying, will threaten the bridge's structural integrity. It should be noted that this reach is currently vulnerable to 0.5 ft of soffit flooding during a 100-year storm. Roadway closure would limit access to the City of Del Mar.
		6.6	Flooding	—[b]	7.1	Soffit wetting would necessitate temporary highway closure, impacting regional traffic. Soffit wetting and drying will threaten the bridge's structural integrity.

SLR = sea level rise; **ft** = feet; **lf** = linear feet; **Hwy 101** = Pacific Coast Highway 101;; **I** = Interstate.

[a] Roadway surface was not flooded; however, soffit wetting could trigger bridge closure.

[b] Soffit wetting depth is either not applicable, or not enough information was available to quantitatively assess; for example, no soffit elevation may be readily available.

[c] Although this asset is not expected to flood, adjacent roadway flooding could occur.

1 mile = 5,280 feet

2.2.1.2 Bikeways and Trails

Five ATPs are vulnerable to sea level rise according to the mapping analysis **(Table 2-3)**. Under 2.5 feet of sea level rise, the San Luis Rey Bike Path, San Dieguito River Park-Coast to Crest Trail, and Trans County Trail are all vulnerable to daily inundation.Daily inundation will limit use of these bikeways and trails in the coastal region for portions of each day and the period of disrupted use will only increase under higher sea level rise scenarios. Furthermore, daily inundation will cause regular wetting and drying of pathway-related infrastructure. Under 6.6 feet of sea level rise, the Coastal Rail Trail becomes vulnerable to flooding and inundation at Loma Alta Creek. Loose dirt pathways are vulnerable to scour from moving water, and wooden structures are vulnerable to rot from regular wetting. Maintenance of coastal ATP is anticipated to become more frequent and increasingly expensive under more severe sea level rise scenarios.

2.2.1.3 Transit

The regional coastal transit route in North County is a portion of the LOSSAN rail corridor, which extends from the city of Oceanside to the city of San Diego downtown area. Train operations on the line within San Diego County include Amtrak's Pacific Surfliner, the Southern California Regional Rail Authority's Metrolink, and the North County Transit District's COASTER and SPRINTER passenger rail services, and Union Pacific and BNSF Railway freight rail services. From this study's mapping analyses and Moffatt and Nichol's (2013) regional bridge assessments, four railway locations were identified as vulnerable to sea level rise **(Table 2-4)**. Similar to roadway bridge sensitivity, when a railway bridge soffit is flooded, it will begin to act like a dam and take on the horizontal loads (i.e., force) of storm flows and debris. When water surface elevations reach the soffit, it may be necessary

Table 2-3. North County – ATP Asset Vulnerability

No.	ATP Asset	SLR Scenario (ft)	Hazard Type	Distance Impacted (lf)	Hazard Impacts
2	San Luis Rey Bike Path	2.5	Inundation	2,100	Daily wetting and drying at the pathway between I-5 and Hwy 101, disrupting the connection from upland to coast.
		6.6	Flooding and inundation	2,170	Daily wetting and drying at the pathway between I-5 and Hwy 101, disrupting the connection from upland to coast.
4	Coastal Rail Trail @ Loma Alta Creek	2.5	No hazard	0	No impact
		6.6	Flooding and inundation	750	Daily wetting and drying of the pathway along S Pacific St will limit access to Buccaneer Beach Park.
14	San Dieguito River Park – Coast to Crest Trail	2.5	Flooding and inundation	8,220	Daily wetting and drying of large stretches of the pathway will limit access at the Del Mar Fairgrounds and east to Fairbanks Ranch Country Club.
		6.6	Flooding and inundation	10,300	Daily wetting and drying of large stretches of the pathway will limit access at the Del Mar Fairgrounds and east to Fairbanks Ranch Country Club.
17	Trans County Trail	2.5	Flooding and inundation	1,360	Adjacent to Carmel Valley Rd, daily inundation of isolated locations will require repair or adaptation. Larger reaches of the path will be inaccessible during 100-year storm conditions.
		6.6	Flooding and inundation	4,980	Adjacent to Carmel Valley Rd, daily wetting and drying will likely cause permanent closure of the trail west of I-5.
20	San Dieguito River Park – Coast to Crest Trail	2.5	No hazard	0	No impact
		6.6	Flooding and inundation	3,100	Daily wetting and drying of the pathway along the east shore of the lagoon will disrupt pedestrian access entering Del Mar from San Diego.

ATP = active transportation pathway; **SLR** = sea level rise; **ft** = feet; **lf** = linear feet;
Hwy 101 = Pacific Coast Highway 101; **I** = Interstate.

1 mile = 5,280 feet

Table 2-4. North County – Transit Asset Vulnerability

No.	Transit Asset	SLR Scenario (ft)	Hazard Type	Distance Impacted (lf)	Soffit Wetting Depth (ft)	Hazard Impacts
7	Railroad @ Buena Vista Lagoon Bridge	2.5	Flooding	0	2.4	Soffit wetting would necessitate temporary railway closure, impacting regional transit. Wetting and drying of the bridge could cause damage and require maintenance and repair.
		6.6	Flooding	—[a]	6.5	Soffit wetting would necessitate temporary railway closure, impacting regional transit. Wetting and drying of the bridge could cause damage and require maintenance and repair.
13	Railroad @ San Dieguito Lagoon (South Abutment)	2.5	Flooding	20	6.9	Soffit wetting would necessitate temporary railway closure, impacting regional transit. It should be noted that this reach is currently vulnerable to 4.4 ft of soffit wetting during a 100-year storm.
		6.6	Flooding and inundation	2,630	11.0	Daily function of the COASTER will be disrupted by daily wetting and drying. Rail transit from city of San Diego to North County may be terminated.
18	Railroad @ Los Peñasquitos Lagoon	2.5	Flooding	—[a]	3.1	Soffit wetting would necessitate temporary railway closure, impacting regional transit. It should be noted that this reach is currently vulnerable to 1.7 ft of soffit wetting during a 100-year storm.
		6.6	Flooding	—[a]	7.1	Soffit wetting would necessitate temporary railway closure, impacting regional transit. Wetting and drying of the bridge could cause damage and require maintenance and repair.
16	Railroad @ Del Mar Bluffs	2.5	Bluff retreat	440	—[b]	Storm-induced vulnerabilities may occur in the areas of Seagrove Park and Little Orphan Alley. The railroad is not vulnerable to flooding; however, storm wave impacts will potentially cause bluff failure and railroad undermining.
		6.6	Bluff retreat	2,410	—[b]	Sea level rise and storm-induced bluff erosion threatens large reaches of the railroad along central Del Mar.

SLR = sea level rise; **ft** = feet; **lf** = linear feet.

[a] Not enough information was available for a quantitative assessment.

[b] Soffit wetting depth is either not applicable, or not enough information was available to quantitatively assess; for example, no soffit elevation may be readily available.

1 mile = 5,280 feet

to temporarily close the bridge at the discretion of the owner. In railway engineering, railroad elevation is typically referenced as the elevation of the rail and ballast; however, for this study, the bridge soffit elevation is used as the railroad elevation of interest because it is the first component to interact with the water surface. Sea level rise vulnerability is unique for railways because detour options depend upon the bus transfer network, and temporary closures may affect large populations.

Under 2.5 feet of sea level rise and a 100-year storm, the railroad could experience flooding at four locations: Buena Vista Lagoon, San Dieguito Lagoon, Del Mar Bluffs, and Los Peñasquitos Lagoon. Under 6.6 feet of sea level rise and a 100-year storm, these locations would experience exacerbated flooding. Flooding at these locations would necessitate temporary regional railway closure for several hours, affecting commuters and visitors. Additionally, flooding of railway bridges threatens the longevity of these structures, which would potentially experience corrosion of reinforced steel. This can cause cracking and spalling of concrete and reduce the tension strength of the reinforced steel. Additionally, storm flows could wash out rock and gravel material used to protect and support the rail.

Under 6.6 feet of sea level rise, the railroad is vulnerable to daily inundation at the San Dieguito Lagoon and increasingly vulnerable to bluff retreat at the Del Mar Bluffs. Note that the vulnerability assessment maps depict flooding at the Del Mar Bluffs and not bluff retreat. However, due to the high elevation of the railway, the flood layer is interpreted to extend beneath the railway, implying that bluff retreat must therefore have occurred to make space for water to penetrate. The most severe inundation at the San Dieguito Lagoon would terminate railway access between the city of San Diego and North County. Major renovations of the rail in the city of Del Mar would be necessary to protect railway functioning throughout the region under 6.6 feet of sea level rise.

2.2.2 South San Diego County

For the purposes of this study, South San Diego County (South County) spans the coastal reach from Los Peñasquitos Lagoon in San Diego south to Imperial Beach, at the U.S./Mexico border. Inundation and flood hazard maps of 2.5-foot and 6.6-foot sea level rise scenarios are provided for La Jolla to downtown San Diego in **Figures 2-7 and 2-8** and for downtown San Diego to Imperial Beach in **Figures 2-9 and 2-10**. Each figure calls out specific assets and locations of vulnerabilities that correspond to a summary table of vulnerability in the sections that follow.

It is important to note that the transit at and south of the Old Town Transit Center is shown as flooded under 6.6 feet of sea level rise. For various reasons, this might be an example of where site-specific analyses would be useful. The Old Town Transit Center is an important part of the regional transportation network because the Green Line Trolley and the railroad both pass through it and may be affected. Additionally, access to the San Diego International Airport by local roadways such as North Harbor Drive may warrant site specific analysis.

Figure 2-6. Regional Transportation Assets in South San Diego County

Table 2-5. South County – Roadway Asset Vulnerability

No.	Roadway Asset	SLR Scenario (ft)	Hazard Type	Distance Impacted (lf)	Hazard Impacts
30	SR-75	2.5	Flooding	18,920 (approx. 3.6 mi)	Three large stretches of both the northbound and southbound SR-75 are vulnerable to lane closures during a 100-year storm. Access from Imperial Beach to Coronado will be temporarily disrupted, significantly impacting operations at U.S. Naval Bases. Flooding typically comes from the San Diego Bay side.
		6.6	Flooding and inundation	34,600 (approx. 6.6 mi)	The majority of SR-75 is vulnerable to daily wetting and drying, stemming from San Diego Bay.

SLR = sea level rise; **ft** = feet; **lf** = linear feet; **SR** = State Route; **mi** = miles.

1 mile = 5,280 feet

2.2.2.1 Roadways

Roadway vulnerability to sea level rise was assessed for South County and is summarized in **Table 2-5**. One regional roadway, SR-75 was identified as vulnerable. SR-75 is an integral link between the cities of Imperial Beach and Coronado, with the only available detour being an extensive trip through the cities of San Diego, National City, and Chula Vista. SR-75 not only connects two communities, but it also provides vital transportation to several U.S. Naval facilites, including Naval Air Station North Island, Naval Amphibious Base Coronado, and Naval Outlying Landing Field. Although storm waves and coastal erosion could eventually encroach on SR-75 through Silver Strand State Beach under both 2.5-foot and 6.6-foot sea level rise scenarios, SR-75 is more vulnerable to flooding from the San Diego Bay side, where existing land elevations are the lowest. Flooding from a 100-year storm would cause lane closures, and potentially temporary closure of the roadway, eliminating access from Imperial Beach to both Coronado and the U.S. Naval bases. Under 6.6 feet of sea level rise, daily inundation is expected to regularly disrupt roadway travel. Adaptive measures would be required to ensure access to Naval facilities, Silver Strand State Beach, and neighboring communities.

2.2.2.2 Bikeways and Trails

Six ATPs are vulnerable to sea level rise according to the above mapping analysis **(Table 2-6)**. Under 2.5 feet of sea level rise, the North Harbor Drive Bike Path is vulnerable to flooding, and the Embarcadero Bike Path, Sweetwater Loop and River Trail, and Bayshore Bikeway are all vulnerable to flooding and inundation. Under 6.6 feet of sea level rise, all the above ATPs are more vulnerable to inundation, and the Coastal Rail Trail and Ocean Beach Bike Path also become vulnerable at the southern and seaward ends, respectively. It should be noted that the North Harbor Drive Bike Path and Embarcadero Bike Path are connected and make up a segment of the broader California Coast Trail. The Ocean Beach Bike Path is part of the San Diego River Trail network.

Flooding and daily inundation will limit use of these bikeways and trails in the coastal region for portions of each day. As a result, almost all public bikeways and trails along the San Diego River and San Diego Bay will become dysfunctional, with limited coastal public water access and more frequent and expensive maintenance and repair events. Loose dirt pathways are vulnerable to scour from moving water, and wooden structures are vulnerable to rot from regular wetting. The time period of disrupted use will only lengthen under higher sea level rise scenarios, such as 6.6 feet of sea level rise.

2.2.2.3 Transit

The regional coastal transit routes in South County include the railway line traveling through the San Diego region and trolley lines throughout the city of San Diego. Mapping analysis identified the Green,

CLICK HERE to see animation of Inundation and Flood Hazards below

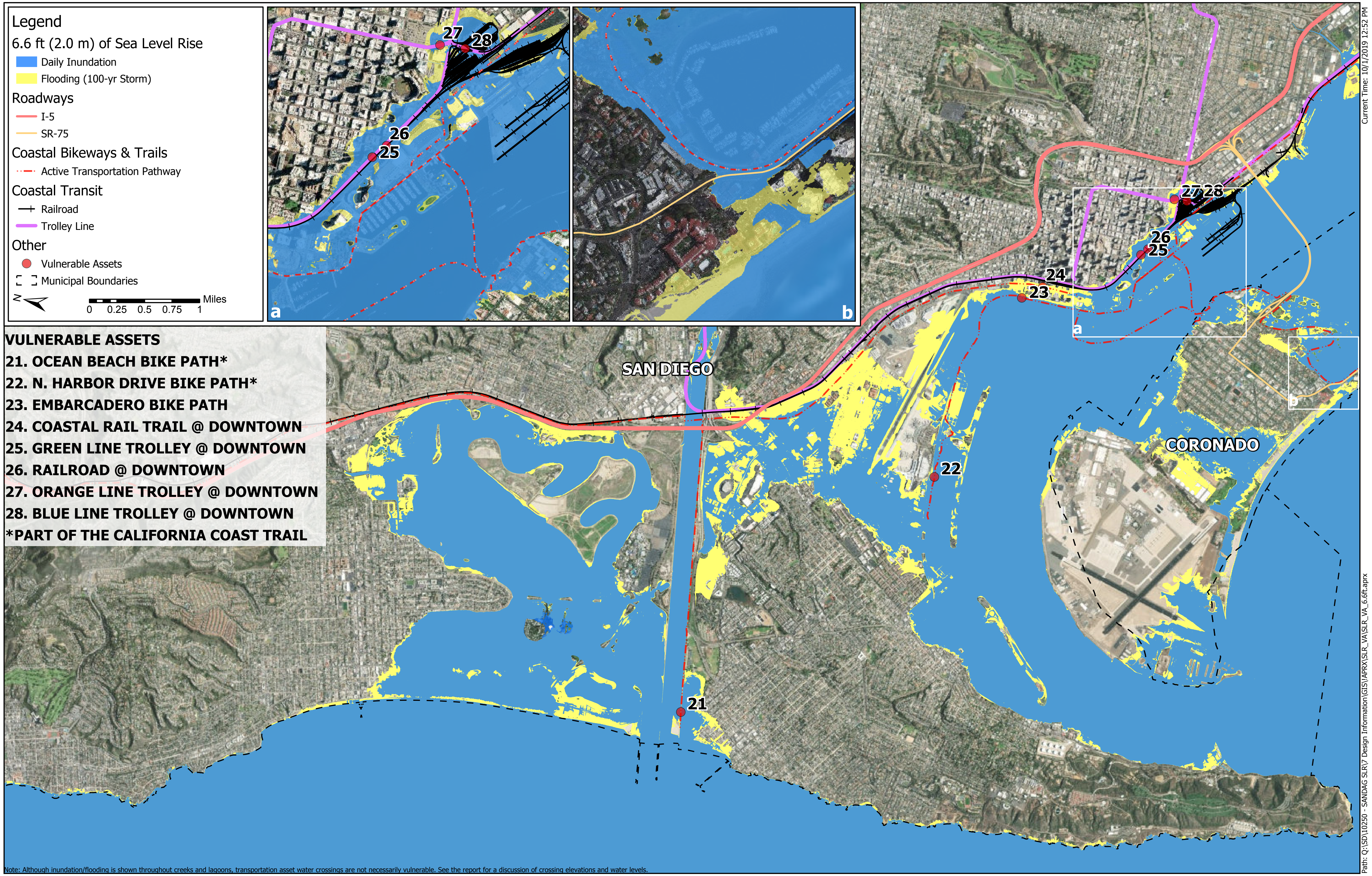
Figure 2-7. Inundation and Flood Hazards – San Diego – 2.5 ft SLR

Note: Although inundation/flooding is shown throughout creeks and lagoons, transportation asset water crossings are not necessarily vulnerable. See the report for a discussion of crossing elevations and water levels.

Note: Flooding is depicted in yellow on this map to clearly show the difference between flooding and daily inundation. In the animation, flooding is shown in blue.

CLICK HERE to see animation of Inundation and Flood Hazards below

Figure 2-8. Inundation and Flood Hazards – San Diego – 6.6 ft SLR



VULNERABLE ASSETS
21. OCEAN BEACH BIKE PATH*
22. N. HARBOR DRIVE BIKE PATH*
23. EMBARCADERO BIKE PATH
24. COASTAL RAIL TRAIL @ DOWNTOWN
25. GREEN LINE TROLLEY @ DOWNTOWN
26. RAILROAD @ DOWNTOWN
27. ORANGE LINE TROLLEY @ DOWNTOWN
28. BLUE LINE TROLLEY @ DOWNTOWN
*PART OF THE CALIFORNIA COAST TRAIL

Note: Although inundation/flooding is shown throughout creeks and lagoons, transportation asset water crossings are not necessarily vulnerable. See the report for a discussion of crossing elevations and water levels.

Note: Flooding is depicted in yellow on this map to clearly show the difference between flooding and daily inundation. In the animation, flooding is shown in blue.

Figure 2-9. Inundation and Flood Hazards – San Diego to Imperial Beach – 2.5 ft SLR

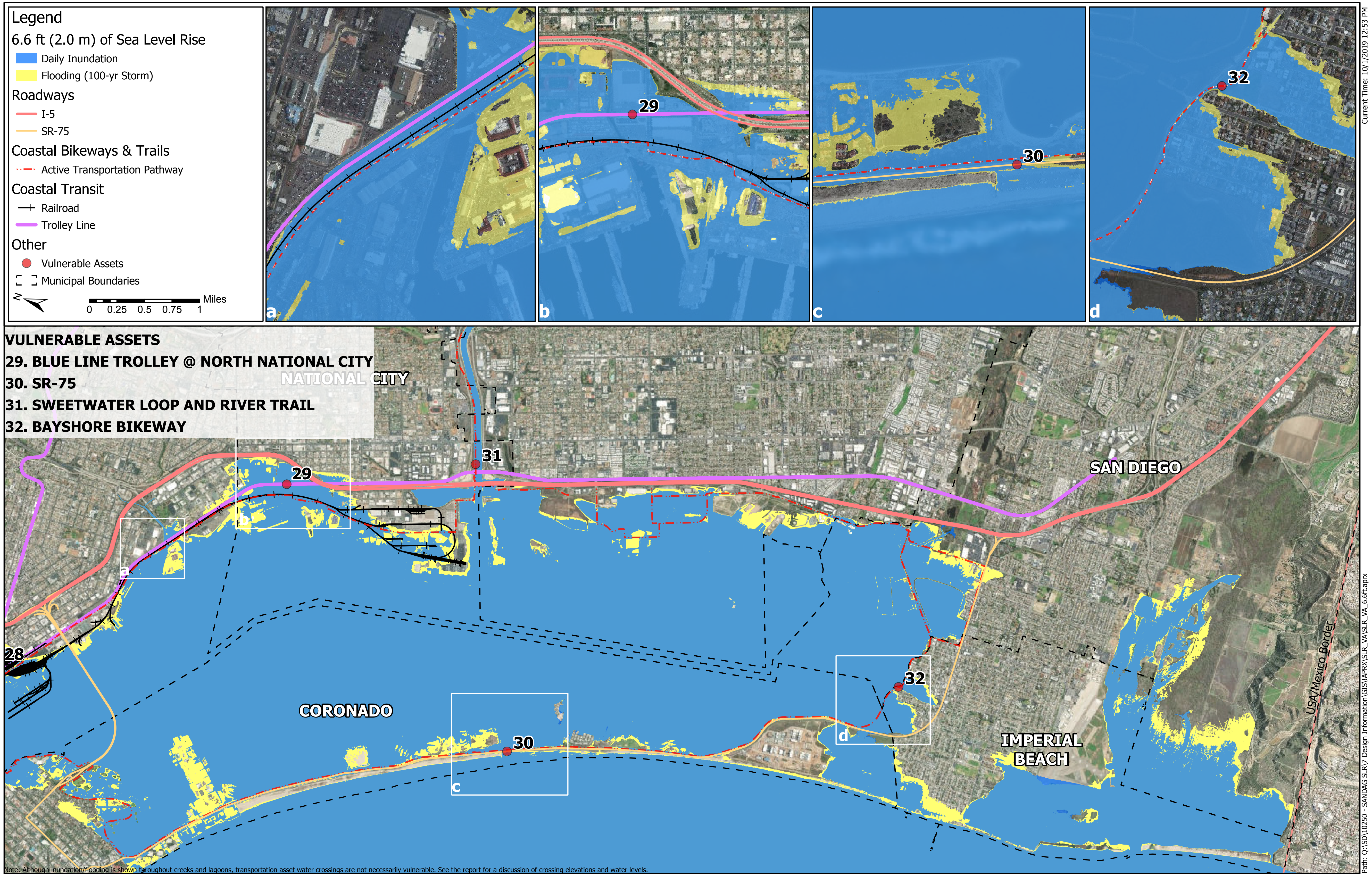
CLICK HERE to see animation of Inundation and Flood Hazards below

Note: Although inundation/flooding is shown throughout creeks and lagoons, transportation asset water crossings are not necessarily vulnerable. See the report for a discussion of crossing elevations and water levels.

Note: Flooding is depicted in yellow on this map to clearly show the difference between flooding and daily inundation. In the animation, flooding is shown in blue.

Figure 2-10. Inundation and Flood Hazards – San Diego to Imperial Beach – 6.6 ft SLR

CLICK HERE to see animation of Inundation and Flood Hazards below



Note: Although inundation/flooding is shown throughout creeks and lagoons, transportation asset water crossings are not necessarily vulnerable. See the report for a discussion of crossing elevations and water levels.

Current Time: 10/1/2019 12:53 PM

Path: Q:\SD\10250 - SANDAG SLR\7 Design Information\GIS\APRX\SLR_VA\SLR_VA_6.6ft.aprx

Note: Flooding is depicted in yellow on this map to clearly show the difference between flooding and daily inundation. In the animation, flooding is shown in blue.

Orange, and Blue Line Trolley routes to be vulnerable in the areas of downtown San Diego and north National City (**Table 2-7**).

The Green Line Trolley is vulnerable to flooding at the Seaport Village and Convention Center under 2.5 feet of sea level rise and additionally vulnerable to inundation at the MTS Trolley Plaza under 6.6 feet of sea level rise. Flooding threatens to temporarily shut down the Green Line, as flooding events typically occur on the order of several hours. Inundation of the Green Line threatens to permanently close this public transportation asset. The Green Line is a significant mode of transportation for both San Diego residents and visitors, as this route provides access to many popular areas of town, including the Embarcadero and the Convention Center.

The Orange Line and Blue Line Trolley routes are vulnerable to flooding and inundation at 6.6 feet of sea level rise specifically at the MTS Trolley Plaza in downtown San Diego. Daily inundation of these lines threatens to permanently close use in this area, affecting trolley use from El Cajon to downtown San Diego, and from Tijuana, Mexico, to downtown San Diego.

The Blue Line Trolley is additionally vulnerable to flooding under 2.5 feet of sea level rise and inundation under 6.6 feet of sea level rise in North National City. Flooding threatens to temporarily shut down the Blue Line for up to several hours. Daily inundation of the Blue Line would threaten to permanently close this public transportation asset. The Blue Line is used by South County residents, as well as both visitors and commuters from Mexico, to travel to downtown San Diego. Loss of this asset could have wide-ranging implications, including loss of access to employment and/or the amenities and public centers of San Diego.

Table 2-6. South County – ATP Asset Vulnerability

No.	ATP Asset	SLR Scenario (ft)	Hazard Type	Distance Impacted (lf)	Hazard Impacts
21	**Ocean Beach Bike Path - San Diego River Trail**	2.5	No hazard	0	No impact.
		6.6	Flooding	1,000	Temporary disruption for a small section of the pathway could occur during 100-year storm conditions. Minimal functional impact is anticipated.
22	**N. Harbor Drive Bike Path - California Coastal Trail**	2.5	Flooding	510	Flooding at Spanish Landing Park will limit access in isolated locations during a 100-year storm.
		6.6	Flooding and inundation	4,450	Daily wetting and drying will render the pathway no longer functional, eliminating access to the waterfront and San Diego International Airport.
23	**Embarcadero Bike Path - California Coastal Trail**	2.5	Flooding and inundation	3,410	Flooding and inundation north of San Diego County Administration Building will disrupt waterfront access.
		6.6	Flooding and inundation	11,000 (approx. 2.1 mi)	Almost the entire pathway is vulnerable to daily wetting and drying. The pathway will no longer be functional.
24	**Coastal Rail Trail @ Downtown**	2.5	No hazard	0	No impact.
		6.6	Flooding and inundation	3,420	Daily wetting and drying will impact the southern start/finish of the pathway along Pacific Hwy, impacting access to San Diego Waterfront Park.
31	**Sweetwater Loop and River Trail**	2.5	Flooding and inundation	530	A short reach of the pathway will be threatened just east of I-5, reducing the accessibility of inland recreation to San Diego Bay.
		6.6	Flooding and inundation	800	A short reach of the pathway will be threatened just east of I-5, reducing the accessibility of inland recreation to San Diego Bay.
32	**Bayshore Bikeway**	2.5	Flooding and inundation	48,650 (approx. 9.2 mi)	Large reaches of the pathway will be affected by daily wetting and drying and intense flooding during storm conditions. Disconnected sections of the trail will still be accessible.
		6.6	Flooding and inundation	104,660 (approx. 19.8 mi)	The majority of the pathway will become inaccessible due to daily wetting and drying.

SLR = sea level rise; **ft** = feet; **lf** = linear feet; **SR** = State Route; **mi** = miles; **I** = Interstate.

1 mile = 5,280 feet

Table 2-7. South County – Transit Asset Vulnerability

No.	Transit Asset	SLR Scenario (ft)	Hazard Type	Distance Impacted (lf)	Hazard Impacts
26	**Railroad @ Downtown**	2.5	Flooding	4,960	Temporary flooding of the railroad downtown along Harbor Drive at the San Diego Convention Center. This major business and tourist district would be temporarily disrupted.
		6.6	Flooding and inundation	6,700 (approx. 1.3 mi)	Daily wetting and drying will likely permanently close railroad access along Harbor Drive at the San Diego Convention Center.
25	**Green Line Trolley @ Downtown**	2.5	Flooding	4,960	Temporary flooding of downtown trolley along Harbor Drive at the San Diego Convention Center. This major business and tourist district would be temporarily disrupted.
		6.6	Flooding and inundation	6,700 (approx. 1.3 mi)	Daily wetting and drying will likely permanently close Green Line access along Harbor Drive, the San Diego Convention Center, and MTS Trolley Plaza.
27	**Orange Line Trolley @ Downtown**	2.5	No hazard	0	No impact.
		6.6	Flooding and inundation	1,400	Daily wetting and drying will likely permanently close Orange Line access in the area of the MTS Trolley Plaza downtown.
28	**Blue Line Trolley @ Downtown**	2.5	No hazard	0	No impact.
		6.6	Flooding and inundation	2,430	Daily wetting and drying will likely permanently close Blue Line access in the area of the MTS Trolley Plaza downtown, eliminating trolley access to Tijuana.
29	**Blue Line Trolley @ North National City**	2.5	Flooding	3,330	Vulnerable at North National City to 100-year storm conditions, temporarily disrupting access from Tijuana to Downtown San Diego.
		6.6	Flooding and inundation	13,760 (approx. 2.6 mi)	Daily wetting and drying will likely permanently close the Blue Line south of downtown San Diego, eliminating trolley access to Tijuana.

SLR = sea level rise; **ft** = feet; **lf** = linear feet; **MTS** = Metropolitan Transit System.

1 mile = 5,280 feet

2.3 Vulnerability Assessment Scoring Tool

This section uses the **Vulnerability Assessment Scoring Tool (VAST)**, developed by the U.S. Department of Transportation, to quantitatively evaluate the vulnerability of select regional transportation assets in the San Diego region to the impacts of sea level rise. VAST can also be used to evaluate risks to transportation facilities from other climate stressors such as changes in precipitation and temperature. A primary goal of this pilot VAST analysis is to determine the usefulness of the tool for future vulnerability assessments. Because of this pilot study goal, VAST analysis was not performed on all vulnerable regional transportation infrastructure. In order to identify which six assets would be evaluated in phase 1, the project team surveyed local jurisdictional leaders during SANDAG's October 2018 SPWG meeting. The working group members were presented with a list of transportation assets which were identified as vulnerable in CoSMoS 3.0 for the 50cm (1.6ft) and 150cm (4.6 ft) of sea level rise scenarios. From that list, the working group members identified which assets were of greatest concern; the assets that received the most responses were carried forward for this VAST analysis and are listed below. VAST was applied to three different types of transportation including roadways, railways, and bikeways/pedestrian trails.

After the Phase 1 analyses were completed, SANDAG used VAST to further explore the tool's functionality at evaluating impacts to individual roadways at various reaches. As such, SANDAG began a Phase 2 effort to evaluate impacts along the full reaches of Coast Hwy 101 in North County and SR-75 in South County. The regional roadway assets evaluated in Phase 2 are listed below. Due to the slight difference between the regional transportation focus of Phase 1 and the regional roadway focus of Phase 2, results of the two phases are not directly comparable and should be considered as independent analyses.

PHASE 1

Analyses of SPWG Selected Assets

Roadways

- Carlsbad Boulevard at Las Encinas Creek
- SR-75 at the Silver Strand

Transit

- Railroad at Del Mar Bluffs
- Green Line Trolley

Bikeways and Trails

- San Luis Rey Bike Trail
- Bayshore Bikeway

PHASE 2

Analyses of Regional Roadways (coast Hwy 101 and SR-75)

Coast Hwy 101

- San Luis Rey River
- Loma Alta Creek
- Buena Vista Lagoon
- Agua Hedionda Lagoon
- Las Encinas Creek
- Batiquitos Lagoon
- San Elijo Lagoon
- Camino Del Mar
- Torrey Pines

SR-75

- Glorietta Bay
- Fiddler's Cove
- Coronado Cays

VAST PROCESS

The VAST process to quantify asset vulnerability on a scale of 1 to 4 (low to high)s summarized in the steps below and depicted on Figure 2-11:

1 Select Climate Stressors

- Sea level rise (2.5-foot and 6.6-foot scenarios and a 100-year storm)

2 Select Asset Type

- Regional transportation assets (roadways, transit, bikeways, and trails)

3 Identify Exposure Characteristics and Gather Data

- Elevation of asset
- Length of impacted asset

4 Identify Sensitivity Characteristics and Gather Data

- Degree of historical flooding
- Presence of coastal flood protection
- Impaired access to critical facilities
- Disruption duration

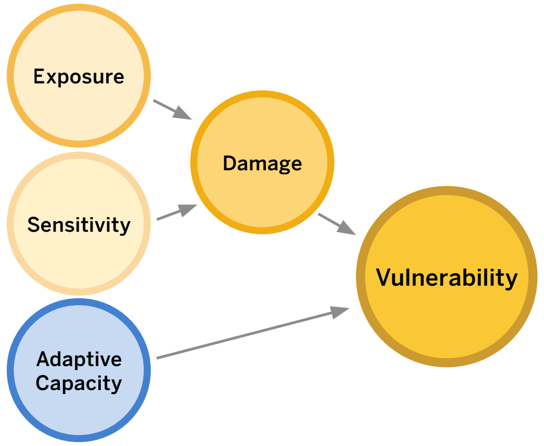
5 Identify Adaptive Capacity Characteristics and Gather Data

- Detour length
- Annual average daily traffic (AADT)
- Feasibility of adaptation

6 Calculate Damage and Vulnerability

- Exposure + sensitivity = damage
- Damage + adaptive capacity = vulnerability

Figure 2-11. VAST Framework



VAST operates in a Microsoft Excel workbook. Characteristics and data that populate the exposure, sensitivity, and adaptive capacity fields were determined using recommendations made by the VAST guidelines and modified when necessary using the best judgment of the project team. All data were used to create a score, which was weighted according to significance and used to calculate vulnerability. For example, the length of an impacted asset was the primary data input to determine Exposure. Certain lengths of impact were given exposure scores as follows:

EXPOSURE SCORE	
Linear feet of Impact	Score
0	NE
0 to 50	1
50 to 1000	2
1000 to 10,000	3
>10,000	4

NE Not evaluated (i.e., no exposure)

Several assumptions were necessary to identify certain vulnerabilities. For example, access to critical facilities was roughly defined to include, but not be limited to, roads which provide access to hospitals, police stations, city halls, naval infrastructure, and other vital public assets. However, critical facility access could be otherwise defined depending on the scope of a project, such as a railway or highway's critical function for shipping. Additionally, VAST analysis does not incorporate considerations of social impacts including environmental justice concerns. Further details regarding data assumptions and sources can be found in the full exported VAST analysis provided in Appendix C to this guidance document. Indicators of vulnerability within exposure, sensitivity, and adaptive capacity are weighted according to approximate degree of significance, as shown in Appendix C.

2.3.1 Results

Using data-driven analyses, the following three subsets of vulnerability were evaluated: exposure (results presented in **Table 2-8**), sensitivity (results presented in **Table 2-9**), and adaptive capacity (results presented in **Table 2-10**). The following narrative describes the considerations and results for the three subsets of vulnerability.

2.3.1.1 Exposure

Phase 1: SPWG Selected Assets

The exposure analysis determines whether an asset will experience a given stressor. The exposure of each asset was approximated for two sea level rise scenarios (2.5 feet and 6.6 feet) and 100-year storm impacts. Two characteristics were used to identify exposure: elevation of the asset and length of the impacted asset. Greater influence was given to the length of impacted asset in calculating exposure. Length of impacted asset was derived from Section 2.2. Under 2.5 feet of sea level rise, the Bayshore Bikeway was found to be most exposed, followed by SR-75, the Green Line Trolley, San Luis Rey Bike Trail, the portion of the Railroad at the Del Mar Bluffs, and, finally, Carlsbad Boulevard at Las Encinas Creek.

The Bayshore Bikeway was considerably impacted by sea level rise, with up to 104,660 linear feet (20 miles) directly exposed to flooding and inundation. It is important to note that portions of the Bayshore Bikeway occupy local roads within the cities of Imperial Beach and Chula Vista. Adjacent to the Silver Strand section of the Bayshore Bikeway is SR-75, the second most exposed asset, with up to 34,600 linear feet (6.6 miles) of exposed roadway.

The Bayshore Bikeway and SR-75 also have the lowest elevations of the transportation assets included in VAST, approximately 8.2 feet NAVD88 and 9.5 feet NAVD88, respectively. Low elevation increases an asset's exposure to sea level rise. The low elevations of the Green Line Trolley and San Luis Rey Bike Trail expose them to sea level rise under the low 2.5-foot sea level rise scenario. It is important to note that the Railroad at Del Mar along the bluff area is at a high elevation (approximately 48.4 feet NAVD88) but is still exposed to sea level rise through the potential of bluff erosion. For instance, Del Mar Bluffs experienced four significant collapses in 2018 (Lee, pers. comm. 2019). Further detail of Railroad exposure at the Del Mar Bluffs was evaluated in the Del Mar Sea Level Rise Vulnerability Assessment (ESA 2016), which is summarized in Appendix B.

Phase 2: Regional Roadways (Coast Hwy 101 & SR-75)

As described above, the exposure of each of these roadways was estimated for two sea level rise scenarios (2.5 feet and 6.6 feet) and 100-year storm impacts. Exposure was determined by analyzing the elevation of the asset and the length of the impacted asset. Greater influence was given to the length of each impacted asset in calculating exposure. Length of impacted asset was derived from Section 2.2. Under 2.5 and 6.6 feet of sea level rise, the Loma Alta Creek Bridge, San Dieguito Lagoon Bridge, and each segment of SR-75 were found to be equally exposed.

As shown in **Table 2-8**, the greatest levels of exposure along Hwy 101 in North County for all conditions, assuming scores of 1.2 and above, were found at the following locations:

GREATEST LEVEL OF EXPOSURE

- Loma Alta Creek
- Buena Vista Lagoon
- Agua Hedionda Lagoon
- San Elijo Lagoon
- Camino Del Mar

The reaches of SR-75 in South County (Glorietta Bay, Fiddler's Cove and Coronado Cays) were equally exposed during both sea level rise scenarios, and these reaches were more exposed than Hwy 101 in North County.

Table 2-8. Asset Exposure

Exposure			Sea Level Rise									
			2.5 ft		6.6 ft		2.5ft		6.6 ft		2.5 ft	6.6 ft
			Elevation of Asset				Length of Impacted Asset				Exposure Scores	
	Asset ID	Asset Name	ft NAVD88	Score	ft NAVD88	Score	Linear Feet	Score	Linear Feet	Score		
PHASE 1: SPWG Selected Assets	1	Carlsbad Blvd @ Las Encinas Creek	14.6	1	14.6	1	50	1	1,000	2	1	1.8
	2	SR-75 @ the Silver Strand	9.5	2	9.5	2	18,820 (approx. 3.6 mi)	4	34,600	4	3.6	3.6
	3	Railroad @ Del Mar Bluffs	48.4	NE	48.4	NE	440	2	2,410	3	1.6	2.4
	4	Green Line Trolley	9.5	2	9.5	2	4,960	3	6,700	3	2.8	2.8
	5	Bayshore Bikeway	8.2	3	8.2	3	48,650 (approx. 9.2 mi)	4	104,660	4	3.8	3.8
	6	San Luis Rey Bike Trail	9.6	2	9.6	2	2,100	3	2,170	3	2.8	2.8
PHASE 2: Regional Coastal Roadway Assets	7	S. Coast Hwy @ San Luis Rey River	24	NE	24	NE	0	1	500	2	0.8	1.6
	8	S. Coast Hwy @ Loma Alta Creek	13	1	13	1	80	2	325	2	1.8	1.8
	9	Carlsbad Blvd @ Buena Vista Lagoon Bridge	11	2	11	2	35	1	1,530	3	1.2	2.8
	10	Carlsbad Blvd @ Aqua Hedionda Lagoon	18	NE	18	NE	0	1	1,200	3	0.8	2.4
	11	Carlsbad Blvd @ Las Encinas Creek	15	1	15	1	50	1	1,000	2	1	1.8
	12	Carlsbad Blvd @ Batiquitos Lagoon Bridge	13	1	13	1	0	1	350	2	1	1.8
	13	Hwy 101 @ San Elijo Lagoon Bridge	13	1	13	1	190	2	1,700	3	1.8	2.6
	14	Camino Del Mar @ San Dieguito Lagoon Bridge	9	2	9	2	40	1	2,240	3	1.2	2.8
	15	Coast Hwy 101 @ Torrey Pines Bridge	19	NE	19	NE	0	1	0	1	0.8	0.8
	16	SR-75 @ Glorietta Bay	9	2	9	2	2,750	3	6,500	3	2.8	2.8
	17	SR-75 @ Fiddler's Cove	9	2	9	2	1,150	3	5,000	3	2.8	2.8
	18	SR-75 @ Coronado Cays	10	2	10	2	4,300	3	4,800	3	2.8	2.8

ft = feet; **SPWG** = Shoreline Preservation Working Group; **SR** = State Route; **NE** = not evaluated (because elevation exceeds elevation of projected water levels under sea level rise).

1 mile = 5,280 feet

2.3.1.2 Sensitivity

Phase 1: SPWG Selected Assets

The sensitivity analysis determines whether an asset will be damaged or disrupted from exposure to a particular stressor or stressors. The sensitivity of each asset was approximated using four descriptive characteristics: degree of historical flooding, presence of coastal flood protection, impaired access to critical facilities, and disruption duration.

Carlsbad Boulevard at Las Encinas Creek and the Bayshore Bikeway are known to have experienced regular historical flooding. Carlsbad Boulevard is most sensitive to high wave events, such as a 100-year wave event (see Figures 2-2 and 2-3). The Bayshore Bikeway is less sensitive to swell events due to its bayside location, but its low elevation is often overtopped by king tides.

The presence of coastal flood protection increases the probability that an asset will be protected from coastal erosion. Carlsbad Boulevard is well protected by a rock revetment. The Green Line Trolley is protected by critical infrastructure and development such as the Embarcadero and San Diego Convention Center. The Railroad at the Del Mar Bluffs sits atop consolidated sand bluffs, in part protected by isolated retaining walls of varying condition. Recent SANDAG studies (SANDAG, 2017) have identified a need for adaptation in response to compounding bluff failures documented by local coastal researchers (Young, 2018). SR-75 is deemed sensitive due to its oceanfront protective beach and limited bay-side protection. The Bayshore Bikeway is similarly protected by beach on its ocean side at the Silver Strand; however, it is minimally protected on the bay side. Lastly, the San Luis Rey Bike Trail does not benefit from any major form of flood protection.

Impaired access to critical facilities is a significant indicator of sensitivity. Flooding of Carlsbad Boulevard at Las Encinas Creek would disrupt a significant roadway used by emergency responders and would adversely impact beach access. Coastal flooding would impair SR-75 access to critical Navy facilities, including Fort Emory and Naval Amphibious Base Coronado. Suspended use of the Railroad in Del Mar would interrupt the railway connection between north and south San Diego County, imiting coastal access for COASTER and Amtrak reliant members of the public and impacting goods movement along the rail corridor. Similarly, flooding of the Green Line Trolley would impair access to critical downtown San Diego resources, such as regional transportation hubs and the County Administration Center.

Disruption duration due to flooding is an estimate of how long an asset may be unavailable to public use and how long alternative transport modes and detours may be subjected to increased use. All assets, except for the railroad at Del Mar Bluffs, are anticipated to initially experience a minor disruption duration of approximately four hours. This time period is interpreted by the length of high tide events with which storm waves and precipitation may coincide to induce coastal flooding. For the railroad at Del Mar Bluffs, the Del Mar Bluff Stabilization Project prepared for SANDAG (Leighton Consulting 2010) identified that a bluff failure within 10 feet of the railway centerline would likely shut down its use. This would require emergency inspections and repairs to be dispatched immediately, likely closing the railway for at least one to two weeks (Sanchez, pers. comm. 2019). Disruption durations are approximated and can vary widely should unforeseen accidents, damage, or recovery be required to return the asset to full function.

Phase 2: Regional Roadways (Coast Hwy 101 & SR-75)

The sensitivity analysis for regional roadways is based on four characteristics: degree of historical flooding, presence of coastal flood protection, impaired access to critical facilities, and duration of disruption. The following reaches of Hwy 101 and SR-75 were found to be most sensitive based on scoring a value of 2.5 and above:

MOST SENSITIVE

Hwy 101
- Buena Vista Lagoon
- Las Encinas Creek
- Batiquitos Lagoon
- San Elijo Lagoon
- Camino Del Mar
- Torrey Pines

SR-75
- Glorietta Bay
- Fiddler's Cove
- Coronado Cays

Table 2-9. Asset Sensitivity

	Asset ID	Asset Name	Degree of Historical Storm Damage		Presence of Coastal Flood Protection		Impaired Access to Critical Facilities		Disruption Duration		Sensitivity Score
			1–4[a]	Score	1–4[b]	Score	Yes/No[a]	Score	Hours	Score	Score
PHASE 1: SPWG Selected Assets	1	Carlsbad Blvd @ Las Encinas Creek	3.0	3	1.0	1	1.0	4	4.0	1	2.7
	2	SR-75 @ the Silver Strand	1.0	1	3.0	3	1.0	4	4.0	1	2.4
	3	Railroad @ Del Mar Bluffs	2.0	2	2.0	2	1.0	4	168.0	4	3.3
	4	Green Line Trolley	1.0	1	1.0	1	1.0	4	4.0	1	2.2
	5	Bayshore Bikeway	3.0	3	4.0	4	0.0	1	4.0	1	1.8
	6	San Luis Rey Bike Trail	1.0	1	4.0	4	0.0	1	4.0	1	1.3
PHASE 2: Regional Coastal Roadway Assets	7	S. Coast Hwy @ San Luis Rey River	1.0	1	1.0	1	0	1	0	1	0.6
	8	S. Coast Hwy @ Loma Alta Creek	3.0	3	1.0	1	0	1	24	3	2.0
	9	Carlsbad Blvd @ Buena Vista Lagoon Bridge	3.0	3	1.0	1	1	4	12	3	3.2
	10	Carlsbad Blvd @ Aqua Hedionda Lagoon	1.0	1	1.0	1	1	4	4	1	2.2
	11	Carlsbad Blvd @ Las Encinas Creek	4.0	4	4.0	4	1	4	12	3	3.8
	12	Carlsbad Blvd @ Batiquitos Lagoon Bridge	2.0	2	3.0	3	1	4	4	1	2.7
	13	Hwy 101 @ San Elijo Lagoon Bridge	3.0	3	3.0	3	1	4	4	1	2.7
	14	Camino Del Mar @ San Dieguito Lagoon Bridge	2.0	2	1.0	1	1	4	4	1	2.9
	15	Coast Hwy 101 @ Torrey Pines Bridge	2.0	2	1.0	1	1	4	4	1	2.5
	16	SR-75 @ Glorietta Bay	2.0	2	1.0	1	1	4	4	1	2.5
	17	SR-75 @ Fiddler's Cove	2.0	2	1.0	1	1	4	4	1	2.5
	18	SR-75 @ Coronado Cays	2.0	2	1.0	1	1	4	4	1	2.5

[a] **Yes** = 1.0; **No** = 0.0.

[a] **1** = no known historical coastal storm damage; **2** = episodic historical storm damage (approximately less than 1 event per year); **3** = annual historical storm damage (approximately 1 or more event per year); **4** = frequent and damaging historical flooding (approximately 4 or more events per year).

[b] **1** = protected by hard structure (e.g. seawall); **2** = protected by consolidated bluff; **3** = protected by beach; **4** = no significant protection.

2.3.1.3 Adaptive Capacity

Phase 1: SPWG Selected Assets

Adaptive capacity determines how well a transportation asset can cope with damage and/or service disruption. The adaptive capacity of each asset was considered through an estimated feasibility of adaptation, detour length, and AADT. Feasibility of adaptation is defined as a cumulative assessment of technical, economic, and political feasibility of adaptation measures.

The San Luis Rey Bike Trail and Bayshore Bikeway were identified as the most adaptive, due to the relatively low cost of replacement and flexibility to be either raised on boardwalks or relocated inland. Carlsbad Boulevard at Las Encinas Creek was the next most adaptive, owing most of its capacity to adapt to the available option to either limit traffic to one lane or to relocate the southbound roadway onto the right-of-way of northbound Carlsbad Boulevard. This option was identified in the City of Carlsbad's Sea Level Rise Vulnerability Assessment (Moffatt & Nichol 2017a).

The Railroad at Del Mar Bluffs was identified with a low adaptive capacity to sea level rise. To ultimately solve the coastal flooding and erosion problems at the Del Mar Bluffs, the bluffs would either need to be entirely hardened by revetment or seawall (likely not permittable by resource agencies), or the Railroad would need to be relocated. Recently, SANDAG prepared a study on bluff stabilization and railway relocation and identified relocation costs in the area of $3 billion (SANDAG, 2017). Both San Diego Forward: the 2015 Regional Plan and City of Del Mar's Sea-Level Rise Adaptation Plan recognize the relocation of the railroad as an important improvement necessary for the overall functioning of the LOSSAN corridor.

The Green Line Trolley was found to have a low adaptive capacity to sea level rise. This stems from the very high public use of the trolley (approximately 37,000 persons per day), and the difficulty that would come from attempting to reroute the Green Line through the highly developed downtown area of San Diego (MTS 2015). Similarly, SR-75 experiences very high use (approximately 23,000 vehicles per day). However, SR-75 was determined to be the least adaptive to coastal flooding because of its inability to be relocated. SR-75 provides necessary access to federal defense facilities that require coastal access. Therefore, should sea level rise threaten the regular use of SR-75, it would likely need to be elevated in place to maintain public access. This effort would entail significant environmental and economic issues.

Phase 2: Regional Roadways (Coast Hwy 101 & SR-75)

The adaptive capacity was estimated for regional roadways using the same methodology as Phase 1. When evaluating the detour length, alternate routes were selected that avoided assets which are vulnerable to daily inundation. For example, the detour length of 5.9 miles for Camino Del Mar assumed a detour along I-5 since Jimmy Durante Boulevard is vulnerable to 6.6 ft. of sea level rise. Locations along I-5 which are identified as vulnerable to a 100-year storm are considered passable after a 4-hour period of delay. The following reaches of Hwy 101 and SR-75 were found to be most able to adapt after scoring a value of 2.4 and above:

MOST FEASIBILEY ADAPTIVE

Hwy 101
- Loma Alta Creek
- Buena Vista Lagoon
- Agua Hedionda Lagoon
- Las Encinas Creek
- Batiquitos Lagoon
- San Elijo Lagoon
- Camino Del Mar

SR-75
- Glorietta Bay
- Fiddler's Cove
- Coronado Cays

Table 2-10. Asset Adaptive Capacity

	Asset ID	Asset Name	Feasibility of Adaptation		Detour Length		AADT		Adaptive Capacity Score
			1–4[a]	Score	Miles	Score	People per Day	Score	Score
PHASE 1: SPWG Selected Assets	1	Carlsbad Blvd @ Las Encinas Creek	2.0	2	4.0	2	15,200.0	3	2.2
	2	SR-75 @ the Silver Strand	4.0	4	22.7	4	23,000.0	3	3.8
	3	Railroad @ Del Mar Bluffs	4.0	4	8.5	3	4,657.0[b]	1	3.2
	4	Green Line Trolley	3.0	3	2.3	2	37,462.0	4	3.0
	5	Bayshore Bikeway	1.0	1	8.4	3	794.0	1	1.4
	6	San Luis Rey Bike Trail	1.0	1	1.0	1	708.0	1	1.0
PHASE 2: Regional Coastal Roadway Assets	7	S. Coast Hwy @ San Luis Rey River	1.0	1	4.0	2	9,000	1	1.2
	8	S. Coast Hwy @ Loma Alta Creek	3.0	3	1.8	2	16,918	3	2.8
	9	Carlsbad Blvd @ Buena Vista Lagoon Bridge	3.0	4	8.5	3	19,400	3	3.2
	10	Carlsbad Blvd @ Aqua Hedionda Lagoon	4.0	4	2.3	2	20,894	4	3.6
	11	Carlsbad Blvd @ Las Encinas Creek	3.0	3	8.4	3	19,167	4	3.0
	12	Carlsbad Blvd @ Batiquitos Lagoon Bridge	3.0	3	3.1	2	19,167	3	2.8
	13	Hwy 101 @ San Elijo Lagoon Bridge	2.0	2	4.1	2	20,682	4	2.4
	14	Camino Del Mar @ San Dieguito Lagoon Bridge	2.0	2	5.9	3	18,500	3	2.4
	15	Coast Hwy 101 @ Torrey Pines Bridge	2.0	3	8.8	3	19,600	3	3.2
	16	SR-75 @ Glorietta Bay	3.0	3	20.5	4	22,899	4	3.4
	17	SR-75 @ Fiddler's Cove	3.0	3	20.5	4	22,899	4	3.4
	18	SR-75 @ Coronado Cays	3.0	3	20.5	4	22,899	4	3.4

AADT = annual average daily traffic; **SR** = State Route.

[a] Technical, economic, and political feasibility of adaptation: 1 = very high feasibility; 2 = high feasibility; 3 = medium feasibility; 4 = low feasibility.

[b] AADT values for the railway represent only the COASTER ridership, and not the railway used by Amtrak Surfliner or the BNSF freight activity.

Table 2-11. Asset Vulnerability for the Phase 1 Analysis

Asset ID	Asset Name	Sea Level Rise	
		2.5 ft	6.6 ft
		Vulnerability	
1	Carlsbad Blvd @ Las Encinas Creek	2.0	2.2
2	SR-75 @ the Silver Strand	3.3	3.3
3	Railroad @ Del Mar Bluffs	2.7	3.0
4	Green Line Trolley	2.7	2.7
5	Bayshore Bikeway	2.3	2.3
6	San Luis Rey Bike Trail	1.7	1.7

ft = feet; SR = State Route.

2.3.1.4 Overall Asset Vulnerability

Vulnerability is calculated by averaging exposure, sensitivity, and adaptive capacity scores. Phase 1 VAST findings are presented in Table 2-11 and detailed below. The Phase 1 pilot analysis compared the three different types of transportation modes of roadway, rail, and bike/pedestrian trail. The Phase 2 pilot analysis findings follow those of the Phase 1 analysis.

The Phase 1 VAST analysis identified SR-75 as the most vulnerable regional transportation asset in the San Diego region, followed by the Railroad at Del Mar Bluffs and Green Line Trolley. SR-75 is located at low elevation along a sand spit which is threatened by flooding both from the open ocean and San Diego Bay. Because SR-75 provides access to critical Navy facilities and is unable to adapt, except at significant cost, it was deemed the most vulnerable. The Railroad at Del Mar Bluffs is vulnerable to coastal erosion and flooding, any degree of which could cause extended railway closures affecting COASTER and Amtrak users as well as freight transportation. The railroad is particularly vulnerable due to the limited availability of feasible long-term solutions. Both San Diego Forward: the 2015 Regional Plan and City of Del Mar's Sea-Level Rise Adaptation Plan recognize the relocation of the railroad as an important improvement necessary for the overall functioning of the LOSSAN corridor. The Green Line Trolley is the next most vulnerable because of its low elevation, connectivity to critical facilities, and low adaptive capacity to be relocated within the high-density development in downtown San Diego.

The Bayshore Bikeway is the fourth most vulnerable asset, mostly because of its extensive length of exposed pathway (up to 20 miles). This is followed by Carlsbad Boulevard at Las Encinas Creek, which is currently vulnerable to extreme storm scenarios, an exposure which only increases as sea level rises. However, Carlsbad Boulevard's short length of impact and relatively high adaptive capacity makes it the fifth most vulnerable asset. Lastly, the San Luis Rey Bike Trail is least vulnerable, due to its short length of exposure, low sensitivity, and high adaptive capacity.

It is worth noting that using two sea level rise scenarios did not affect the final results drastically. All assets are predicted to become more vulnerable under the higher sea level rise scenario. The only major difference between the two scenarios is that the Railroad became the second most vulnerable asset due to the heightened impacts of 6.6 feet of sea level rise on bluff erosion within Del Mar.

Table 2-12. Asset Vulnerability for Phase 2 Analysis

Asset ID	Asset Name	Sea Level Rise	
		2.5 ft	6.6 ft
		Vulnerability	
7	S. Coast Hwy @ San Luis Rey River	0.9	1.1
8	S. Coast Hwy @ Loma Alta Creek	2.2	2.2
9	Carlsbad Blvd @ Buena Vista Lagoon	2.5	3.1
10	Carlsbad Blvd @ Aqua Hedionda Lagoon	2.2	2.7
11	Carlsbad Blvd @ Las Encinas Creek	2.6	2.9
12	Carlsbad Blvd @ Batiquitos Lagoon Bridge	2.2	2.4
13	Hwy 101 @ San Elijo Lagoon Bridge	2.4	2.6
14	Camino Del Mar @ San Dieguito Lagoon Bridge	2.0	2.6
15	Coast Hwy 101 @ Torrey Pines Bridge	2.2	2.2
16	SR-75 @ Glorietta Bay	2.9	2.9
17	SR-75 @ Fiddler's Cove	2.9	2.9
18	SR-75 @ Coronado Cays	2.9	2.9

ft = feet; SR = State Route.

Phase 2 VAST findings are presented in Table 2-12 and detailed below.

The phase 2 VAST Analysis identified SR-75 in Coronado as the most vulnerable regional roadway asset in San Diego County with each roadway segment equally vulnerable. Hwy 101 in North County also possesses significant vulnerability with one lagoon reach more vulnerable than any other site under sea level rise of 6.6 feet.

The SR-75 roadway is at one of the lowest elevations studied and the longest to be impacted. The roadway is built on a sand spit which is threatened by flooding both from the open ocean and San Diego Bay as identified in phase I. SR-75 provides critical access to Navy facilities and other vital community resources and is unable to adapt except at significant cost.

The order of concern for Hwy 101 in North County is as follows: Carlsbad Blvd at Buena Vista Lagoon and at Encinas Creek, and Hwy 101 at San Elijo Lagoon based on minimum scores of 2.4 and greater for sea level rise of 2.5 feet. For sea level rise of 6.6 feet, the concern includes the same reaches, and increases to include Hwy 101 at Aqua Hedionda Lagoon and Camino Del Mar Bridge and scores of 2.6 and higher. Carlsbad Blvd at Batiquitos Lagoon and Hwy 101 at Torrey Pines and Loma Alta Creek are scored lower overall due to their slightly higher elevations. This route is an emergency evacuation route and provides access to and from critical facilities such as hospitals, city halls, police stations, and fire stations.

2.3.2 VAST Conclusions and Lessons Learned

The VAST tool was piloted to test its applicability to a variety of asset types and evaluate its potential for use in future local and regional vulnerability assessments. To accomplish this goal, the tool was used to quantitatively assess the vulnerability of a subset of transportation assets identified as vulnerable to sea level rise (Section 2.2) through the Phase 1 and Phase 2 analyses described in Section 2.3.1.

Overall, the comparison of Phase 1 and Phase 2 VAST analyses indicates that the tool is useful for both diverse transportation modes (Phase 1) and for one transportation mode analyzed at various locations (Phase 2). In both cases, the VAST tool can be used for different objectives. Comparing different transportation modes (Phase 1) helps the planner understand the potential investment priorities of a multi-modal transportation system. In contrast, comparing one transportation mode along an entire reach provides the transportation engineer with information useful for focusing on the problem locations and for prioritizing adaptation strategies to maintain the route's viability. VAST is a useful first-order indicator of potential problem sites for varying transportation modes, and for various reaches within one transport mode. It is robust and reliable in its function and worthy of additional utilization for transportation planning in the face of sea level rise.

The results of the VAST assessment have revealed two broad influences on transportation asset vulnerability:

1. Coastal squeeze, or the pinning of an asset between the ocean and upland development, tends to be the leading cause of vulnerability. For example, SR-75 is squeezed between rising sea level on both the ocean and bay sides, versus Carlsbad Boulevard at Las Encinas Creek, which can feasibly be retreated inland. SR-75 was identified as significantly more vulnerable than Carlsbad Boulevard.
2. Assets that are exposed to sea level rise and provide access to critical facilities are highly vulnerable and could therefore be deemed critical transportation assets. Access to critical facilities is a basic public service, without which a community could greatly suffer. Critical transportation assets include, but are not limited to, roads, transit routes, and ATPs that provide access to hospitals, police stations, city halls, Naval infrastructure, and other vital public assets.

Additional VAST analysis could be used to understand the vulnerability of local and sub-regional roads and how flooding of these roads could impact access to regional transportation assets. For example, flooding along North Harbor Drive could impact access to the downtown trolley lines, I-5, and the San Diego International Airport.

Overall, the VAST tool was effective and is recommended for future use with consideration of the lessons learned as discussed in **Box 2-1.** A vulnerability assessment method similar to VAST was used in the City of Carlsbad Sea Level Rise Vulnerability Assessment (Moffatt and Nichol 2017a). The VAST method was found to be more effective regarding transportation assets because VAST recommended indicators of exposure, sensitivity, and adaptive capacity which help direct the user, leading to a more consistent outcome across users and assets. VAST also encourages a formal documentation of substantiated expert opinion and professional judgment through the crucial use of a variety of data sources.

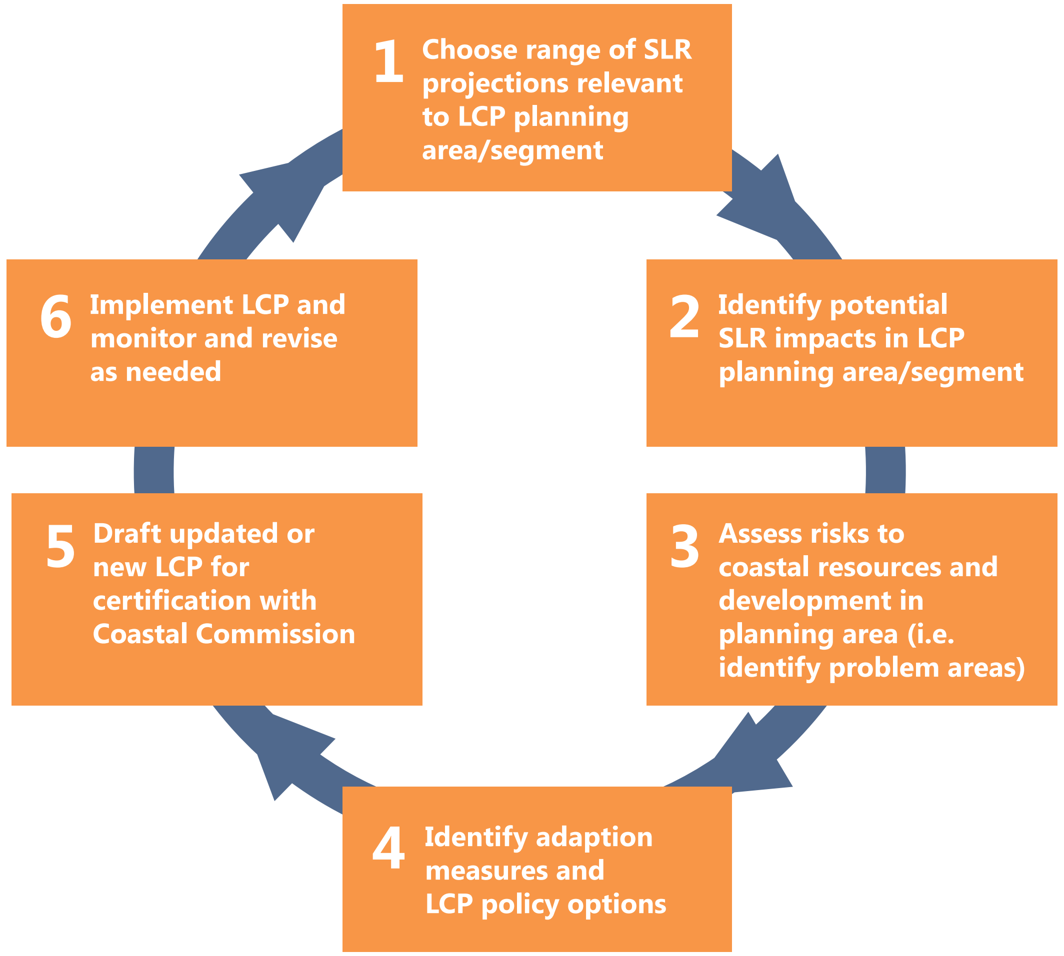
Box 2-1: VAST analyses lessons learned

1. VAST is most effective when comparing asset vulnerability within a specific category. For instance, it is difficult to compare the vulnerability of railway versus roadway because the purposes and value to the community are assessed by different metrics.
2. The VAST library of indicators is often not appropriate for use across separate asset categories. To compare roadways, transit, and bikeways and trails in this analysis, the project team needed to create new parameters such as feasibility of adaptation.
3. The value of an asset to a community would be an ideal metric for sensitivity, but this concept is difficult to gauge without public and stakeholder engagement and/or economic analysis. For instance, railway ridership data were publicly available; however, the economic value added through its use by BNSF freight trains is not easily identifiable. This may be where its greatest value lies, but it was not included in this pilot vulnerability assessment. Other factors, such as the location of employment centers, are also not captured.
4. VAST provides a framework to direct the user through a deliberate process of assessing vulnerability and is therefore approachable and repeatable for the layperson. Additionally, because VAST provides this published framework, it is transparent and avoids the "black box" approach of other risk assessments.
5. VAST was developed specifically for transportation infrastructure. VAST is uniquely suited for transportation because of the quantitative aspects of transportation (e.g., length, AADT, detour length). However, VAST is designed with the flexibility for individual control so that assets of other types could potentially be inputted and evaluated using this system. As stated earlier, this experience leads the team to conclude that assets of the same type should be evaluated against one another. This would be especially true for assets of such different function and makeup as beaches, public accessways, parcels, critical infrastructure, transportation infrastructure, and environmentally sensitive lands.
6. The VAST framework provides both recommended indicators of vulnerability, and the opportunity for creating unique indicators. Creating unique indicators was found to be an important aspect of analysis to accomodate the unique goals of the vulnerability assessment. However, there is no limit to the number of unique indicators which can be created, such as capturing costs of repair/replacement, economic impacts, etc. This creates a need to be clear and firm with the scope of the assessment.
7. Definitions of exposure, sensitivity, and adaptive capacity are important to the use of VAST. For the purposes of this study, the focus was on infrastructure and how sea level rise affects its integrity and use. Alternatively, VAST could be steered towards a focus on communities and social impact of sea level rise through redefining exposure, sensitivity, and adaptive capacity with a focus on communities and environmental justice. For instance, the definition of sensitivity could be changed from the degree of damage and disruption incurred on an asset, to the degree of damage and disruption incurred on a community by way of asset flooding. Such distinctions demonstrate the flexibility of analysis provided through VAST, and the need for clearly defining the scope.

PHOTO: GOOGLE STREET VIEW

03

Adaptation Planning Best Practices



This graphic shows the basic SLR planning process provided in the Coastal Commission's Sea Level Rise Policy Guidance, with steps 1-3 conducted for vulnerability assessment and steps 4-6 for adaptation planning.

3 Adaptation Planning Best Practices

Effective adaptation planning improves community resilience, and this chapter synthesizes sea level rise adaptation planning best practices from around the region. Interviews were conducted with planning staff and local practitioners at coastal jurisdictions in August 2018 to understand successful strategies and common pitfalls in the planning process, including lessons learned related to regional transportation infrastructure. The status of these planning efforts are included in **Table 3-1**.

Best practices are methods that were identified by at least two local jurisdictions during the interviews. Best practices were also presented to the Shoreline Preservation Working Group (SPWG) in October 2018 for further discussion. Funding was frequently identified as a barrier to adaptation planning and implementation progress, and this topic is explored in detail in Section 4.2. The following best practices are included to address the needs of jurisdictions currently in the initial stages of sea level rise planning and to document lessons learned for all jurisdictions since policy updates will be required as sea level rise science and our understanding of adaptation strategies improves over time.

Table 3-1. Sea Level Rise Adaptation Planning Efforts – Status as of November 2019

No.	Local Jurisdiction/Agency	Sea Level Rise Planning Process	Status
1	Caltrans	Caltrans District 11 Technical Report	Vulnerability Assessment (September 2019)
2	City of Oceanside	LCP Update	Vulnerability Assessment (Sept. 2018), Adaptation Plan in progress , policy update in progress.
3	City of Carlsbad	LCP and Zoning Code Update	Vulnerability Assessment (Dec. 2017), policy update in progress
4	City of Encinitas	USACE Encinitas–Solana Beach Coastal Storm Damage Reduction Project	Waiting for federal appropriation (50-year commitment)
5	City of Solana Beach	USACE Encinitas–Solana Beach Coastal Storm Damage Reduction Project; certified Land Use Plan	Waiting for federal appropriation (50-year commitment); Implementation Plan (needed for LCP) in progress
6	City of Del Mar	LCP Update	Vulnerability Assessment (Sept. 2016), Adaptation Plan (May 2018), Sediment Management Plan (Aug. 2018), Wetland Habitat Migration Assessment (Aug. 2018), CCC review of LCP amendment in progress
7	City of San Diego	Climate Resilient San Diego	Vulnerability Assessment in progress
8	City of Coronado	—	Vulnerability Assessment in Progress to initialize the planning process
9	City of National City	Planning through the Port of San Diego Process	See Port of San Diego in this table
10	City of Chula Vista	Planning through the Port of San Diego Process. Project-specific planning on Chula Vista Bayfront Harbor District Road Improvements	See Port of San Diego in this table Sea Level Rise Analysis (Jan. 2017)
11	Imperial Beach	LCP, General Plan, and Climate Action Plan Update	Vulnerability Assessment and Adaptation Strategy (Sept. 2016), LCP policy update in progress
12	Port of San Diego	AB 691 Compliance/Port Master Plan Update	Assessment for State Lands Commission in progress (June 2019) , Port Master Plan Update in progress
13	San Diego County Regional Airport Authority	Resilience Plan	Vulnerability Assessment (June 2019)
14	SANDAG/Caltrans	North Coast Corridor Program	Sea Level Rise Analysis Report (Sept. 2013)

LCP = local coastal program; **USACE** = U.S. Army Corps of Engineers; **CCC** = California Coastal Commission; **AB** = Assembly Bill.

3.1 **Best Practice 1:** Collaboration

Collaboration was the best practice that all jurisdictions identified as critical to a successful process. Sea level rise planning can be daunting for local jurisdictions. The San Diego Regional Climate Collaborative (Collaborative) is a network for public agencies that was established in 2012 to share expertise, leverage resources, and advance comprehensive solutions to facilitate climate change planning. The importance of membership and participation in the Collaborative was highlighted by each of the local jurisdictions in the interviews. Through funding from a 2015 National Oceanographic and Atmospheric Agency Regional Coastal Resilience Grant, the Collaborative has been able to bring together experts and scientists to provide training and discuss tools for climate change planning at the local and regional level. For example, Coastal Storm Modeling System (CoSMoS) experts from the U.S. Geological Survey came to the Collaborative to provide local jurisdictions the opportunity to ask questions about the CoSMoS tool. This unique opportunity for local planners to communicate directly with the modelers was foundational for effective use of the CoSMoS tool, interpretation of modeling results, and communication of vulnerability assessment results. In addition, the Collaborative created opportunities for local jurisdictions to dialogue with local, State, and federal jurisdictions and agencies from outside the San Diego region. For example, conversations with representatives from the City of Goleta and City of San Clemente revealed that redevelopment and shoreline protection policies were especially challenging to develop, signaling to San Diego jurisdictions that additional time and creativity may be required to address these issues. As a member of the Alliance of Regional Collaboratives for Climate Adaptation (ARCCA), the Collaborative is a central forum to communicate San Diego regional priorities to funders and leaders at the State and federal level.

SANDAG was also recognized in the interviews with local jurisdictions as facilitating regional collaboration through the SPWG (pictured in the photo below). This diverse stakeholder group allows for dynamic conversations about regional challenges, opportunities, and solutions. Further, multiple jurisdictions discussed coordinating with other jurisdictions that were further along in the planning process that had similar vulnerabilities to incorporate specific best practices and lessons learned.

Finally, multiple jurisdictions emphasized bringing in other departments and disciplines early in the planning process to ease implementation of policies and bring sea level rise adaptation to the forefront of capital improvement project planning. Soliciting feedback from the California Coastal Commission (CCC) early and often throughout the process was also recommended by multiple jurisdictions. Box 3-1 highlights the Cardiff Living Shoreline Project, the planning and implementation of which required significant collaboration between project partners and permitting agencies.

SANDAG

Box 3-1: Cardiff Living Shoreline Project

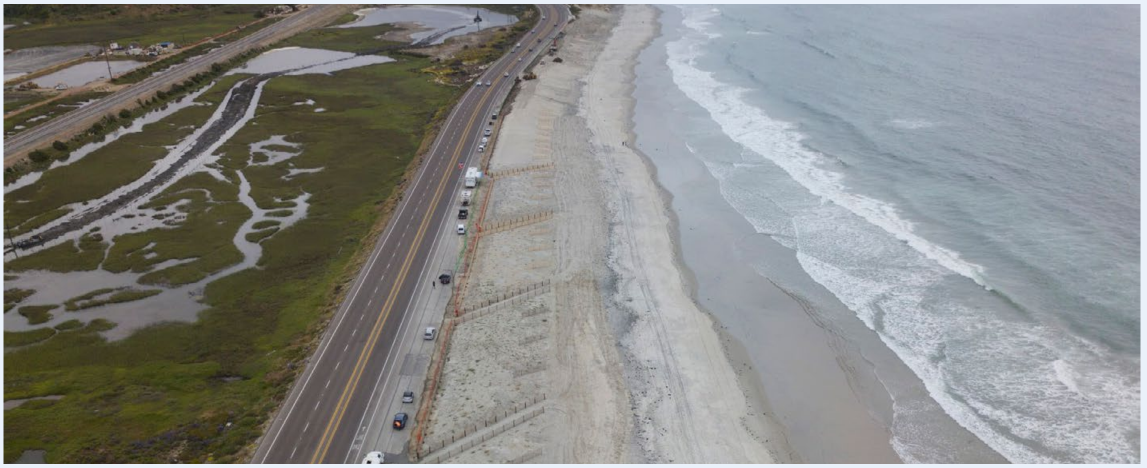


PHOTO: CITY OF ENCINITAS

The Cardiff Living Shoreline Project, completed in June 2019, extends a half-mile between Restaurant Row and South Cardiff State Beach. The project protects Coast Hwy 101 from ocean surges using man-made materials, native materials and locally sourced dune plants, which provide increased biodiversity and wildlife habitat. Sand dunes provide a number of ecological and human benefits, including wildlife habitat for native and migrating species and landward protection from sea level rise and storm surge flooding. The shoreline now supports flowering native plant species with coastal dune plants beginning to take root. It's anticipated that the protected dunes will host endangered species, like the Snowy Plover, that depend on undisturbed sand for roosting habitat. The project also provides for improved public access to the beach. A new pedestrian pathway was constructed alongside the dunes and runs the full length of the one-half mile project site.

The Cardiff Living Shoreline project was led by the State Coastal Conservancy and the City of Encinitas, in partnership with the Nature Collective, California State Parks, the University of California Los Angeles (UCLA), Scripps Institution of Oceanography at the University of California San Diego (UCSD), and U.S. Fish & Wildlife Service. Funding for the $2.5 million project substantially came from the California Coastal Conservancy, the California Ocean Protection Council, the U.S. Fish & Wildlife Service and the San Diego Association of Governments (SANDAG). Because the Cardiff Living Shoreline is the first of its kind in San Diego, an Adaptive Management and Monitoring Plan was required in the CCC's approval to both inform other coastal communities considering such adaptive measures in the future and inform the maintenance and adaptation program for this pilot project. Requirements for the Adaptive Management and Monitoring Plan include developing a long-term strategy for Highway 101, pursuing beach nourishment projects, maintaining the proposed dune system based on defined maintenance triggers, adapting the proposed dune system based on performance, and abandoning the proposed dune system and accelerating a long-term strategy if necessary. The plan includes criteria for evaluating the performance of the project, as well as triggers for adaptive management or abandonment of the project if necessary. In addition, the CCC permit also required biological monitoring for sensitive species and grunion and dune monitoring, among other conditions.

Sources: http://encinitasca.gov/Government/Departments/City-Manager/Environmental-Services/Coastal-Zone-Management
http://encinitasca.gov/Home/City-News/ArticleID/142

3.2 Best Practice 2: Conduct Outreach

Maximizing public participation is a core principle in the CCC Sea Level Rise Policy Guidance (SLR Policy Guidance). While engaging members of the public in sea level rise planning can be challenging, requiring considerable investment of time and resources, local jurisdictions recognized its importance and identified the following four lessons learned for successful outreach efforts:

1. **Gain common understanding by making sea level rise science tangible**

Several jurisdictions highlighted the benefit of using maps and historical photos, tying sea level rise impacts to past flooding events. For example, the City of Del Mar included historical beach erosion and flooding photos impacting critical transportation infrastructure in their Vulnerability Assessment **(Figures 3-2a and 3-2b)**. Using layperson's terminology and avoiding technical discussions was also key in engaging the general public in sea level rise planning efforts **(Figure 3-1)**. Planners found being honest about the limitations of the modeling methods was valuable in gaining confidence among the general public. For instance, the City of Oceanside added the word "potential" to the legends of maps that depicted sea level rise scenarios, emphasizing that the maps are a tool to discuss potential risks based on the best available science.

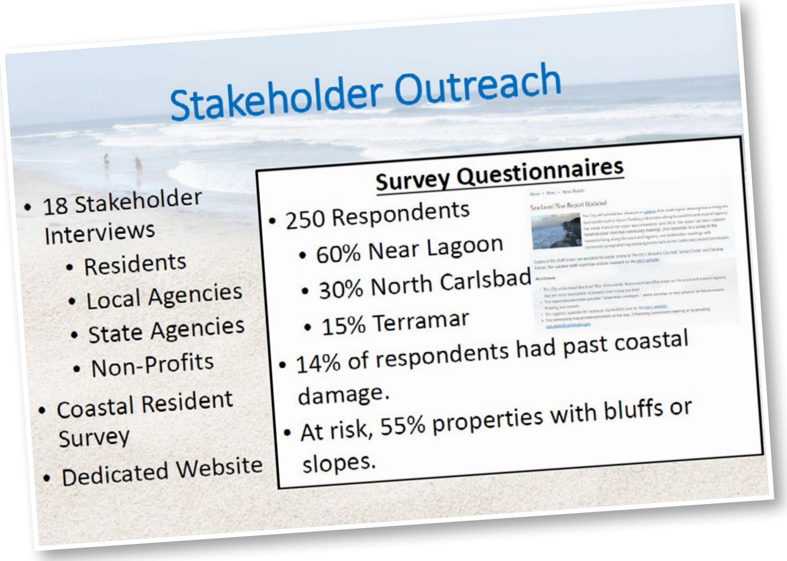
Figure 3-1. Resilient Imperial Beach Public Workshop

Figure 3-2a. From City of Del Mar Vulnerability Assessment Public Workshop.

Figure 3-2b. City of Del Mar – 1941 Train Wreck

PHOTO: CITY OF ENCINITAS

Figure 3-3. City of Carlsbad Stakeholder Outreach



Stakeholder Outreach

- 18 Stakeholder Interviews
  - Residents
  - Local Agencies
  - State Agencies
  - Non-Profits
- Coastal Resident Survey
- Dedicated Website

Survey Questionnaires

- 250 Respondents
  - 60% Near Lagoon
  - 30% North Carlsbad
  - 15% Terramar
- 14% of respondents had past coastal damage.
- At risk, 55% properties with bluffs or slopes.

2. Emphasize public safety to develop an understanding of the urgency

Each jurisdiction has a responsibility to protect health, safety, and welfare. Sea level rise planning is consistent with, and a central element in, maintaining public health and safety. For example, Section 30253 of the California Coastal Act states in part:

New development shall do all of the following:

> **(a)** Minimize risks to life and property in areas of high geologic, flood, and fire hazard.
>
> **(b)** Assure stability and structural integrity, and neither create nor contribute significantly to erosion, geologic instability, or destruction of the site or surrounding area or in any way require the construction of protective devices that would substantially alter natural landforms along bluffs and cliffs...

Thus, Section 30253 requires new development to minimize risks from hazards, to avoid creating or contributing significantly to erosion and geologic instability, and to not in any way require construction of armoring that substantially alters natural landforms along bluffs and cliffs. Local jurisdictions have policies that are consistent with Section 30253 of the California Coastal Act as well as other hazard mitigation policies.

3. Targeted outreach

Many jurisdictions emphasized the need for targeted outreach efforts to engage specific groups in sea level rise planning. The groups critical for each jurisdiction's planning effort are specific to the community. The City of Carlsbad, for example, sent postcards with survey questions to each landowner with property that was identified as vulnerable to sea level rise **(Figure 3-3)**. The City of Oceanside designed online surveys for both residents and tourists. In addition to property owners and tourists, multiple jurisdictions mentioned direct outreach to environmental organizations, governmental entities, politicians, non-governmental organizations, and community groups as needed. Combining these focused outreach efforts with community-wide engagement provides valuable feedback from a variety of different perspectives.

4. Outreach and Survey Questionnaires

Once members of the public and political leadership have engaged in the process, it is important to continue and maintain the engagement with regular updates and opportunities to provide feedback throughout the sea level rise planning process.

3.3 Best Practice 3: Prepare a Vulnerability Assessment

The critical first step in adaptation planning is developing an understanding of who or what may be impacted by sea level rise by completing a vulnerability assessment. As described in Chapter 2, Vulnerability Assessment, local jurisdictions can evaluate their exposure to future rates of sea level rise using the best available science through sea level rise viewers and models such as the CoSMoS model. Applying models to determine the risk a community faces requires knowledge and data specific to that community. Data gaps, including locations of critical electrical and other infrastructure, commonly required additional time to identify and fill. Some jurisdictions created advisory groups to document assumptions, select sea level rise scenarios, and validate vulnerability results. Facilitating advisory groups takes additional time and effort but can result in a more widely embraced vulnerability assessment.

For jurisdictions that are still working on their vulnerability assessment, the recent recommendation by the OPC and CCC to use the H++ scenario is an additional challenge. This conservative H++ scenario is recommended for projects with little to no adaptive capacity that would be irreversibly destroyed or significantly costly to repair, including infrastructure. Should the H++ level of sea level rise occur, this would have considerable public health, public safety, or environmental impacts. No probability of likelihood is associated with the H++ scenario that could lead to a 10.2 feet of sea level rise by 2100 in the San Diego region (see Table 31 of OPC 2018). As such, a best practice for dealing with the H++ scenario, similar to other sea level rise scenarios in the second half of the century, is to establish triggers, which instigate actions when specific thresholds are crossed.

Risk assessments were also completed by some jurisdictions to help identify priorities through rating of vulnerabilities. For example, the City of Carlsbad included rating based on exposure, sensitivity, and adaptive capacity in the 2017 Sea Level Rise Vulnerability Assessment (Figure 3-4). The methodology used by the City of Carlsbad (Moffatt & Nichol 2017a) is similar to VAST in that both approaches use the same three characteristics of vulnerability.However, VAST encourages the consideration of many variables that affect vulnerability. Further, VAST's indicators are data-driven and create a quantitative vulnerability result, as opposed to the more "black box" approach of Moffatt & Nichol (2017a), which relies more on expert opinion. Despite these advantages in VAST, the Moffatt & Nichol (2017a) risk assessment approach allows for a wider scope of assets (e.g., environmentally sensitive lands, parcels, critical infrastructure), whereas VAST was developed specifically to assess transportation infrastructure.

PHOTO: SEE APPENDIX A

Figure 3-4. City of Carlsbad Vulnerability Assessment Rating.

Exposure is the degree to which an asset or resource is susceptible to coastal hazards such as flooding, inundation and bluff erosion for a given sea level rise scenario. The mapped hazard zones, shown in Section 5 and Attachment B were used to rate the level of exposure to a given asset or category.

Category	Rating	Explanation
Exposure	Low (1)	Asset or resource partially exposed to flooding, inundation or bluff erosion.
	Moderate (2)	Asset or resource moderately exposed to flooding, inundation or bluff erosion.
	High (3)	The majority of the asset or resource is exposed to flooding, inundation or bluff erosion.

Sensitivity is the degree to which the function of an asset or resource would be impaired (i.e., weakened, compromised or damaged) by the impacts of sea level rise. Example: Carlsbad Boulevard in the vicinity of Tamarack Beach has a high sensitivity to sea level rise because even minor flooding can cause significant disruption in service.

Category	Rating	Explanation
Sensitivity	Low (1)	Asset or resource is not affected or minimally affected by coastal hazards at a given sea level rise scenario.
	Moderate (2)	A moderately sensitive asset or resource may experience minor damage or temporary service interruption due to coastal hazard impacts, but can recover relatively easily.
	High (3)	A highly sensitive asset or resource would experience major damage or long-term service interruptions due to coastal hazard impacts, requiring significant effort to restore/rebuild to original condition.

Adaptive capacity is the inherent ability of an asset or resource to adjust to sea level rise impacts without the need for significant intervention or modification. Example: Some wetland habitat has a high adaptive capacity due to their ability to naturally migrate landward and upward with rising water levels provided adequate space exists.

Category	Rating	Explanation
Adaptive Capacity	Low (1)	Asset or resource can easily be adapted or has the ability and conditions to adapt naturally.
	Moderate (2)	Asset or resource can be adapted with minor additional effort.
	High (3)	Asset or resource has limited ability to adapt without significant changes.

3.4 Best Practice 4: Develop Adaptation Policies

Following completion of the vulnerability assessment, a jurisdiction is ready to consider adaptation strategies and develop policies that address sea level rise and adaptation. Many of the jurisdictions that were interviewed had completed their vulnerability assessments and were transitioning into developing adaptation policies for new or updated local coastal programs (LCPs). While many jurisdictions have experience implementing the coastal hazard policies of the Coastal Act through their LCPs, adaptation planning for increased hazards associated with sea level rise presents a new challenge due to the uncertainty in sea level rise timing and amounts. However, as local jurisdictions progress into the policy development phase of sea level rise planning, there were several lessons learned.

A critical first step in adaptation policy development is evaluating available adaptation strategies. Some strategies may appear to be available, but are actually infeasible due to technical, economic, or social considerations. Multiple jurisdictions used economic analysis to help determine which adaptation strategies were the most cost-effective. The City of Imperial Beach, for example, completed a detailed economic analysis to evaluate the tradeoffs between recreational use, ecological value, storm damage, and construction, as well as maintenance costs, for five adaptation strategies as a component of the City of Imperial Beach's 2016 Sea Level Rise Assessment. Throughout the interviews, most jurisdictions favored beach nourishment and identified challenges with implementing a managed retreat strategy. Many jurisdictions also identified an interest in developing a decision-making framework or screening criteria to determine appropriate strategies based on geomorphic constraints, land use setting, and vulnerability over time. In order for this framework to be effective, regular monitoring of screening criteria using a robust monitoring protocol is required. This monitoring protocol would establish and monitor triggers for implementation of adaptation strategies. For example, repetitive loss, storm damage, or specific beach widths would trigger actions or restrictions on redevelopment.

Developing adaptation policies and strategies can be extremely challenging and contentious, even when there is broad agreement and support for the conclusions of the vulnerability assessment. Maintaining public and political support as jurisdictions transition into this phase of adaptation planning is critical. Continuing to articulate strategies within the context of risks, resources, and public safety is important. Sea level rise adaptation requires a phased implementation approach with near-term, mid-term, and long-term strategies. It is important to align sea level rise adaptation planning with other local and regional plans, including General Plans, hazard mitigation plans, climate action plans, and capital improvement plans.

3.5 Best Practice 5: Pursue Multi-Jurisdictional Planning Efforts

Planning for sea level rise in the design phase of new projects and project improvements within each jurisdiction will improve the regional transportation network. However, regional transportation planning, as with any multi-jurisdictional planning effort, provides another layer of complexity. Focused cross-jurisdictional planning (e.g., North Coast Corridor [NCC] Public Works Plan/Transportation and Resource Enhancement Program [Program] **[see Box 3-2]** and the North County Mayors Rail Working Group) are important to address vulnerable regional assets outside of a single jurisdiction's control. Multi-jurisdictional planning can help build political and financial support for addressing these vulnerable regional assets, as well as ensure that adjustments are compatible with local communities. SANDAG can also continue to provide a critical regional perspective, facilitating communication with State and federal entities, as well as coordination on critical projects within the region.

Several individuals at the October 2018 SPWG meeting brought up the need for regional prioritization of transportation assets. The VAST tool discussed in Section 2.3, Vulnerability Assessment Scoring Tool, of this guidance is a potential tool for both regional and local prioritization of assets.

Box 3-2: NCC Program

SANDAG and Caltrans developed the North Coast Corridor Public Works Plan/Transportation and Resource Enhancement Program (NCC Program) after more than 10 years of stakeholder collaboration and public input. The resulting NCC Program provides an implementation blueprint for a $6.5 billion, 40-year program of rail, highway, environmental, and coastal access improvements along 27 miles of coastline and some of the largest remaining coastal lagoons in California. Six cities in the San Diego region lie entirely or partially within the NCC: San Diego, Solana Beach, Del Mar, Encinitas, Carlsbad, and Oceanside. Local land use decisions have generally encouraged low-density, single-use development supported by an extensive highway and arterial network, resulting in inadequate transit facilities and services, traffic congestion, travel delays, and incomplete bike and pedestrian networks. The NCC Program implements a framework for alternative modes of transportation by improving the existing coastal rail corridor and adding express lanes on I-5 that allow for express buses, vanpools, and carpools. Sea level rise was considered in the design of new rail and highway bridges which will feature longer spans with fewer piers in the water. The smaller footprint of these bridges will help to improve tidal flow in many of the lagoons, resulting in healthier coastal environments.

The CCC approved LCP amendments for the four Cities within the corridor that have certified LCPs affected by the scope of transportation improvements within the NCC Program—San Diego, Encinitas, Carlsbad, and Oceanside—to resolve any potential policy conflicts between the Cities' LCPs and the NCC Program. The LCPs were amended to create narrowly-defined overlay zones that identify specific rail, highway, transit, bicycle, pedestrian, community, and resource enhancement projects envisioned to occur within each City's jurisdictional boundaries. The overlays include general policy language that mirrors the policy language in the NCC Program, but defer more specific project development standards to the language within the NCC Program to allow for more minor changes to the NCC Program requiring NCC Program amendments to occur without requiring amendments to the LCPs, so long as these changes are still consistent with the broader policy language included within the overlay.

In addition to transportation and resource protection benefits, the NCC Program includes unique opportunities for community enhancement projects such as parks, wetland restoration, improved view corridors, and regional gateways. Thus, to address the transportation mobility, coastal access and coastal resource deficiencies, constraints, and needs in the NCC, a comprehensive approach was needed to achieve specific objectives while being sensitive to competing goals and constraints.

Source: *https://www.keepsandiegomoving.com/North-Coast-Corridor/NCCHome.aspx.*

PHOTO: MOFFATT & NICHOL

04

Adaptation Pathways

PHOTO: SANDAG

4 Adaptation Pathways

Adaptation planning involves a range of policies, funding mechanisms, and engineered projects that can be implemented proactively or reactively, depending on the degree of preparedness and the willingness to tolerate risk. Since sea level rise adaptation planning for regional transportation infrastructure is anticipated to require significant multi-jurisdictional coordination and funding, advanced planning is vital. This "Pathways" Section provides regional and local planners flexibility to choose from an array of short- and long-term strategies to integrate into their planning processes. The policies, projects, and funding mechanisms discussed in this Section can be combined with strategies that change behavior, including operational adaptation and educational programs. These adaptation strategies have been developed for consideration of the transportation facilities analyzed in Section 2, but may be applicable to other assets in the region. Given the uncertainty in timing and severity of impacts, it is important to identify triggers which, once reached, indicate that certain adaptation strategies have run their course and planning for new adaptation strategies is needed. For example, thresholds related to the extent of flooding or frequency of damages might be used to trigger implementation of a specific engineered project. Note that for all the strategies in this Section, project-level analyses evaluating the strategies' effectiveness, as well as environmental, economic, and social impacts will be required for further development and approval.

4.1 Policies

Sea level rise adaptation strategies can be integrated into a variety of existing regional and local policy frameworks, such as SANDAG's shoreline management policy documents, local coastal programs (LCPs), General Plans, climate action plans, and local hazard mitigation plans. Policies in these documents provide guidance regarding how to allocate funds, make land use decisions, facilitate public engagement, protect valued resources, and preserve community character, among other issues, and therefore provide the foundation to support or undermine adaptation solutions. The following sections detail regional and local policy updates that can be implemented to encourage adaptation.

4.1.1 Regional Level

As described in **Section 1.2**, SANDAG's Role in Shoreline Management, SANDAG adopted four policy documents that describe the region's approach to shoreline management, with the cornerstone being beach nourishment. While a high, wide beach can help reduce shoreline erosion and flooding, the benefits of beach nourishment are temporary and how much sand is needed, how often it is needed, and where the sand will go once it is placed are topics of ongoing research. Further, SANDAG's existing shoreline management policy framework does not explicitly consider sea level rise; as sea level rises and beach erosion increases, the volume of sand and frequency of nourishment required to mitigate coastal hazards are likely to increase. Depending on variables such as the availability of sand sources, whether neighboring beaches are being nourished, and funding, beach nourishment may need to be combined with other shoreline management to maintain the beach for public access and recreation, and to protect infrastructure and property along the coast, including regional transportation infrastructure, over time.

The following updates to SANDAG's existing policy documents are recommended to incorporate adaptive management and assist the region in making informed decisions and investments to build a more resilient shoreline. All the documents should be revised based on the best available sea level rise science and understanding of adaptation practices, acknowledging that future updates will be needed as our understanding continues to evolve. Below is a summary of the four documents with a list of specific updates compiled from detailed policy analysis shown in Appendix D. These SANDAG policy documents serve to address shoreline management from a regional scale and aim to protect both environmental and built community assets, including transportation infrastructure.

The Shoreline Preservation Strategy (SPS; SANDAG 1993) recommends beach nourishment as the primary shoreline management strategy to address critical erosion areas (Oceanside Harbor through La Jolla Shores, and Silver Strand State Beach to the U.S./Mexico border) on the scale of approximately 30 million cubic yards (cy) of sand across the whole region for initial restoration and nearly 400,000 cy/year thereafter for maintenance.

- As opposed to specific volumes of sand, the emphasis of the strategy should be on trigger-based adaptation, in which nourishment occurs when a threshold (e.g., beach width) is reached. This approach allows the amount of sand and frequency of beach nourishment to adapt as sea level rises. As such, beach nourishment can be the primary near-term sea level rise adaptation strategy for the region; however, the feasibility of beach nourishment as a mid- and long-term sea level rise adaptation strategy varies by littoral cell (described below).[1]
- Beachfilling recommendations need to be revised based on lessons learned from SANDAG's Regional Shoreline Monitoring Program, which began in 1996 and measures the changes in beach width over time, documents the benefits of beach nourishment projects (such as the 2001 and 2012 Regional Beach Sand Projects [RBSPs]), and helps to improve the design of beach fills. For example, using this data enables sand volumes and cost estimates to be determined based on existing conditions.
- Beachfilling recommendations also need to be revised based on the significant progress that has been made to identify sand sources, e.g., SCOUP (SANDAG 2006) upland sources, RSBP I and II offshore sources, and CRSMP (SANDAG and CSMW 2009) coastal sources (e.g., lagoon/harbor maintenance dredging and restoration), because sand sources affect the feasibility of beach nourishment as sea level rises. For example, because major sources of sand off Imperial Beach (Silver Strand Littoral Cell) have not been confirmed to be suitable, the feasibility of beach nourishment as a mid-term sea level rise adaptation strategy is questionable. In contrast, beach nourishment is likely a feasible, cost-effective mid- and long-term sea level rise adaptation strategy for Mission Beach (Mission Bay Littoral Cell) because it has a large, proximal offshore source with excellent sand quality and a naturally wide beach.
- Beachfilling recommendations for the Oceanside Littoral Cell need to be revised to account for geomorphic differences within the cell. The cell includes both narrow, bluff-backed beaches (e.g., Encinitas) and wider, river valley beaches (e.g., Del Mar sand spit). Beachbuilding is more sustainable in wider, river valley settings, whereas along narrow, bluff-backed beaches, retention strategies may be needed in order to sustain sand volumes as sea level rises. Further, along bluff-backed beaches, high amounts of sea level rise may necessitate additional strategies, such as managed retreat, because these areas do not naturally hold significant volumes of sand, evidenced by the fact that these stretches of the San Diego shoreline have historically been critical erosion areas.
- Since beach nourishment may need to be supplemented by sand retention devices to address mid-term sea level rise in the Silver Strand and Oceanside Littoral Cells, the beachfilling recommendations should be revised to reflect the effectiveness of these devices, which still needs to be explored, e.g., through a pilot project.
- The strategy needs to be updated with details about a funding program with a major portion of the required funds for beach nourishment from local and regional sources, as identified in the 1993 document.

The Sand Retention Strategy (SRS; SANDAG 2001) follows up on the SPS and describes how sand retention devices have the potential to increase the cost effectiveness of beach nourishment and possibly reduce environmental effects of beach nourishment by protecting sensitive resources such as reefs and lagoons from sedimentation, and providing new habitat areas.

The conclusion that sand retention devices are economically justified along the more erosive beaches, but not more stable beaches, needs to be revisited in light of sea level rise. To maintain their effectiveness as sea level rises, sand retention devices will have to be adaptable; that is, they must be able to be elevated and enlarged over time, which increases the cost of the devices and affects the previous life-cycle cost analysis. That being said, the increased cost may still be justified since the amount of sand needed for nourishment will increase over time.

- The study only evaluated sand retention devices (e.g., groin, breakwater, or reef) that City of San Diego staff felt were appropriate for their respective communities. Therefore, contacting City of San Diego staff to determine whether there is still interest in the devices identified in the document, or if others are now preferred, and in what locations, is critical for the study to be relevant today. For example, the City of Carlsbad was willing to do a pilot project at South Carlsbad just north of the Las Encinas Creek mouth, but it is unclear whether this is still the case. "The study only evaluated sand retention devices (e.g., groin, breakwater, or reef) that coastal city staff felt were appropriate for their respective communities. Therefore, contacting city staff to determine whether there is still interest in the devices identified in the document, or if others are now preferred, and in what locations, is critical for the study to be relevant today. For example, the City of Carlsbad was willing to do a pilot project at South Carlsbad just north of the Las Encinas Creek mouth, but it is unclear whether this is still the case. Similarly, a prototype-scale pilot study of groin performance was at one point considered in the City of Oceanside, and the City of Oceanside

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[1] Near-term refers to 0–1.5 feet of sea level rise; mid-term refers to 1.5–3 feet of sea level rise; long-term refers to 3–6.6 feet of sea level rise.

may wish to revisit this, considering its current narrow beach (excluding Harbor Beach).

- Because artificial reefs were the previously preferred sand retention device, the study needs to be updated to incorporate findings from recent projects such as the Narrowneck Reef in Australia and a recently initiated study of sand retention reefs sponsored by the California Coastal Conservancy (Everts Coastal 2002).

The Sand Compatibility and Opportunistic Use Program (SCOUP) **Plan** (SANDAG 2006) establishes a process approved by regulatory agencies for environmentally responsible use of opportunistic materials to nourish pre-established receiver sites when materials become available.

- While sea level rise does not affect the regulatory processes and criteria establishing appropriateness and compatibility of potential sources with receiver sites, the plan needs to be updated; SCOUPs will become increasingly important tools to implement beach nourishment because the volume of sand and frequency of nourishment required to mitigate sea level rise impacts are likely to increase. Further, SCOUPs allow local jurisdictions to place smaller volumes of sand as needed on local beaches, which can preserve beach width and minimize storm damage in between larger regional beach sand projects. All of the coastal jurisdictions have SCOUPs, with the exception of the Cities of Del Mar and San Diego.[2]
- The plan needs to be revised to incorporate the findings from the Tijuana River Demonstration Project, which showed that the sediment that was used for beach nourishment from a debris basin within the adjacent Border Field State Park with a high proportion of silts and clays did not harm the nearshore habitat, e.g., cause excessive turbidity (USGS 2012). A discussion is needed of whether loosening of the restrictions on grain size may be warranted on a case-by-case basis to allow for nourishment with less than optimal sand, which would increase the number of potential sand sources and beach nourishment opportunities using opportunistic material. An example of the restrictions on grain size is the 20% to 25% limit on silts and clays in opportunistic sand imposed by the permits for the permits for the Cities of Oceanside, Encinitas, and Solana Beach. In addition, the update should include a recommendation for a similar pilot project with a research institution (e.g., U.S. Geological Survey, Scripps Institute of Oceanography) in the Oceanside Littoral Cell so that findings can inform beach nourishment in that portion of the region.
- Existing SCOUP requirements were, in large part, developed to avoid impacts to intertidal and reef resources. Therefore, the plan needs to be updated to explore whether biological monitoring conducted to supplement SANDAG's existing Regional Shoreline Monitoring Program would determine if less stringent SCOUP requirements (e.g., placing sand in larger volumes, with a larger grain size distribution, or more frequently) would facilitate use of opportunistic materials while still avoiding impacts. Regional biological monitoring could reduce the burden and associated costs for individual cities trying to better take advantage of their SCOUPs.


PHOTO: SANDAG

Coastal Regional Sand Management Plan (CRSMP; SANDAG and CSMW 2009) presents approximately 60 sediment source sites (including upland sources, coastal lagoons/harbors, and offshore sources) and 27 sediment receiver sites from Oceanside to Imperial Beach that are eroding or that have a deficit of sediment. The CRSMP outlines two management alternatives[3] to counteract effects of reduced natural sediment supplies (400,000 cy/year) and achieve the SPS goal of increasing the amount of sediment in the region by 30 million cy over 50 years (600,000 cy/year).[4]

- The plan acknowledges that solutions are needed to address sea level rise; however, specific revisions to the SPS are not included and should be stated.
- The plan declares that SANDAG may need to update the plan on a five- to ten-year basis to keep it current. Updates are now needed to reflect current sediment source and receiver sites.
- Similar to updates needed for the SPS and SRS, the two management alternatives need to be reviewed with respect to sea level rise. For example, the plan found that sand retention devices can reduce long-term beach nourishment costs by approximately 25%, but this cost analysis does not account for the fact that sand retention devices will have to be adaptable (e.g., able to be raised and lengthened) as sea level rise occurs.
- Further, the management alternative involving sediment retention devices assumes that these devices will reduce the need for nourishment by 50%. This assumption should be revised to reflect the effectiveness of these devices, which still needs to be explored (e.g., through a pilot project).
- The plan also concludes that projects should focus on using offshore sand having a benefit-to-cost ratio higher than 1.0, instead of opportunistic sand having a benefit-to-cost ratio less than 1.0, until a cost reduction for use of terrestrial sand can be realized. The plan should be revised based on the latest sand project economics.

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[2] The City of Del Mar is currently pursuing development of a SCOUP to enable the City to more readily accept beach-quality sand, when available, to nourish Del Mar's beaches. Since the City of San Diego is in the early stages of sea level rise planning, it is unknown whether development of a SCOUP will be pursued. Note that the Cities of National City and Chula Vista do not have SCOUPs; however, being located within San Diego Bay, these communities do not have extensive beaches and/or erosion problems that would require beach nourishment.

[3] Management Alternative One involves nourishment only (1,000,000 cy/yr), while Management Alternative Two involves nourishment (500,000 cy/yr) and sediment retention devices. Both Management Alternatives assume that new sediment will come from upland sources, coastal lagoons/harbors, and offshore sources. It is likely that Management Alternative Two would lead to reduced costs over time and accomplish the 30 million cy goal quicker than Management Alternative One.

[4] Placement of up to 30 million cy of sand on the beach at one time is infeasible due to potential impacts to sensitive biological habitat and funding constraints. Hence, placement of the sediment quantity recommended by the SPS will occur in multiple placement projects over time.

PHOTO: JOHN GIBBINS / SAN DIEGO UNION-TRIBUNE

4.1.2 Local Level

The impacts of sea level rise will be felt at the local level, and local responses will be an essential part of effective management of these impacts. The California Coastal Act of 1976 establishes LCPs as a planning mechanism for implementing sea level rise adaptation strategies at the local level. LCPs contain the standards that govern future development and protect resources in the coastal zone. Development located between the sea and the first public road inland of the sea must also be consistent with the public access and recreation policies of the California Coastal Act. Each LCP includes a land use plan and an implementation plan. The land use plan specifies the kinds, locations, and intensity of uses, often mirroring a community's General Plan, and contains a required public access component to ensure that maximum recreational opportunities and public access to the coast are provided. The implementation plan includes measures to implement the land use plan, such as zoning ordinances, often mirroring a community's municipal code. Local governments with coastal resources at risk from sea level rise are encouraged to update their LCPs as a means to prepare for and mitigate these impacts. LCP updates are prepared by local governments and submitted to the CCC for review and certification for consistency with California Coastal Act requirements.

The CCC has made it a high priority to support LCP updates that address sea level rise, as demonstrated by the CCC's SLR Policy Guidance (updated to reflect the best available science [OPC 2018]), Draft Residential Adaptation Policy Guidance (intended to be a companion document to the CCC's SLR Policy Guidance), and investment in the LCP Grant Program. CCC staff are also currently working on an additional adaptation guidance document focused specifically on critical infrastructure, including transportation infrastructure. The goal of updating or developing a new LCP to prepare for sea level rise is to ensure that adaptation occurs in a way that protects both coastal resources and public safety and allows for sustainable economic growth.

The specific local context and existing development patterns must be considered when developing sea level rise policies. This section is limited to LCPs because this planning process often sets the standard for other policy updates at the local level that support adaptation. Because this report is focused on vulnerable regional transportation infrastructure, **Box 4-1** presents adaptation measures identified in the CCC's SLR Policy Guidance for transportation infrastructure. The CCC's SLR Policy Guidance also includes adaptation measures for many other categories of coastal resources that local governments can consider including in their LCPs. While a number of local governments are working on sea level rise updates to their LCPs, to date, none of these updates have been approved by the CCC San Diego District.

Box 4-1: Measures local governments can consider including in their LCPs to protect vulnerable regional transportation infrastructure.

A.29—*Identify priorities for adaptation planning and response: Carry out vulnerability analyses to identify chronic problem areas that are highly subject to erosion, wave impacts, flooding, or other coastal hazards or that maybe become so in the near future. Coordinate with Caltrans and local public works/transportation agencies to address high priority areas and increase monitoring efforts of chronic problem areas.*

A.30—*Add policies to address impacts to transportation routes: If transportation facilities are at risk from sea level rise, coordinate with Caltrans and local public works/transportation agencies to establish new alternative transportation routes or a plan to ensure continued alternative transportation and parking is available that allows for continued access to beaches and other recreation areas.*

A.30a—*Integrate LCP/land use planning processes with transportation planning processes: Updates and changes to LCPs and other land use planning efforts should be jointly planned, evaluated, and implemented with Coordinated System Management Plans, Regional Transportation Plans, and other transportation planning efforts to ensure that long-term land use and access goals and needs are aligned.*

A.31—*Allow for phased implementation of realignment and relocation projects: In some cases it may be necessary to make incremental changes in transportation networks so that access to and along the coast can be maintained while also addressing coastal hazards over the long-term. For example, a phased approach may allow for interim shoreline protection to maintain an existing road alignment while future realignment plans are evaluated and pursued. Such phased approaches should be coordinated with Caltrans and local public works/transportation agencies and aligned with long-term LCP planning and adaptation goals. Individual projects will be implemented through CDPs.*

A.32—*Plan and design transportation systems to accommodate anticipated sea level rise impacts: Ensure that transportation networks are designed to function even if the highest projected sea level rise amounts occur. Efforts to realign, retrofit, and/or protect infrastructure should be coordinated with Caltrans, local public works/transportation agencies, and LCP planning efforts, and individual projects will be implemented through CDPs.*

A.32a—*Retrofit existing transportation infrastructure as necessary: In instances where relocation is not an option, repair damage and/or retrofit existing structures to better withstand sea level rise impacts. For example, use stronger materials, elevate bridges or sections of roadways, and build larger or additional drainage systems to address flooding concerns.*

A.32b—*Build redundancy into the system: Provide alternate routes, as possible, to allow for access to and along the coast in instances in which sections of roadways may become temporarily impassible as a result of coastal hazards. Ensure that alternate route information is provided to residents and visitors to coastal areas.*

Source: *CCC 2018.*

4.2 Projects

Adaptation engineered projects generally fall into four main categories: do nothing, protect, accommodate, and retreat. Choosing to "do nothing" results in the need to react when sea level rise impacts occur. While initial costs are low, preliminary analysis by Moser et al. (2018) suggests that the cost of inaction is likely far greater, by multiple orders of magnitude, than the cost of adaptation. In addition, public access, recreation, and biological resources can be impacted by doing nothing as a result of coastlines being squeezed between rising water levels and inland infrastructure. Ultimately, the post-disaster cleanup is often lacking in vision and leads to reconstruction of the same types of non-resilient strategies, thereby constraining future adaptation options.

When considering which project (or combination of projects) is most appropriate in a particular circumstance, it is important to consider the trade-offs (i.e., who/what will benefit and who/what will be adversely impacted). Over time, a local jurisdiction may implement projects in the following order: protect, accommodate, and retreat. Protection strategies employ some sort of engineered structure or other measure to protect transportation infrastructure from flooding and inundation in its current location. Protection strategies can be further divided into "hard" and "soft" defensive measures. Examples of a hard approach would be to construct a seawall or revetment, while a soft approach may be to nourish beaches with sand or build sand dunes.

Accommodation strategies employ methods that modify existing or design new transportation infrastructure in a manner that decreases hazard risks and therefore increases the resiliency of the infrastructure to the impacts of sea level rise. One example may include floodproofing an asset so that it can continue functioning properly under projected conditions.

Retreat strategies relocate or remove existing transportation infrastructure out of hazard areas and limit the construction of new infrastructure in vulnerable areas. Relocation of transportation facilities will likely need to occur through a phased implementation approach, making incremental changes in transportation networks over time so that access to and along the coast can be maintained while also addressing coastal hazards over the long term. For example, redundant transportation routes could be opened to provide the public with alternative routes should flooding or inundation affect the regional transportation network. The following sections detail engineered projects that can be pursued at the regional and local level to increase the resilience of regional transportation infrastructure identified as vulnerable in this report.

4.2.1 Regional Level

Regional-level planning and projects provide an opportunity for local jurisdictions to solve multiple similar problems with broad cooperative solutions. Working regionally can provide the advantages of cost savings and knowledge transfer. Regional beach sand projects are more cost effective than small-scale projects because of the reduction in required permitting, engineering, and construction contracts. Further, regional pilot projects advance the understanding of adaptation strategies and stimulate regional conversations of how the San Diego region can adapt to sea level rise in a cohesive manner.

Regional Beach Sand Projects

Beach nourishment has been the preferred approach to address the region's sediment deficit and eroding beaches. The SPS recommended an extensive beach nourishment and maintenance program for critical erosion areas, and the CRSMP outlined management alternatives to implement the SPS over 50 years.

In 2001, SANDAG conducted RBSP I, which placed approximately 2.1 million cy of sand dredged from six offshore borrow sites on 12 beaches and represented the first major step in carrying out the long-term vision to managing the region's shoreline. Monitoring results for RBSP I confirmed that the project successfully restored beach widths without significant temporary impacts to public access or shoreline habitat. Monitoring results also revealed the importance of sand grain size. In 2001, nourishment at Torrey Pines State Beach involved a sand grain size similar to the native material, and this sand washed offshore in a single storm and only partially returned to the beach the following summer. In contrast, nourishment at Imperial, Solana, and Cardiff Beaches involved a sand grain coarser than the native material, and this material helped widen the beach for several years (Kalansky et al., 2018 and Ludka et al., 2018). RBSP I had a discernible "life span" of approximately four years, such that beach widths reverted to their narrower pre-RBSP conditions five years after the project. This loss rate of approximately 400,000 cy/year was consistent with the SPS and underscored the need for continued nourishment to maintain the region's beaches.

Figure 4-1. RBSP I and II

Regional Beach Sand Project I (2001)	Regional Beach Sand Project II (2012)
• Placed 2.1 MCY of sand on 12 beaches: Oceanside, North Carlsbad, South Carlsbad, Batiquitos, Leucadia, Moonlight, Cardiff, Fletcher Cove, Del Mar, Torrey Pines, Mission Beach, Imperial Beach • 6 offshore borrow sites • Funded by U.S. Navy, California Division of Boating and Waterways, and region's coastal cities	• Placed 1.5 MCY sand on 8 beaches: Oceanside, North Carlsbad, South Carlsbad, Batiquitos, Moonlight, Cardiff, Fletcher Cove, Imperial Beach • 3 offshore borrow sites • Funded by California Division of Boating and Waterways and region's coastal cities

Thus, in 2012, based on the success of RBSP I, SANDAG conducted RBSP II, which placed approximately 1.5 million cy of sand dredged from three offshore borrow sites on eight beaches. Monitoring results showed that beaches that were nourished by RBSP II were on average 33 feet wider and three to six feet higher in 2015–2016 than in 2009–2010, whereas beaches that were not nourished by RBSP II, like Torrey Pines State Beach, were slightly more eroded in 2015–2016 than in 2009–2010 (CFC, 2019) **Figure 4-1**.

Based on interviews with staff from many of the region's coastal cities and agencies, beach nourishment was also identified as a preferred sea level rise adaptation strategy. SANDAG is currently pursuing funding for a feasibility study for RBSP III, which could lead to implementation of a future project that will build on lessons learned from RBSP I and II, as well as explicitly consider how beach nourishment can be used to protect regional transportation infrastructure as sea level rises, including the need for placing larger volumes of sand more frequently over time while avoiding significant coastal impacts. Because the proximity, quality, and quantity of sand affect the feasibility of beach nourishment, better understanding of existing sand sources and finding new sources is critical to continued implementation of beach nourishment as a sea level rise strategy.

Critical inland and offshore sand sources in the San Diego region include offshore borrow sites, lagoons, and harbors. A discussion of sediment sources and ownership can be found in the Coastal Regional Sediment Management Plan (M&N 2009). Offshore sources, first utilized in RBSP I, are the largest (exceeding 1,000,000 cy of sediment) and consist of a high proportion of sands that tend to be clean of contaminants. However, offshore sources are limited by dredging capabilities and proximity to eroding beaches. Due to the costs of offshore dredging, large-scale projects involving offshore sediment are typically performed every five to 10 years, depending on funding availability. RBSP III plans to include an investigation of a minimum of three offshore borrow sites to better quantify their capacities (SO5, MB-1, and at least one new site in North County; **Table 4-1**).

In addition, six lagoons, three harbors, one river, and one estuary in the region provide sand from either maintenance dredging and/or restoration **(Figure 4-2)**. Maintenance dredging can provide sand on a regular basis, while restoration occurs on a more infrequent basis (decades or longer periods) with wide-ranging sand volumes. These coastal sediment sources can have relatively high percentages of fines and can contain chemical constituents of concern, varying by region and watershed, but testing is required prior to placement, and contaminated sediments are disposed of in an appropriate manner rather than used for beach nourishment.

Due to funding constraints, most lagoons are not dredged to full capacity. For example, the California Department of Fish and Wildlife (CDFW) oversees Batiquitos Lagoon dredging, and the scope of the dredging operations is based on available funding (e.g., from SANDAG and Caltrans) and permit (Encinitas SCOUP) restrictions. The CDFW dredges approximately 118,000 cy of sand from Batiquitos Lagoon every few years, but in actuality, sand volumes that could be dredged are on the order of 300,000 cy or more. The CDFW could potentially obtain an individual permit for beach sand placement in order to dredge and place the full extent of available material. Private companies, NRG Energy and Southern California Edison, are responsible for dredging Agua Hedionda and San Dieguito Lagoons to comply with regulatory permits, but these requirements are often based on minimum environmental criteria, such as channel cross-section/tidal prism, not maximum sand volume for beach nourishment purposes. Agua Hedionda Lagoon dredging may significantly decrease in the future due to the cessation of once-through cooling as required by the State Water Resources Control Board. Once-through-cooling, or OTC, is the process of drawing seawater in from the ocean to cool the powerplant during operation and emitting the warmed seawater back into the ocean after use. The California State Water Resources Control Board has required all coastal power plants to cease OTC operations. Power plants have initiated conversion of their plants to air cooling to replace water cooling. The Agua Hedionda Power Plant has already ceased OTC operations. Without water being drawn into the power plant, the lagoon has the ability to expel sediment that enters its mouth by outgoing ebb tidal flows. Therefore, it could be expected that the rate of sand shoaling in Agua Hedionda Lagoon should decline in the future from historic rates. However, at this time it is likely that the 300,000 cy/year that is dredged from Agua Hedionda represents some fraction of the available material. Also, a much greater volume of sand exists at the San Dieguito Lagoon mouth than the average dredge volumes of 16,000 cy every other year. Similarly, Oceanside Harbor is dredged of approximately 250,000 cy every year, but a

Table 4-1. Offshore Sediment Sources

Offshore Sediment Source		Location	Findings of Previous Investigations[a]	Considerations for Future Investigations
Potential Offshore Sediment Sources for Use in Future RBSPs	**SO-6**	Off South Encinitas (near San Elijo Lagoon)	Used in RBSPs I and II; good to excellent sand quality but limited remaining quantity	Consider re-investigating area used in RBSP I that was north of the San Elijo Joint Powers Authority outfall line, and reoccupying it as a dredge site.
	SO-5	Off Del Mar (near San Dieguito Lagoon)	Used in RBSP II; excellent sand quality and large quantity	Consider expanding investigation footprint to the north to increase area; consider exploring off Solana Beach, near Fletcher Cove, as the submarine geology is similar to Del Mar.
	MB-1	Off Mission Beach	Used in RBSPs I and II; excellent sand quality and large quantity	Consider expanding investigation footprint to the north and south to increase the area.
*Offshore Sediment Sources **Not Suitable** for Future RBSPs Due to Issues with Sand Quality*	**SM-1**	Off the Marine Corps Base Camp Pendleton (near the Santa Margarita River) and just north of Oceanside Harbor	Investigated for RBSP II – suitable to good sand quality	Strongly recommend additional investigations over the historic river delta over a larger area (and farther north) than was originally considered.
	SO-9	Off Oceanside Harbor to the north	Investigated during RBSP I – eliminated due to dredging fine grain sizes	Future use of site may be considered if surface layer of fines is removed and used to backfill previous "pits" (SO-7 off Carlsbad) to access better quality sand beneath surface layer.
	SO-8	Off Oceanside Harbor to the west	Investigated during RBSP I – did not meet grain size criteria	Focus on the historic delta to the San Luis Rey River.
	AH-1	Off North Carlsbad (near Agua Hedionda Lagoon)	Investigated during RBSP I – did not meet grain size criteria	Discard site.
	SO-4	Off Torrey Pines (near Los Peñasquitos Lagoon)	Investigated during RBSP I – did not meet grain size criteria	Discard site.
	TP-1	Off south Torrey Pines (near Black's Beach), north of Scripps Canyon	Investigated for RBSP II – marginal sand quality	Discard site.
	ZS-1	Off Coronado (on Zuniga Shoal)	Investigated for RBSP II – poor sand quality	Discard site.
	SS-2	Off Imperial Beach north end (USACE Area A)	Investigated during RBSP I – did not meet grain size criteria	Discard site.
	SS-1	Off the Tijuana River Estuary	Investigated during RBSP I – eliminated due to dredging cobble; Investigated for RBSP II – suitable to good sand quality	Consider re-investigating area over the historic delta to the Tijuana River.
*Offshore Sediment Sources **Not Suitable** for Future RBSPs Due to Insufficient Sand Quantity*	**SO-7**	Off South Carlsbad (near Batiquitos Lagoon)	Used in RBSP I – yields no more sand	Discard site; maybe consider using it as a backfill site for surface fines over sand in Oceanside.
	TP-2	Between Scripps and La Jolla Canyons	Scripps Institute of Oceanography studies suggest sediment less extensive than TP-1[b]	Discard site.

RBSP = Regional Beach Sand Project; **USACE** = U.S. Army Corps of Engineers.

[a] SANDAG and CSMW 2009, Section 5.1.3.

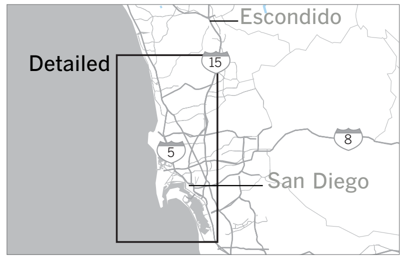
[b] Hogarth et al. 2007.

Figure 4-2

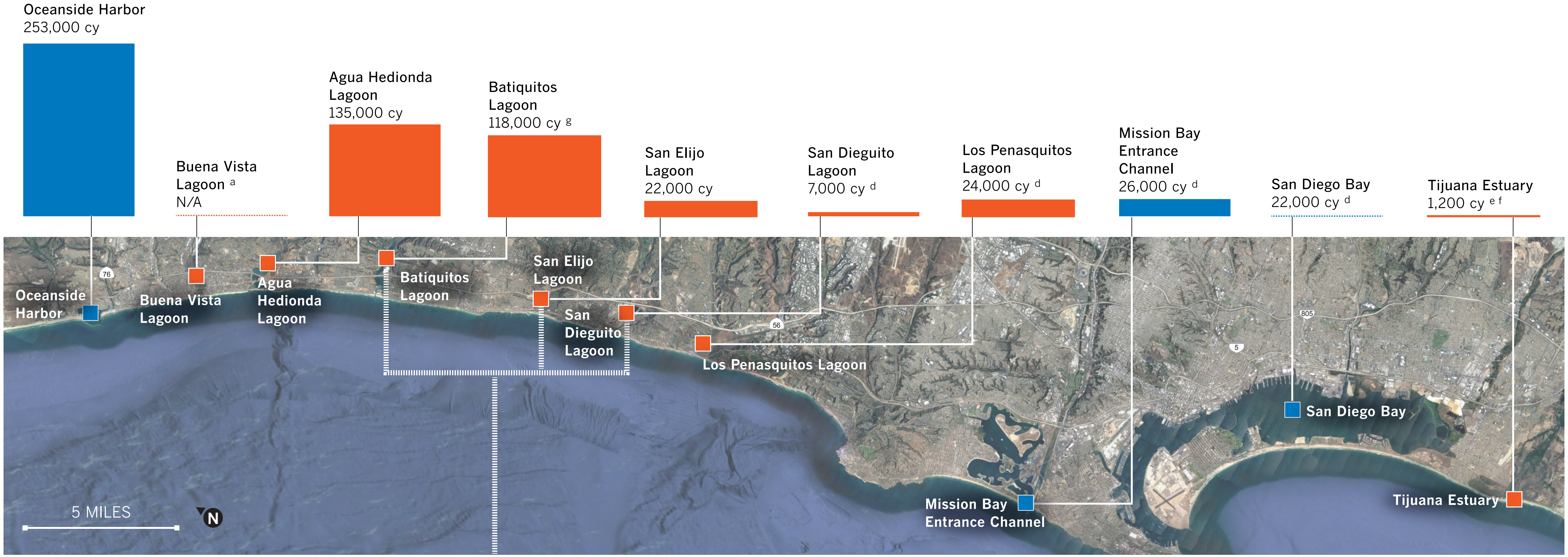
Lagoon and Harbor Sediment Sources

Six lagoons, three harbors, one river, and one estuary in the region provide sand from either maintenance dredging and/or restoration. Maintenance dredging can provide sand on a regular basis, while restoration occurs per decade or longer with wide-ranging sand volumes. All data in cubic yards.

KEY 🟧 Lagoon/Estuary 🟦 Harbor



How much sand is removed annually[g] through maintenance dredging?



How much sand has been removed for restoration?

The Batiquitos Lagoon provides a majority of the sand for beach nourishment at 1,500,000 cy. The San Elijo lagoon is second, providing 456,000 cy and the San Dieguito Lagoon a distant third, providing 40,000 cy.

Sources: SANDAG and CSMW 2009, Section 5.1.3, unless noted otherwise below.

Notes: N/A = not applicable.

a Pending future restoration as part of the NCC Program (see Table ES-3 for maintenance dredging and restoration volumes depending on the freshwater, saltwater, or hybrid alternatives).

b Between 2018 and 2019, restoration of the entire San Elijo Lagoon system involved dredging of approximately 850,000 cy of beach-quality sediment for reuse at local beaches and storage at off-shore sites (CCC CDP 6-16-0275). As a result, future lagoon restoration is not considered a sand source.

c As part of W-19 restoration east of I-5 under the NCC Program, approximately 4,200 cy of additional material will be removed from the river channel within this sand trap area and placed on beach placement sites already identified as part of the SCE inlet maintenance. https:// www.keepsandiegomoving.com/ SanDieguitoLagoon/SDLagoon-intro.aspx

d Estimate based on SANDAG 2017 Regional Beach Monitoring Program, Annual Report (Coastal Frontiers 2017)

e Historical average annual dredge volumes were communicated by Brian Collins of the USFWS on March 6, 2019. The Refuge obtained a 5-year permit from the U.S. Army Corps of Engineers to allow dredging and related inlet maintenance at the Tijuana River mouth to maintain an open inlet and facilitate tidal exchange. The permit would dredging of up to 10,000 cy/year of sandy material that would be beneficially used to enhance the existing barrier sand dune system. http://trnerr.org/tijuana-river-mouth-dredging-project/.

f The Tijuana Estuary Tidal Restoration Program (TETRP) is not anticipated to uncover beach compatible sediment (Personal Communication, Chris Nordby, March 22, 2019).

g Maintenance dredging for Batiquitos Lagoon occurs every few years, not annually. All other maintenance dredging figures are annuall.

Aerial image Google Earth (2019).

larger quantity of sand likely exists there because the dredging focuses only on the navigation channel, and other areas remain shoaled. Thus, as sea level rises and the flood protection benefits of beach nourishment are increasingly in demand, there may be opportunities for the region to support increased dredging within coastal lagoons and harbors.

Further, sediment removed from lagoons and harbors is often not placed at optimum locations on beaches due to limited funds. To maximize the life span of sand placed on beaches from lagoons and harbors, the CRSMP recommends placing less than half of the material upcoast of the lagoon/harbor mouth and more than half of it downcoast to minimize return to lagoons or harbors. Providing as much distance as possible between the placement sites and source lagoons or harbors reduces return flows. However, this approach is more expensive than the status quo. As such, the region may decide to dedicate funding to more strategic sand placement to increase the effectiveness of beach nourishment.

Sand Retention Strategy Pilot Project

As discussed in Section 4.1.1, Regional Level, beach nourishment may need to be supplemented by sand retention devices to sustain sand volumes as sea level rises. The SPS first identified the sand retention devices as a shoreline management tactic, and the SRS and CRSMP concluded that these devices both increase the cost effectiveness of beach nourishment and decrease the amount of sand required to nourish the region annually because less sand would be lost from, and dispersed within, the littoral cell. Specifically, the CRSMP assumes that retention devices would reduce the needed annual nourishment amount by approximately 50%; however, this reduction is an estimate and depends on the type of sediment retention device, its size, and the number and distribution of similar devices throughout the region.

A future pilot project should be implemented to determine the effectiveness of a select sand retention device. This project would assess the technical feasibility, environmental impacts, and political acceptability through a rigorous public review. If feasible, implementation of a pilot sand retention project should be coordinated with a regional beach nourishment effort so that post-project monitoring efforts can be combined. **Table 4-2** summarizes the needs, constraints, and opportunities for sand retention devices considered by each coastal jurisdiction during development of the SRS. This table should be updated through coordination with City staff to reflect present conditions and preferences, and this information will inform development of a regional pilot project. Choosing the right structure for the environment and optimizing its location, configuration, and dimensions, is where real gains in efficiency can be made. Site-specific studies of measures at certain beaches would clarify the likely sand retention measure to be most effective. Funding may be available through the State OPC for pilot siting studies.

4.2.2 Local Level

Sea level rise associated flooding and inundation impacts are unique to each transportation asset as well as their geographic location. Unique impacts require unique solutions. Throughout the coastal jurisdictions in the region, many public entities have begun the process of developing such unique solutions to sea level rise impacts. **Figures 4-3a-c** uses public reports, where possible, to summarize potential local level adaptation strategies to the regional transportation assets identified in this guidance document's vulnerability assessment. Where public reports, such as vulnerability assessments or adaptation plans, were not identified, generalized solutions are provided to kickstart the planning process using state guidance (CCC 2018). A table with the potential local adaptation strategies is also included as **Appendix E**. Local adaptation measures described here represent a range of strategies including protection, accommodation, and retreat. Protection includes both hard and soft armoring and a focus on sediment management in the near term. Accommodation includes strategies such as elevating roadways and raising bridges. When appropriate, retreat has been identified as a potential adaptation strategy for roadways or trails with current vulnerabilities and feasible relocation options.


PHOTO: GOOGLE STREET VIEW

Table 4-2. Sand Retention Strategies

City	Desired Sand Retention Strategy	Discussion
Oceanside	Groin compartment at Buccaneer Beach	Buccaneer Beach is in need of sand retention and is unconstrained; possible modifications to existing federal sand bypassing at Oceanside Harbor to help offset downcoast impacts. An example is placement of harbor sand farther south to benefit south City beaches.
Carlsbad	Reef at South Carlsbad State Beach north beach area (submerged or emergent component)	North Carlsbad too constrained; South Carlsbad State Beach north beach area is in need of sand retention and only moderately constrained
Encinitas	Reef at Moonlight Beach (submerged or emergent component)	Moonlight Beach is in need of sand retention, suitable for habitat improvement, and only moderately constrained
Solana Beach	Reef at Fletcher Cove (submerged or emergent component)	Fletcher Cove is highly in need of sand retention, suitable for habitat improvement, and only moderately constrained
Del Mar	Unknown at this time[a]	Natural sand accretion between San Dieguito River mouth and Powerhouse Park
San Diego	Reef at Torrey Pines State Beach just south of lagoon (submerged or emergent component)	Torrey Pines State Beach just south of lagoon is in need of sand retention, which would help protect Hwy 101 and is unconstrained
Coronado	Extend existing Hotel del Coronado groin or construct new groin to south	Beach off the Shores condominiums is in need of sand retention and is unconstrained; opportunities assessment determined groins not effective unless very long, i.e., 800 ft to maintain all-season fillet, and because long groin would pose major concern for downcoast impacts, groins are not recommended; in lieu of groins, Coronado could consider an offshore breakwater or reef
Imperial Beach	Reef at south end of Seacoast Drive (submerged)	Beach at the south end of Seacoast Drive is in need of sand retention and is unconstrained; reef would need to avoid kelp beds and include surfing component

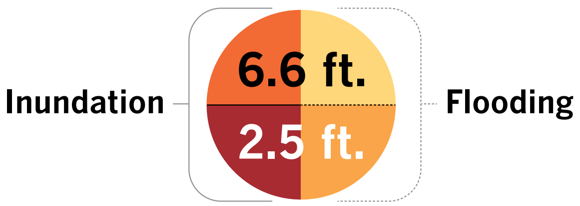
Source: Table 2-5 adapted from SANDAG 2001 (SRS).
Notes: Hwy 101 = Pacific Coast Highway 101; ft = feet.
[a] The City of Del Mar is currently pursuing development of a Shoreline Management Program to implement its Sea Level Rise Adaptation Plan, which includes beach nourishment in conjunction with sand retention measures.

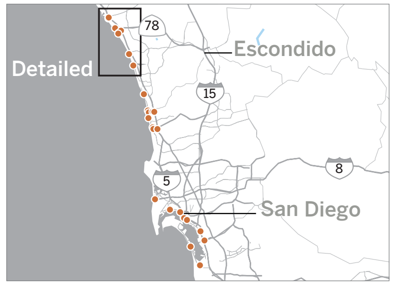
Figure 4-3a

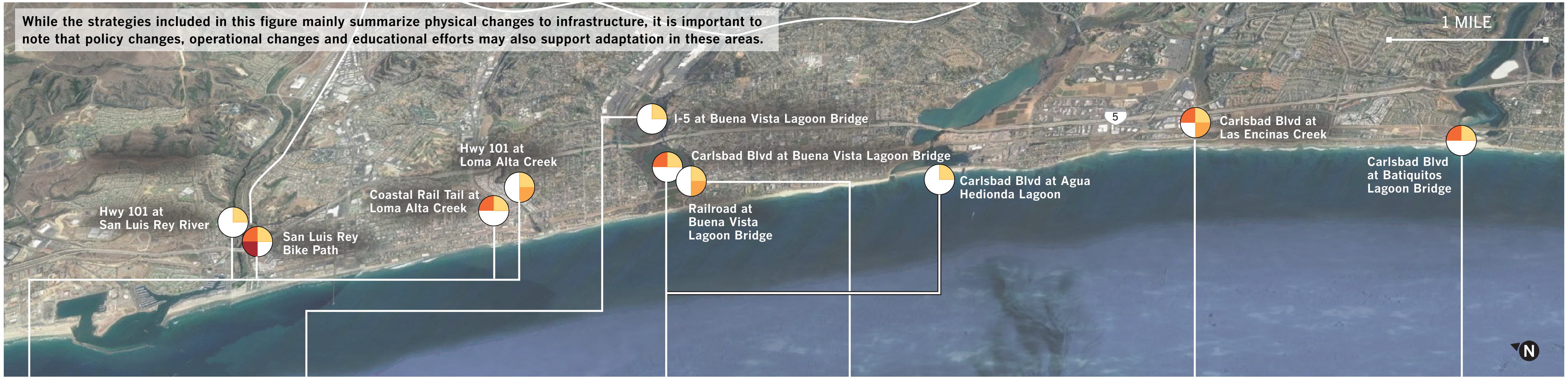
Potential Sea Level Rise Adaptation Strategies

This figure shows the regional transportation assets located within the inundation hazard zone (inundation) and/or flood hazard zone (flooding) for the 2.5-foot and/or 6.6-foot sea level rise scenarios, as discussed in the vulnerability assessment. The potential adaptation strategies listed for each asset were identified from publicly available local L and regional R reports, as well as generalized solutions from State guidance SG (CCC 2018).

KEY (Feet of Sea Level Rise)






While the strategies included in this figure mainly summarize physical changes to infrastructure, it is important to note that policy changes, operational changes and educational efforts may also support adaptation in these areas.

SG Hwy 101 at San Luis Rey River

San Luis Rey Bike Path

Coastal Rail Tail at Loma Alta Creek

Hwy 101 at Loma Alta Creek

Potential adaptation strategies for these assets are adapted from State guidance and include the following:

- Increase bridge abutment rock level
- Elevate bridge and roadway
- Reduce number of lanes and divert traffic to less vulnerable roadway.

Complete roadway retreat may face prohibitive complications.

R I-5 at Buena Vista Lagoon Bridge

This bridge will be replaced as part of future phases of the NCC Program and will be assessed using the best available sea level rise science and guidance.

L Carlsbad Blvd at Buena Vista Lagoon Bridge

Carlsbad Blvd. at Agua Hedionda Lagoon

- Landward relocation of public assets
- Dune or wetland restoration
- Beach nourishment
- Sand retention with nourishment
- Elevating structures
- Coastal armoring

R L Railroad at Buena Vista Lagoon Bridge

This bridge will be replaced as part of future phases of the NCC Program and will be assessed using the best available science sea level rise science and guidance.

- Landward relocation of public assets
- Dune or wetland restoration
- Beach nourishment
- Sand retention with nourishment
- Elevating structures
- Coastal armoring

L Carlsbad Blvd at Las Encinas Creek

- Close one lane of southbound Carlsbad Blvd
- Retreat all traffic to northbound Carlsbad Blvd
- Raise existing revetment
- Construct seawall
- Beach nourishment
- Winter sand dikes
- Nearshore reef
- Elevate southbound roadway on causeway
- Hybrid of the above alternatives

L Carlsbad Blvd at Batiquitos Lagoon Bridge

- Landward relocation of public assets
- Dune or wetland restoration
- Beach nourishment
- Sand retention with nourishment
- Elevating structures
- Coastal armoring

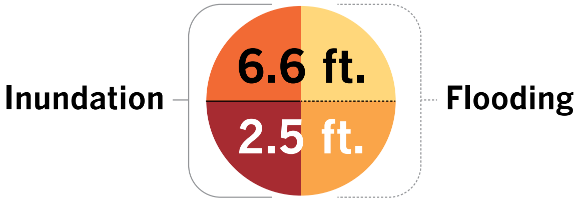
Note: Aerial image Google Earth (2019)

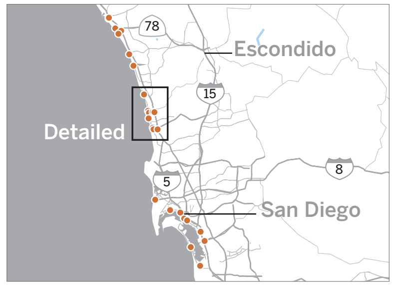
Figure 4-3b

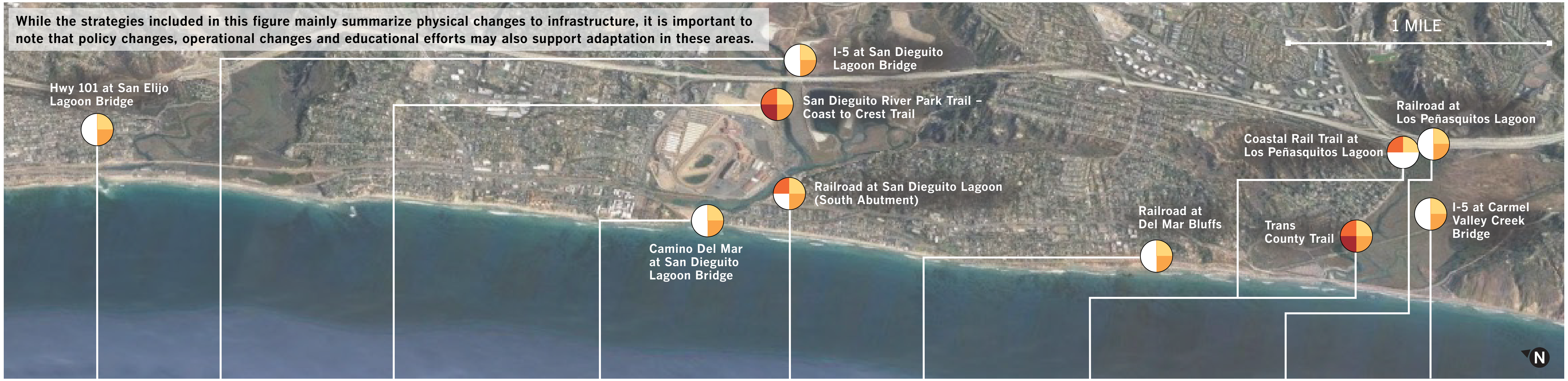
Potential Sea Level Rise Adaptation Strategies

This figure shows the regional transportation assets located within the inundation hazard zone (inundation) and/or flood hazard zone (flooding) for the 2.5-foot and/or 6.6-foot sea level rise scenarios, as discussed in the vulnerability assessment. The potential adaptation strategies listed for each asset were identified from publicly available local L and regional R reports, as well as generalized solutions from State guidance SG (CCC 2018).

KEY (Feet of Sea Level Rise)







While the strategies included in this figure mainly summarize physical changes to infrastructure, it is important to note that policy changes, operational changes and educational efforts may also support adaptation in these areas.

L Hwy 101 at San Elijo Lagoon Bridge

Seismic retrofit required of bridge in short term. Long-term would be bridge replacement with higher and longer bridge.

Hwy 101 at Cardiff State Beach

Short-term protection of North Parking with cobble berm, long-term protection with raised parking lot and seawall

Moffatt & Nichol 2018

Cardiff Living Shoreline Project constructed Spring 2019 to increase coastal protection for Hwy 101.

R I-5 at San Dieguito Lagoon Bridge

This bridge is in the process of being replaced as part of Phase 1 of the NCC Program and sea level rise is not expected to pose any risk to the proposed bridge (analyzed up to 66 in. of sea level rise with a fluvial flood).

L San Dieguito River Park Trail – Coast to Crest Trail

- River channel dredging
- Reservoir management
- Levees
- Elevate structures
- Relocate public infrastructure

L Camino Del Mar at San Dieguito Lagoon Bridge

City of Del Mar is in the process of replacing the bridge, which will require sea level rise analysis.

R Railroad at San Dieguito Lagoon (South Abutment)

This bridge will be replaced as part of future phases of the NCC Program and will be assessed using the best available science sea level rise science and guidance.

R Railroad at Del Mar Bluffs

SANDAG is currently working to stabilize the Del Mar Bluffs. Previous Phases 1, 2, and 3 of stabilizing were completed in 2003, 2007, and 2009. Future improvements may involve a tunnel/trench to remove the tracks from the bluffs. Future track replacements will be assessed using the best available science sea level rise science and guidance.

SG Trans County Trail

Coastal Rail Trail at Los Peñasquitos Lagoon

Potential adaptation strategies for these assets are adapted from State guidance and include the following:

- Separate trail from lagoon by a levee
- Flood-proof the trail so disruption is only temporary or elevate on boardwalk
- Relocate trail to the roadside

R Railroad at Los Peñasquitos Lagoon

Improvements to these railway bridges are pending a final decision on whether a trench or tunnel is built in the City of Del Mar, noted above, and will be assessed using the best available science sea level rise science and guidance.

R I-5 at Carmel Valley Creek Bridge

This bridge will be replaced as part of future phases of the NCC Program and will be assessed using the best available science sea level rise science and guidance

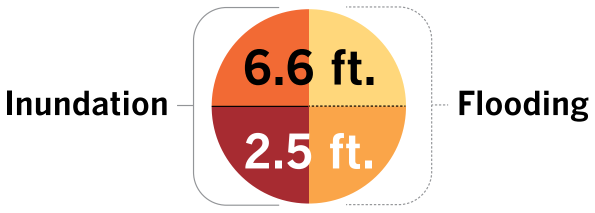
Note: Aerial image Google Earth (2019)

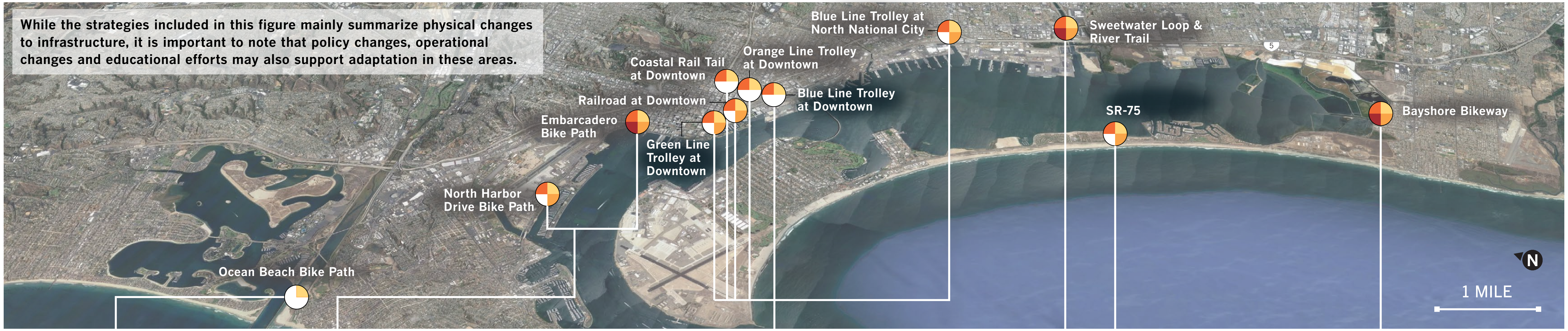
Figure 4-3c

Potential Sea Level Rise Adaptation Strategies

This figure shows the regional transportation assets located within the inundation hazard zone (inundation) and/or flood hazard zone (flooding) for the 2.5-foot and/or 6.6-foot sea level rise scenarios, as discussed in the vulnerability assessment. The potential adaptation strategies listed for each asset were identified from publicly available local L and regional R reports, as well as generalized solutions from State guidance SG (CCC 2018). It is anticipated that improvements to these facilities would be coordinated with other proposed adaptation projects for transportation facilities surrounding the San Diego Bay. These improvements would likely require a coordinated effort between the appropriate bayfront cities, Port of San Diego, MTS, NCTD, Caltrans, San Diego County Airport Authority, and SANDAG.

KEY (Feet of Sea Level Rise)





While the strategies included in this figure mainly summarize physical changes to infrastructure, it is important to note that policy changes, operational changes and educational efforts may also support adaptation in these areas.

SG Ocean Beach Bike Path

Potential adaptation strategies for these assets are adapted from State guidance and include the following:

- Levees or raised revetment
- Elevate on boardwalk
- Relocate bike path inland

SG North Harbor Drive Bike Path ▲
SG Embarcadero Bike Path ▲

The Embarcadero Bike Path and N Harbor Drive Bike Path will be among the first land-based assets flooded in downtown City of San Diego and will likely be part of city-wide adaptation planning. Potential adaptation strategies for these assets are adapted from State guidance and include the following.

- Raised seawall/bulkhead to keep water out
- Bike path elevated with fill, essentially creating a levee
- Relocate bike path away from waterfront

R Coastal Rail Tail at Downtown
R Railroad at Downtown
R Green Line Trolley at Downtown
R Orange Line Trolley at Downtown
R Blue Line Trolley at Downtown
R Blue Line Trolley at North National City

Blue Line, Orange Line, and Green Line Trolley flooding is anticipated to occur simultaneously with or after flooding of other critical infrastructure. The Railroad and Coastal Rail Trail will also be impacted in downtown San Diego.

Adaptation strategies for transportation facilities in this area, therefore, will likely be part of a greater coordination and sea level rise planning effort amongst several jurisdictions and agencies.

SG Sweetwater Loop & River Trail

The vulnerability for this trail stems from the low-point under I-5. Due to the infeasibility of raising I-5 in order to raise the trail, the Sweetwater Loop trail could be maintained as a floodable asset.

Potential adaptation strategies for this assets are adapted from State guidance and include the following:

- Separate trail from river with flood-proof wall
- Elevate above I-5
- Relocate inland

L SG SR-75

Potential strategies for Imperial Beach:

- Elevate SR-75
- Armoring Imperial Beach coastline
- Phased relocation/retreat
- Sand nourishment
- Hybrid dune and cobble
- Five groins with sand nourishment

Potential strategies for Coronado adapted from State guidance:

- Seawall, revetment, vegetated sand dune, beach nourishment
- Stormwater management best management practices, elevate trail on boardwalk
- Relocate trail to the roadside

L SG Bayshore Bikeway

Potential strategies for Imperial Beach:

- Elevate critical roads including the Bayshore bike path.
- Incrementally elevate the streets through regular resurfacing.

▲ Facilities are part of the larger California Coastal Trail System.

4.2.3 Statewide Example Projects

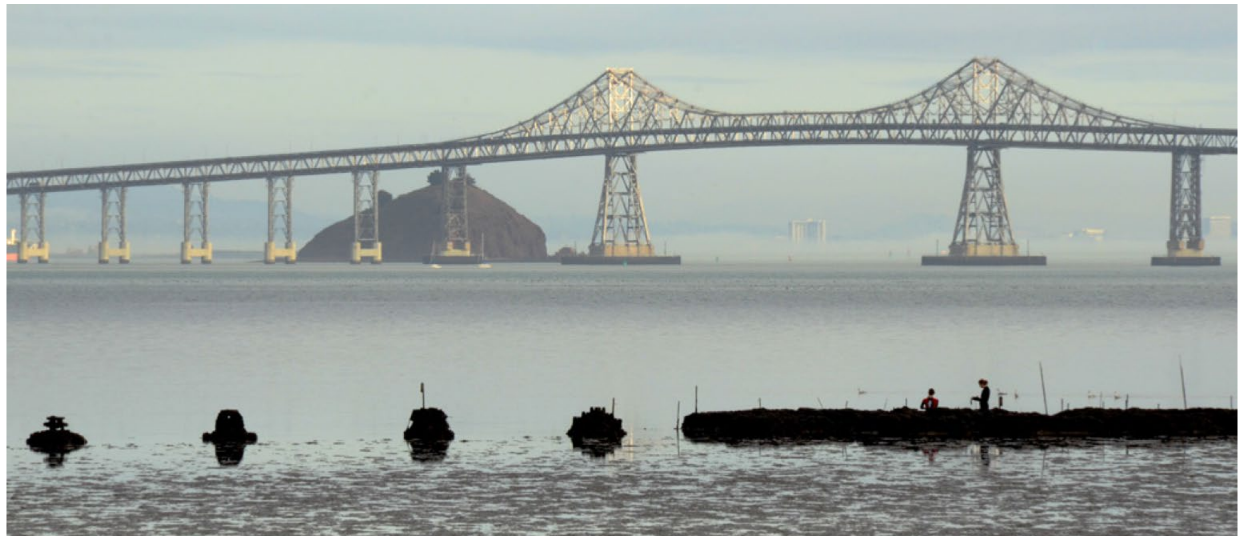
Creative and practical solutions will be necessary to adapt coastal infrastructure to sea level rise and storm impacts. Across the State of California, such projects are being designed, constructed, and tested. The following four project types may be suitable for some areas in San Diego County. These projects also have co-benefits, such as attenuating wave energy, reducing erosion, accreting sediment, creating fish and wildlife habitat, and providing outdoor recreation (Judge et al., 2017). These types of projects may be pursued in coordination with infrastructure improvements, such as bridge re-design, highlighted in Box 4-2.

Humboldt Coastal Dune Vulnerability and Adaptation Climate Ready Project – Humboldt County, CA

This project fortified a 32-mile coastal dune system with vegetation management, including removal of invasive species, planting native species, and installing sand fences. Coastal dunes improve biodiversity through habitat restoration and improve protection from/resilience to sea level rise and coastal storms. Coastal protection is provided by an elevated buffer between ocean and landward development or sensitive habitat, a reserve of sand to offset potential beach loss, and a natural capacity to capture wind-blown sand and grow. Coastal dunes are one of only a few soft engineering solutions for coastal resilience along shorelines facing the open ocean. Dunes are most likely to succeed along shorelines with existing/historic dunes, or where wide beach widths are maintained. Existing/historic dunes in San Diego County include beaches adjacent to the mouth of the Santa Margarita River, San Luis Rey River, San Diego River, and Tijuana River, as well as along the City of Coronado and SR-75 at the Silver Strand. Wide beaches could potentially facilitate dune establishment at Oceanside Harbor Beach, Ponto Beach at Batiquitos Lagoon, and south Mission Beach. This strategy was piloted in 2019 in the City of Encinitas through the Cardiff Beach Living Shoreline Project which restored vegetated dunes, and increased storm protection with the construction of a buried rock revetment, and cobble berm to dissipate wave energy.

Hamilton Wetland Restoration Project – Novato, CA

A horizontal levee is being constructed on the former Hamilton Army Airfield and the adjacent North Antenna Field (NAF) and Bel Marin Keys Unit V (BMKV) properties along the San Pablo Bay. A range of wetland habitat types are being restored to buffer inland development from sea level rise and coastal storms. Wetland habitat can absorb wave and storm surge energy, while the last line of defense levee which borders the wetland provides a barrier between high water levels and development. Additionally, should sediment inputs be sufficient, wetland habitat can capture suspended sediment and gain elevation as sea level rises. Similar solutions could potentially be explored in San Diego County at lagoons, river mouths, and bays.



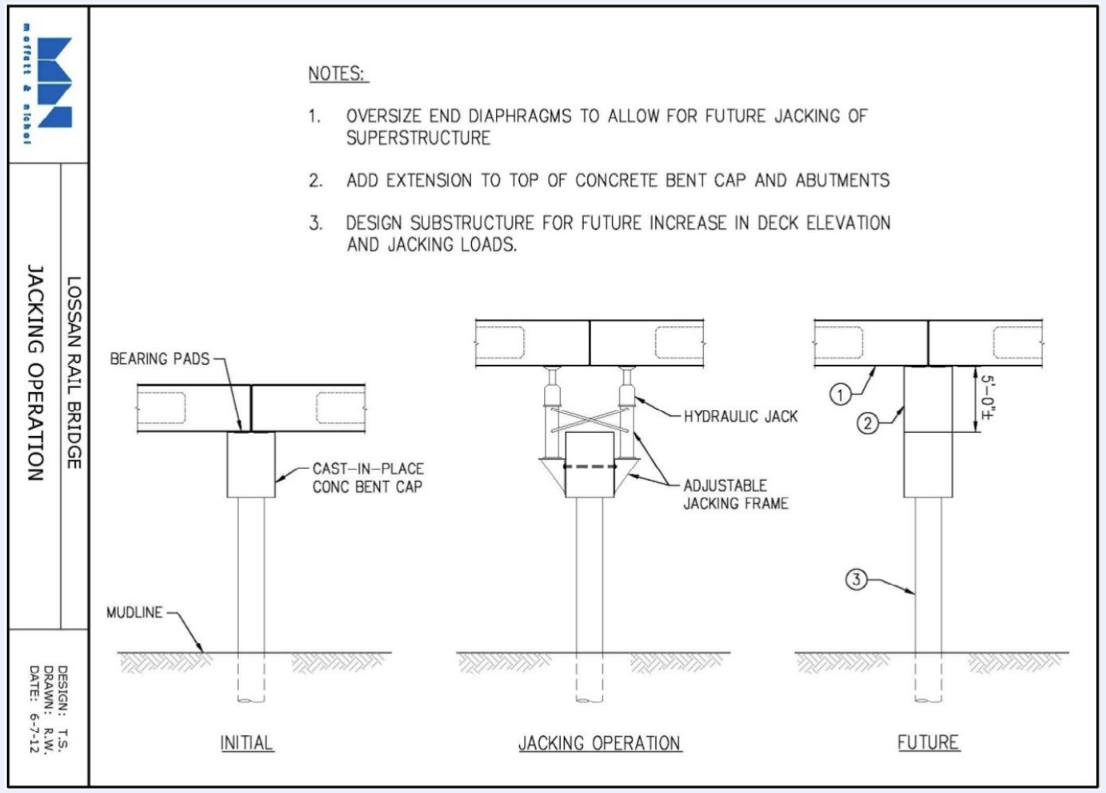
San Francisco Bay Living Shorelines Project – San Rafael, CA

This project created nearshore eelgrass and oyster reef habitat approximately 200 meters offshore of San Rafael within the San Francisco Bay. The eelgrass and oysters improved habitat value and water quality benefiting a number of bird and marine species. The physical habitat also reduced wave energy at the shoreline by 30 percent which promoted sediment accretion, and therefore reduced coastal erosion. Similar solutions could potentially be explored in San Diego County at lagoons, river mouths, and bays.

Seal Beach Sediment Augmentation – Seal Beach, CA

This pilot project added a thin layer of dredged material to the Seal Beach National Wildlife Refuge wetland. The wetland elevation was incrementally raised to compensate for land subsidence and sea level rise, protecting wetland and avian habitat, and reducing storm surge and wave energy. In the face of sea level rise, the addition of a thin-layer of sediment was identified as a feasible method to maintain wetlands which are cut off from natural sediment inputs. Thin-layer sediment addition could potentially be implemented at all wetlands within San Diego County to maintain their protective benefits well into the future.

Box 4-2: Adaptive Engineering of Bridges



NOTES:

1. OVERSIZE END DIAPHRAGMS TO ALLOW FOR FUTURE JACKING OF SUPERSTRUCTURE
2. ADD EXTENSION TO TOP OF CONCRETE BENT CAP AND ABUTMENTS
3. DESIGN SUBSTRUCTURE FOR FUTURE INCREASE IN DECK ELEVATION AND JACKING LOADS.

Many bridges located along lagoons and river inlets throughout San Diego County are identified as vulnerable to sea level rise. One possible method to prepare for sea level rise is to design bridge structures, and the roadways which approach them, that can be raised in the future. This adaptive management technique may be less costly and less impactful to the environment than complete bridge and approach replacement.

As an example, the LOSSAN rail bridge, shown in the image above, could be designed as a pre-cast bridge with an over-sized foundation. It would be constructed at the appropriate elevation for design conditions and then raised in the future to accommodate changes in sea level. The bridge would be raised incrementally with shims inserted between a series of small-scale vertical motions of the bridge. To facilitate this activity, design could include the following features, contingent upon site-specific conditions:

- Simple span precast box beams,
- Bearing pads under the box beams so that beams are not permanently connected to the substructure,
- Oversized end diaphragms of the box beams to allow space to jack the bridge,
- Substructure (piers, abutments, foundations) designed for the final raised condition,
- Pier walls (if not a pile structure) that readily accommodate an increase in elevation,
- Pile caps that extend beyond the face of the pier wall to make it easy to jack the bridge utilizing the bridge's own foundations for bearing,
- Pile caps designed to support the future loads, and
- Widened earthen berms at bridge approaches during initial construction to allow for raising of the berms to meet future raised bridge elevations.

Source: M&N, 2013

4.3 Funding Mechanisms

Regional agencies and local governments often take the lead in identifying adaptation strategies and then are required to find funds or devise locally acceptable financing mechanisms to implement them. This is a significant burden and responsibility for the safety of the State's residents **(Box 4-3)**. Grant opportunities have catalyzed sea level rise adaptation planning for many local jurisdictions in the San Diego region; however, in all of the interviews conducted for this project (see Chapter 3), planning staff bemoaned the widespread inadequacy of available funds for adaptation related activities. This barrier to adaptation prevails even when most jurisdictions have not entered the implementation stage, which is significantly more expensive than the planning stage. Further, funds for monitoring and evaluation are historically very difficult to obtain for extended periods of time (e.g., beyond five years), adding concern that the funding future for local adaptation faces serious hurdles.

Box 4-3: Funding sources to support coastal safety measures.

State officials along the East and Gulf Coasts are pushing for projects worth billions of dollars to protect populous coastal regions from rising oceans and extreme weather.

For example, in Massachusetts—where a tidal surge last year pushed the water level at Boston Harbor to the highest ever recorded, causing flooding—Governor Charlie Baker proposed raising the tax on real-estate transfers by 50% in much of the state to generate more than $1 billion over the next decade. The funds would help local communities fortify infrastructure from sea walls to flood-control systems. Governor Baker's administration has already spent more than $600 million on preparing for, and mitigating the effects of, climate change, but his new plan, which needs approval by the Democratic-led legislature, designates an ongoing funding source for the issue.

Source: *Levitz and McWhirter 2019.*

Moser et al. (2018) investigated the nature of adaptation funding challenges local communities in California face based on an online survey and multiple stakeholder workshops and found this central issue: "climate change is ongoing, but funding comes and goes." The paper explained that each grant only funds a piece of the work, and there are few foundations specifically dedicated to adaptation. In addition, those interviewed reported that it would be a full-time job to find and write grants to ensure all aspects of adaptation were supported, despite grant aggregation sites.[5] Thus, "simply providing more funding" to local governments, while critical, will not in and of itself be enough. If there is no capacity to apply for funding or no capacity to administer funds, making more funds available will not fix the problem.

In order to prevent sea level rise impacts to regional transportation infrastructure and avoid increased costs for operation, maintenance and repair, regional agencies and local governments need easier access to existing funds and support on how to create and manage new funding. This section describes a variety of both existing and new local, regional, State, and federal funding sources. These sources can be used to not only fund sea level rise adaptation projects, but also projects that incorporate resilience into their design. It is increasingly well established that adaptation funding is not simply about finding funding for a specific project; rather, it is about funding incremental and marginal costs associated with adding resilience to existing assets (e.g., Keenan 2018). To generate the necessary funding, jurisdictions will need to be proactive, think creatively, and consider new opportunities, such as pilot projects or public-private partnerships, partnerships with non-profits that can accept private charitable contributions, in addition to traditional funding sources. Multi-benefit projects that combine sea level rise adaptation with water supply, flood control, stormwater management, or other benefits can increase funding opportunities. Each of the mechanisms described below can generate additional revenue for implementing adaptation, and more than one source may be needed at any one time to make a project feasible.

4.3.1 Regional/Local Level

Regional/local taxes and loans provide an opportunity to generate a steady revenue stream to operationalize implementation of sea level rise adaptation strategies over time. In general, spending on infrastructure can be categorized as either capital spending or operations and maintenance (from (1) "pay-as-you-go" funds generated from taxes, fees, and other revenue sources and/or (2) loans, in which local governments issue bonds or other debt instruments to borrow money to be paid off at a later date, with interest) (CSIWG 2018).

4.3.1.1 Taxes

Local governments and entities can impose a variety of taxes and fees to fund sea level rise adaptation projects.

- **General Tax:** General taxes are approved by a majority vote and support basic services. General tax revenue may not be dedicated to a specific project or used to finance debt. Some jurisdictions in California have used general tax revenue to fund adaptation projects as line items in their general fund budgets. Additionally, some local governments have proposed general tax increases through the passage of a separate expenditure plan. In this approach, the general tax increase and the expenditure plan are proposed as independent ballot measures, again requiring a majority vote by jurisdiction voters (Keenan 2018).
- **Sales Tax:** California has a state-mandated minimum sales tax of 7.25%. Counties, cities, and districts are allowed to increase the sales tax in increments of 0.125% up to a total of 10.25%. General sales taxes are approved by a majority vote, while sales taxes with a specific purpose require a two-thirds supermajority vote for approval. For example, in November 2018, the City of Oceanside approved a 0.5% sales tax increase for seven years to fund general City of Oceanside purposes. A comparison of current annual sales tax revenues with potential annual sales tax revenues found that even a 0.25% increase in sales tax could raise a substantial amount of money for each coastal city, and if levied in all coastal cities in the San Diego region, the money generated would be just under $14 million per year. In November 2016, SANDAG added a regional 0.5% sales tax increase (Measure A) to the ballot which would have raised about $18.2 billion over its lifespan of 40 years to fund transportation repairs, public transit expansion, open space preservation, and beach nourishment projects; however, Measure A failed to obtain a two-thirds supermajority vote for approval. A future regional sales tax could be tied directly to climate change adaptation for vulnerable regional transportation infrastructure.
- **Transit Occupancy Tax:** Transient Occupancy Taxes (TOTs) are levied on travelers staying overnight in hotels, homes, or other accommodations for less than 30 days. TOTs have been implemented throughout the San Diego region and are generally easier to pass than other taxes because they are paid by the out-of-town tourists and not by local residents. TOT as a general tax are approved by a majority vote, while TOT as a special tax with a specific purpose, such as beach nourishment, requires a two-thirds supermajority vote for approval. For example, the City of Solana Beach has a TOT of 13%; 10% goes to the General Fund and the other 3% goes toward sand replenishment. Similarly, in the City of Encinitas, with a TOT of 10%, 8% goes to the General Fund and the other 2% goes toward sand replenishment. A comparison of current annual TOT revenue with potential annual TOT revenue found that even a 1% increase can raise a substantial amount of money for each coastal city, and if levied in all the 11 coastal cities, the money generated would be just under $28 million per year. For comparison, RBSP II cost approximately $26 million from planning through construction.

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[5] For example, State funding programs are summarized here: http://resilientca.org/topics/investing-in-adaptation/ and https://fundingwizard.arb.ca.gov/ (even though the latter is not specific to adaptation-related needs).

PHOTO: MOFFATT & NICHOL, 2019

- **Parcel Tax:** A parcel tax is a tax on each parcel of property collected as part of a property tax bill. However, unlike property tax, parcel tax cannot be based on property value. Typically, it is a flat tax that does not vary with the size or characteristics of a parcel. Parcel taxes require a two-thirds supermajority vote for approval. Parcel taxes may be collected by a city, county, or special district or may span multiple jurisdictions. For example, in June 2016, the San Francisco Bay Area passed Measure AA with 70% approval, authorizing a 20-year, $12 parcel tax to raise approximately $25 million annually, or $500 million over 20 years, to fund restoration projects in the Bay with adaptation co-benefits, such as flood protection. As the first regional parcel tax measure in California's history, Measure AA established mechanisms to collect the tax by working with tax assessors in each of the nine Bay Area counties (Figure 4-4).

- **Documentary Transfer Tax:** A Documentary Transfer Tax is an excise tax on the transfer of interests in real estate. Counties are authorized to tax at $0.55 per $500 of the property value. Cities may impose the tax of $0.275 per $500, that is credited to the payment of the county tax. San Diego County currently imposes a Documentary Transfer Tax of $0.275 per $500.

- **Special Assessment District:** Special Assessment Districts or Benefit Assessment Districts are commonly established to finance road, utility, and other infrastructure improvements by distributing debt repayment across property owners receiving special benefits from the project. In California, Special Assessment Districts have been used for adaptation projects through Geological Hazard Abatement Districts (GHADs) to finance projects to increase public safety and protect specific properties from geological hazards like erosion. GHADs are established in one of two ways: through a petition signed by owners of at least 10% of the real property in the district, or through a majority vote in the local legislative body. GHADs can levy and collect assessments, and these assessments attach as liens on a property and are collected simultaneously and in the same manner as general property taxes. There are currently 35 GHADs organized in California, and most of these are concentrated in the San Francisco Bay Area and coastal Los Angeles County (Center for Ocean Solutions 2018). In 1994, a GHAD was formed in the City of Encinitas to protect property along Neptune Avenue from coastal bluff erosion, landslides, failures, and other geologic hazards. It was intended to finance bluff maintenance programs; however, individual property owners ended up financing their own construction of sea walls to protect their property, such that the GHAD is considered inactive.

Figure 4-4. Measure AA Parcel Tax Photo

- **Property Tax Increment Financing or Tax Increment Financing Districts:** Local jurisdictions may use property tax increment revenue models to capture the increase in assessed property value within a defined district for the purpose of repaying debt utilized to make improvements within the same district. Historically, economic development agencies in California used Tax Increment Financing (TIF) Districts to finance public facilities, services, and affordable housing development before the State prohibited this use by economic development agencies in 2011. Today, under a revised statutory authority, Infrastructure Finance Districts and Enhanced Infrastructure Finance Districts use property tax increment revenues to finance infrastructure projects. Some local governments in California are considering the potential of TIF to finance adaptation projects. In recent years, the City of Los Angeles has been studying the use of an Enhanced Infrastructure Finance District to finance ecological restoration and flood control improvements along a corridor of the Los Angeles River in coordination with U.S. Army Corps of Engineers. Similarly, the City of San Francisco is considering the potential of an Infrastructure Finance District over Port Authority property to finance part of the San Francisco Seawall. Outside of California, local governments have used property tax increment revenues to finance infrastructure projects that have adaptation co-benefits. For example, the Chicago Transit Authority established TIF Districts to finance public transportation infrastructure improvements for the replacement of aging transit tracks, bridges, and viaducts so as to increase the resilience of the system. It should be noted that one of the limitations of TIF is that the TIF District must increase in value, and with sea level rise impacts, there may be circumstances where districts are decreasing in value faster than improvements can mitigate the risk. To minimize this problem, jurisdictions may encourage greater densities to facilitate speculation and growth. The trade-offs between density adequate enough to support value capture mechanisms, community character, and hazard mitigation will likely shape coastal adaptation discourse for many years to come (Keenan 2018).

- **Development Impact Fees:** Impact fees could be charged to finance adaptation projects to address impacts associated with increasing exposure of new development to coastal hazards. However, since the scale of revenue generated by impact fees is dependent on the scale of development, there may not be parity between projects and the capital necessary to fund mitigation (Keenan 2018). The CCC uses two fees to account for the impacts of shoreline protection: a sand mitigation fee and a public recreation fee. The sand mitigation fee is intended to mitigate for the loss of sand supply and loss of recreational beaches in front of structures. The public recreation fee addresses the loss of public recreation based upon the loss of beach area physically occupied by the coastal structure. In the San Diego region, these fees are deposited into interest-bearing accounts managed by SANDAG and are released to local jurisdictions when a qualified project is ready for implementation. Fees collected by each jurisdiction remain generally separate, for use in that jurisdiction. While these funds can aid local governments in paying for beach nourishment and recreational improvements (e.g., public beach accessways, beach parking, and restrooms), applicants can also propose projects to provide a direct benefit to the public in lieu of paying fees.

4.3.1.2 Bonds

Local governments and entities can also issue a variety of bonds to fund all or a portion of an adaptation strategy. General Obligation (GO) Bonds are commonly used to finance public infrastructure and may be backed by revenues generated from local property tax or fees. Local government GO Bond issuances require a two-thirds supermajority vote for approval. In addition to issuing GO Bonds for dedicated adaptation projects, local governments may incorporate adaptation goals in broader GO Bond financed projects. For example, the City of Berkeley issued $100 million of GO Bonds to repair and upgrade the city's aging infrastructure. In phase one of implementation, the City of Berkeley included adaptation strategies like green infrastructure and bioswale installation for stormwater management in coordination with the city's Resilience Strategy (Keenan 2018).

Table 4-3 summarizes additional bonds that could be used for adaptation purposes but are not yet in wide use by local governments.

4.3.2 Federal/State Level

Grant funding can be an important catalyst to planning and implementation projects. State and federal grants generally require local cost share and additional administration costs, but can be an important tool particularly for larger programs and projects. Once local jurisdictions identify priorities for funding, a review of available grant opportunities and associated eligibility criteria can be a good start toward funding. Grants can also be used to help a jurisdiction identify priorities. For example, the pilot VAST analysis included within this document was paid for in part through a Senate Bill 1 Planning Grant from Caltrans.

Tables 4-4 and 4-5 summarize federal and State grant opportunities that can be used for regional transportation infrastructure

Table 4-3. Special Bonds

Special Bonds	Description	Application
Catastrophe (Cat) Bonds	Local governments sponsor Cat Bonds to insure against natural disaster damages and recovery efforts. Cat Bonds are 'triggered' when a pre-defined event/threshold occurs. If the triggering event does not happen, investors that funded the collateral account are paid their principal and interest (premiums payments made by the sponsor). If the trigger event happens, the sponsor may use the balance of the bond funds, including the principal. Cat Bonds have high rates of return and short terms (3-5 years), making them optimal for low-probability, high impact events.	The California Earthquake Authority sponsors Cat Bonds as an insurer-of-last-resort for households at risk of earthquake damage. While use of Cat Bonds by local governments is more nascent, the New York Metropolitan Transportation Authority issued a bond in 2013 to insure its facilities against storm events and renewed in 2017 with added earthquake coverage.
Resilience Bonds	Resilience bonds provide rebates to the sponsor local government to make investments that reduce exposure and risk that is reflected in the reduced investment risk to investors and reduced premiums from the sponsor. The major challenge is to link risk with investments to justify the rebates. By putting a price on the risk reduction that would be achieved from a resilience project, resilience bonds can be used to reduce the cost of Cat bonds (rebate on the catastrophe insurance policy, where cost savings can be used for financing to the resilience project).	Interest in resilience bonds is rapidly growing partly due to the growing climate risks and expected losses, partly due to the requirement for many infrastructure projects to carry insurance, and partly due to the pressure to find financing for upgrades/retrofits or new infrastructure projects.
Green Bonds	Local governments may issue bonds to fund projects with environmental or climate adaptation benefits. Under the umbrella of green bonds are Environmental Impact Bonds (EIBs), which follow a "pay for success" model whereby investors receive a higher rate of return if a certain predetermined environmental objective is met.	Green Bonds have been primarily used in California for renewable energy, energy efficiency, low-carbon transportation, sustainable water infrastructure, and pollution control; however, there is a consolidated effort in California to help facilitate more adaptation-specific Green Bond issuances.
Capital Appreciation Bonds (CABs)	Local governments may issue CABs in which the bond principle and accumulated interest is repaid in a single balloon payment when the bond reaches maturity. While CABs allow local governments to defer bond repayment, accumulated interest is compounded, resulting in a greater overall cost.	CABs have not yet been used to finance adaptation projects in California. CABs might be appropriate for emergency adaptation investments where cash supplies are limited in a post-recovery setting; however, caution should be exercised in evaluating the use of CABs.
Private Activity Bonds (PABs)	Private Activity Bonds allow for private developers to access tax-exempt interest rates for certain qualified projects. State or local governments can issue private activity bonds on behalf of a project's private developer for transportation projects that receive Title 23 assistance, including assistance from the Transportation Infrastructure Finance and Innovation Act (TIFIA).	PABs have not yet been used to finance transportation projects in California. PABs can also be used for other qualifying adaptation related infrastructure projects such as sewage facilities and green building projects.

Source: Keenan 2018, DOT 2019

Table 4-4. Key Federal Resilient Transportation Infrastructure Grant Opportunities

Agency	Grant Name	Description	Website
Federal Emergency Management Agency (FEMA)	Flood Mitigation Assistance Program	Provides funds for flood hazard mitigation projects and plan development with the goal of reducing or eliminating claims under the National Flood Insurance Program (NFIP)	**Cal OES (administrator):** http://www.caloes.ca.gov/cal-oes-divisions/hazard-mitigation/pre-disaster-flood-mitigation **FEMA (funder):** https://www.fema.gov/flood-mitigation-assistance-grant-program
FEMA	Pre-Disaster Mitigation Program	Provides funds for hazard mitigation planning and projects on an annual basis to reduce reliance on federal funding in future disasters	**Cal OES (administrator):** http://www.caloes.ca.gov/cal-oes-divisions/hazard-mitigation/pre-disaster-flood-mitigation **FEMA (funder):** https://www.fema.gov/pre-disaster-mitigation-grant-program
National Oceanographic and Atmospheric Agency (NOAA)	Coastal Resilience Grants	Provide funds for projects that build resilience to extreme events and climate impacts in coastal communities by protecting coastal property and life, strengthening the local economy, and conserving and restoring coastal environments	https://www.fisheries.noaa.gov/grant/noaa-coastal-resilience-grants
U.S. Army Corps of Engineers (USACE)	Continuing Authorities Program (CAP)	Provides funding for feasibility study and implementation of water and environmental projects related to flood control, aquatic ecosystem restoration, erosion control and prevention, and storm damage reduction without additional project specific congressional authorization; feasibility study is federally funded up to $100,000 and any additional costs are shared 50/50 with the project non-federal-agency sponsor; cost share of implementation is determined by project-specific legislation authorizing a project partnership agreement between the USACE and the non-federal-agency sponsor	https://www.nae.usace.army.mil/missions/public-services/continuing-authorities-program/
USACE	Planning Studies	Partnership with the USACE to conduct planning studies to support floodplain management	https://www.nae.usace.army.mil/missions/public-services/planning-assistance-to-states/
U.S. Department of Transportation (DOT)	Better Utilizing Investments to Leverage Development (BUILD; formerly known as Transportation Investment Generating Economic Recovery (TIGER))	Provides funds to support transportation infrastructure projects with significant local and regional impact, including road, bridge, transit, rail, port, and intermodal projects	https://www.transportation.gov/BUILDgrants
DOT	Build America Bureau	Provides a variety of credit financing and grants for transportation and infrastructure projects, which may include adaptation goals or provide adaptation co-benefits, including climate retrofits and system redundancy investments	https://www.transportation.gov/build-america
DOT	Federal Transit Administration	Provides a variety of funds to improve public transportation systems, including adaptation co-benefits such as greater accessibility for vulnerable populations	https://www.transit.dot.gov/grants

Source: CCC 2018; Keenan 2018.

Table 4-5. Key State Resilient Transportation Infrastructure Grant Opportunities adaptation.

Agency	Grant Name	Description	Website
California Coastal Conservancy	Proposition 68	Provide funds to assist coastal communities with adaptation to climate change	https://scc.ca.gov/grants/proposition-68-grants/
California Coastal Conservancy	Climate Ready Program	Provide funds to support multi-benefit projects that use natural systems to assist communities in adapting to the impacts of climate change, including shoreline planning and design to adapt to rising sea levels	http://scc.ca.gov/climate-change/climate-ready-program/
California Department of Transportation (Caltrans)	Active Transportation Program	Provides funds for alternative and active transportation solutions	https://dot.ca.gov/programs/local-assistance/fed-and-state-programs/active-transportation-program
Caltrans	Low Carbon Transit Operations Program (LCTOP)	Provide operating and capital assistance for transit agencies to reduce greenhouse gas emission and improve mobility, with a priority on serving disadvantaged communities; projects may provide adaptation co-benefits, such as new or expanded bus or rail services and intermodal transit facilities, and equipment acquisition, fueling, maintenance and other costs to operate those services or facilities	https://dot.ca.gov/programs/rail-and-mass-transportation/low-carbon-transit-operations-program-lctop
Caltrans	Sustainable Communities Grants	Provide funds to maintain and integrate multi-modal transportation systems; funds are intended to support and implement Regional Transportation Plan Sustainable Communities Strategies (where applicable) and to ultimately achieve the State's greenhouse gas reduction targets	https://dot.ca.gov/programs/transportation-planning/regional-planning/sustainable-transportation-planning-grants
Caltrans	Transit and Intercity Rail Capital Program (TIRCP)	Provides funds for transformative capital improvements that will modernize California's intercity, commuter, and urban rail systems, and bus and ferry transit systems to reduce emissions of greenhouse gases by reducing congestion and vehicle miles traveled; projects may provide adaptation co-benefits	https://dot.ca.gov/programs/rail-and-mass-transportation/transit-and-intercity-rail-capital-program
Division of Boating and Waterways	Shoreline Erosion Control and Public Beach Restoration Programs	Shoreline Erosion Control Program provides funds (up to 50 percent of nonfederal project costs) to assist in the planning and construction of all types of beach erosion control and shoreline stabilization measures; Public Beach Restoration Program provides funds (up to 85 percent of nonfederal project costs at non-state beaches) to assist in the planning and construction of engineered placement of sand on the beach/nearshore environment	https://dbw.parks.ca.gov/?page_id=28766
Ocean Protection Council (OPC)	Proposition 1 Grants	Provides funding for marine managed areas, coastal and ocean water quality impacts, fisheries, and climate change adaptation	http://www.opc.ca.gov/2015/05/prop1/
OPC	Proposition 68	Provides funding for scientific research and monitoring, restoration or other on-the-ground projects that improve ecosystem health and water quality, and planning and/or implementation projects that advance climate resiliency	http://www.opc.ca.gov/prop-68-funding/
OPC	Proposition 84 Grants	Provides funds to support adaptive management, marine conservation, and research to address ocean acidification, sustainable fisheries and aquaculture, sea level rise adaptation, erosion control and coastal sediment management	http://www.opc.ca.gov/prop-84/

Source: CCC 2018; Keenan 2018.
Note: In 2018, California voters voted to approve a bond measure (Proposition 68), which will provide $400 million for climate adaptation and resiliency projects, among others. As currently planned, funding will become available to local governments in 2019.

PHOTO: GOOGLE STREET VIEW

05

Conclusions And Next Steps

5 Conclusions and Next Steps

This document evaluates potential sea level rise impacts to regional transportation infrastructure, provides an overview of best planning practices, and presents adaptation Pathways in order to facilitate an inclusive, cost effective, and proactive approach to addressing sea level rise impacts to regional transportation infrastructure.

5.1 Conclusions

The first step in planning for sea level rise is to identify and evaluate the vulnerability of regional transportation assets. As described in Chapter 2, the vulnerability assessment presents analysis and mapping of region-wide sea level rise hazards using the Coastal Storm Modeling System (CoSMoS) 3.0 Phase 2 model to evaluate the degree to which important regional assets are susceptible to projected sea level rise. Regional transportation assets located within the inundation hazard zone and/or flood hazard zone for 2.5-foot and/or 6.6-foot sea level rise scenarios were evaluated based on two planning zones: North San Diego County and South San Diego County. The results identified a total of 32 regional transportation assets (12 roadway assets, 11 ATP assets, and 9 transit assets) which may become vulnerable to flooding and/or inundation under sea level rise. Vulnerabilities span from threats to structural integrity, to disruption of asset function, to barriers to adaptation, and more.

Chapter 3 provides a synthesis of adaptation planning best practices. It is based on a series of interviews with staff from coastal jurisdictions about lessons learned when conducting vulnerability assessments and updating or preparing local policies and plans to address sea level rise. Collaboration was the best practice that all jurisdictions identified as critical to a successful process, including participation in the San Diego Regional Climate Collaborative (SDRCC) and the SANDAG Shoreline Preservation Working Group (SPWG). Multiple jurisdictions also emphasized including other departments and disciplines early on in the planning process, especially to bring adaptation projects to the forefront of capital improvement project planning. Soliciting feedback from the California Coastal Commission early on and frequently throughout the process was also recommended by multiple jurisdictions. Outreach was identified as a best practice in order to gain a common understanding by making sea level rise science tangible and to emphasize public safety to develop an understanding of urgency. In particular, many jurisdictions emphasized the need for targeted outreach to engage specific groups in sea level rise planning. The third and fourth best practices were identified as completing a vulnerability assessment and developing adaptation strategies, or policies, respectively. Lastly, multi-jurisdictional planning was also identified as a best practice to address vulnerable assets outside of the control of a single jurisdiction and to help build to political and financial support.

Chapter 4 focuses on "adaptation Pathways" which lays out policies, funding mechanisms, and projects that may be considered at the regional or local level to minimize risks from hazards and maintain a functioning regional transportation system. Sea level rise adaptation strategies can be integrated into a variety of existing regional and local policy frameworks, such as updates to SANDAG's shoreline management policy documents, local coastal programs, General Plans, climate action plans, and local hazard mitigation plans. Policies in these documents provide guidance regarding how to allocate funds, make land use decisions, facilitate public engagement, protect valued resources, and preserve community character, among other issues, and therefore provide the foundation to support, or undermine, adaptation solutions. Funding mechanisms, such as taxes, development impact fees, and bonds are options that may be available to fund all or a portion of an adaptation strategy. In terms of projects, regional beach sand replenishment projects for critical erosion areas may be effective, as the CRSMP has outlined management alternatives to implement over the next 50 years. The document recommends a sand retention pilot project that could reduce needed annual nourishment by up to 50%. Additionally, several local projects, either proposed or underway, are also summarized in this document.

Through careful planning, communities can reduce the risk of costly damage from coastal hazards, can ensure the coastal economy continues to thrive, and can protect coastal habitats, public access and recreation, and other coastal resources for current and future generations.

PHOTO: SEE APPENDIX A

5.2 Next Steps

Next steps for planning and implementing sea level rise adaptation strategies include informing public and private entities of the usefulness of the VAST tool for future vulnerability assessments and defining SANDAG's role to implement or facilitate adaptation strategies in the region.

5.2.1 Local Jurisdiction's Role

Local jurisdictions are responsible for implementing adaptation projects for transportation facilities within their jurisdictional boundaries. The exception to this is with regard to facilities such as I-5, the Coronado portion of SR-75 (managed by Caltrans), and heavy and light rail facilities (managed by MTS, NCTD, and BNSF). Improvements to these facilities will likely be coordinated by SANDAG in conjunction with local jurisdictions, and transportation agencies, as outlined in Section 5.2.2, below. Many local jurisdictions have prepared or will prepare adaptation plans, which are a first step in determining the types of adaptation strategies that may be appropriate for any given transportation facility. Targeted outreach and engagement of specific groups was emphasized as an important component of sea level rise planning for many local jurisdictions. Project planning, design, permitting, and project implementation will be completed by local jurisdictions via their established capital improvement process. Where appropriate, local jurisdictions may coordinate with neighboring jurisdictions to facilitate the development of adaptation projects and policies that serve transportation assets that cross jurisdictional boundaries. Adaptation strategies may be integrated into local coastal programs, General Plans, climate action plans, local hazard mitigation plans, and other local or regional documents.

5.2.2 SANDAG's Role

As a regional agency, SANDAG can facilitate beneficial coordination and collaboration amongst its member agencies, as well as support jurisdictions in the region as they work towards adaptation

5.2.2.1 Adaptation Pathways

SANDAG intends to implement or facilitate the adaptation options presented in Chapter 4, as follows:

- Pursue funding for a feasibility study for RBSP III, which could lead to implementation of a future regional beach sand nourishment project.
- Consider opportunities for funding to update the SPS to account for sea level rise (this document guides future RBSPs).
- As part of the existing Regional Shoreline Monitoring Program, consider adding biological monitoring to the Program's scope of work to help facilitate SCOUP implementation.
- Discuss sand retention pilot and related policies with SPWG and staff from local jurisdictions. If pursued, this would be coordinated with a future beach sand nourishment project.
- Implement improvements to I-5 and the LOSSAN corridor, noted in Figures 4-3a and 4-3b as outlined in San Diego Forward: The Regional Plan (2015).

5.2.2.2 Ongoing Regional Planning Activities

Every four years, SANDAG prepares and updates a Regional Plan in collaboration with the 18 cities and County of San Diego, along with regional, State, and federal partners. The Regional Plan includes the Regional Transportation Plan (RTP) and its Sustainable Communities Strategy (SCS) and the Regional Comprehensive Plan. The Regional Plan is built on an integrated set of public policies, strategies, and investments to maintain, manage, and improve the transportation system so that it meets the diverse needs of the San Diego region. Future iterations of the Regional Plan will consider how climate change may affect the performance of the future transportation network and how proposed projects, policies, and programs can improve the region's ability to adapt to climate impacts.This includes policies to ensure that the built environment, (including proposed transportation projects), the natural environment, and the public are resilient to impacts from wildfire, flooding, extreme heat, and sea level rise. As such, opportunities to fund adaptation projects and incorporate adaptation planning into the development process for capital projects, policies, or programs to enhance local planning and community-wide resiliency will be explored.

In addition, SANDAG can help facilitate coordination on locally led projects and help communicate best practices for adaptation planning via working groups and other regional and State forums, such as SDRCC and the Alliance of Regional Collaboratives for Climate Adaptation (ARCCA). This could lead to assistance with project and/or plan implementation and guidance on incorporating adaptation policies into other planning documents (e.g., climate action plans, General Plans), or other similar efforts to help ensure the San Diego region is resilient to climate change. As a first step, SANDAG is developing a multi-disciplinary Regional Adaptation Needs Assessment to increase understanding of climate adaptation, identify opportunities and resources to address local and regional needs, and guide future adaptation planning, implementation, and funding priorities for the region. SANDAG will continue to coordinate with local, regional, and State partners on possible opportunities identified in the Regional Adaptation Needs Assessment.

PHOTO: SEE APPENDIX A

PHOTO: GOOGLE STREET VIEW

06

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SOURCE: GOOGLE STREET VIEW, 2019

A

APPENDICES A-E

APPENDIX A: SITE PHOTOGRAPHS

Hwy 101 @ San Luis Rey River

SOURCE: GOOGLE STREET VIEW, 2019

San Luis Rey Bike Path

SOURCE: MOFFATT & NICHOL, 2019

Hwy 101 @ Loma Alta Creek

SOURCE: MOFFATT & NICHOL, 2019

I-5 @ Buena Vista Lagoon

SOURCE: GOOGLE STREET VIEW, 2019

Railroad @ Buena Vista Lagoon Bridge

SOURCE: GOOGLE STREET VIEW, 2019

Carlsbad Blvd. @ Buena Vista Lagoon Bridge

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

Carlsbad Blvd. @ Las Encinas Creek

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

Carlsbad Blvd. @ Batiquitos Lagoon Bridge

SOURCE: MOFFATT & NICHOL, 2019

Hwy 101 @ San Elijo Lagoon Bridge

SOURCE: MOFFATT & NICHOL, 2019

Camino Del Mar @ San Dieguito Lagoon Bridge

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

I-5 @ San Dieguito Lagoon Bridge

SOURCE: GOOGLE STREET VIEW, 2019

Railroad @ San Dieguito Lagoon

SOURCE: GOOGLE STREET VIEW, 2019

San Dieguito River Park—Coast to Crest Trail

SOURCE: GOOGLE STREET VIEW, 2019

SOURCE: GOOGLE STREET VIEW, 2019

Railroad @ Del Mar Bluffs

Source: California Coastal Records Project (www.californiacoastline.org)

I-5 Carmel Valley Creek Bridge

SOURCE: GOOGLE STREET VIEW, 2019

Railroad @ Los Penasquitos Lagoon

SOURCE: GOOGLE STREET VIEW, 2019

Trans County Trail

SOURCE: GOOGLE STREET VIEW, 2019

Ocean Beach Bike Path

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

N. Harbor Drive Bike Path

SOURCE: GOOGLE STREET VIEW, 2019

Embarcadero Bike Path

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

Railroad @ Green Line Trolley @ Downtown

SOURCE: GOOGLE STREET VIEW, 2019

Orange Line Trolley @ Downtown

SOURCE: GOOGLE STREET VIEW, 2019

Blue Line Trolley @ Downtown

SOURCE: GOOGLE STREET VIEW, 2019

Blue Line Trolley @ North National City

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: GOOGLE STREET VIEW, 2019

Sweetwater Loop and River Trail

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SR-75

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

Bayshore Bikeway

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

SOURCE: MOFFATT & NICHOL, 2019

APPENDIX B: JURISDICTIONAL SUMMARY

Oceanside

Vulnerabilities adapted from the September 2018 City of Oceanside Coastal Hazard Vulnerability Assessment revised draft.

Roadways

Asset	SLR Scenario	Hazard Type	Hazard Findings per Local Assessment	Link to Regional Study
I-5	5.7 ft	None	No vulnerability to hazards.	Vulnerabilities reported for 6.6ft SLR scenario at Buena Vista Lagoon Bridge.
S. Coast Highway	5.7 ft	Flooding	High exposure and vulnerability to hazards. Currently experiences flooding at Buena Vista Lagoon under 1% annual chance riverine flood event. Flood extent and frequency will become more frequent, leading to major service disruption.	Riverine flood events outside the scope of regional analyses. Similar vulnerabilities reported at San Luis Rey River and Loma Alta Creek.
CA Route 78	5.7 ft	Flooding	High exposure and vulnerability to hazards. Currently experiences flooding east of I-5 junction under 1% annual chance riverine flood event. Flood extent and frequency will become more frequent, leading to major service disruption.	Not included in regional analysis.
CA Route 76	5.7 ft	Flooding	High exposure and vulnerability to hazards. Currently experiences flooding east of I-5 junction under 1% annual chance riverine flood event. Flood extent and frequency will become more frequent, leading to major service disruption.	Not included in regional analysis.
Local Roads	5.7 ft	Flooding	Medium to medium-high vulnerability to hazards. Potential disruption of critical pathways for emergency services and community access.	Not included in regional analysis.

Bikeways and Trails

Asset	SLR Scenario	Hazard Type	Hazard Impacts per Local Assessment	Link to Regional Study
Bicycle Routes	5.7 ft	Flooding	3.2 – 3.5 miles of routes impacted. Potential loss of mobility for pedestrians and bicyclists within coastal zone. Low to medium-high vulnerability depending on asset.	Regional analysis includes similar findings for the San Luis Rey Bike Path with 6.6 ft of SLR.
Trails	5.7 ft	Flooding	5.8 – 5.9 miles of trails impacted. Potential loss of mobility for pedestrians and bicyclists within coastal zone. Low to medium-high vulnerability depending on asset.	Trails not explicitly analyzed within regional study, but similarities to bicycle route vulnerabilities likely.

Transit

Asset	SLR Scenario	Hazard Type	Hazard Impacts per Local Assessment	Link to Regional Study
NCTD Railroad	5.7 ft	Flooding	High exposure and vulnerability to hazards. Currently experiences flooding east of Oceanside Harbor under 1% annual chance riverine flood event. Flood extent and frequency will become more frequent, leading to major service disruption.	Vulnerabilities at this location currently not included as part of the regional analysis, but similar vulnerabilities located at other nearby locations.

Carlsbad

Vulnerabilities adapted from the December 2017 City of Carlsbad Sea Level Rise Vulnerability Assessment.

Roadways

Asset	SLR Scenario	Hazard Type	Hazard Impacts per Local Assessment	Link to Regional Study
Carlsbad Blvd, North Reach	1.6 ft	Flooding/ Bluff Erosion	Partial exposure to flooding and bluff erosion during extreme storms, localized to Buena Vista Lagoon crossing. Moderate overall vulnerability.	1.6 ft SLR scenario not included in regional analysis, similar impacts noted for 2.5 ft SLR scenario.
	6.6 ft		Increased exposure to hazards at Buena Vista Lagoon. High overall vulnerability.	Same SLR scenario used in regional analysis. SLR vulnerability results in agreement.
Carlsbad Blvd, Middle Reach	1.6 ft	Bluff Erosion	High exposure and vulnerability to bluff erosion hazards.	1.6 ft SLR scenario not included in regional analysis, similar impacts noted for 2.5 ft SLR scenario.

Asset	SLR Scenario	Hazard Type	Hazard Impacts per Local Assessment	Link to Regional Study
	6.6 ft	Flooding/ Bluff Erosion	Increased exposure to bluff erosion hazards and exposure to flooding during extreme storm events. High vulnerability	Same SLR scenario used in regional analysis. SLR vulnerability results in agreement.
Carlsbad Blvd, South Reach	1.6 ft	Bluff Erosion	Low exposure to bluff erosion for southbound boulevard near Las Encinas Creek. Overall moderate vulnerability.	1.6 ft SLR scenario not included in regional analysis, similar impacts noted for 2.5 ft SLR scenario.
	6.6 ft	Flooding/ Bluff Erosion	Increased hazard exposure affecting both northbound and southbound lanes near Las Encinas Creek and Batiquitos Lagoon. High overall vulnerability.	Same SLR scenario used in regional analysis. SLR vulnerability results in agreement.

Bikeways and Trails

Asset	SLR Scenario	Hazard Type	Hazard Impacts per Local Assessment	Link to Regional Study
Lateral Beach Access Trails, North Reach	1.6 ft	Inundation, Erosion, Flooding	Moderate exposure of trails in Hosp Grove Park and along Carlsbad Blvd. Moderate vulnerability overall due to high adaptive capacity.	Access trails not included as part of regional analysis.
	6.6 ft	Inundation, Flooding	Increased trail exposure, but overall vulnerability remains moderate.	Access trails not included as part of regional analysis.
Lateral Beach Access Trails, Middle Reach	1.6 ft	Inundation, Erosion, Flooding	Moderate exposure of trails along Agua Hedionda Lagoon and Carlsbad Blvd. Moderate overall vulnerability.	Access trails not included as part of regional analysis.
	6.6 ft	Inundation, Flooding	Increased trail exposure, but overall vulnerability remains moderate.	Access trails not included as part of regional analysis.
Lateral Beach, South Reach	1.6 ft	Inundation, Flooding	Moderate exposure of trails along Batiquitos Lagoon and Carlsbad Blvd. Moderate overall vulnerability.	Access trails not included as part of regional analysis.
	6.6 ft	Inundation, Flooding	Increased trail exposure, but overall vulnerability remains moderate.	Access trails not included as part of regional analysis.

Transit

Vulnerabilities to regional transit resources were not explicitly identified within the SLR vulnerability assessment.

Encinitas

Vulnerabilities adapted from the January 2018 City of Encinitas Climate Action Plan.

Roadways

Asset	SLR Scenario	Hazard Type	Hazard Impacts per Local Assessment	Link to Regional Study
Highway 101	1.6 ft	Flooding, Erosion	Sections of Highway 101 near San Elijo Lagoon will experience flooding impacts.	1.6 ft SLR scenario not included in regional analysis, similar impacts noted for 2.5 ft SLR scenario.
	6.6 ft		Flood impacts will become more severe near San Elijo Lagoon. Erosion impacts are projected south of the Self-Realization Fellowship Temple.	Same SLR scenario used in regional analysis. SLR vulnerability results in agreement.

Bikeways and Trails

Vulnerabilities to bikeway and trail resources were not explicitly identified within the Climate Action Plan.

Transit

Vulnerabilities to regional transit resources were not explicitly identified within the Climate Action Plan.

Solana Beach

This LUP is a planning and policy document and as such does not include an evaluation or analysis of the various sea level rise (SLR) scenarios and possible local implications.

Del Mar

Vulnerabilities adapted from the July 2016 City of Del Mar Coastal Hazards, Vulnerability, and Risk Assessment.

Roadways

Asset	SLR Scenario	Hazard Type	Hazard Impacts per Local Assessment	Link to Regional Study
17th to 29th Streets, West	2030+ (1 ft)	Coastal Flooding	High exposure to flooding on the western ends of local streets during significant coastal storm events.	Local streets not included in regional analysis.
17th to 29th Streets, East	2070+ (3.2 ft)	Riverine Flooding	High exposure to flooding on the eastern ends of local streets during significant riverine flood events.	Local streets not included in regional analysis.
Coast Blvd	2070+ (3.2 ft)	Coastal Flooding	High exposure to flooding during extreme coastal storm events. Moderate exposure from 2030-2070.	Local streets not included in regional analysis.

Asset	SLR Scenario	Hazard Type	Hazard Impacts per Local Assessment	Link to Regional Study
Camino Del Mar	2070+ (3.2 ft)	Coastal Flooding, Riverine Flooding	High exposure to flooding during extreme coastal storm events. Moderate exposure from 2030-2070. Moderate exposure to extreme riverine flooding from 2030-2100.	Additional vulnerabilities noted in regional analysis for 6.6 ft SLR scenario.
San Dieguito Drive	2070+ (3.2 ft)	Riverine Flooding	High exposure to flooding during significant riverine flood events. Moderate exposure 2030-2070.	Local streets not included in regional analysis.
Jimmy Durante Bridge	2070+ (3.2 ft)	Riverine Flooding	High exposure to flooding during significant riverine flood events. Moderate exposure 2030-2070.	Local streets not included in regional analysis.
Jimmy Durante Blvd	2030+ (1 ft)	Riverine Flooding	Moderate exposure to extreme riverine flooding from 2030-2100.	Local streets not included in regional analysis.

Bikeways and Trails

Asset	SLR Scenario	Hazard Type	Hazard Impacts per Local Assessment	Link to Regional Study
Riverpath Del Mar	2070+ (3.2 ft)	Riverine Flooding	High exposure to flooding during significant riverine flood events. Moderate exposure 2030-2070.	Not included in regional analysis.

Transit

Asset	SLR Scenario	Hazard Type	Hazard Impacts per Local Assessment	Link to Regional Study
LOSSAN Railroad	2030+ (1 ft)	Bluff Erosion	Current localized vulnerability will extend along the full portion of bluff areas before 2030. Severe hazard exposure occurs beyond this timeframe.	Additional coastal flooding vulnerability described in regional study for 6.6 ft SLR scenario.

San Diego Bay

Vulnerabilities adapted from January 2012 Sea Level Rise Adaptation Strategy for San Diego Bay.

Roadways

Asset	SLR Scenario	Hazard Type	Hazard Impacts per Local Assessment	Link to Regional Study
18th and 24th Streets at Paradise Creek	2050 Extreme Event	Flooding	Access functions of roads impaired due to flooding during extreme storm event.	Local streets not included in regional analysis.
	2100 Daily Conditions		Access functions of roads impaired on a daily basis due to tidal flooding.	Local streets not included in regional analysis.
Shelter Island Drive	2100 Daily Conditions	Flooding	Access functions of roads impaired on a daily basis due to tidal flooding.	Local streets not included in regional analysis.
N. Harbor Drive	2100 Daily Conditions	Flooding	Access functions of roads impaired on a daily basis due to tidal flooding.	Local streets not included in regional analysis.
Harbor Drive, Market St to 5th Ave	2100 Daily Conditions	Flooding	Access functions of roads impaired on a daily basis due to tidal flooding.	Local streets not included in regional analysis.
Multiple Midway Streets	2100 Extreme Event	Flooding	Access functions of roads impaired due to flooding during extreme storm event.	Local streets not included in regional analysis.

Bikeways and Trails

Asset	SLR Scenario	Hazard Type	Hazard Impacts per Local Assessment	Link to Regional Study
Shoreline Pathways	2050 Daily Conditions	Flooding	High exposure to flood hazards for coastal trails throughout San Diego Bay.	More specific locations and vulnerabilities included in regional study.

Transit

Vulnerabilities to regional transit resources were not explicitly identified within the Sea Level Rise Adaptation Strategy.

Imperial Beach

Vulnerabilities adapted from September 2016 City of Imperial Beach Sea Level Rise Assessment.

Roadways

Asset	SLR Scenario	Hazard Type	Hazard Impacts per Local Assessment	Link to Regional Study
Roadways, Open Coast	1.6 ft	Inundation, Flooding, Erosion	Ocean Lane and Seacoast Drive impacted. Slight flooding from Carnation Ave to 3rd Street.	Local streets not included in regional analysis.
	3.3 ft		Increased flooding eastward along central roads that intersect Seacoast Drive between Donax Avenue and Imperial Beach Boulevard.	Local streets not included in regional analysis.
	6.6 ft		Considerable vulnerability increase extending to Alabama, Cherry Ave, and Cypress.	Local streets not included in regional analysis.
Roadways, Bay	1.6 ft	Inundation, Flooding, Erosion	Impacts to SR-75 south past Cypress Avenue. Cypress Avenue impacted between 8th and 10th Avenues.	1.6 ft SLR scenario not included in regional analysis. Impacts to SR-75 expanded upon for 2.5 ft SLR scenario.
	3.3 ft		Expansion of vulnerability along Delaware, 7th, 8th, and 9th streets.	Results in agreement with regional analysis of SR-75 for 2.5 ft SLR scenario.
	6.6 ft		Hazards extend to Delaware and 8th Street. Extension of flooding along 8th Street between Palm Avenue and Imperial Beach Blvd.	Results in agreement with regional analysis of SR-75 for 6.6 ft SLR scenario.
Roadways, Estuary	1.6 ft	Inundation, Flooding, Erosion	Minimal vulnerability along Iris Avenue.	Local streets not included in regional analysis.
	3.3 ft		Expansion of flood zones between 5th Street and Louden Lane.	Local streets not included in regional analysis.
	6.6 ft		Areas of flooding extend in all directions along Imperial Beach Boulevard from Ebony Avenue to Grove Avenue. Flood areas expand between Fern and Iris Avenue east to Connecticut Street.	Local streets not included in regional analysis.

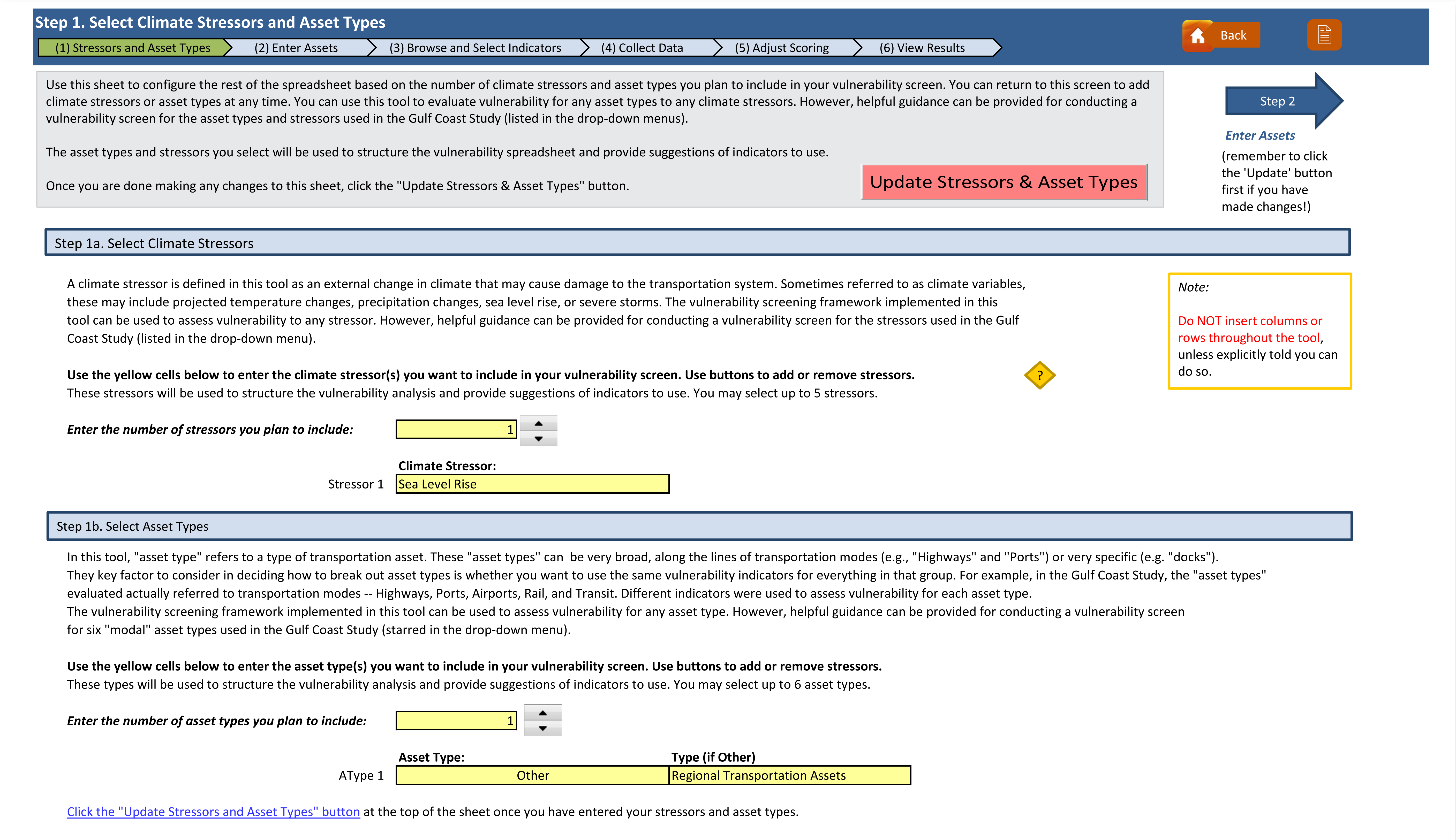
Bikeways and Trails

Asset	SLR Scenario	Hazard Type	Hazard Impacts per Local Assessment	Link to Regional Study
Bikeways and Trails, Open Coast	1.6 ft	Inundation, Flooding, Erosion	Trails and paths along Seacoast Drive Impacted.	Not included in regional analysis.
	3.3 ft		Minimal expansion of vulnerability along Imperial Beach Boulevard.	Not included in regional analysis.
	6.6 ft		Continued expansion of trail vulnerabilities along Palm Avenue and Imperial Beach Boulevard.	Not included in regional analysis.
Bikeways and Trails, Bay	1.6 ft	Inundation, Flooding, Erosion	Slight expansion of vulnerability of trails south along 7th Street and east along the Silver Strand Bikeway.	Not included in regional analysis.
	3.3 ft		Bike and walking trails along 7th Street and Cypress Avenue vulnerable.	Not included in regional analysis.
	6.6 ft		Impacts expand to pockets along Palm Avenue between 8th and 9th Street.	Not included in regional analysis.
Bikeways and Trails, Estuary	1.6 ft	Inundation, Flooding, Erosion	Minimal vulnerability of trails and pathways along Iris Avenue.	Not included in regional analysis.
	3.3 ft		Increased vulnerability of trails and pathways along Iris Avenue.	Not included in regional analysis.
	6.6 ft		Impacts to bike trails along Iris Avenue extend east to Connecticut Street and up to Imperial Beach Boulevard.	Not included in regional analysis.

Transit

Vulnerabilities to regional transit resources were not explicitly identified within the Sea Level Rise Assessment.

APPENDIX C



Step 1. Select Climate Stressors and Asset Types

Use this sheet to configure the rest of the spreadsheet based on the number of climate stressors and asset types you plan to include in your vulnerability screen. You can return to this screen to add climate stressors or asset types at any time. You can use this tool to evaluate vulnerability for any asset types to any climate stressors. However, helpful guidance can be provided for conducting a vulnerability screen for the asset types and stressors used in the Gulf Coast Study (listed in the drop-down menus).

The asset types and stressors you select will be used to structure the vulnerability spreadsheet and provide suggestions of indicators to use.

Once you are done making any changes to this sheet, click the "Update Stressors & Asset Types" button.

Enter Assets

(remember to click the 'Update' button first if you have made changes!)

Step 1a. Select Climate Stressors

A climate stressor is defined in this tool as an external change in climate that may cause damage to the transportation system. Sometimes referred to as climate variables, these may include projected temperature changes, precipitation changes, sea level rise, or severe storms. The vulnerability screening framework implemented in this tool can be used to assess vulnerability to any stressor. However, helpful guidance can be provided for conducting a vulnerability screen for the stressors used in the Gulf Coast Study (listed in the drop-down menu).

Note:

Do NOT insert columns or rows throughout the tool, unless explicitly told you can do so.

Use the yellow cells below to enter the climate stressor(s) you want to include in your vulnerability screen. Use buttons to add or remove stressors.
These stressors will be used to structure the vulnerability analysis and provide suggestions of indicators to use. You may select up to 5 stressors.

Enter the number of stressors you plan to include: 1

	Climate Stressor:
Stressor 1	Sea Level Rise

Step 1b. Select Asset Types

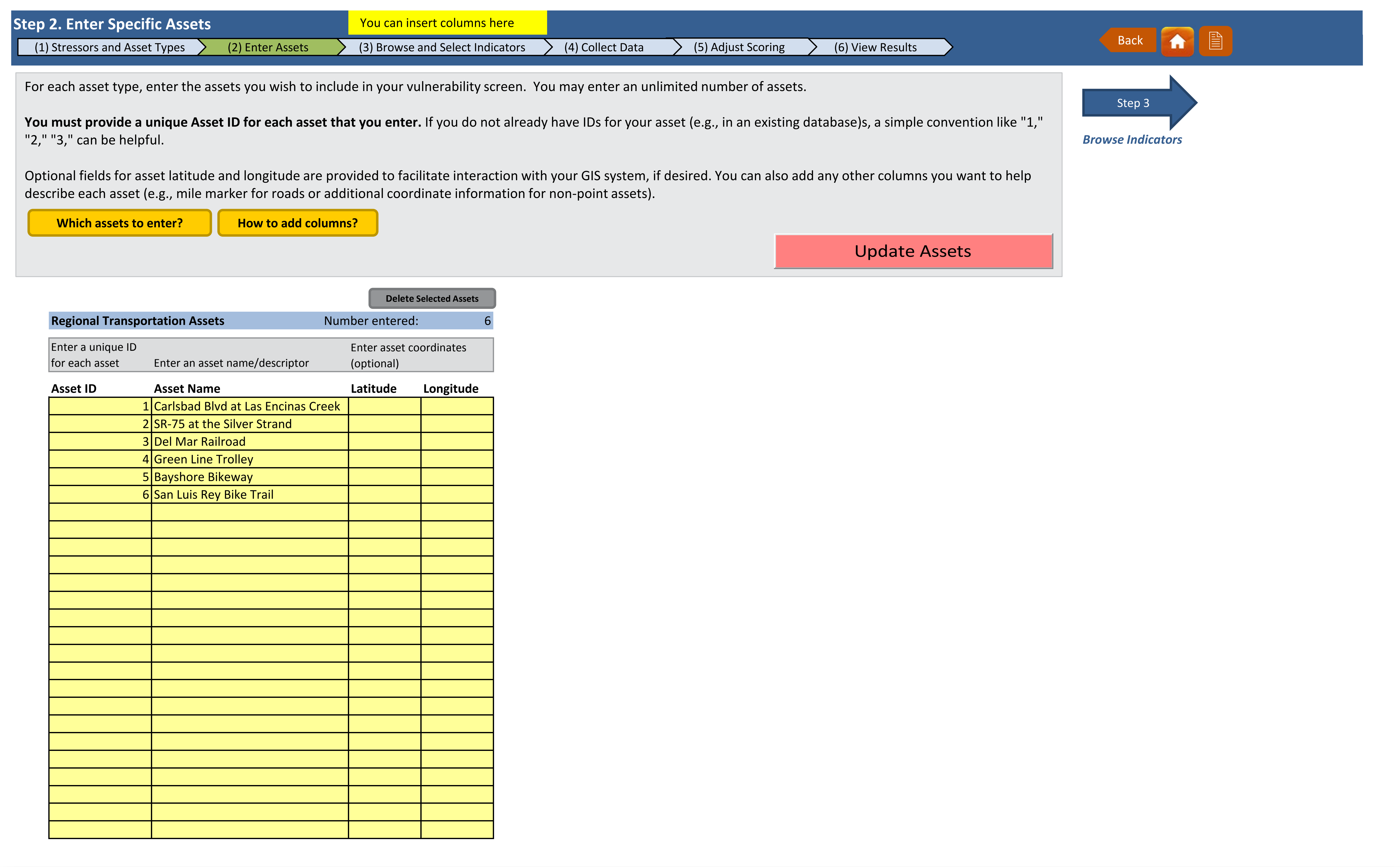
In this tool, "asset type" refers to a type of transportation asset. These "asset types" can be very broad, along the lines of transportation modes (e.g., "Highways" and "Ports") or very specific (e.g. "docks").
They key factor to consider in deciding how to break out asset types is whether you want to use the same vulnerability indicators for everything in that group. For example, in the Gulf Coast Study, the "asset types" evaluated actually referred to transportation modes -- Highways, Ports, Airports, Rail, and Transit. Different indicators were used to assess vulnerability for each asset type.
The vulnerability screening framework implemented in this tool can be used to assess vulnerability for any asset type. However, helpful guidance can be provided for conducting a vulnerability screen for six "modal" asset types used in the Gulf Coast Study (starred in the drop-down menu).

Use the yellow cells below to enter the asset type(s) you want to include in your vulnerability screen. Use buttons to add or remove stressors.
These types will be used to structure the vulnerability analysis and provide suggestions of indicators to use. You may select up to 6 asset types.

Enter the number of asset types you plan to include: 1

	Asset Type:	**Type (if Other)**
AType 1	Other	Regional Transportation Assets

Click the "Update Stressors and Asset Types" button at the top of the sheet once you have entered your stressors and asset types.



Step 2. Enter Specific Assets

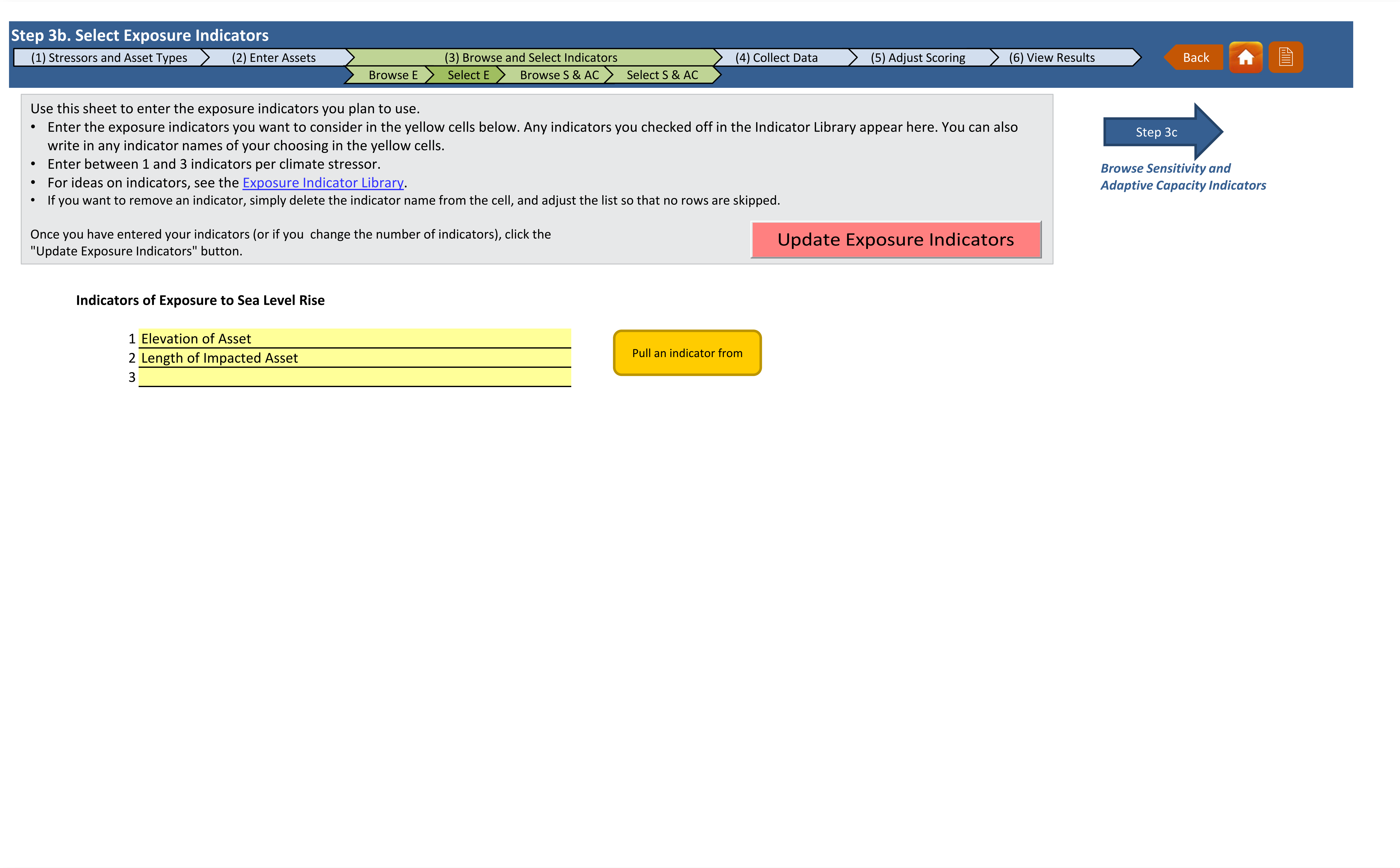
For each asset type, enter the assets you wish to include in your vulnerability screen. You may enter an unlimited number of assets.

You must provide a unique Asset ID for each asset that you enter. If you do not already have IDs for your asset (e.g., in an existing database)s, a simple convention like "1," "2," "3," can be helpful.

Optional fields for asset latitude and longitude are provided to facilitate interaction with your GIS system, if desired. You can also add any other columns you want to help describe each asset (e.g., mile marker for roads or additional coordinate information for non-point assets).

Regional Transportation Assets Number entered: 6

Enter a unique ID for each asset	Enter an asset name/descriptor	Enter asset coordinates (optional)	
Asset ID	**Asset Name**	**Latitude**	**Longitude**
1	Carlsbad Blvd at Las Encinas Creek		
2	SR-75 at the Silver Strand		
3	Del Mar Railroad		
4	Green Line Trolley		
5	Bayshore Bikeway		
6	San Luis Rey Bike Trail		



Step 3b. Select Exposure Indicators

Use this sheet to enter the exposure indicators you plan to use.

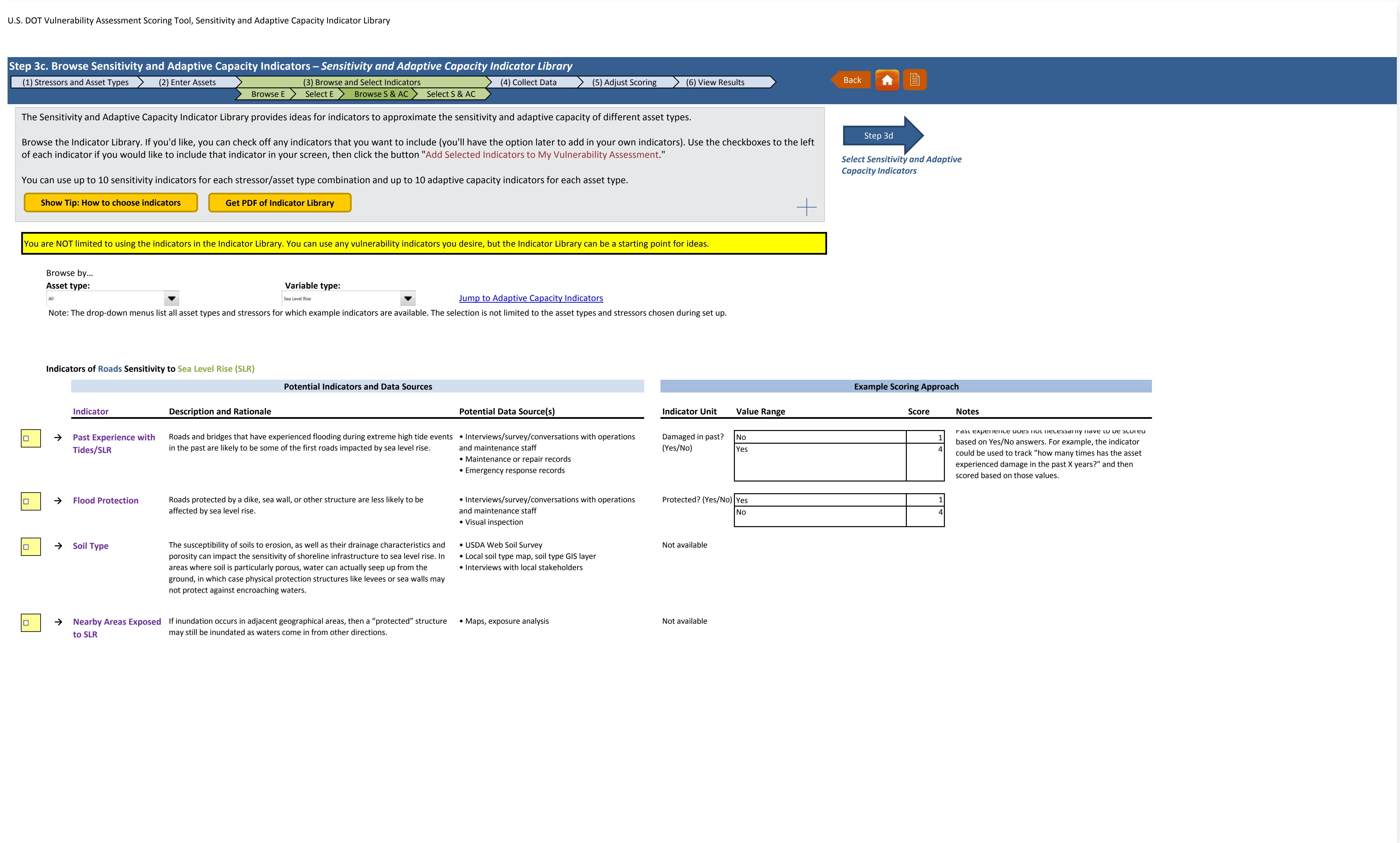
- Enter the exposure indicators you want to consider in the yellow cells below. Any indicators you checked off in the Indicator Library appear here. You can also write in any indicator names of your choosing in the yellow cells.
- Enter between 1 and 3 indicators per climate stressor.
- For ideas on indicators, see the Exposure Indicator Library.
- If you want to remove an indicator, simply delete the indicator name from the cell, and adjust the list so that no rows are skipped.

Once you have entered your indicators (or if you change the number of indicators), click the "Update Exposure Indicators" button.

Browse Sensitivity and Adaptive Capacity Indicators

Indicators of Exposure to Sea Level Rise

1 Elevation of Asset
2 Length of Impacted Asset
3



U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Step 3c. Browse Sensitivity and Adaptive Capacity Indicators – *Sensitivity and Adaptive Capacity Indicator Library*

Select Sensitivity and Adaptive Capacity Indicators

The Sensitivity and Adaptive Capacity Indicator Library provides ideas for indicators to approximate the sensitivity and adaptive capacity of different asset types.

Browse the Indicator Library. If you'd like, you can check off any indicators that you want to include (you'll have the option later to add in your own indicators). Use the checkboxes to the left of each indicator if you would like to include that indicator in your screen, then click the button "Add Selected Indicators to My Vulnerability Assessment."

You can use up to 10 sensitivity indicators for each stressor/asset type combination and up to 10 adaptive capacity indicators for each asset type.

You are NOT limited to using the indicators in the Indicator Library. You can use any vulnerability indicators you desire, but the Indicator Library can be a starting point for ideas.

Browse by...

Asset type: All

Variable type: Sea Level Rise

Jump to Adaptive Capacity Indicators

Note: The drop-down menus list all asset types and stressors for which example indicators are available. The selection is not limited to the asset types and stressors chosen during set up.

Indicators of Roads Sensitivity to Sea Level Rise (SLR)

		Potential Indicators and Data Sources			Example Scoring Approach			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Tides/SLR**	Roads and bridges that have experienced flooding during extreme high tide events in the past are likely to be some of the first roads impacted by sea level rise.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Flood Protection**	Roads protected by a dike, sea wall, or other structure are less likely to be affected by sea level rise.	• Interviews/survey/conversations with operations and maintenance staff • Visual inspection	Protected? (Yes/No)	Yes No	1 4	
☐	→	**Soil Type**	The susceptibility of soils to erosion, as well as their drainage characteristics and porosity can impact the sensitivity of shoreline infrastructure to sea level rise. In areas where soil is particularly porous, water can actually seep up from the ground, in which case physical protection structures like levees or sea walls may not protect against encroaching waters.	• USDA Web Soil Survey • Local soil type map, soil type GIS layer • Interviews with local stakeholders	Not available			
☐	→	**Nearby Areas Exposed to SLR**	If inundation occurs in adjacent geographical areas, then a "protected" structure may still be inundated as waters come in from other directions.	• Maps, exposure analysis	Not available			

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Bridges Sensitivity to Sea Level Rise

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)					
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**			**Score**	**Notes**
☐	→	Past Experience with Tides/SLR	Bridges that have experienced flooding during extreme high tide events in the past are likely to be some of the first roads impacted by sea level rise.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No			1	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
						Yes			4	
☐	→	Approach Elevation	Bridge approaches are often the most affected part of the bridge. Approaches that are closer to the water surface are more sensitive to flooding from sea level rise, storm surge, or heavy rain.	• LiDAR data • Asset management system	Approach elevation (feet above water surface)	0	5	=	4	
						5	10	=	3	
						10	15	=	2	
						Not a water crossing or > 15 ft.		=	1	
☐	→	Navigational Clearance of Bridge	Bridges with less clearance above the waterway are more likely to be affected by sea level rise; operational changes may be needed if certain sized vessels no longer have sufficient clearance as sea level rises.	• National Bridge Inventory, Item 39 (Navigation Vertical Clearance)	Navigational Clearance (feet)	0	5	=	4	
						6	10	=	3	
						11	20	=	2	
						21	+	=	1	
☐	→	Bridge Height	Bridges with less clearance above the waterway are more likely to be at risk of waters reaching the bridge deck.	• LiDAR data • Asset management system	Embankment height (meters)	0	0.5	=	4	
						0.5	1.5	=	2	
						1.5	2	=	2	
						2	+	=	1	
☐	→	Soil Type	The susceptibility of soils to erosion, as well as their drainage characteristics and porosity can impact the sensitivity of shoreline infrastructure to sea level rise. In areas where soil is particularly porous, water can actually seep up from the ground, in which case physical protection structures like levees or sea walls may not protect against encroaching waters.	• USDA Web Soil Survey • Local soil type map, soil type GIS layer • Interviews with local stakeholders	Not available					
☐	→	Nearby Areas Exposed to SLR	If inundation occurs in adjacent geographical areas, then a "protected" structure may still be inundated as waters come in from other directions.	• Maps, exposure analysis	Not available					

Indicators of Rail Lines Sensitivity to Sea Level Rise

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	Past Experience with Tides/SLR	Rail segments that have experienced flooding during extreme high tide events in the past are likely to be some of the first rail segments impacted by sea level rise.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No	1	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
						Yes	4	
☐	→	Drainage System Performance	Rail segments that have experienced drainage system performance issues are more likely to experience flooding or drainage issues from sea level rise.	• Interviews/survey/conversations with operations and maintenance staff	Performance issues in past? (Yes/No)	No	1	
						Yes	4	
☐	→	Elevation	Assets that are elevated above ground level may be shielded from exposure to sea level rise.	• Interviews/survey/conversations with operations and maintenance staff	Elevated? (Yes/No)	Yes	1	
						No	4	
☐	→	Soil type	Whether rail assets are sensitive to sea level rise may also depend on the type of soil and substrate of the rail. More porous soils may allow water to more easily infiltrate and destabilize the rail bed, while more compact soils may divert rising waters elsewhere	• USDA Web Soil Survey • Local soil type map, soil type GIS layer • Interviews with local stakeholders	Not available			
☐	→	Protection	Whether a rail asset is protected from sea level rise by other physical or man-made barriers could also be a sensitivity indicator.	• Interviews/survey/conversations with operations and maintenance staff • Visual inspection	Not available			

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

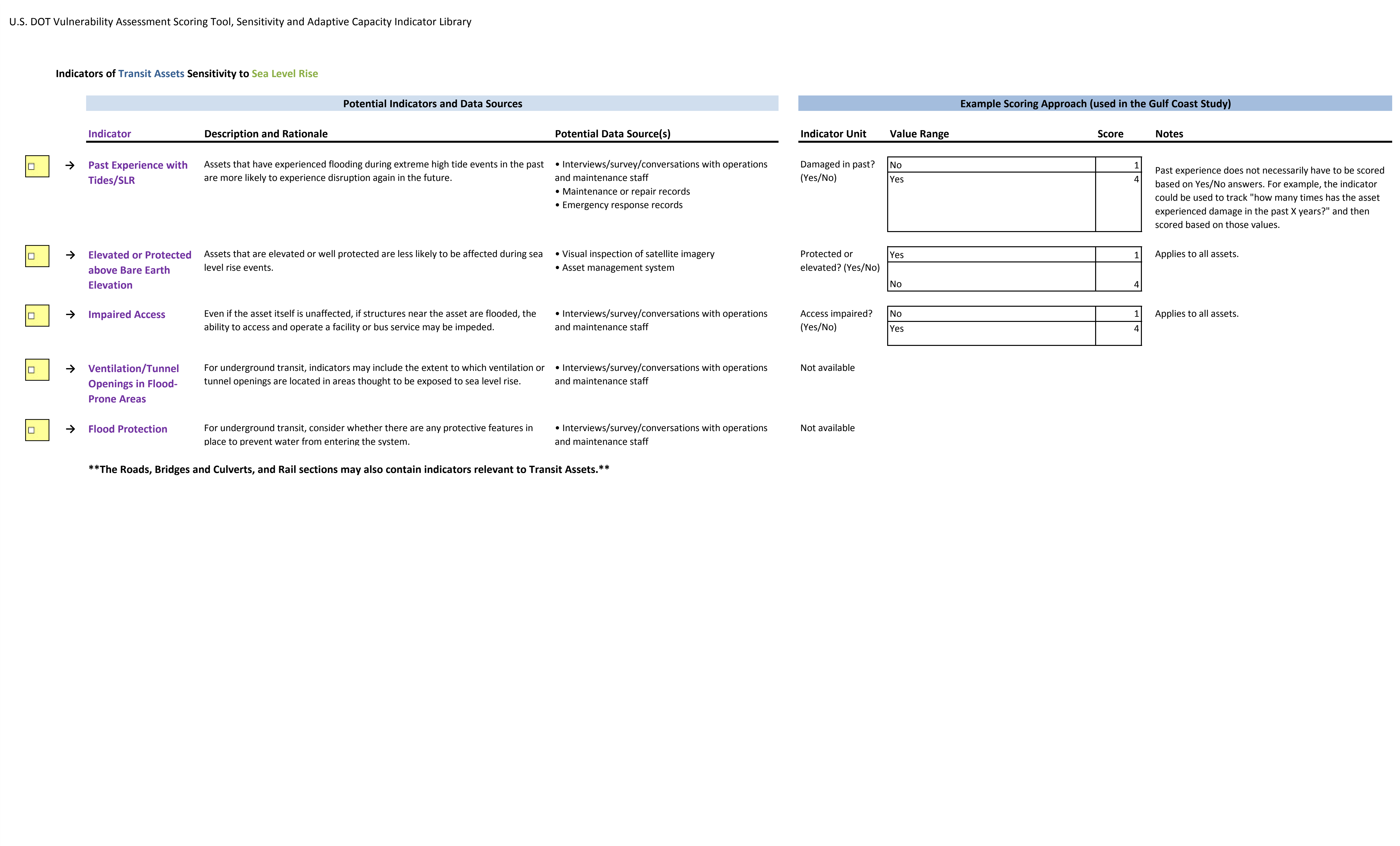
Indicators of Ports Sensitivity to Sea Level Rise

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Tides/SLR**	Ports that have experienced previous issues with tidal variation are more likely to be sensitive to sea level rise.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Shoreline Protection**	Ports with shoreline protection such as bulkheads or riprap are less sensitive to sea level rise than those without.	• Visual inspection of satellite imagery	Protected? (Yes/No)	Yes No	1 4	
☐	→	**Age of Wharves, Structures**	Older wharves and structures may have been built to lower standards and/or be in poorer condition compared to newer structures, and therefore more susceptible to damage.	• Interviews/survey/conversations with operations and maintenance staff	Age (years)	0 25 = 25 50 = 50 75 = 75 + =	1 2 3 4	
☐	→	**Elevation Relative to Sea Level**	Height of docks and other key port infrastructure, relative to the current sea level could be evaluated. If all of the key infrastructure is currently significantly above high tides, then a certain amount of sea level rise could occur without causing problems for the ports.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐	→	**Height of Drainage Outlets Relative to Sea Level**	Even if sea level rise is not sufficient to inundate a port, if it blocks a drainage outlet, then the port may flood during precipitation events.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐	→	**Floating or Fixed**	Floating docks are less likely to be affected by sea level rise. Deeper waters would actually make it easier for larger vessels to access and work in ports.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐	→	**Type of Operations**	The type operations on ports may change based on changes in sea level.	• Interviews/survey/conversations with operations and maintenance staff	Not available			

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Airports Sensitivity to Sea Level Rise

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Tides/SLR**	Airports that have experienced flooding during extreme high tide events in the past are likely to be some of the first roads impacted by sea level rise.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Height of Drainage Discharge**	If drainage system discharge point is below projected sea level rise, airport would be affected.	• Visual inspection of satellite imagery • Asset management system • Elevation data (NED or LiDAR)		Height of drainage discharge is lower than projected sea level rise for the area Height of drainage discharge is higher than projected sea level rise for the area	1 4	
☐	→	**Drainage System Pipe Condition**	Pipes in poor condition are more likely to cause drainage and chronic flooding issues.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff	Pipe Condition	Excellent Good Fair Poor	1 1 4 4	
☐	→	**Evidence of Blowouts**	Blowouts indicate that joints are failing and/or pipes are collapsing. A higher number of blowouts would therefore indicate a higher sensitivity to future precipitation levels, exacerbated by sea level rise. Blowouts occur when a leak, failure, or collapse in the drainage pipe begins to suck in sediment and creates a depression in the field.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance records	Number of blowouts	0 0 = 1 2 = 3 5 = 5 + =	1 2 3 4	
☐	→	**Age of Drainage System**	In older drainage systems, joints can fall apart over time. The older the drainage system, the more likely it is to fail during a flooding event.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff	Age (years)	0 25 = 25 30 = 30 50 = 50 + =	1 2 3 4	
☐	→	**Adjacent to Areas Exposed to Sea Level Rise**	If inundation occurs in adjacent geographical areas, then even protected structures may still be inundated as waters come in from other directions.	• Interviews/survey/conversations with operations and maintenance staff • Maps	Not available			
☐	→	**Access Roads Vulnerable to Sea Level Rise**	An airport itself may not be vulnerable to sea level rise, but the roads that access it could be.	• Interviews/survey/conversations with operations and maintenance staff • Roads vulnerability assessment	Not available			



U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Transit Assets Sensitivity to Sea Level Rise

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Tides/SLR**	Assets that have experienced flooding during extreme high tide events in the past are more likely to experience disruption again in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Elevated or Protected above Bare Earth Elevation**	Assets that are elevated or well protected are less likely to be affected during sea level rise events.	• Visual inspection of satellite imagery • Asset management system	Protected or elevated? (Yes/No)	Yes No	1 4	Applies to all assets.
☐	→	**Impaired Access**	Even if the asset itself is unaffected, if structures near the asset are flooded, the ability to access and operate a facility or bus service may be impeded.	• Interviews/survey/conversations with operations and maintenance staff	Access impaired? (Yes/No)	No Yes	1 4	Applies to all assets.
☐	→	**Ventilation/Tunnel Openings in Flood-Prone Areas**	For underground transit, indicators may include the extent to which ventilation or tunnel openings are located in areas thought to be exposed to sea level rise.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐	→	**Flood Protection**	For underground transit, consider whether there are any protective features in place to prevent water from entering the system.	• Interviews/survey/conversations with operations and maintenance staff	Not available			

****The Roads, Bridges and Culverts, and Rail sections may also contain indicators relevant to Transit Assets.****

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Roads Adaptive Capacity

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)					
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**			**Score**	**Notes**
☐	→	**Replacement Cost**	Replacement costs for each asset are used as a rough proxy for the ease in which assets could be repaired or replaced. Resources are assumed to be more easily mobilized for lower cost repairs, and replacement costs may indicate overall complexity, size, and expense of the asset itself.	• Asset management system • National Bridge Inventory, Item 96 (Total Project Cost)	Replacement cost (USD)	0	$1,000,000	=	1	
						$1,000,000	$10,000,000	=	2	
						$10,000,000	$100,000,000	=	3	
						$100,000,000	+	=	4	
☐	→	**Detour Length**	Detour length is used as an indicator of redundancy in the system. Segments with longer detour lengths assumed to have less adaptive capacity than segments with shorter detours.	• National Bridge Inventory provides detour length for bridges in the database (Item 19)	Detour length (km)	0	10	=	1	
						10	30	=	2	
						30	50	=	3	
						50	+	=	4	
☐	→	**Disruption Duration**	Disruption duration is used to indicate the timeframes necessary to restore service to assets following impacts of each of the variables. Length of time for the disruption to clear is an indicator of how well the system can deal with the climate impact.	• Interviews/survey/conversations with staff • Incident management system		Hours			1	
						Days			2	
						Weeks			3	
						Months			4	
☐	→	**FHWA Roadway Functional Classification**	Functional classification characterizes the type of services roadways are intended to provide (e.g., interstate vs. arterial vs. local). Roadways with a higher functional classification may cause greater system disruptions if damaged.	• Asset management system • GIS analysis	Not available					
☐	→	**Evacuation Route**	Roads designated as evacuation routes could have a greater consequence if damaged (and, thus, lower adaptive capacity).	• Internal agency data/emergency plans • Asset management system • GIS analysis	Not available					
☐	→	**Annual Average Daily Traffic (AADT)**	AADT is the volume of vehicle traffic of a road for a year divided by 365 days. Roadways with higher traffic volumes would affect more drivers/traffic and cause a greater disruption if damaged.	• Agency datasets • Asset management system	Not available					
☐	→	**Historical Repair Cost**	Historical repair costs for each asset are used as a proxy for the ease in which assets could be repaired or replaced in future events. In locations where historical repair costs for specific assets are available, this information might prove to be a more accurate indicator, particularly if those costs could be associated with specific weather events.	• Interviews/survey/conversations with staff • Asset management system • Post-event damage reports	Not available					
☐	→	**Access to Critical Areas**	Roads that provide the only access to critical areas are more significant to the adaptive capacity of the larger response system.	• Maps • Emergency planning department • Stakeholder interviews	Not available					

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Bridges Adaptive Capacity

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)					
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**			**Score**	**Notes**
☐	→	**Replacement Cost**	Replacement costs for each asset are used as a rough proxy for the ease in which assets could be repaired or replaced. Resources are assumed to be more easily mobilized for lower cost repairs, and replacement costs may indicate overall complexity, size, and expense of the asset itself.	• Asset management system • National Bridge Inventory, Item 96 (Total Project Cost)	Replacement cost (USD)	0 $1,000,000 $10,000,000 $100,000,000	$1,000,000 $10,000,000 $100,000,000 +	= = = =	1 2 3 4	
☐	→	**Detour Length**	Detour length is used as an indicator of redundancy in the system. Bridges with longer detour lengths assumed to have less adaptive capacity than bridges with shorter detours.	• National Bridge Inventory provides detour length for bridges in the database (Item 19)	Detour length (km)	0 10 30 50	10 30 50 +	= = = =	1 2 3 4	The relative burden of a detour can length can vary by location. The example shown is the "bins" for Mobile, AL.
☐	→	**Disruption Duration**	Disruption duration is used to indicate the timeframes necessary to restore service to assets following impacts of each of the variables. Length of time for the disruption to clear is an indicator of how well the system can deal with the climate impact.	• Interviews/survey/conversations with staff • Incident management system		Hours Days Weeks Months			1 2 3 4	
☐	→	**FHWA Roadway Functional Classification**	Functional classification characterizes the type of services roadways are intended to provide (e.g., interstate vs. arterial vs. local). Bridges carrying roadways with a higher functional classification may cause greater system disruptions if damaged.	• Asset management system • GIS analysis	Not available					
☐	→	**Evacuation Route**	Bridges that contain designated evacuation routes could have a greater consequence if damaged (and, thus, lower adaptive capacity).	• Internal agency data/emergency plans • Asset management system • GIS analysis	Not available					
☐	→	**Annual Average Daily Traffic (AADT)**	AADT is the volume of vehicle traffic of a road for a year divided by 365 days. Bridges with higher traffic volumes would affect more drivers/traffic and cause a greater disruption if damaged.	• National Bridge Inventory, Item 29--Average Daily Traffic • Agency datasets • Asset management system	Not available					
☐	→	**Historical Repair Cost**	Historical repair costs for each asset are used as a proxy for the ease in which assets could be repaired or replaced in future events. In locations where historical repair costs for specific assets are available, this information might prove to be a more accurate indicator, particularly if those costs could be associated with specific weather events.	• Interviews/survey/conversations with staff • Asset management system • Post-event damage reports	Not available					
☐	→	**Access to Critical Areas**	Bridges that provide the only access to critical areas are more significant to the adaptive capacity of the larger response system.	• Maps • Emergency planning department • Stakeholder interviews	Not available					

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

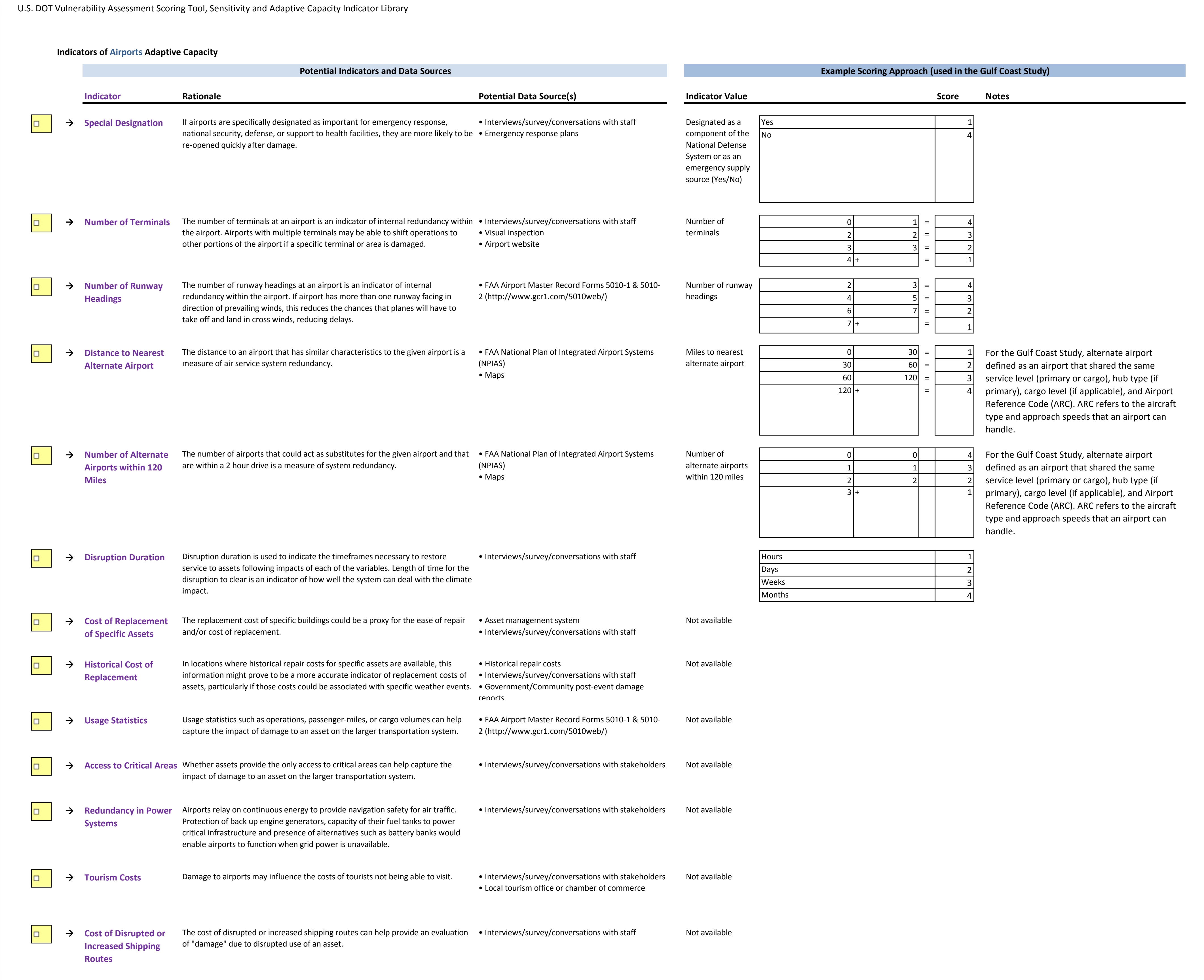
Indicators of Rail Lines Adaptive Capacity

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)				
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**		**Score**	**Notes**
☐	→	**Presence of Bridges along Segment**	Bridges are generally more expensive to replace than rail; the speed to recover from damage to bridges along a segment of rail may therefore be longer than segments without bridges.	• Visual inspection of segments	Bridge along segment? (Yes/No)	Yes		4	
						No		1	
☐	→	**Signaling**	Signaling can be expensive and time-intensive to replace.	• Interviews/survey/conversations with staff		Signaled		4	
						Not signaled		1	
☐	→	**Evacuation Plans**	Rail companies with a plan in place are expected to suffer less damage and recover more quickly from storms.	• Interviews/survey/conversations with staff		Plan in place		4	
						No plan		1	
☐	→	**Part of Disaster Relief Recovery Plan**	Rail assets that are part of a larger disaster relief recovery plan may be expedited for return to service.	• Interviews/survey/conversations with staff	Part of a disaster relief recovery plan? (Yes/No)	Yes		4	
						No		1	
☐	→	**Ability to Reroute System**	Systems and segments that can flexibly reroute will be more resilient to damage, track obstructions, and outages.	• Interviews/survey/conversations with staff		Limited	Assets are physically fixed	4	
						Low	Assets are inflexible	3	
						Medium	Assets are somewhat flexible	2	
						High	Assets are highly flexible	1	
☐	→	**Interchange Utility**	This is a yard-specific measure of the interchange between carriers, which is of importance in the ability to transfer all cars within yards.	• Interviews/survey/conversations with staff	Quality of interchange utility	Poor		4	
						Good		1	
☐	→	**Disruption Duration**	Disruption duration is used to indicate the timeframes necessary to restore service to assets following impacts of each of the variables. Length of time for the disruption to clear is an indicator of how well the system can deal with the climate impact.	• Interviews/survey/conversations with staff • Incident management system		Hours		1	
						Days		2	
						Weeks		3	
						Months		4	
☐	→	**Replacement Cost**	Specific replacement cost of assets or specific sub-components could serve as a proxy for how easy that asset would be to repair or replace if damaged.	• Asset management system • Interviews/survey/conversations with staff	Not available				
☐	→	**Number of Rail Lines**	The number of rail lines serving a specific location can capture the redundancy of a system.	• Satellite imagery • Visual inspection	Not available				

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Ports Adaptive Capacity

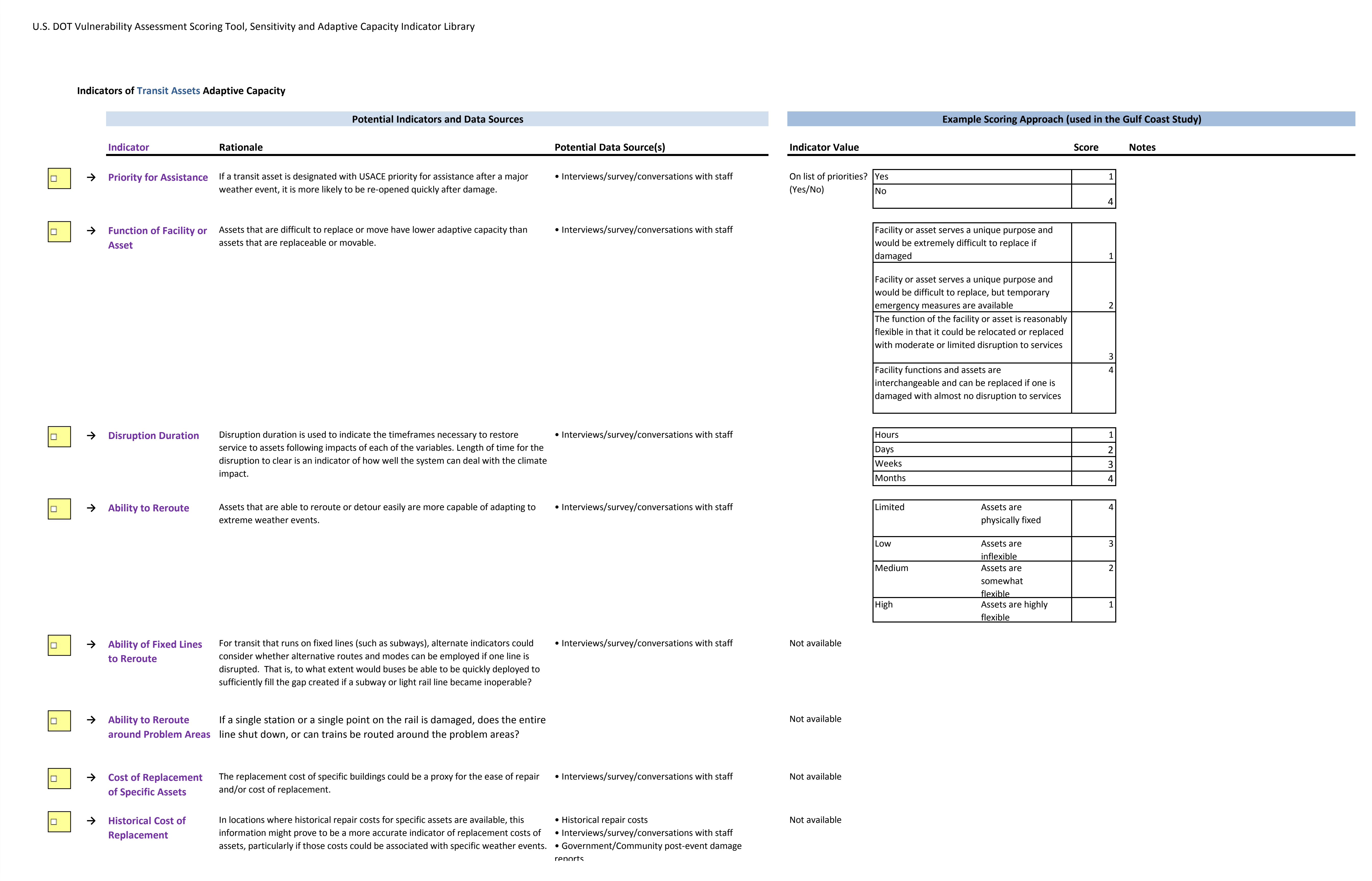
		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)		
		Indicator	**Rationale**	**Potential Data Source(s)**	**Indicator Value**	**Score**	**Notes**
☐	→	Redundancy within a Facility	Operational disruptions are less likely to occur if other parts of the same facility can be substituted in the event of minor damage.	• Interviews/survey/conversations with staff	Can easily shift operations within the facility	1	
					…	2	
					…	3	
					Cannot shift operations	4	
☐	→	Redundancy across Facilities	Serious operation disruptions are less likely to occur if other facilities can be substituted in the event of major damage.	• Interviews/survey/conversations with staff	Can easily shift operations to another facility	1	
					…	2	
					…	3	
					Cannot shift operations	4	
☐	→	Disruption Duration	Disruption duration is used to indicate the timeframes necessary to restore service to assets following impacts of each of the variables. Length of time for the disruption to clear is an indicator of how well the system can deal with the climate impact.	• Interviews/survey/conversations with staff	Hours	1	
					Days	2	
					Weeks	3	
					Months	4	
☐	→	Availability of Supplies and Repair Equipment	The extent to which supplies and repair equipment are stockpiled could be an indicator of how quickly ports would be able to recover from damage.	• Interviews/survey/conversations with staff	Not available		
☐	→	Sharing Equipment across Ports, Agencies	Agreements with other ports or agencies to share equipment or facilities to maintain operations after a major event could be indicators of adaptive capacity.	• Interviews/survey/conversations with staff	Not available		
☐	→	Cost of Replacement of Specific Assets	The replacement cost of specific buildings could be a proxy for the ease of repair and/or cost of replacement.	• Interviews/survey/conversations with staff	Not available		
☐	→	Historical Cost of Replacement	In locations where historical repair costs for specific assets are available, this information might prove to be a more accurate indicator of replacement costs of assets, particularly if those costs could be associated with specific weather events.	• Historical repair costs • Interviews/survey/conversations with staff • Government/Community post-event damage reports	Not available		
☐	→	Usage Statistics	Usage statistics such as operations, passenger-miles, or cargo volumes can help capture the impact of damage to an asset on the larger transportation system.	• Interviews/survey/conversations with staff	Not available		
☐	→	Access to Critical Areas	Whether assets provide the only access to critical areas can help capture the impact of damage to an asset on the larger transportation system.	• Interviews/survey/conversations with staff • Emergency planning department	Not available		
☐	→	Tourism Costs	Damage to ports may influence the costs of tourists not being able to visit.	• Interviews/survey/conversations with staff	Not available		
☐	→	Cost of Disrupted or Increased Shipping Routes	The cost of disrupted or increased shipping routes can help provide an evaluation of "damage" due to disrupted use of an asset.	• Interviews/survey/conversations with staff	Not available		



U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Airports Adaptive Capacity

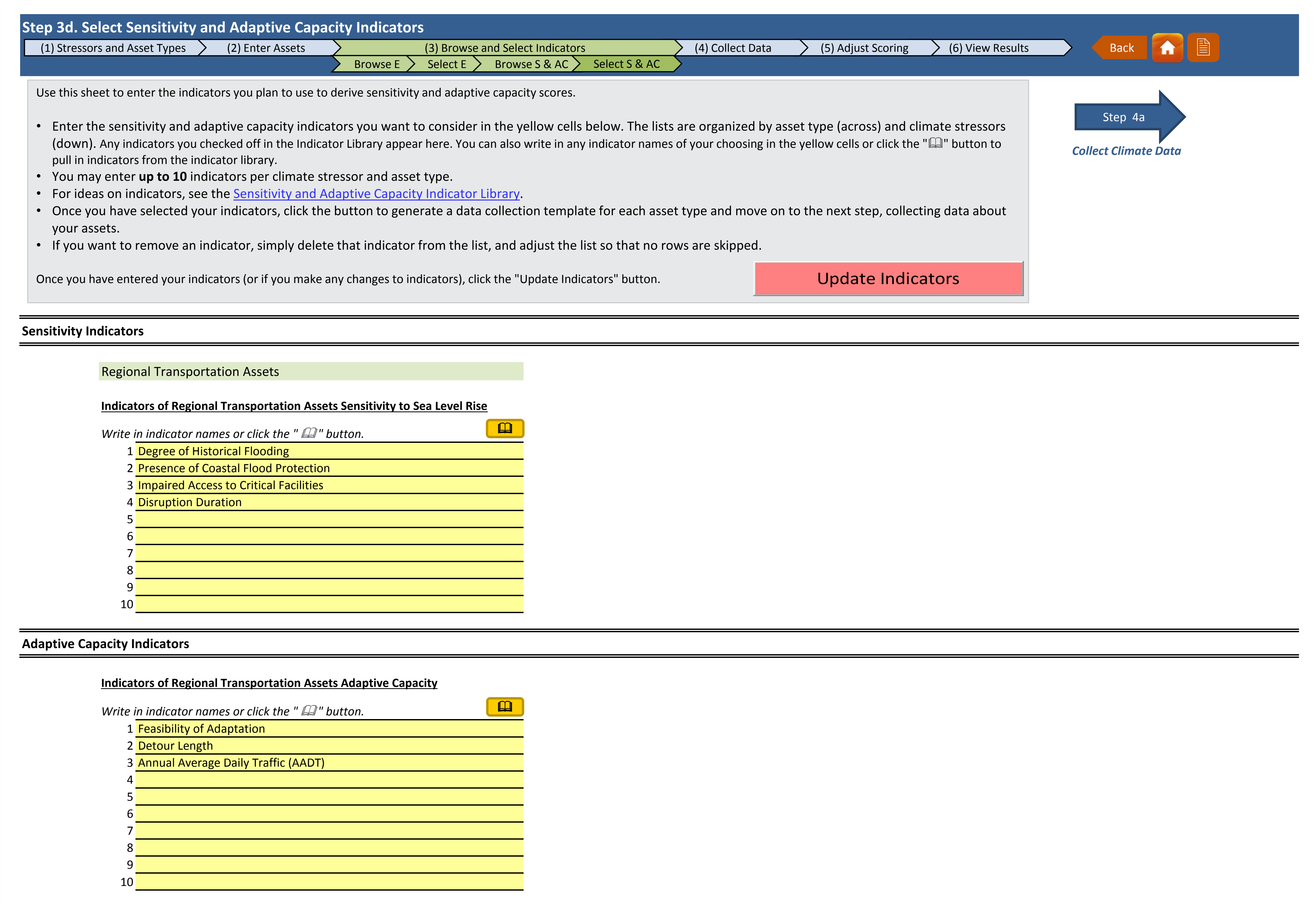
	Potential Indicators and Data Sources		Example Scoring Approach (used in the Gulf Coast Study)			
Indicator	**Rationale**	**Potential Data Source(s)**	**Indicator Value**		**Score**	**Notes**
☐ → **Special Designation**	If airports are specifically designated as important for emergency response, national security, defense, or support to health facilities, they are more likely to be re-opened quickly after damage.	• Interviews/survey/conversations with staff • Emergency response plans	Designated as a component of the National Defense System or as an emergency supply source (Yes/No)	Yes No	1 4	
☐ → **Number of Terminals**	The number of terminals at an airport is an indicator of internal redundancy within the airport. Airports with multiple terminals may be able to shift operations to other portions of the airport if a specific terminal or area is damaged.	• Interviews/survey/conversations with staff • Visual inspection • Airport website	Number of terminals	0 1 = 2 2 = 3 3 = 4 + =	4 3 2 1	
☐ → **Number of Runway Headings**	The number of runway headings at an airport is an indicator of internal redundancy within the airport. If airport has more than one runway facing in direction of prevailing winds, this reduces the chances that planes will have to take off and land in cross winds, reducing delays.	• FAA Airport Master Record Forms 5010-1 & 5010-2 (http://www.gcr1.com/5010web/)	Number of runway headings	2 3 = 4 5 = 6 7 = 7 + =	4 3 2 1	
☐ → **Distance to Nearest Alternate Airport**	The distance to an airport that has similar characteristics to the given airport is a measure of air service system redundancy.	• FAA National Plan of Integrated Airport Systems (NPIAS) • Maps	Miles to nearest alternate airport	0 30 = 30 60 = 60 120 = 120 + =	1 2 3 4	For the Gulf Coast Study, alternate airport defined as an airport that shared the same service level (primary or cargo), hub type (if primary), cargo level (if applicable), and Airport Reference Code (ARC). ARC refers to the aircraft type and approach speeds that an airport can handle.
☐ → **Number of Alternate Airports within 120 Miles**	The number of airports that could act as substitutes for the given airport and that are within a 2 hour drive is a measure of system redundancy.	• FAA National Plan of Integrated Airport Systems (NPIAS) • Maps	Number of alternate airports within 120 miles	0 0 1 1 2 2 3 +	4 3 2 1	For the Gulf Coast Study, alternate airport defined as an airport that shared the same service level (primary or cargo), hub type (if primary), cargo level (if applicable), and Airport Reference Code (ARC). ARC refers to the aircraft type and approach speeds that an airport can handle.
☐ → **Disruption Duration**	Disruption duration is used to indicate the timeframes necessary to restore service to assets following impacts of each of the variables. Length of time for the disruption to clear is an indicator of how well the system can deal with the climate impact.	• Interviews/survey/conversations with staff		Hours Days Weeks Months	1 2 3 4	
☐ → **Cost of Replacement of Specific Assets**	The replacement cost of specific buildings could be a proxy for the ease of repair and/or cost of replacement.	• Asset management system • Interviews/survey/conversations with staff	Not available			
☐ → **Historical Cost of Replacement**	In locations where historical repair costs for specific assets are available, this information might prove to be a more accurate indicator of replacement costs of assets, particularly if those costs could be associated with specific weather events.	• Historical repair costs • Interviews/survey/conversations with staff • Government/Community post-event damage reports	Not available			
☐ → **Usage Statistics**	Usage statistics such as operations, passenger-miles, or cargo volumes can help capture the impact of damage to an asset on the larger transportation system.	• FAA Airport Master Record Forms 5010-1 & 5010-2 (http://www.gcr1.com/5010web/)	Not available			
☐ → **Access to Critical Areas**	Whether assets provide the only access to critical areas can help capture the impact of damage to an asset on the larger transportation system.	• Interviews/survey/conversations with stakeholders	Not available			
☐ → **Redundancy in Power Systems**	Airports relay on continuous energy to provide navigation safety for air traffic. Protection of back up engine generators, capacity of their fuel tanks to power critical infrastructure and presence of alternatives such as battery banks would enable airports to function when grid power is unavailable.	• Interviews/survey/conversations with stakeholders	Not available			
☐ → **Tourism Costs**	Damage to airports may influence the costs of tourists not being able to visit.	• Interviews/survey/conversations with stakeholders • Local tourism office or chamber of commerce	Not available			
☐ → **Cost of Disrupted or Increased Shipping Routes**	The cost of disrupted or increased shipping routes can help provide an evaluation of "damage" due to disrupted use of an asset.	• Interviews/survey/conversations with staff	Not available			



U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Transit Assets Adaptive Capacity

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)				
		Indicator	**Rationale**	**Potential Data Source(s)**	**Indicator Value**			**Score**	**Notes**
☐	→	**Priority for Assistance**	If a transit asset is designated with USACE priority for assistance after a major weather event, it is more likely to be re-opened quickly after damage.	• Interviews/survey/conversations with staff	On list of priorities? (Yes/No)	Yes		1	
						No		4	
☐	→	**Function of Facility or Asset**	Assets that are difficult to replace or move have lower adaptive capacity than assets that are replaceable or movable.	• Interviews/survey/conversations with staff		Facility or asset serves a unique purpose and would be extremely difficult to replace if damaged		1	
						Facility or asset serves a unique purpose and would be difficult to replace, but temporary emergency measures are available		2	
						The function of the facility or asset is reasonably flexible in that it could be relocated or replaced with moderate or limited disruption to services		3	
						Facility functions and assets are interchangeable and can be replaced if one is damaged with almost no disruption to services		4	
☐	→	**Disruption Duration**	Disruption duration is used to indicate the timeframes necessary to restore service to assets following impacts of each of the variables. Length of time for the disruption to clear is an indicator of how well the system can deal with the climate impact.	• Interviews/survey/conversations with staff		Hours		1	
						Days		2	
						Weeks		3	
						Months		4	
☐	→	**Ability to Reroute**	Assets that are able to reroute or detour easily are more capable of adapting to extreme weather events.	• Interviews/survey/conversations with staff		Limited	Assets are physically fixed	4	
						Low	Assets are inflexible	3	
						Medium	Assets are somewhat flexible	2	
						High	Assets are highly flexible	1	
☐	→	**Ability of Fixed Lines to Reroute**	For transit that runs on fixed lines (such as subways), alternate indicators could consider whether alternative routes and modes can be employed if one line is disrupted. That is, to what extent would buses be able to be quickly deployed to sufficiently fill the gap created if a subway or light rail line became inoperable?	• Interviews/survey/conversations with staff	Not available				
☐	→	**Ability to Reroute around Problem Areas**	If a single station or a single point on the rail is damaged, does the entire line shut down, or can trains be routed around the problem areas?		Not available				
☐	→	**Cost of Replacement of Specific Assets**	The replacement cost of specific buildings could be a proxy for the ease of repair and/or cost of replacement.	• Interviews/survey/conversations with staff	Not available				
☐	→	**Historical Cost of Replacement**	In locations where historical repair costs for specific assets are available, this information might prove to be a more accurate indicator of replacement costs of assets, particularly if those costs could be associated with specific weather events.	• Historical repair costs • Interviews/survey/conversations with staff • Government/Community post-event damage reports	Not available				



Step 3d. Select Sensitivity and Adaptive Capacity Indicators

Use this sheet to enter the indicators you plan to use to derive sensitivity and adaptive capacity scores.

- Enter the sensitivity and adaptive capacity indicators you want to consider in the yellow cells below. The lists are organized by asset type (across) and climate stressors (down). Any indicators you checked off in the Indicator Library appear here. You can also write in any indicator names of your choosing in the yellow cells or click the "📖" button to pull in indicators from the indicator library.
- You may enter **up to 10** indicators per climate stressor and asset type.
- For ideas on indicators, see the Sensitivity and Adaptive Capacity Indicator Library.
- Once you have selected your indicators, click the button to generate a data collection template for each asset type and move on to the next step, collecting data about your assets.
- If you want to remove an indicator, simply delete that indicator from the list, and adjust the list so that no rows are skipped.

Once you have entered your indicators (or if you make any changes to indicators), click the "Update Indicators" button.

Sensitivity Indicators

Regional Transportation Assets

Indicators of Regional Transportation Assets Sensitivity to Sea Level Rise

Write in indicator names or click the "📖" button.

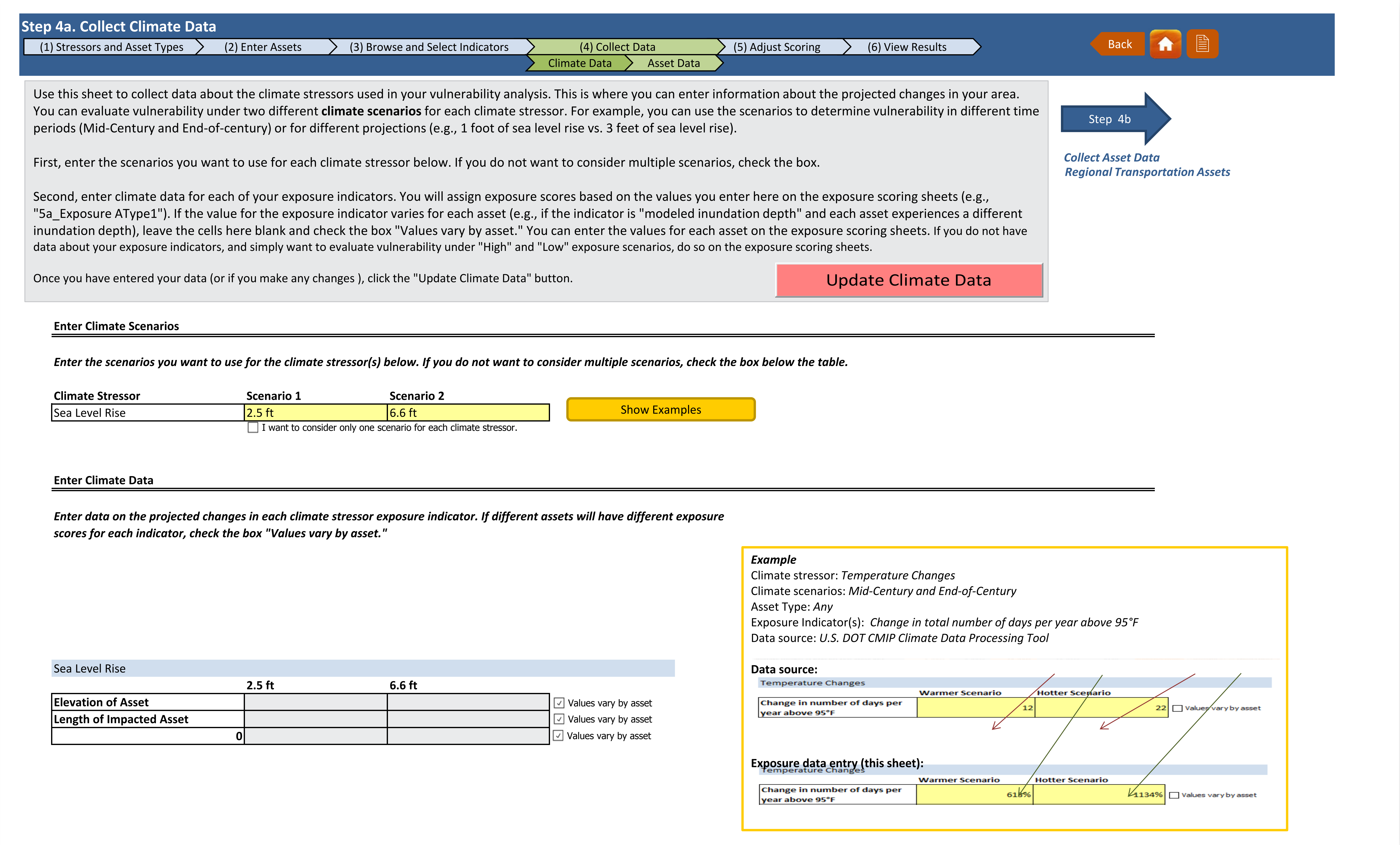
1 Degree of Historical Flooding
2 Presence of Coastal Flood Protection
3 Impaired Access to Critical Facilities
4 Disruption Duration
5
6
7
8
9
10

Adaptive Capacity Indicators

Indicators of Regional Transportation Assets Adaptive Capacity

Write in indicator names or click the "📖" button.

1 Feasibility of Adaptation
2 Detour Length
3 Annual Average Daily Traffic (AADT)
4
5
6
7
8
9
10



Step 4a. Collect Climate Data

Use this sheet to collect data about the climate stressors used in your vulnerability analysis. This is where you can enter information about the projected changes in your area. You can evaluate vulnerability under two different **climate scenarios** for each climate stressor. For example, you can use the scenarios to determine vulnerability in different time periods (Mid-Century and End-of-century) or for different projections (e.g., 1 foot of sea level rise vs. 3 feet of sea level rise).

First, enter the scenarios you want to use for each climate stressor below. If you do not want to consider multiple scenarios, check the box.

Second, enter climate data for each of your exposure indicators. You will assign exposure scores based on the values you enter here on the exposure scoring sheets (e.g., "5a_Exposure AType1"). If the value for the exposure indicator varies for each asset (e.g., if the indicator is "modeled inundation depth" and each asset experiences a different inundation depth), leave the cells here blank and check the box "Values vary by asset." You can enter the values for each asset on the exposure scoring sheets. If you do not have data about your exposure indicators, and simply want to evaluate vulnerability under "High" and "Low" exposure scenarios, do so on the exposure scoring sheets.

Once you have entered your data (or if you make any changes), click the "Update Climate Data" button.

Collect Asset Data
Regional Transportation Assets

Enter Climate Scenarios

Enter the scenarios you want to use for the climate stressor(s) below. If you do not want to consider multiple scenarios, check the box below the table.

Climate Stressor	Scenario 1	Scenario 2
Sea Level Rise	2.5 ft	6.6 ft

☐ I want to consider only one scenario for each climate stressor.

Enter Climate Data

Enter data on the projected changes in each climate stressor exposure indicator. If different assets will have different exposure scores for each indicator, check the box "Values vary by asset."

Sea Level Rise

	2.5 ft	6.6 ft	
Elevation of Asset			☑ Values vary by asset
Length of Impacted Asset			☑ Values vary by asset
0			☑ Values vary by asset

Example
Climate stressor: *Temperature Changes*
Climate scenarios: *Mid-Century and End-of-Century*
Asset Type: *Any*
Exposure Indicator(s): *Change in total number of days per year above 95°F*
Data source: *U.S. DOT CMIP Climate Data Processing Tool*

Data source:

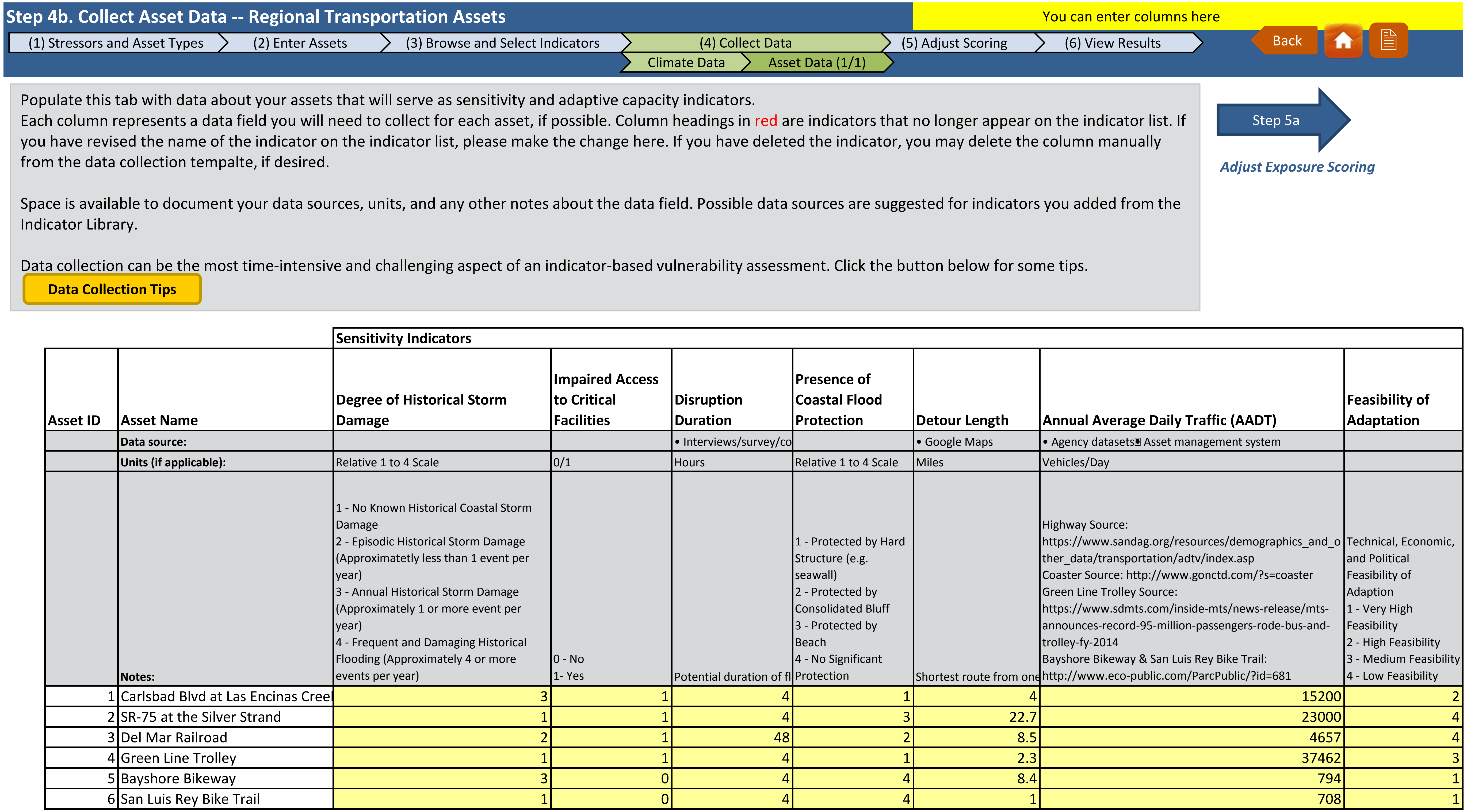
Temperature Changes

	Warmer Scenario	Hotter Scenario	
Change in number of days per year above 95°F	12	22	☐ Values vary by asset

Exposure data entry (this sheet):

Temperature Changes

	Warmer Scenario	Hotter Scenario	
Change in number of days per year above 95°F	613%	1134%	☐ Values vary by asset



Step 4b. Collect Asset Data -- Regional Transportation Assets

You can enter columns here

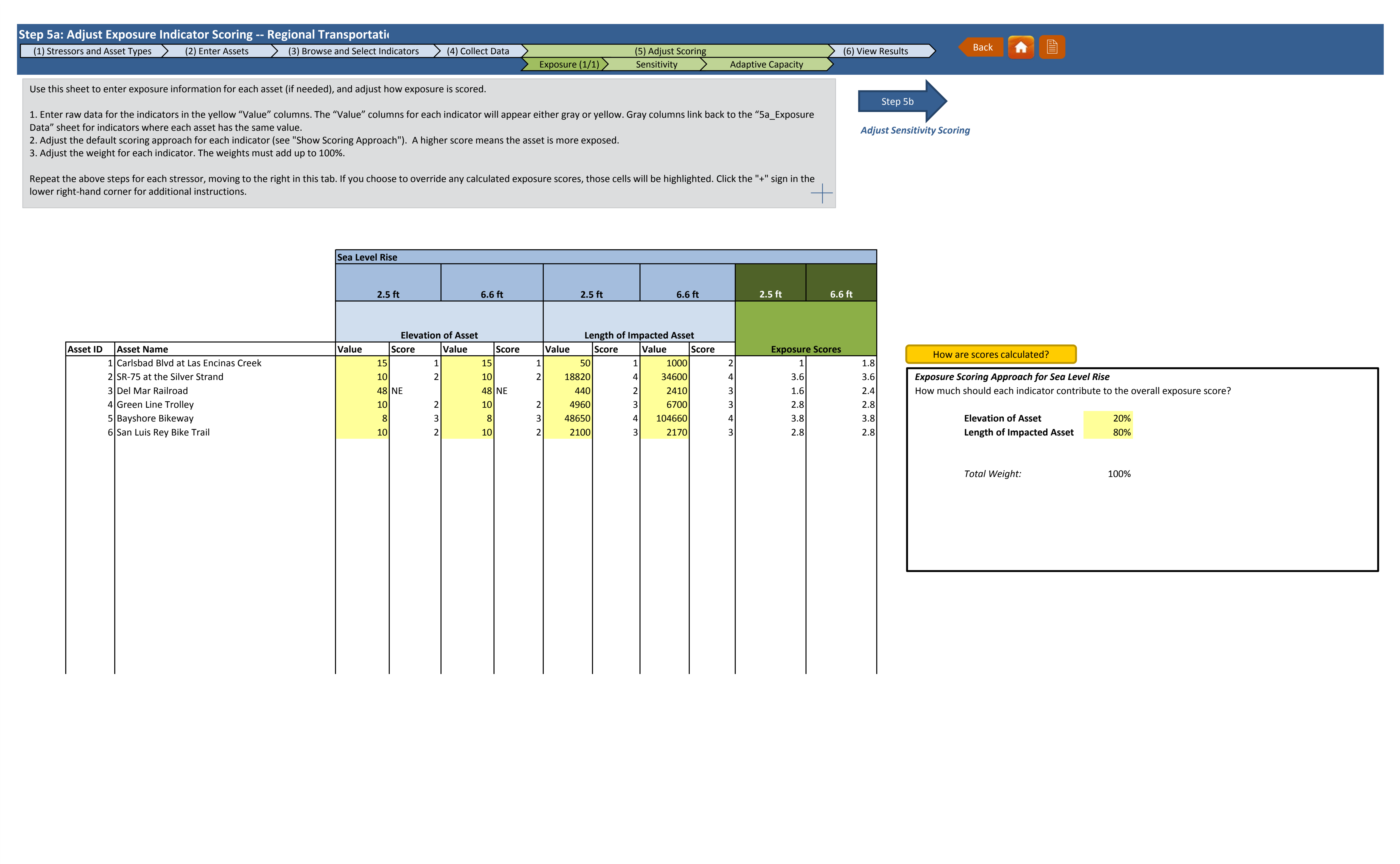
Populate this tab with data about your assets that will serve as sensitivity and adaptive capacity indicators.
Each column represents a data field you will need to collect for each asset, if possible. Column headings in red are indicators that no longer appear on the indicator list. If you have revised the name of the indicator on the indicator list, please make the change here. If you have deleted the indicator, you may delete the column manually from the data collection tempalte, if desired.

Space is available to document your data sources, units, and any other notes about the data field. Possible data sources are suggested for indicators you added from the Indicator Library.

Data collection can be the most time-intensive and challenging aspect of an indicator-based vulnerability assessment. Click the button below for some tips.

Adjust Exposure Scoring

		Sensitivity Indicators						
Asset ID	Asset Name	Degree of Historical Storm Damage	Impaired Access to Critical Facilities	Disruption Duration	Presence of Coastal Flood Protection	Detour Length	Annual Average Daily Traffic (AADT)	Feasibility of Adaptation
	Data source:			• Interviews/survey/co		• Google Maps	• Agency datasets◘ Asset management system	
	Units (if applicable):	Relative 1 to 4 Scale	0/1	Hours	Relative 1 to 4 Scale	Miles	Vehicles/Day	
	Notes:	1 - No Known Historical Coastal Storm Damage 2 - Episodic Historical Storm Damage (Approximatetly less than 1 event per year) 3 - Annual Historical Storm Damage (Approximately 1 or more event per year) 4 - Frequent and Damaging Historical Flooding (Approximately 4 or more events per year)	0 - No 1- Yes	Potential duration of fl	1 - Protected by Hard Structure (e.g. seawall) 2 - Protected by Consolidated Bluff 3 - Protected by Beach 4 - No Significant Protection	Shortest route from one	Highway Source: https://www.sandag.org/resources/demographics_and_other_data/transportation/adtv/index.asp Coaster Source: http://www.gonctd.com/?s=coaster Green Line Trolley Source: https://www.sdmts.com/inside-mts/news-release/mts-announces-record-95-million-passengers-rode-bus-and-trolley-fy-2014 Bayshore Bikeway & San Luis Rey Bike Trail: http://www.eco-public.com/ParcPublic/?id=681	Technical, Economic, and Political Feasibility of Adaption 1 - Very High Feasibility 2 - High Feasibility 3 - Medium Feasibility 4 - Low Feasibility
1	Carlsbad Blvd at Las Encinas Creel	3	1	4	1	4	15200	2
2	SR-75 at the Silver Strand	1	1	4	3	22.7	23000	4
3	Del Mar Railroad	2	1	48	2	8.5	4657	4
4	Green Line Trolley	1	1	4	1	2.3	37462	3
5	Bayshore Bikeway	3	0	4	4	8.4	794	1
6	San Luis Rey Bike Trail	1	0	4	4	1	708	1



Step 5a: Adjust Exposure Indicator Scoring -- Regional Transportati

Adjust Sensitivity Scoring

Use this sheet to enter exposure information for each asset (if needed), and adjust how exposure is scored.

1. Enter raw data for the indicators in the yellow “Value” columns. The “Value” columns for each indicator will appear either gray or yellow. Gray columns link back to the “5a_Exposure Data” sheet for indicators where each asset has the same value.
2. Adjust the default scoring approach for each indicator (see "Show Scoring Approach"). A higher score means the asset is more exposed.
3. Adjust the weight for each indicator. The weights must add up to 100%.

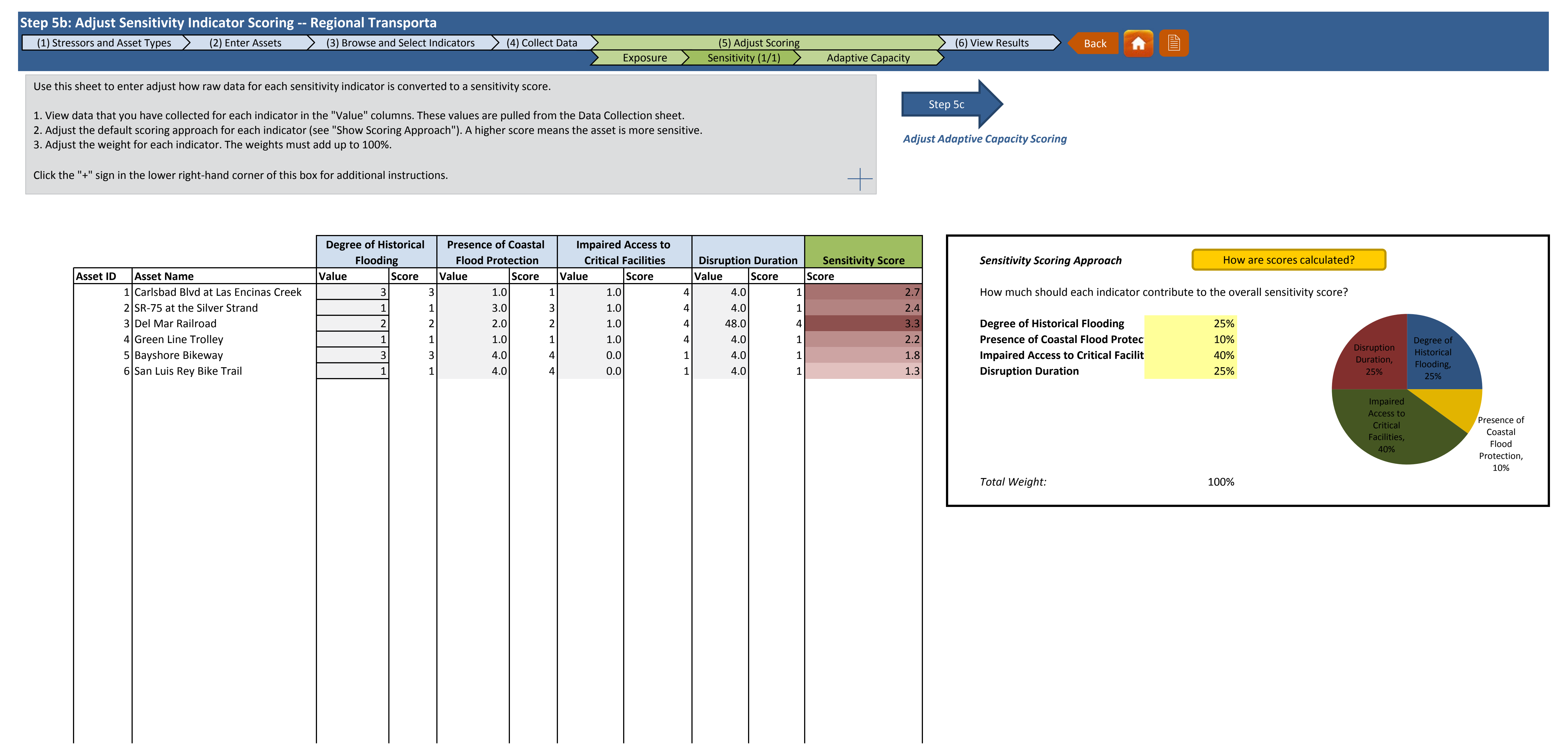
Repeat the above steps for each stressor, moving to the right in this tab. If you choose to override any calculated exposure scores, those cells will be highlighted. Click the "+" sign in the lower right-hand corner for additional instructions.

		Sea Level Rise									
		2.5 ft		6.6 ft		2.5 ft		6.6 ft		2.5 ft	6.6 ft
		Elevation of Asset				Length of Impacted Asset				Exposure Scores	
Asset ID	Asset Name	Value	Score	Value	Score	Value	Score	Value	Score		
1	Carlsbad Blvd at Las Encinas Creek	15	1	15	1	50	1	1000	2	1	1.8
2	SR-75 at the Silver Strand	10	2	10	2	18820	4	34600	4	3.6	3.6
3	Del Mar Railroad	48	NE	48	NE	440	2	2410	3	1.6	2.4
4	Green Line Trolley	10	2	10	2	4960	3	6700	3	2.8	2.8
5	Bayshore Bikeway	8	3	8	3	48650	4	104660	4	3.8	3.8
6	San Luis Rey Bike Trail	10	2	10	2	2100	3	2170	3	2.8	2.8

Exposure Scoring Approach for Sea Level Rise

How much should each indicator contribute to the overall exposure score?

Elevation of Asset	20%
Length of Impacted Asset	80%
Total Weight:	100%



Step 5b: Adjust Sensitivity Indicator Scoring -- Regional Transporta

Use this sheet to enter adjust how raw data for each sensitivity indicator is converted to a sensitivity score.

1. View data that you have collected for each indicator in the "Value" columns. These values are pulled from the Data Collection sheet.
2. Adjust the default scoring approach for each indicator (see "Show Scoring Approach"). A higher score means the asset is more sensitive.
3. Adjust the weight for each indicator. The weights must add up to 100%.

Click the "+" sign in the lower right-hand corner of this box for additional instructions.

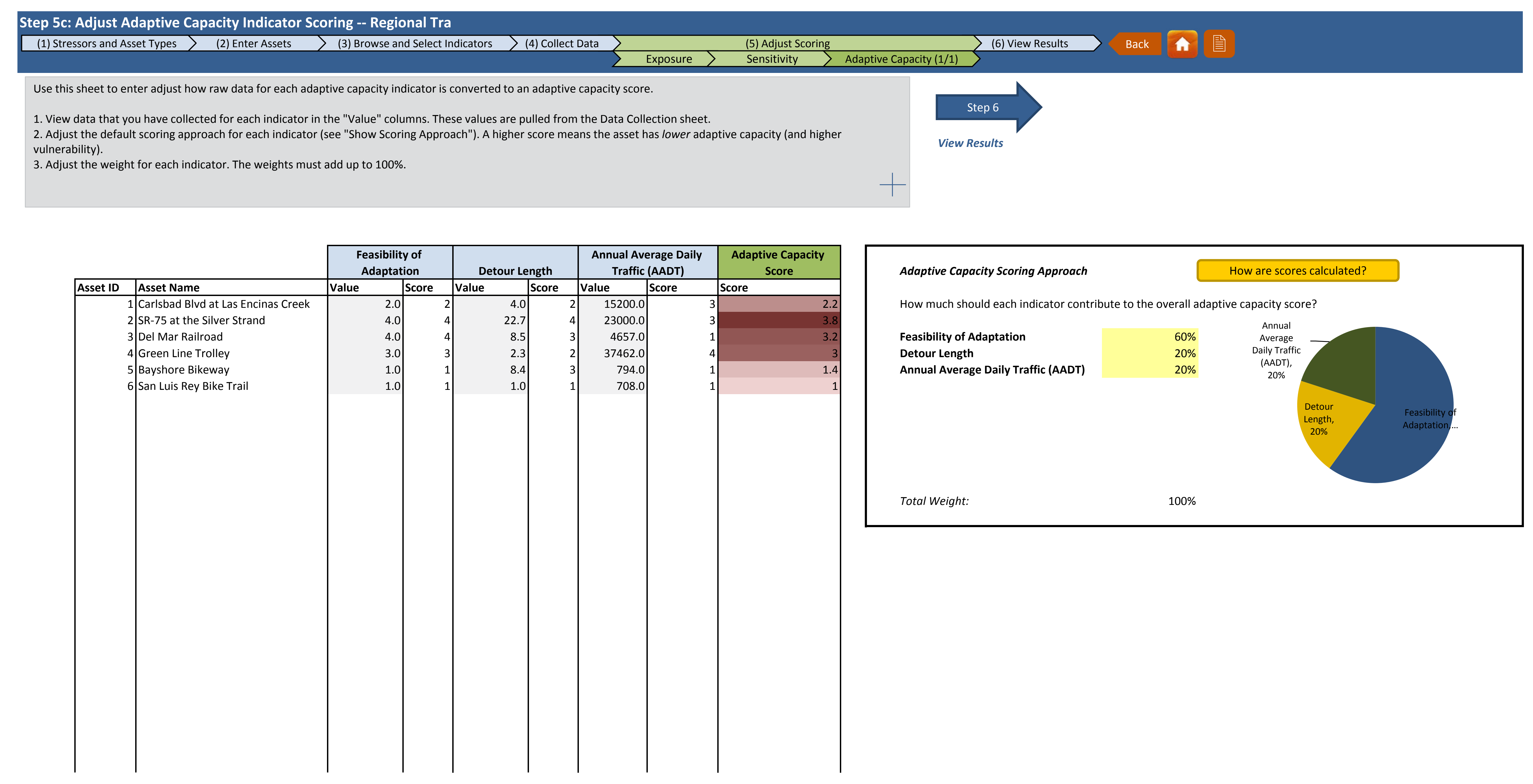
Adjust Adaptive Capacity Scoring

		Degree of Historical Flooding		Presence of Coastal Flood Protection		Impaired Access to Critical Facilities		Disruption Duration		Sensitivity Score
Asset ID	Asset Name	Value	Score	Value	Score	Value	Score	Value	Score	Score
1	Carlsbad Blvd at Las Encinas Creek	3	3	1.0	1	1.0	4	4.0	1	2.7
2	SR-75 at the Silver Strand	1	1	3.0	3	1.0	4	4.0	1	2.4
3	Del Mar Railroad	2	2	2.0	2	1.0	4	48.0	4	3.3
4	Green Line Trolley	1	1	1.0	1	1.0	4	4.0	1	2.2
5	Bayshore Bikeway	3	3	4.0	4	0.0	1	4.0	1	1.8
6	San Luis Rey Bike Trail	1	1	4.0	4	0.0	1	4.0	1	1.3

Sensitivity Scoring Approach

How much should each indicator contribute to the overall sensitivity score?

Degree of Historical Flooding	25%
Presence of Coastal Flood Protec	10%
Impaired Access to Critical Facilit	40%
Disruption Duration	25%
Total Weight:	100%



Use this sheet to enter adjust how raw data for each adaptive capacity indicator is converted to an adaptive capacity score.

1. View data that you have collected for each indicator in the "Value" columns. These values are pulled from the Data Collection sheet.
2. Adjust the default scoring approach for each indicator (see "Show Scoring Approach"). A higher score means the asset has *lower* adaptive capacity (and higher vulnerability).
3. Adjust the weight for each indicator. The weights must add up to 100%.

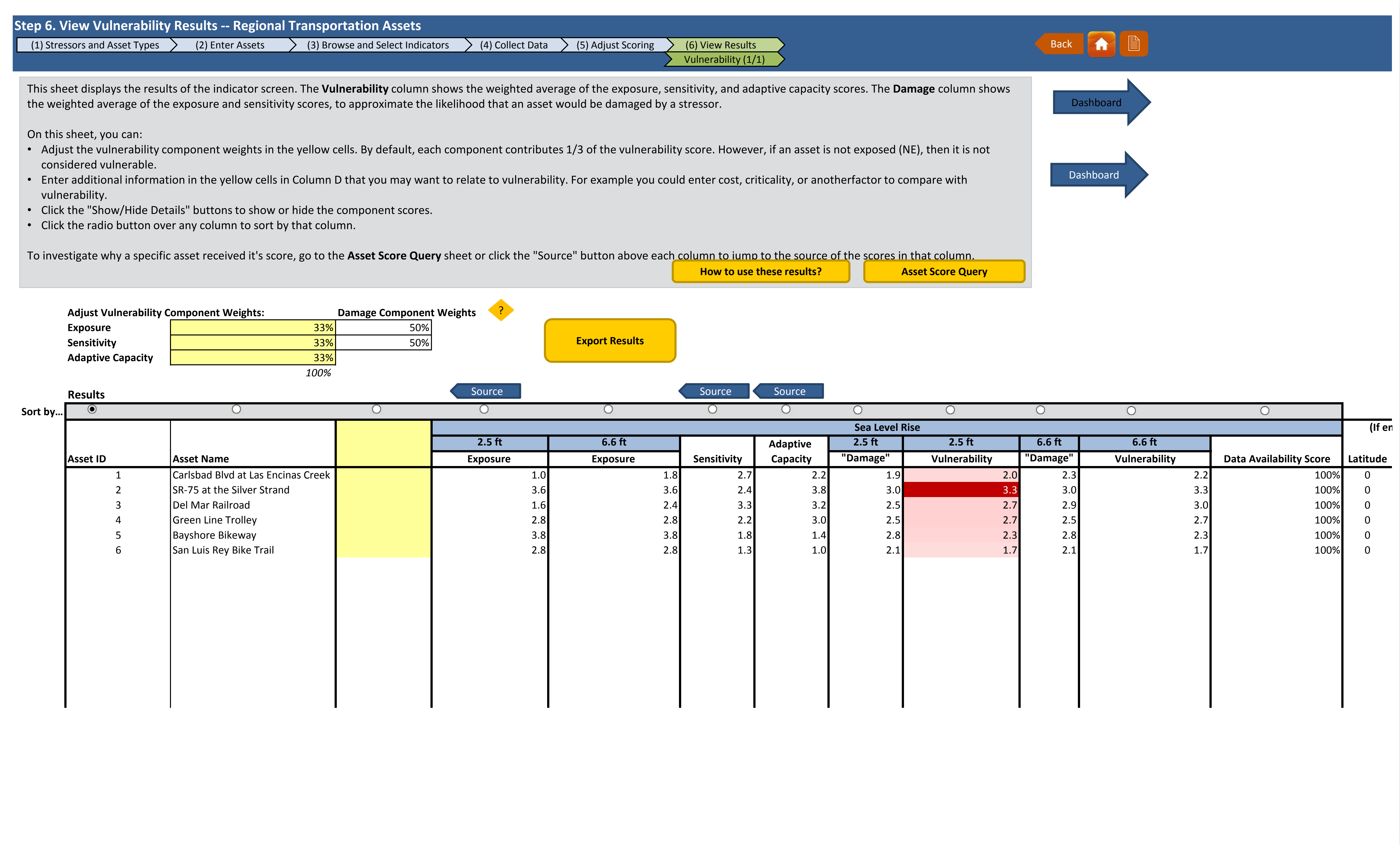
		Feasibility of Adaptation		Detour Length		Annual Average Daily Traffic (AADT)		Adaptive Capacity Score
Asset ID	Asset Name	Value	Score	Value	Score	Value	Score	Score
1	Carlsbad Blvd at Las Encinas Creek	2.0	2	4.0	2	15200.0	3	2.2
2	SR-75 at the Silver Strand	4.0	4	22.7	4	23000.0	3	3.8
3	Del Mar Railroad	4.0	4	8.5	3	4657.0	1	3.2
4	Green Line Trolley	3.0	3	2.3	2	37462.0	4	3
5	Bayshore Bikeway	1.0	1	8.4	3	794.0	1	1.4
6	San Luis Rey Bike Trail	1.0	1	1.0	1	708.0	1	1

Adaptive Capacity Scoring Approach

How are scores calculated?

How much should each indicator contribute to the overall adaptive capacity score?

Feasibility of Adaptation	60%
Detour Length	20%
Annual Average Daily Traffic (AADT)	20%
Total Weight:	100%



Step 6. View Vulnerability Results -- Regional Transportation Assets

This sheet displays the results of the indicator screen. The **Vulnerability** column shows the weighted average of the exposure, sensitivity, and adaptive capacity scores. The **Damage** column shows the weighted average of the exposure and sensitivity scores, to approximate the likelihood that an asset would be damaged by a stressor.

On this sheet, you can:

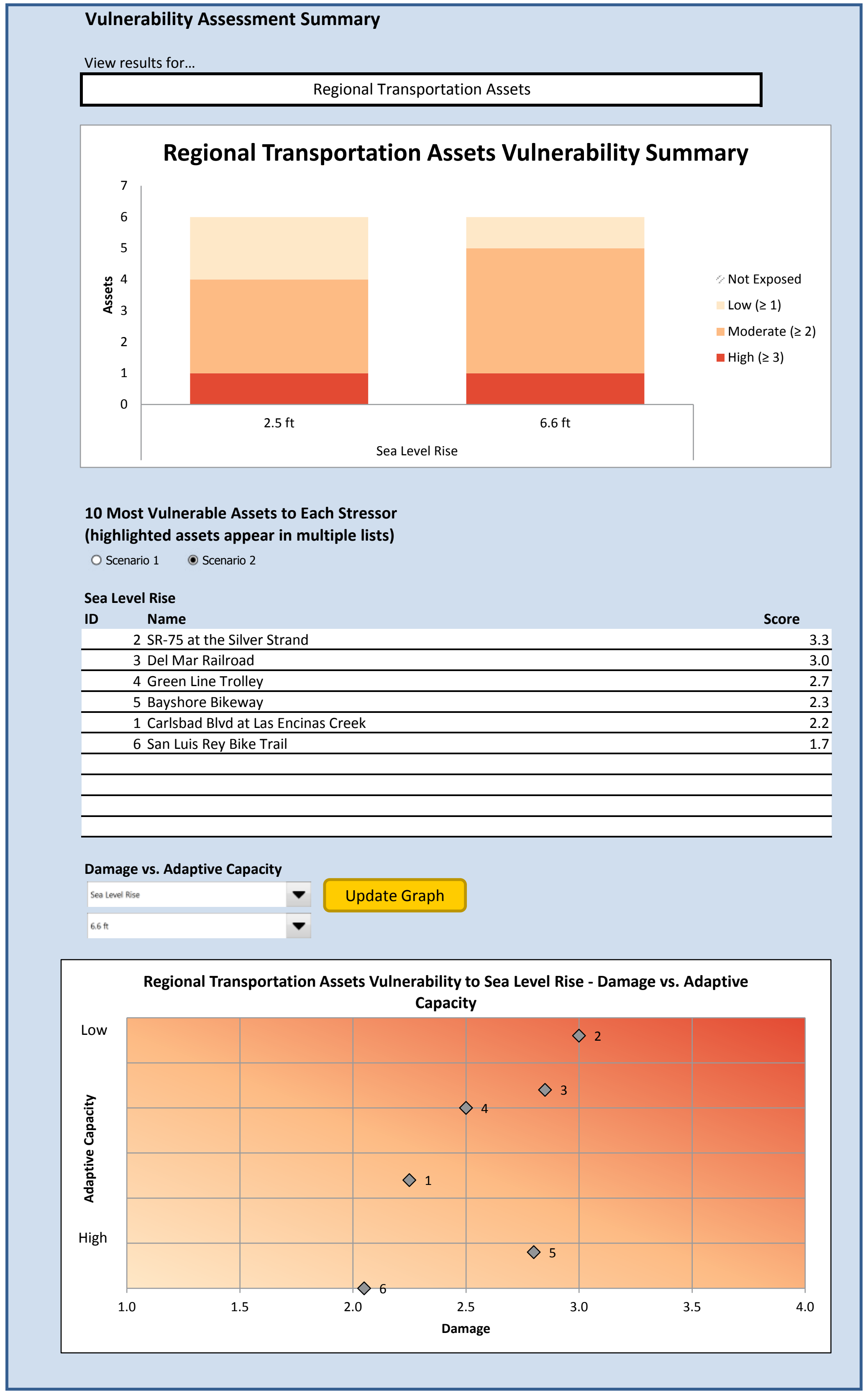
- Adjust the vulnerability component weights in the yellow cells. By default, each component contributes 1/3 of the vulnerability score. However, if an asset is not exposed (NE), then it is not considered vulnerable.
- Enter additional information in the yellow cells in Column D that you may want to relate to vulnerability. For example you could enter cost, criticality, or anotherfactor to compare with vulnerability.
- Click the "Show/Hide Details" buttons to show or hide the component scores.
- Click the radio button over any column to sort by that column.

To investigate why a specific asset received it's score, go to the **Asset Score Query** sheet or click the "Source" button above each column to jump to the source of the scores in that column.

	Adjust Vulnerability Component Weights:	Damage Component Weights
Exposure	33%	50%
Sensitivity	33%	50%
Adaptive Capacity	33%	
	100%	

Results

				Source		Source	Source						
Sort by...	●	○	○	○	○	○	○	○	○	○	○	○	
				Sea Level Rise									(If en
				2.5 ft	6.6 ft		Adaptive	2.5 ft	2.5 ft	6.6 ft	6.6 ft		
	Asset ID	Asset Name		Exposure	Exposure	Sensitivity	Capacity	"Damage"	Vulnerability	"Damage"	Vulnerability	Data Availability Score	Latitude
	1	Carlsbad Blvd at Las Encinas Creek		1.0	1.8	2.7	2.2	1.9	2.0	2.3	2.2	100%	0
	2	SR-75 at the Silver Strand		3.6	3.6	2.4	3.8	3.0	3.3	3.0	3.3	100%	0
	3	Del Mar Railroad		1.6	2.4	3.3	3.2	2.5	2.7	2.9	3.0	100%	0
	4	Green Line Trolley		2.8	2.8	2.2	3.0	2.5	2.7	2.5	2.7	100%	0
	5	Bayshore Bikeway		3.8	3.8	1.8	1.4	2.8	2.3	2.8	2.3	100%	0
	6	San Luis Rey Bike Trail		2.8	2.8	1.3	1.0	2.1	1.7	2.1	1.7	100%	0



Vulnerability Assessment Summary

View results for...

Regional Transportation Assets

10 Most Vulnerable Assets to Each Stressor
(highlighted assets appear in multiple lists)

○ Scenario 1 ● Scenario 2

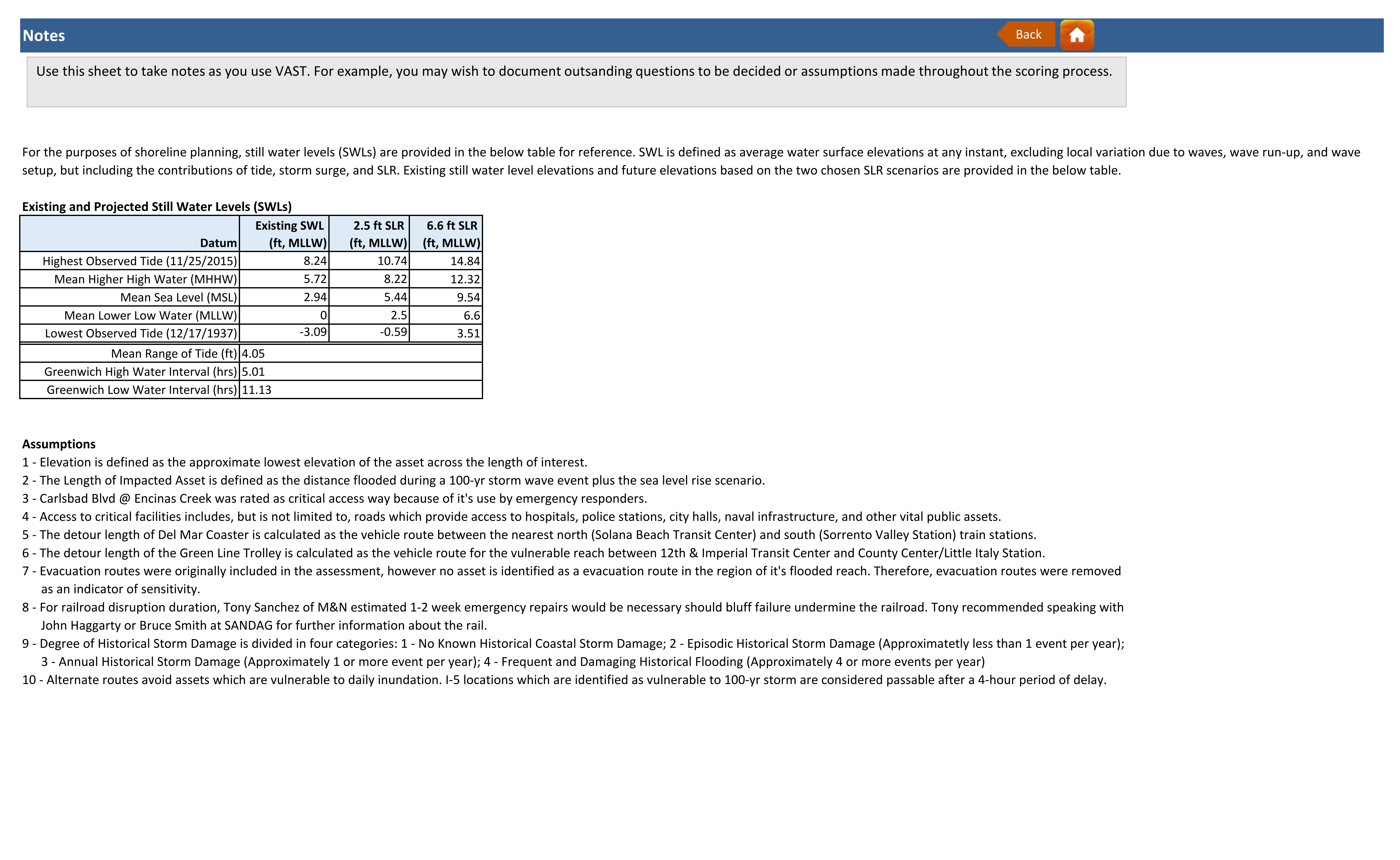
Sea Level Rise

ID	Name	Score
2	SR-75 at the Silver Strand	3.3
3	Del Mar Railroad	3.0
4	Green Line Trolley	2.7
5	Bayshore Bikeway	2.3
1	Carlsbad Blvd at Las Encinas Creek	2.2
6	San Luis Rey Bike Trail	1.7

Damage vs. Adaptive Capacity

Sea Level Rise

6.6 ft



Notes

Use this sheet to take notes as you use VAST. For example, you may wish to document outsanding questions to be decided or assumptions made throughout the scoring process.

For the purposes of shoreline planning, still water levels (SWLs) are provided in the below table for reference. SWL is defined as average water surface elevations at any instant, excluding local variation due to waves, wave run-up, and wave setup, but including the contributions of tide, storm surge, and SLR. Existing still water level elevations and future elevations based on the two chosen SLR scenarios are provided in the below table.

Existing and Projected Still Water Levels (SWLs)

Datum	Existing SWL (ft, MLLW)	2.5 ft SLR (ft, MLLW)	6.6 ft SLR (ft, MLLW)
Highest Observed Tide (11/25/2015)	8.24	10.74	14.84
Mean Higher High Water (MHHW)	5.72	8.22	12.32
Mean Sea Level (MSL)	2.94	5.44	9.54
Mean Lower Low Water (MLLW)	0	2.5	6.6
Lowest Observed Tide (12/17/1937)	-3.09	-0.59	3.51

Mean Range of Tide (ft)	4.05
Greenwich High Water Interval (hrs)	5.01
Greenwich Low Water Interval (hrs)	11.13

Assumptions

1 - Elevation is defined as the approximate lowest elevation of the asset across the length of interest.

2 - The Length of Impacted Asset is defined as the distance flooded during a 100-yr storm wave event plus the sea level rise scenario.

3 - Carlsbad Blvd @ Encinas Creek was rated as critical access way because of it's use by emergency responders.

4 - Access to critical facilities includes, but is not limited to, roads which provide access to hospitals, police stations, city halls, naval infrastructure, and other vital public assets.

5 - The detour length of Del Mar Coaster is calculated as the vehicle route between the nearest north (Solana Beach Transit Center) and south (Sorrento Valley Station) train stations.

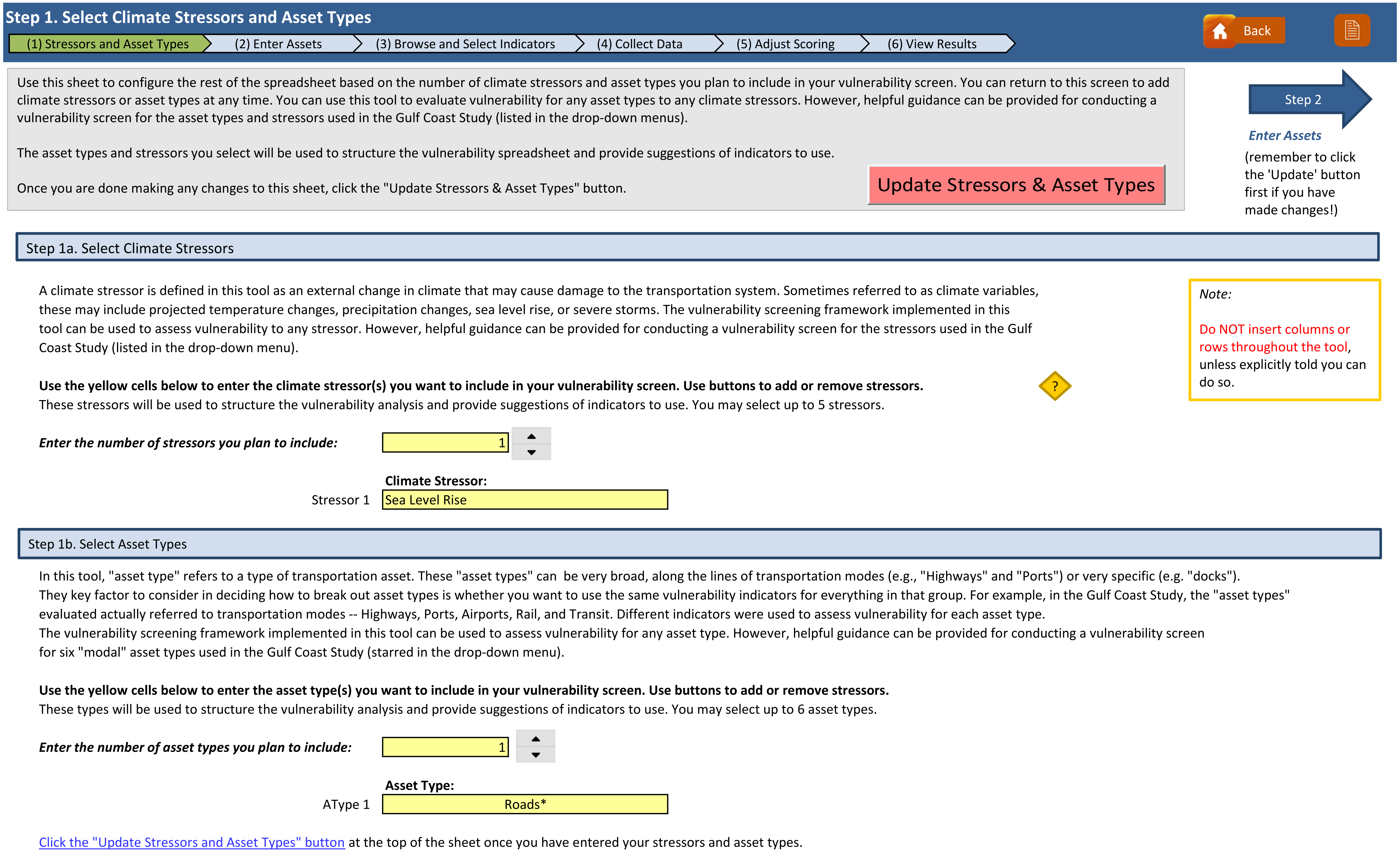
6 - The detour length of the Green Line Trolley is calculated as the vehicle route for the vulnerable reach between 12th & Imperial Transit Center and County Center/Little Italy Station.

7 - Evacuation routes were originally included in the assessment, however no asset is identified as a evacuation route in the region of it's flooded reach. Therefore, evacuation routes were removed as an indicator of sensitivity.

8 - For railroad disruption duration, Tony Sanchez of M&N estimated 1-2 week emergency repairs would be necessary should bluff failure undermine the railroad. Tony recommended speaking with John Haggarty or Bruce Smith at SANDAG for further information about the rail.

9 - Degree of Historical Storm Damage is divided in four categories: 1 - No Known Historical Coastal Storm Damage; 2 - Episodic Historical Storm Damage (Approximatetly less than 1 event per year); 3 - Annual Historical Storm Damage (Approximately 1 or more event per year); 4 - Frequent and Damaging Historical Flooding (Approximately 4 or more events per year)

10 - Alternate routes avoid assets which are vulnerable to daily inundation. I-5 locations which are identified as vulnerable to 100-yr storm are considered passable after a 4-hour period of delay.



Step 1. Select Climate Stressors and Asset Types

Use this sheet to configure the rest of the spreadsheet based on the number of climate stressors and asset types you plan to include in your vulnerability screen. You can return to this screen to add climate stressors or asset types at any time. You can use this tool to evaluate vulnerability for any asset types to any climate stressors. However, helpful guidance can be provided for conducting a vulnerability screen for the asset types and stressors used in the Gulf Coast Study (listed in the drop-down menus).

The asset types and stressors you select will be used to structure the vulnerability spreadsheet and provide suggestions of indicators to use.

Once you are done making any changes to this sheet, click the "Update Stressors & Asset Types" button.

Enter Assets

(remember to click the 'Update' button first if you have made changes!)

Step 1a. Select Climate Stressors

A climate stressor is defined in this tool as an external change in climate that may cause damage to the transportation system. Sometimes referred to as climate variables, these may include projected temperature changes, precipitation changes, sea level rise, or severe storms. The vulnerability screening framework implemented in this tool can be used to assess vulnerability to any stressor. However, helpful guidance can be provided for conducting a vulnerability screen for the stressors used in the Gulf Coast Study (listed in the drop-down menu).

Use the yellow cells below to enter the climate stressor(s) you want to include in your vulnerability screen. Use buttons to add or remove stressors.
These stressors will be used to structure the vulnerability analysis and provide suggestions of indicators to use. You may select up to 5 stressors.

Note:

Do NOT insert columns or rows throughout the tool, unless explicitly told you can do so.

Enter the number of stressors you plan to include: 1 ▲▼

	Climate Stressor:
Stressor 1	Sea Level Rise

Step 1b. Select Asset Types

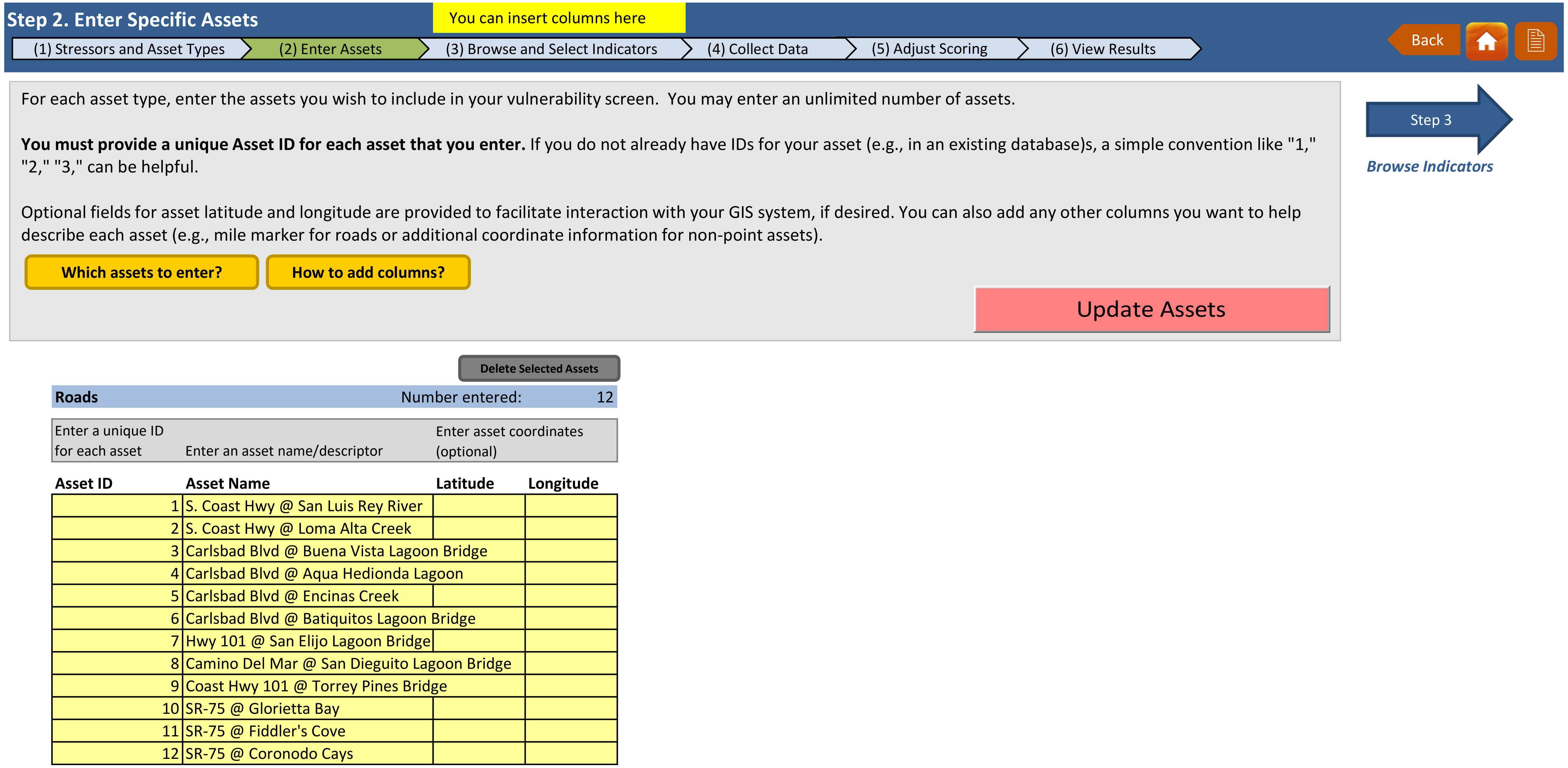
In this tool, "asset type" refers to a type of transportation asset. These "asset types" can be very broad, along the lines of transportation modes (e.g., "Highways" and "Ports") or very specific (e.g. "docks").
They key factor to consider in deciding how to break out asset types is whether you want to use the same vulnerability indicators for everything in that group. For example, in the Gulf Coast Study, the "asset types" evaluated actually referred to transportation modes -- Highways, Ports, Airports, Rail, and Transit. Different indicators were used to assess vulnerability for each asset type.
The vulnerability screening framework implemented in this tool can be used to assess vulnerability for any asset type. However, helpful guidance can be provided for conducting a vulnerability screen for six "modal" asset types used in the Gulf Coast Study (starred in the drop-down menu).

Use the yellow cells below to enter the asset type(s) you want to include in your vulnerability screen. Use buttons to add or remove stressors.
These types will be used to structure the vulnerability analysis and provide suggestions of indicators to use. You may select up to 6 asset types.

Enter the number of asset types you plan to include: 1 ▲▼

	Asset Type:
AType 1	Roads*

Click the "Update Stressors and Asset Types" button at the top of the sheet once you have entered your stressors and asset types.



Step 2. Enter Specific Assets

For each asset type, enter the assets you wish to include in your vulnerability screen. You may enter an unlimited number of assets.

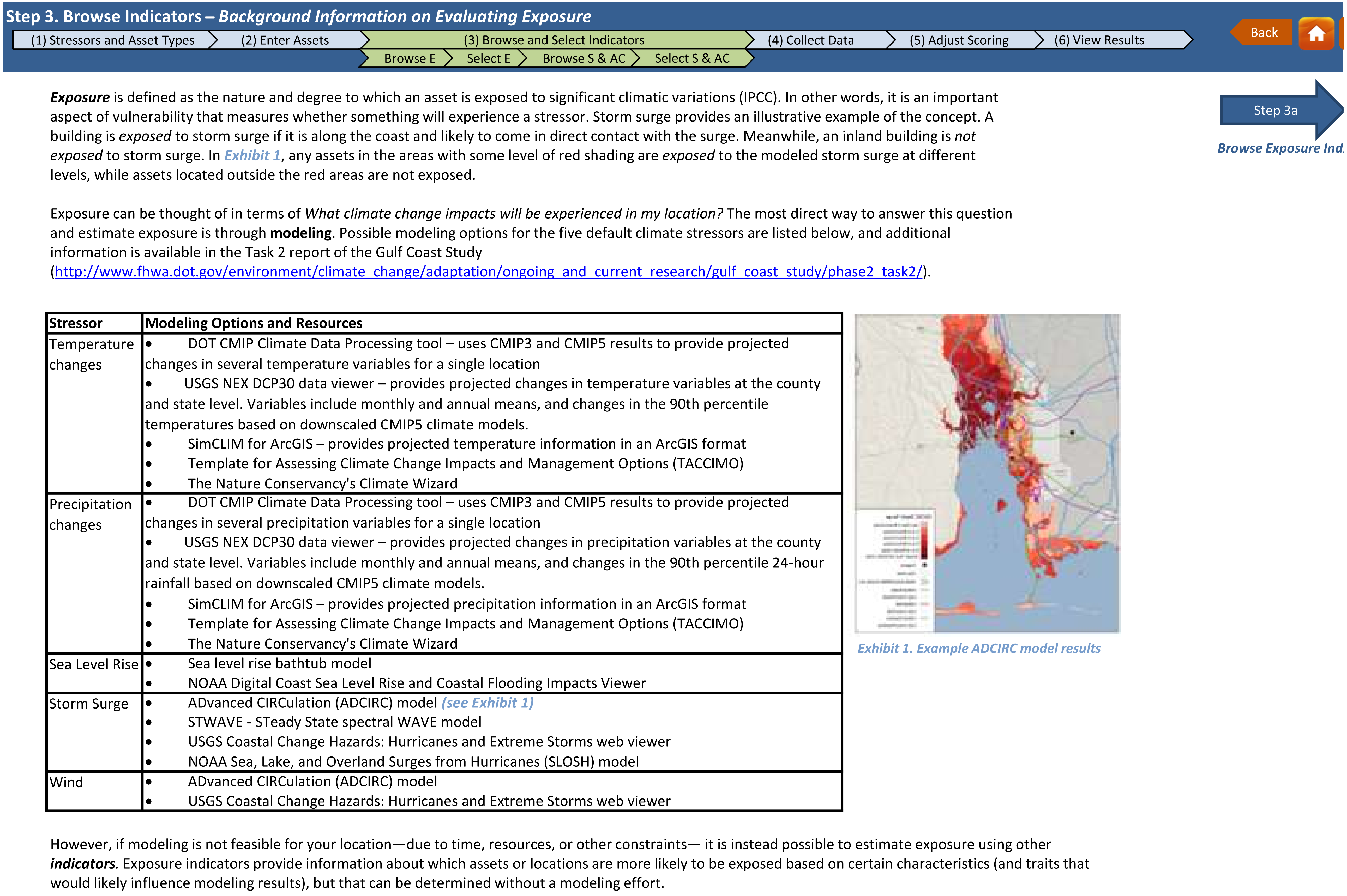
You must provide a unique Asset ID for each asset that you enter. If you do not already have IDs for your asset (e.g., in an existing database)s, a simple convention like "1," "2," "3," can be helpful.

Optional fields for asset latitude and longitude are provided to facilitate interaction with your GIS system, if desired. You can also add any other columns you want to help describe each asset (e.g., mile marker for roads or additional coordinate information for non-point assets).

Roads Number entered: 12

Enter a unique ID for each asset | Enter an asset name/descriptor | Enter asset coordinates (optional)

Asset ID	Asset Name	Latitude	Longitude
1	S. Coast Hwy @ San Luis Rey River		
2	S. Coast Hwy @ Loma Alta Creek		
3	Carlsbad Blvd @ Buena Vista Lagoon Bridge		
4	Carlsbad Blvd @ Aqua Hedionda Lagoon		
5	Carlsbad Blvd @ Encinas Creek		
6	Carlsbad Blvd @ Batiquitos Lagoon Bridge		
7	Hwy 101 @ San Elijo Lagoon Bridge		
8	Camino Del Mar @ San Dieguito Lagoon Bridge		
9	Coast Hwy 101 @ Torrey Pines Bridge		
10	SR-75 @ Glorietta Bay		
11	SR-75 @ Fiddler's Cove		
12	SR-75 @ Coronodo Cays		



Step 3. Browse Indicators – *Background Information on Evaluating Exposure*

Exposure is defined as the nature and degree to which an asset is exposed to significant climatic variations (IPCC). In other words, it is an important aspect of vulnerability that measures whether something will experience a stressor. Storm surge provides an illustrative example of the concept. A building is *exposed* to storm surge if it is along the coast and likely to come in direct contact with the surge. Meanwhile, an inland building is *not exposed* to storm surge. In *Exhibit 1*, any assets in the areas with some level of red shading are *exposed* to the modeled storm surge at different levels, while assets located outside the red areas are not exposed.

Exposure can be thought of in terms of *What climate change impacts will be experienced in my location?* The most direct way to answer this question and estimate exposure is through **modeling**. Possible modeling options for the five default climate stressors are listed below, and additional information is available in the Task 2 report of the Gulf Coast Study (http://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/phase2_task2/).

Stressor	Modeling Options and Resources
Temperature changes	• DOT CMIP Climate Data Processing tool – uses CMIP3 and CMIP5 results to provide projected changes in several temperature variables for a single location • USGS NEX DCP30 data viewer – provides projected changes in temperature variables at the county and state level. Variables include monthly and annual means, and changes in the 90th percentile temperatures based on downscaled CMIP5 climate models. • SimCLIM for ArcGIS – provides projected temperature information in an ArcGIS format • Template for Assessing Climate Change Impacts and Management Options (TACCIMO) • The Nature Conservancy's Climate Wizard
Precipitation changes	• DOT CMIP Climate Data Processing tool – uses CMIP3 and CMIP5 results to provide projected changes in several precipitation variables for a single location • USGS NEX DCP30 data viewer – provides projected changes in precipitation variables at the county and state level. Variables include monthly and annual means, and changes in the 90th percentile 24-hour rainfall based on downscaled CMIP5 climate models. • SimCLIM for ArcGIS – provides projected precipitation information in an ArcGIS format • Template for Assessing Climate Change Impacts and Management Options (TACCIMO) • The Nature Conservancy's Climate Wizard
Sea Level Rise	• Sea level rise bathtub model • NOAA Digital Coast Sea Level Rise and Coastal Flooding Impacts Viewer
Storm Surge	• ADvanced CIRCulation (ADCIRC) model *(see Exhibit 1)* • STWAVE - STeady State spectral WAVE model • USGS Coastal Change Hazards: Hurricanes and Extreme Storms web viewer • NOAA Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model
Wind	• ADvanced CIRCulation (ADCIRC) model • USGS Coastal Change Hazards: Hurricanes and Extreme Storms web viewer

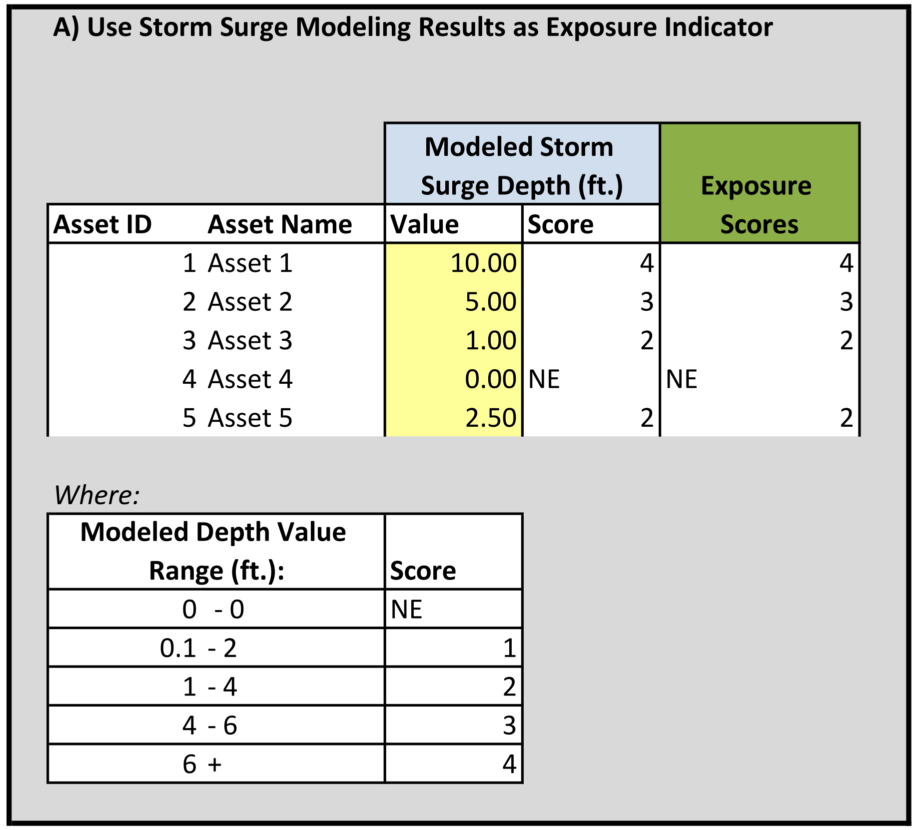
Exhibit 1. Example ADCIRC model results

However, if modeling is not feasible for your location—due to time, resources, or other constraints— it is instead possible to estimate exposure using other ***indicators***. Exposure indicators provide information about which assets or locations are more likely to be exposed based on certain characteristics (and traits that would likely influence modeling results), but that can be determined without a modeling effort.

For example, storm surge exposure can be modeled using models such as the ADvanced CIRCulation (ADCIRC) model, which will provide a detailed map of storm surge inundation depth for a modeled storm. However, without ADCIRC modeling, it is still possible to estimate which assets are more likely to be exposed than others based on factors (aka indicators) such as the asset's elevation and proximity to coastline.

The Exposure Indicator Library on the following tab provides suggestions for ways to estimate exposure—including modeling, but also other indicators for if modeling results are not available. Browse the indicator library and then enter data about your exposure on the Exposure Scoring tabs.

Example -- Storm Surge Exposure using modeling vs. using other indicators

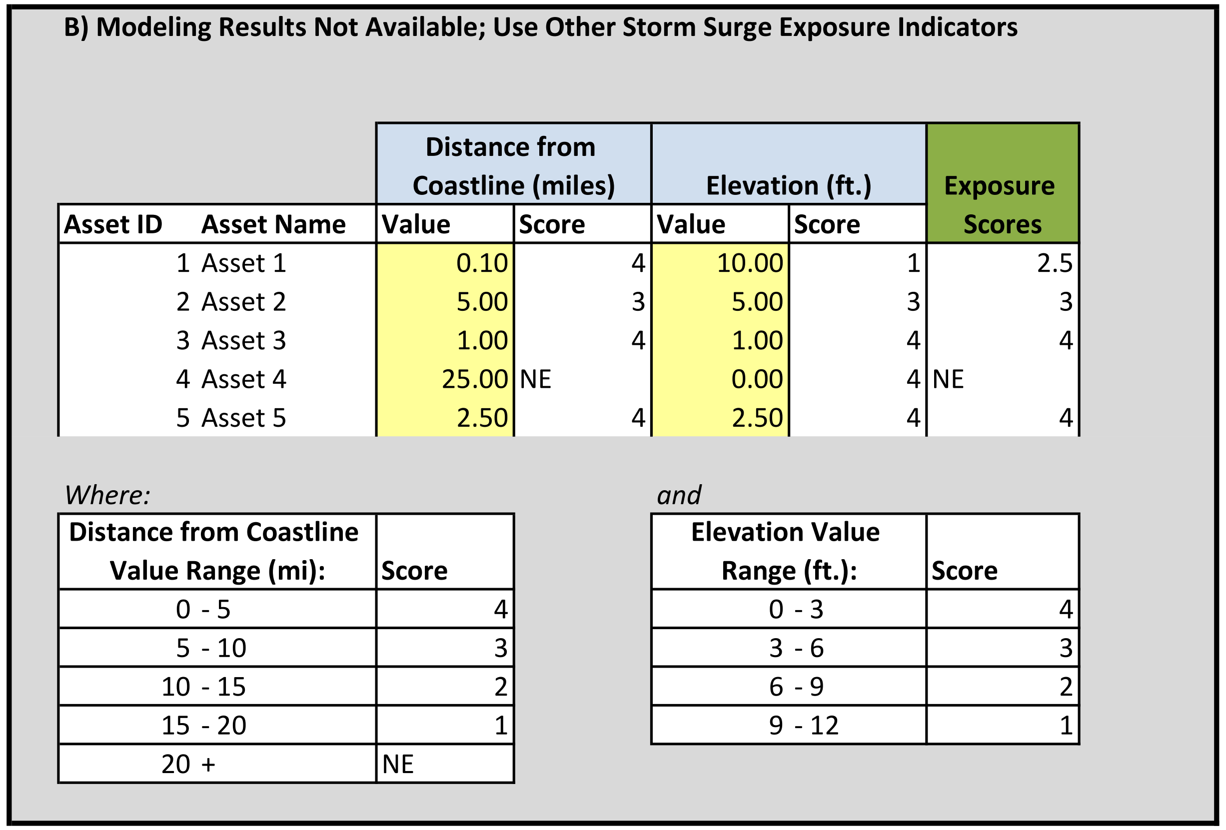


A) Use Storm Surge Modeling Results as Exposure Indicator

		Modeled Storm Surge Depth (ft.)		Exposure Scores
Asset ID	**Asset Name**	**Value**	**Score**	
1	Asset 1	10.00	4	4
2	Asset 2	5.00	3	3
3	Asset 3	1.00	2	2
4	Asset 4	0.00	NE	NE
5	Asset 5	2.50	2	2

Where:

Modeled Depth Value Range (ft.):	Score
0 - 0	NE
0.1 - 2	1
1 - 4	2
4 - 6	3
6 +	4



B) Modeling Results Not Available; Use Other Storm Surge Exposure Indicators

		Distance from Coastline (miles)		Elevation (ft.)		Exposure Scores
Asset ID	**Asset Name**	**Value**	**Score**	**Value**	**Score**	
1	Asset 1	0.10	4	10.00	1	2.5
2	Asset 2	5.00	3	5.00	3	3
3	Asset 3	1.00	4	1.00	4	4
4	Asset 4	25.00	NE	0.00	4	NE
5	Asset 5	2.50	4	2.50	4	4

Where:

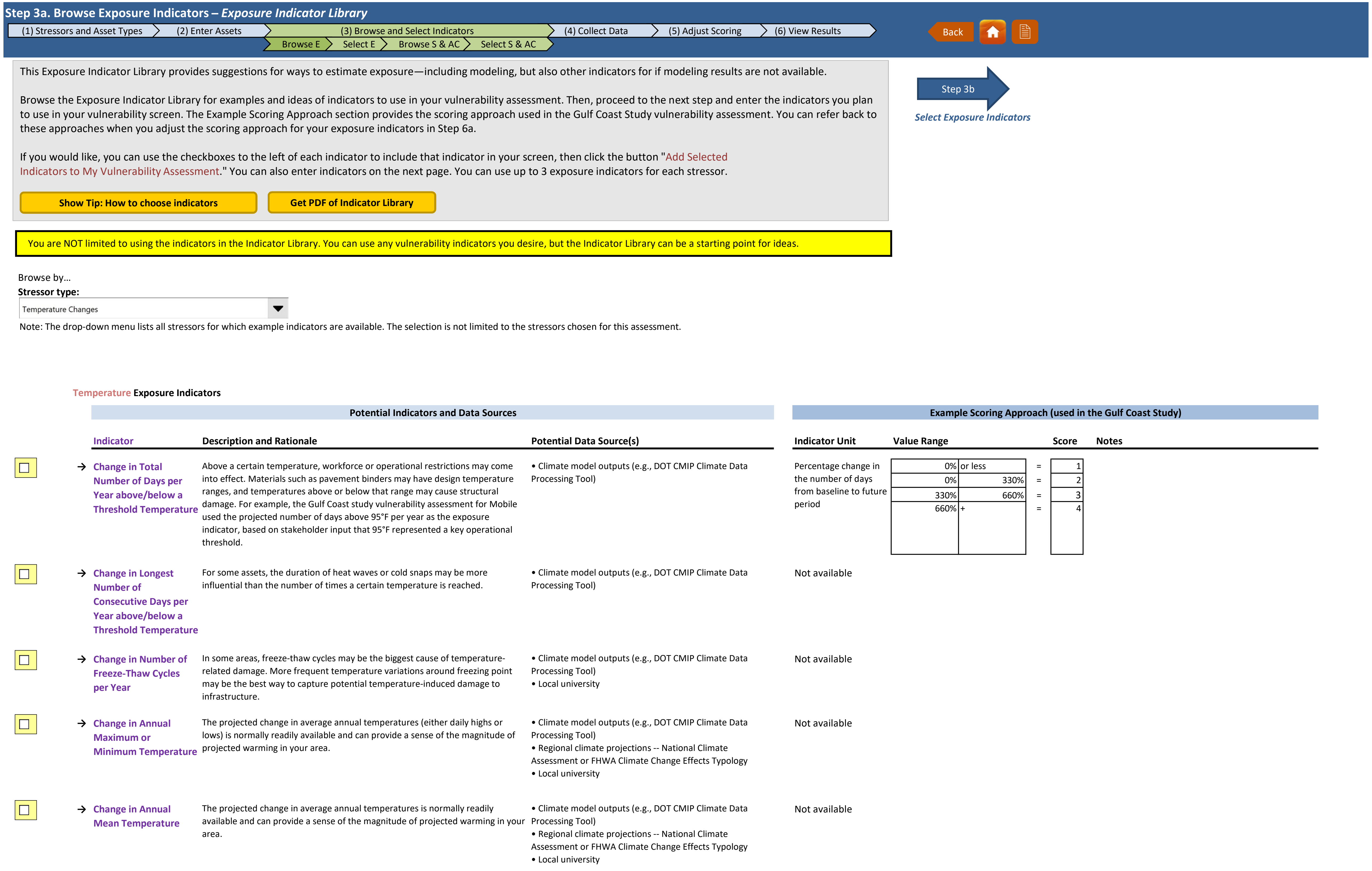
Distance from Coastline Value Range (mi):	Score
0 - 5	4
5 - 10	3
10 - 15	2
15 - 20	1
20 +	NE

and

Elevation Value Range (ft.):	Score
0 - 3	4
3 - 6	3
6 - 9	2
9 - 12	1

Note: NE stands for "Not Exposed"

U.S. DOT Vulnerability Assessment Scoring Tool, Exposure Indicator Library



Step 3a. Browse Exposure Indicators – *Exposure Indicator Library*

This Exposure Indicator Library provides suggestions for ways to estimate exposure—including modeling, but also other indicators for if modeling results are not available.

Browse the Exposure Indicator Library for examples and ideas of indicators to use in your vulnerability assessment. Then, proceed to the next step and enter the indicators you plan to use in your vulnerability screen. The Example Scoring Approach section provides the scoring approach used in the Gulf Coast Study vulnerability assessment. You can refer back to these approaches when you adjust the scoring approach for your exposure indicators in Step 6a.

If you would like, you can use the checkboxes to the left of each indicator to include that indicator in your screen, then click the button "Add Selected Indicators to My Vulnerability Assessment." You can also enter indicators on the next page. You can use up to 3 exposure indicators for each stressor.

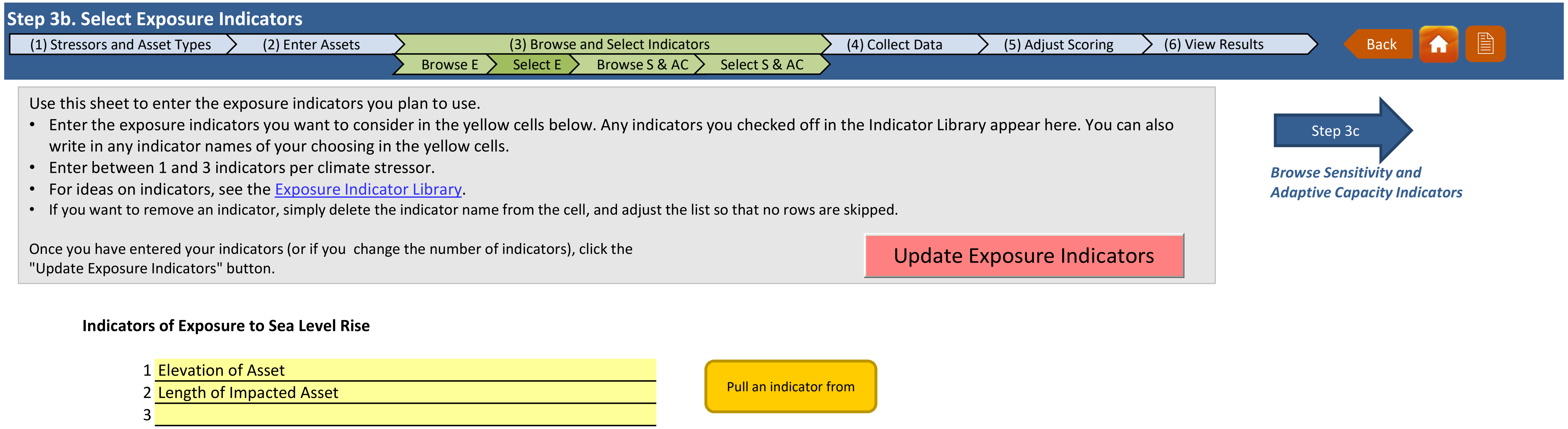
Select Exposure Indicators

You are NOT limited to using the indicators in the Indicator Library. You can use any vulnerability indicators you desire, but the Indicator Library can be a starting point for ideas.

Browse by...
Stressor type:
Temperature Changes
Note: The drop-down menu lists all stressors for which example indicators are available. The selection is not limited to the stressors chosen for this assessment.

Temperature **Exposure Indicators**

	Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
	Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	**Change in Total Number of Days per Year above/below a Threshold Temperature**	Above a certain temperature, workforce or operational restrictions may come into effect. Materials such as pavement binders may have design temperature ranges, and temperatures above or below that range may cause structural damage. For example, the Gulf Coast study vulnerability assessment for Mobile used the projected number of days above 95°F per year as the exposure indicator, based on stakeholder input that 95°F represented a key operational threshold.	• Climate model outputs (e.g., DOT CMIP Climate Data Processing Tool)	Percentage change in the number of days from baseline to future period	0% or less = 0% 330% = 330% 660% = 660% + =	1 2 3 4	
☐	**Change in Longest Number of Consecutive Days per Year above/below a Threshold Temperature**	For some assets, the duration of heat waves or cold snaps may be more influential than the number of times a certain temperature is reached.	• Climate model outputs (e.g., DOT CMIP Climate Data Processing Tool)	Not available			
☐	**Change in Number of Freeze-Thaw Cycles per Year**	In some areas, freeze-thaw cycles may be the biggest cause of temperature-related damage. More frequent temperature variations around freezing point may be the best way to capture potential temperature-induced damage to infrastructure.	• Climate model outputs (e.g., DOT CMIP Climate Data Processing Tool) • Local university	Not available			
☐	**Change in Annual Maximum or Minimum Temperature**	The projected change in average annual temperatures (either daily highs or lows) is normally readily available and can provide a sense of the magnitude of projected warming in your area.	• Climate model outputs (e.g., DOT CMIP Climate Data Processing Tool) • Regional climate projections -- National Climate Assessment or FHWA Climate Change Effects Typology • Local university	Not available			
☐	**Change in Annual Mean Temperature**	The projected change in average annual temperatures is normally readily available and can provide a sense of the magnitude of projected warming in your area.	• Climate model outputs (e.g., DOT CMIP Climate Data Processing Tool) • Regional climate projections -- National Climate Assessment or FHWA Climate Change Effects Typology • Local university	Not available			



Step 3b. Select Exposure Indicators

Use this sheet to enter the exposure indicators you plan to use.

- Enter the exposure indicators you want to consider in the yellow cells below. Any indicators you checked off in the Indicator Library appear here. You can also write in any indicator names of your choosing in the yellow cells.
- Enter between 1 and 3 indicators per climate stressor.
- For ideas on indicators, see the Exposure Indicator Library.
- If you want to remove an indicator, simply delete the indicator name from the cell, and adjust the list so that no rows are skipped.

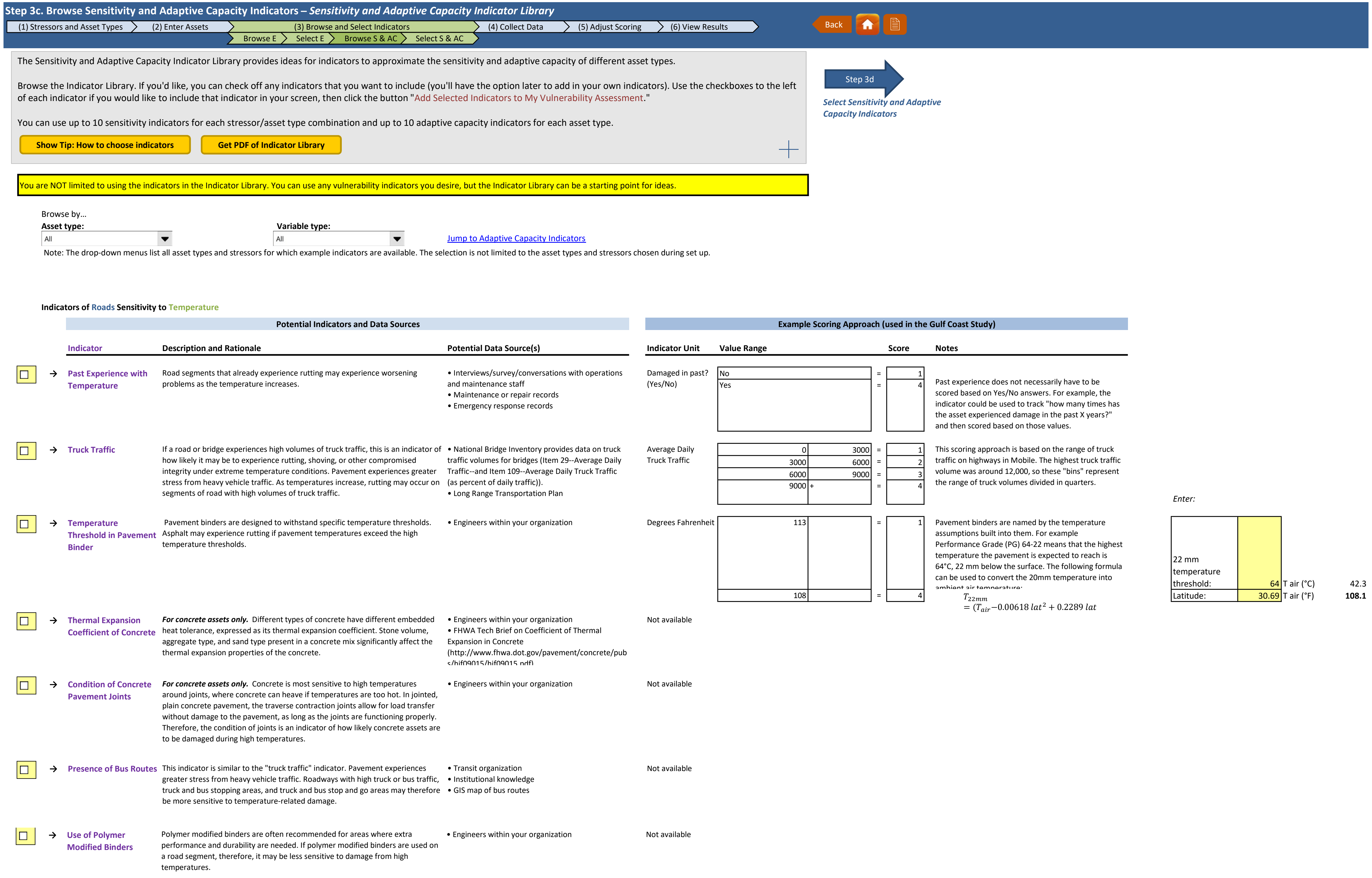
Once you have entered your indicators (or if you change the number of indicators), click the "Update Exposure Indicators" button.

Browse Sensitivity and Adaptive Capacity Indicators

Indicators of Exposure to Sea Level Rise

1 Elevation of Asset
2 Length of Impacted Asset
3

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library



Step 3c. Browse Sensitivity and Adaptive Capacity Indicators – *Sensitivity and Adaptive Capacity Indicator Library*

The Sensitivity and Adaptive Capacity Indicator Library provides ideas for indicators to approximate the sensitivity and adaptive capacity of different asset types.

Browse the Indicator Library. If you'd like, you can check off any indicators that you want to include (you'll have the option later to add in your own indicators). Use the checkboxes to the left of each indicator if you would like to include that indicator in your screen, then click the button "Add Selected Indicators to My Vulnerability Assessment."

You can use up to 10 sensitivity indicators for each stressor/asset type combination and up to 10 adaptive capacity indicators for each asset type.

Select Sensitivity and Adaptive Capacity Indicators

You are NOT limited to using the indicators in the Indicator Library. You can use any vulnerability indicators you desire, but the Indicator Library can be a starting point for ideas.

Browse by...

Asset type: All

Variable type: All

Jump to Adaptive Capacity Indicators

Note: The drop-down menus list all asset types and stressors for which example indicators are available. The selection is not limited to the asset types and stressors chosen during set up.

Indicators of Roads Sensitivity to Temperature

		Potential Indicators and Data Sources		**Example Scoring Approach (used in the Gulf Coast Study)**					
	Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**			**Score**	**Notes**
☐	**Past Experience with Temperature**	Road segments that already experience rutting may experience worsening problems as the temperature increases.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes		= =	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	**Truck Traffic**	If a road or bridge experiences high volumes of truck traffic, this is an indicator of how likely it may be to experience rutting, shoving, or other compromised integrity under extreme temperature conditions. Pavement experiences greater stress from heavy vehicle traffic. As temperatures increase, rutting may occur on segments of road with high volumes of truck traffic.	• National Bridge Inventory provides data on truck traffic volumes for bridges (Item 29--Average Daily Traffic--and Item 109--Average Daily Truck Traffic (as percent of daily traffic)). • Long Range Transportation Plan	Average Daily Truck Traffic	0 3000 6000 9000	3000 6000 9000 +	= = = =	1 2 3 4	This scoring approach is based on the range of truck traffic on highways in Mobile. The highest truck traffic volume was around 12,000, so these "bins" represent the range of truck volumes divided in quarters.
☐	**Temperature Threshold in Pavement Binder**	Pavement binders are designed to withstand specific temperature thresholds. Asphalt may experience rutting if pavement temperatures exceed the high temperature thresholds.	• Engineers within your organization	Degrees Fahrenheit	113 108		= =	1 4	Pavement binders are named by the temperature assumptions built into them. For example Performance Grade (PG) 64-22 means that the highest temperature the pavement is expected to reach is 64°C, 22 mm below the surface. The following formula can be used to convert the 20mm temperature into ambient air temperature: $T_{22mm} = (T_{air} - 0.00618\, lat^2 + 0.2289\, lat$
☐	**Thermal Expansion Coefficient of Concrete**	***For concrete assets only.*** Different types of concrete have different embedded heat tolerance, expressed as its thermal expansion coefficient. Stone volume, aggregate type, and sand type present in a concrete mix significantly affect the thermal expansion properties of the concrete.	• Engineers within your organization • FHWA Tech Brief on Coefficient of Thermal Expansion in Concrete (http://www.fhwa.dot.gov/pavement/concrete/pubs/hif09015/hif09015.pdf)	Not available					
☐	**Condition of Concrete Pavement Joints**	***For concrete assets only.*** Concrete is most sensitive to high temperatures around joints, where concrete can heave if temperatures are too hot. In jointed, plain concrete pavement, the traverse contraction joints allow for load transfer without damage to the pavement, as long as the joints are functioning properly. Therefore, the condition of joints is an indicator of how likely concrete assets are to be damaged during high temperatures.	• Engineers within your organization	Not available					
☐	**Presence of Bus Routes**	This indicator is similar to the "truck traffic" indicator. Pavement experiences greater stress from heavy vehicle traffic. Roadways with high truck or bus traffic, truck and bus stopping areas, and truck and bus stop and go areas may therefore be more sensitive to temperature-related damage.	• Transit organization • Institutional knowledge • GIS map of bus routes	Not available					
☐	**Use of Polymer Modified Binders**	Polymer modified binders are often recommended for areas where extra performance and durability are needed. If polymer modified binders are used on a road segment, therefore, it may be less sensitive to damage from high temperatures.	• Engineers within your organization	Not available					

Enter:

22 mm temperature threshold:	64	T air (°C)	42.3
Latitude:	30.69	T air (°F)	**108.1**

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Bridges Sensitivity to Temperature

	Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)					
	Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**			**Score**	**Notes**
☐ →	**Past Experience with Temperature**	Road segments that already experience rutting may experience worsening problems as the temperature increases.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No		=	1	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
					Yes		=	4	
☐ →	**Truck Traffic**	If a road or bridge experiences high volumes of truck traffic, this is an indicator of how likely it may be to experience rutting, shoving, or other compromised integrity under extreme temperature conditions. Pavement experiences greater stress from heavy vehicle traffic. As temperatures increase, rutting may occur on segments of road with high volumes of truck traffic.	• National Bridge Inventory provides data on truck traffic volumes for bridges (Item 29--Average Daily Traffic--and Item 109--Average Daily Truck Traffic (as percent of daily traffic)). • Long Range Transportation Plan	Average Daily Truck Traffic	0	3000	=	1	These value ranges are based on the range of truck traffic on bridges in Mobile. The highest truck traffic volume was around 12,000, so these "bins" represent the range of truck volumes divided in quarters.
					3000	6000	=	2	
					6000	9000	=	3	
					9000	+	=	4	
☐ →	**Temperature Threshold in Pavement Binder**	Pavement binders are designed to withstand specific temperature thresholds. Asphalt may experience rutting if pavement temperatures exceed the high temperature thresholds.	• Engineers within your organization	Degrees Fahrenheit	113		=	1	Pavement binders are named by the temperature assumptions built into them. For example Performance Grade (PG) 64-22 means that the highest temperature the pavement is expected to reach is 64°C, 22 mm below the surface. The following formula can be used to convert the 20mm temperature into ambient air temperature: $T_{22mm} = (T_{air} - 0.00618\, lat^2 + 0.2289\, lat$
					108		=	4	
☐ →	**Thermal Expansion Coefficient of the Concrete**	***For concrete assets only*** . Different types of concrete have different embedded heat tolerance, expressed as its thermal expansion coefficient. Stone volume, aggregate type, and sand type present in a concrete mix significantly affect the thermal expansion properties of the concrete.	• Engineers within your organization • FHWA Tech Brief on Coefficient of Thermal Expansion in Concrete (http://www.fhwa.dot.gov/pavement/concrete/pubs/hif09015/hif09015.pdf)	Not available					
☐ →	**Condition of Concrete Pavement Joints**	***For concrete assets only*** . Concrete is most sensitive to high temperatures around joints, where concrete can heave if temperatures are too hot. In jointed, plain concrete pavement, the traverse contraction joints allow for load transfer without damage to the pavement, as long as the joints are functioning properly. Therefore, the condition of joints is an indicator of how likely concrete assets are to be damaged during high temperatures.	• Asset management system • Maintenance personnel • Engineers within your organization	Not available					
☐ →	**Presence of Bus Routes**	This indicator is similar to the "truck traffic" indicator. Pavement experiences greater stress from heavy vehicle traffic. Roadways with high truck or bus traffic, truck and bus stopping areas, and truck and bus stop and go areas may therefore be more sensitive to temperature-related damage.	• Transit organization • Institutional knowledge • GIS map of bus routes	Not available					
☐ →	**Use of Polymer Modified Binders**	Polymer modified binders are often recommended for areas where extra performance and durability are needed. If polymer modified binders are used on a road segment, therefore, it may be less sensitive to damage from high temperatures.	• Engineers within your organization	Not available					

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Rail Lines Sensitivity to Temperature

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)				
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**		**Score**	**Notes**
☐	→	**Past Experience with Temperature**	Rail segments that have experienced damage during extreme temperatures in the past may be sensitive to higher or more frequent periods of extreme temperatures in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	= =	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Rail Design**	Some types of rail, such as continuously-welded rail, are more prone to buckling.	• Rail owners and operators in your organization		Jointed Continuously-welded rail (CWR)	= =	1 4	
☐	→	**Maintenance Frequency**	Tracks that are frequently monitored and maintained by running tampers along the lines are more likely to have a stable ballast that is less sensitive to buckling during periods of extreme temperatures.	• Rail owners and operators in your organization • Maintenance records or interviews with maintenance staff		Regularly maintained Irregularly maintained	= =	1 4	
☐	→	**Ballast Type**	Tracks with rock ballast are more sensitive than tracks on concrete slab, since the concrete provides more support for the rail.	• Rail owners and operators in your organization		Concrete slab Rock ballast	= =	1 4	
☐	→	**Shade**	Areas exposed to direct sunlight are more likely to buckle. Conversely, shaded areas of track are less likely to buckle.	• Rail owners and operators in your organization		Shaded Unshaded	= =	1 4	
☐	→	**Rail-neutral Temperature**	The temperature threshold before rails start to compress and buckle. The lower the rail-neutral temperature, the more likely a rail segment may be to buckle during extreme heat.	• Rail owners and operators in your organization	Not available				
☐	→	**Rail Curvature**	The more curved a section of rail, the more likely it is to experience track buckling due to high temperatures.	• Rail owners and operators in your organization	Not available				
☐	→	**Permafrost**	An indicator of whether the rail line is built over permafrost. As temperatures rise, permafrost is likely to become less stable. Therefore, rail lines on permafrost are more sensitive to temperature increases.	• Rail owners and operators in your organization	Not available				

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Ports Sensitivity to Temperature

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)				
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**		**Score**	**Notes**
☐	→	**Past Experience with Temperature**	Ports that have experienced damage during past heat events have demonstrated sensitivity to heat and are likely to be damaged if exposed in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No	=	1	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
						Yes	=	4	
☐	→	**Size of Paved Asphalt Areas**	Pavement can buckle or sink in high temperatures. The extent of paved asphalt areas is therefore an indicator of sensitivity to heat.	• Visual inspection of satellite imagery • Port operators		No or negligible asphalt area	=	1	
						Small asphalt area	=	2	
						Medium asphalt area	=	3	
						Large asphalt area	=	4	
☐	→	**Reliance on Electrical Power**	Electric signals may be damaged by exposure to water from flooding during storm surge.	• Port owners and operators in your organization		Facility is not reliant on electrical power	=	1	
						Some components require electricity, but are not fundamental to the facility's function	=	2	
						Fundamental function requires electricity, but backup generators are available	=	3	
						Fundamental function of the facility requires electrical power	=	4	
☐	→	**Materials Handled**	The temperature sensitivity of the materials handled at a port is an indicator of the port's sensitivity to temperatures. If materials stored or handled at the facility are perishable or otherwise possibly damaged by high temperatures, they will be more sensitive to temperature changes.	• Ports owners and operators in your organization		Aluminum	=	1	
						Assorted	=	2.5	
						Break bulk	=	1	
						Cement	=	1	
						Coal	=	1	
						Containers	=	1	
						Floating equipment	=	1	
						Hazardous materials	=	1	
						Iron	=	1	
						Metal products	=	1	
						None	=	1	
						Passengers	=	2	
						Perishables	=	4	
						Petroleum products	=	1	
						Piling, slabs, girders	=	1	
						Seafood	=	4	
						Ship services	=	1	
						Stone, sand, gravel	=	1	
						Wood products	=	1	
☐	→	**Frequency of Breaks**	Safety regulations might require personnel to take more frequent breaks or work different shifts depending on temperature conditions. The extent to which additional days requiring more breaks or schedule shifts would slow down productivity.	• Ports owners and operators in your organization	Not available				
☐	→	**Safety Regulation Threshold**	The threshold for safety regulations as compared to the projected changes in temperature may indicate some level of sensitivity of labor in ports to temperature.	• Ports owners and operators in your organization	Not available				

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Airports Sensitivity to Temperature

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)				
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**		**Score**	**Notes**
☐	→	**Past Experience with Temperature**	Paved areas at airports can experience temperature-related damage such as pavement expansion/contraction, rutting, and discoloration). Runways that already experience damage from temperature may experience worsening problems as the temperature increases.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	= =	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Runway Surface Pavement Type**	Runway surface material will impact how sensitive the runways are to heat-related issues such as expansion/contraction, discoloration, degradation, etc. Asphalt is typically more susceptible to heat-related problems than concrete, as long as there is adequate space for concrete expansion/contraction.	• Airport engineers • FAA Airport Master Record Forms 5010-1 & 5010-2 (http://www.gcr1.com/5010web/)		Asphalt Asphalt/concrete Concrete		4 3 2	
☐	→	**Runway Condition**	Assets in already poor condition may be more sensitive to weather-related damage.	• FAA Airport Master Record Forms 5010-1 & 5010-2 (http://www.gcr1.com/5010web/)		Excellent Good Fair Poor		1 2 3 4	
☐	→	**Runway Length**	As temperatures increase, air density decreases, meaning aircraft need longer runways or reduced payloads in order to take off. Runways exceeding current take-off requirement lengths are less likely to become unusable in high temperatures.	• FAA Airport Master Record Forms 5010-1 & 5010-2 (http://www.gcr1.com/5010web/)	Long enough to function in future temperature conditions? (Yes/No)	Yes No		1 4	
☐	→	**Airport Elevation**	Elevation influences the relationship between temperature and air density. Therefore, airport elevation could be considered in determining whether runway lengths would be sufficient under future temperature conditions.	• FAA Airport Master Record Forms 5010-1 & 5010-2 (http://www.gcr1.com/5010web/) • Local LiDAR data • National Elevation Dataset	Not available				
☐	→	**Thermal Expansion Coefficient of the Concrete**	***For concrete assets only.*** Concrete expands and contracts as the temperature changes. Different types of concrete have different embedded heat tolerance, expressed as its thermal expansion coefficient. Stone volume, aggregate type, and sand type present in a concrete mix significantly affect the thermal expansion properties of the concrete.	• Runway engineers • FHWA Tech Brief on Coefficient of Thermal Expansion in Concrete (http://www.fhwa.dot.gov/pavement/concrete/pubs/hif09015/hif09015.pdf)	Not available				
☐	→	**Condition of Concrete Pavement Joints**	***For concrete assets only*** . Concrete is most sensitive to high temperatures around joints, where concrete can heave if temperatures are too hot. In jointed, plain concrete pavement, the traverse contraction joints allow for load transfer without damage to the pavement, as long as the joints are functioning properly. Therefore, the condition of joints is an indicator of how likely concrete assets (like runways) are to be damaged during high temperatures.	• Asset management system • Maintenance personnel • Engineers within your organization	Not available				
☐	→	**Use of Warm-Mix Asphalts**	Airports are beginning to experiment with lower embodied-energy warm-mix asphalts that may also have differing operational thermal performance than conventional mixes. Warm-mix asphalt may have different heat susceptibility than the existing airport pavement materials.	• Airport engineers	Not available				
☐	→	**Use of Polymer Modified Binders**	Polymer modified binders are often recommended for areas where extra performance and durability are needed. If polymer modified binders are used in airports, therefore, it may be less sensitive to damage from high temperatures.	• Airport engineers	Not available				

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Transit Assets Sensitivity to Temperature

	Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)					
	Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**			**Score**	**Notes**
☐ →	**Past Experience with Temperature**	Transit assets that already experience damage during heat events may experience worsening problems as the temperature increases.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records		No			1	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
					Yes			4	
☐ →	**Age of Buses**	High temperatures can cause cooling system breakdowns on buses. Newer buses are better suited to handling higher temperatures.	• Interviews/survey/conversations with operations and maintenance staff	Age (years)	0	25	=	4	Applies to bus fleet only.
					25	30	=	3	
					30	50	=	2	
					50	+	=	1	

****Please reference Roads, Bridges and Culverts, and Rail sections for other indicators relevant to your Transit Assets.****

Indicators of Roads Sensitivity to Heavy Precipitation

	Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)					
	Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**			**Score**	**Notes**
☐ →	**Past Experience with Precipitation**	Roads that have experienced damage during past heavy rain events are more likely to be damaged if exposed in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No			1	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
					Yes			4	
☐ →	**Propensity for Ponding**	If an asset is located at a relatively low elevation compared to surrounding areas, water may tend to "pond" there, causing flooding during heavy precipitation events.	• Elevation data (LiDAR, GIS)	Ponding score (median number of neighboring "cells' with Elevation	0	42	=	1	Value ranges based on range of ponding scores for assets in Mobile, AL.
					42	84	=	2	
					84	126	=	3	
					126	+	=	4	
☐ →	**Percentage of Impervious Surface**	Assets with greater impermeability to water are more likely to experience issues with flooding and run-off from precipitation.	• USGS National Land Cover Database 2006 Impervious Surfaces	Percentage of area surrounding the asset with below-average	0%	25%	=	1	In the Gulf Coast Study, used compared asset's imperviousness to the average impermeability in the City of Mobile (27%). Could also score % impervious surface on its own.
					25%	50%	=	2	
					50%	75%	=	3	
					75%	100%	=	4	
☐ →	**Proximity to the Coast**	Areas near the coast, to where water drainage flows, could back up and flood sooner than the inland areas.	• GIS analysis • Interviews/survey/conversations with operations and maintenance staff	Not available					

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Bridges Sensitivity to Heavy Precipitation

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)					
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**			**Score**	**Notes**
☐	→	Past Experience with Precipitation	Bridges that have experienced damage during past heavy rain events are more likely to be damaged if exposed in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No			1	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
						Yes			4	
☐	→	Propensity for Ponding	If an asset is located at a relatively low elevation compared to surrounding areas, water may tend to "pond" there, causing flooding during heavy precipitation events.	• Analysis of local LiDAR data	Ponding score (median number of neighboring "cells' with Elevation Higher than the asset)	0	42	=	1	Value ranges based on range of ponding scores for assets in Mobile, AL.
						42	84	=	2	
						84	126	=	3	
						126	+	=	4	
☐	→	Percentage of Impervious Surface	Assets with greater impermeability to water are more likely to experience issues with flooding and run-off from precipitation.	• USGS National Land Cover Database 2006 Impervious Surfaces	Percentage of area surrounding the asset with below-average impermeability	0%	25%	=	1	In the Gulf Coast Study, used compared asset's imperviousness to the average impermeability in the City of Mobile (27%). Could also score % impervious surface on its own.
						25%	50%	=	2	
						50%	75%	=	3	
						75%	100%	=	4	
☐	→	Approach Elevation	Bridge approaches are often the most affected part of the bridge. Approaches that are closer to the water surface are more sensitive to flooding from sea level rise, storm surge, or heavy rain.	• LiDAR data • Asset management system	Approach elevation (feet above water surface)	0	5	=	4	
						5	10	=	3	
						10	15	=	2	
						Not a water crossing or > 15 ft.		=	1	
☐	→	Bridge Age	Older bridges may have been built to outdated design standards, rendering them more sensitive to precipitation events than bridges designed more recently.	• National Bridge Inventory, Item 27 (Year Built) • Asset management system	Age (years)	0	25	=	1	
						25	50	=	2	
						50	75	=	3	
						75	+	=	4	
☐	→	Scour Rating	Bridges that have already been identified as having problems with scour are more likely to be damaged during precipitation events.	• National Bridge Inventory, Item 113 (Scour Critical Bridges) • Asset management system		N	Not over waterway		1	
						U	Not evaluated		No data	
						T	Likely low risk		1	
						9	Likely low risk		1	
						8	Stable		2	
						7	Countermeasures in		2	
						6	Not evaluated		No data	
						5	Stable		2	
						4	Stable		3	
						3	Scour critical		4	
						2	Scour critical		4	
						1	Scour critical		4	
						0	Scour critical		4	
						99	Miscoded data		No data	
☐	→	Channel Condition	This item describes the physical conditions associated with the flow of water through the bridge such as stream stability and the condition of the channel, riprap, slope protection, or stream control devices including spur dikes. Bridges with erosion or bank failure will be more sensitive to flooding and high stream flows.	• National Bridge Inventory, Item 61 (Channel Condition Rating)	Channel Condition Rating	0	1	=	4	
						2	4	=	3	
						5	7	=	2	
						8	9	=	1	
						N		=	No data	
☐	→	Culvert Condition	This item evaluates the alignment, settlement, joints, structural condition, scour, and other items associated with culverts. Bridges with deterioration in culvert conditions may be more sensitive to damage from flooding.	• National Bridge Inventory, Item 62 (Culvert Condition Rating)	Culvert Condition Rating	0	1	=	4	
						2	4	=	3	
						5	7	=	2	
						8	9	=	1	
						N		=	No data	
☐	→	Frequency that Water Overtops a Bridge	This item appraises the waterway opening with respect to passage of flow through the bridge. Bridges that are subject to more frequent overtopping may be sensitive to damage from flooding impacts.	• National Bridge Inventory, Item 71 (Waterway Adequacy)		Remote or slight change of overtopping roadway approaches			1	
						Slight or occasional overtopping of roadway approaches; insignificant delays			2	
						Occasional/frequent overtopping; significant delays			3	
						Bridge closed			4	
☐	→	Proximity to the Coast	Areas near the coast, to where water drainage flows, could back up and flood sooner than the inland areas.	• GIS analysis • Interviews/survey/conversations with operations and maintenance staff	Not available					

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Rail Lines Sensitivity to Heavy Precipitation

	Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
	Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐ →	**Past Experience with Precipitation**	Rail segments that have experienced drainage system performance issues are more likely to experience flooding or drainage issues from heavy rainfall events.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐ →	**Propensity for Ponding**	If an asset is located at a relatively low elevation compared to surrounding areas, water may tend to "pond" there, causing flooding during heavy precipitation events.	• Analysis of local LiDAR data	Ponding score (median number of neighboring "cells' with Elevation	0 42 = 42 84 = 84 126 = 126 + =	1 2 3 4	Value ranges based on range of ponding scores for assets in Mobile, AL.
☐ →	**Percentage of Impervious Surface**	Assets with greater impermeability to water are more likely to experience issues with flooding and run-off from precipitation.	• USGS National Land Cover Database 2006 Impervious Surfaces	Percent of asset with above average impermeability	0% 25% = 25% 50% = 50% 75% = 75% 100% =	1 2 3 4	In the Gulf Coast Study, used compared asset's imperviousness to the average impermeability in the City of Mobile (27%). Could also score % impervious surface on its own.
☐ →	**Undercut Track**	Undercut rail lines are at a lower elevation relative to surrounding areas and are thus more sensitive to damage from heavy precipitation. Rail lines can be undercut, especially when they pass under overpasses or other obstacles, in order to accommodate larger, double-stacked trains. If it is unknown whether a specific rail line is undercut, whether it passes under an overpass may indicate that it has been.	• Visual inspection of satellite imagery • Interviews/survey/conversations with operations and maintenance staff • Asset management system	Passes under overpass (and likely undercut)? (Yes/No)	No Yes	1 4	
☐ →	**Ballast Type**	Certain types of ballast anchor the track more firmly than others and may be less sensitive to wash-outs from heavy rainfall. In Mobile, for example, limestone ballast is considered more sensitive to washouts than granite ballast.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff		Granite Limestone	1 4	
☐ →	**Electric Signals**	Electric signals may be damaged by exposure to water from flooding during heavy rainfalls.	• Interviews/survey/conversations with operations and maintenance staff	Electric signals present? (Yes/No)	No Yes	1 4	
☐ →	**Soil Type**	Rail that is on soil that is susceptible to erosion or flooding (e.g., in low-lying, marsh areas or areas with fill) may be more sensitive to washouts.	• USDA Web Soil Survey • Local soil type map, soil type GIS layer • Interviews with local stakeholders	Not available			
☐ →	**Maintenance Frequency**	Tracks that are frequently monitored and maintained by running tampers along the lines are more likely to have a stable ballast that can withstand impacts from flooding.	• Rail owners and operators in your organization • Maintenance records or interviews with maintenance staff	Not available			
☐ →	**Condition of Drainage System**	Drainage systems in poor condition are more likely to cause flooding issues than systems in better condition.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐ →	**Materials Used in Drainage System**	Certain types of drainage materials may be more sensitive to damage from heavy precipitation. The materials used in a drainage system can help indicate the drainage capacity of a rail asset. The material used may also serve a a proxy for condition of the drainage system.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐ →	**Design Capacity of Drainage System**	The design capacity of a drainage system can help understand how well it can divert water from a rail asset.	• Asset management system • Interviews/survey/conversations with engineers or operations and maintenance staff	Not available			
☐ →	**Age of Drainage System**	Older drainage systems are more likely to have been built to outdated drainage needs and/or be in worse condition than newer systems.	• Asset management system • Interviews/survey/conversations with engineers or operations and maintenance staff	Not available			

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Ports Sensitivity to Heavy Precipitation

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Precipitation**	Ports that have experienced damage during past heavy rain events are more likely to be damaged if exposed in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Propensity for Ponding**	If an asset is located at a relatively low elevation compared to surrounding areas, water may tend to "pond" there, causing flooding during heavy precipitation events.	• Analysis of local LiDAR data	Ponding score (median number of neighboring "cells' with Elevation	0 42 = 42 84 = 84 126 = 126 + =	1 2 3 4	Value ranges based on range of ponding scores for assets in Mobile, AL.
☐	→	**Percentage of Impervious Surface**	Assets with greater impermeability to water are more likely to experience issues with flooding and run-off from precipitation.	• USGS National Land Cover Database 2006 Impervious Surfaces	Percent of asset with above average impermeability	0% 25% = 25% 50% = 50% 75% = 75% 100% =	1 2 3 4	In the Gulf Coast Study, used compared asset's imperviousness to the average impermeability in the City of Mobile (27%). Could also score % impervious surface on its own.
☐	→	**Age of Wharves, Structures**	Older wharves and structures may have been built to lower standards and/or be in poorer condition compared to newer structures, and therefore more susceptible to damage.	• Asset management system • Departmental records • Interviews/survey/conversations with operations and maintenance staff	Age (years)	0 25 = 25 50 = 50 75 = 75 + =	1 2 3 4	
☐	→	**Materials Handled**	The precipitation-related sensitivity of the materials handled at a port is an indicator of the port's sensitivity to precipitation. If materials stored or handled at the facility are perishable or otherwise damaged by water, they will be more sensitive to precipitation-related damage.	• Interviews/survey/conversations with operations and maintenance staff		Aluminum Assorted Break bulk Cement Coal Containers Floating equipment Hazardous materials Iron Metal products None Passengers Perishables Petroleum products Piling, slabs, girders Seafood Ship services Stone, sand, gravel Wood products	1 2.5 1 1 3 3 4 4 1 1 1 4 4 2 1 4 4 1 4	
☐	→	**Sediment Buildup**	Dredging needs typically increase during periods of heavy rain, since the rain causes erosion and runoff that can build up in the waterways. How prone a port's waterway is to sediment build up could be an indicator of precipitation sensitivity.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐	→	**Materials Sensitive to Freezing**	In colder climates, winter precipitation could cause damage from freezing. Indicators could evaluate the use of materials or equipment that may be particularly sensitive to freezing conditions.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐	→	**Condition of Drainage System**	Drainage systems in poor condition are more likely to cause flooding issues than systems in better condition.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐	→	**Design Capacity of Drainage System**	The design capacity of a drainage system can help understand whether the current drainage system is considered sufficient, or whether key infrastructure at a port are located in the areas most likely to flood if the system backs up.	• Interviews/survey/conversations with operations and maintenance staff	Not available			

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Airports Sensitivity to Heavy Precipitation

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)					
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**			**Score**	**Notes**
☐	→	**Past Experience with Precipitation**	Airports that have experienced damage during past heavy rain events are more likely to be damaged if exposed in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records • Flight delay records	Damaged in past? (Yes/No)	No			1	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
						Yes			4	
☐	→	**Age of Drainage System**	In older drainage systems, joints will degrade over time. The older the drainage system, the more likely it is to fail during a heavy rain event.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff	Age (years)	0	25	=	1	
						25	30	=	2	
						30	50	=	3	
						50	+	=	4	
☐	→	**Drainage System Pipe Condition**	Pipes in poor condition are more likely to cause drainage and chronic flooding issues.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff	Pipe Condition	Excellent			1	
						Good			1	
						Fair			4	
						Poor			4	
☐	→	**Evidence of Blowouts**	Blowouts indicate that joints are failing and/or pipes are collapsing. A higher number of blowouts would therefore indicate a higher sensitivity to future precipitation levels. Blowouts occur when a leak, failure, or collapse in the drainage pipe begins to suck in sediment and creates a depression in the field.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance records	Number of blowouts	0	0	=	1	
						1	2	=	2	
						3	5	=	3	
						5	+	=	4	
☐	→	**Propensity for Ponding**	If an airport is located at a relatively low elevation compared to surrounding areas, water may tend to "pond" there, causing flooding during heavy precipitation events.	• Analysis of local LiDAR data	Ponding score (median number of neighboring "cells' with Elevation	0	42	=	1	Value ranges based on range of ponding scores for assets in Mobile, AL.
						42	84	=	2	
						84	126	=	3	
						126	+	=	4	
☐	→	**Percentage of Impervious Surface**	Airports with greater impermeability to water are more likely to experience issues with flooding and run-off from precipitation.	• USGS National Land Cover Database 2006 Impervious Surfaces	Percent of asset with above average impermeability	0%	25%	=	1	In the Gulf Coast Study, used compared asset's imperviousness to the average impermeability in the City of Mobile (27%). Could also score % impervious surface on its own.
						25%	50%	=	2	
						50%	75%	=	3	
						75%	100%	=	4	
☐	→	**Airport Traffic/Congestion Levels**	Airports with higher levels of traffic are more likely to be affected by changes in weather-related delays from precipitation changes.	• FAA Airport Master Record Forms 5010-1 & 5010-2 (http://www.gcr1.com/5010web/)	Total Operations (annual)	0	100,000		1	
						100,000	250,000		2	
						250,000	500,000		3	
						500,000	+		4	
☐	→	**Soil Type**	Some soil types may be more susceptible to movement or sliding (e.g., mud or fill is more susceptible to movement than sand). Therefore, infrastructure built on these more susceptible soil types are more likely to be damaged during rain events.	• USDA Web Soil Survey • Local soil type map, soil type GIS layer • Interviews with local stakeholders		Sand			1	Fill and mud are relatively more susceptible to movement or sliding than sand.
						Mix of sand, mud, or fill			2.5	
						Fill			4	
						Mud			4	
☐	→	**Runway Condition**	Assets in already poor condition may be more sensitive to weather-related damage.	• FAA Airport Master Record Forms 5010-1 & 5010-2 (http://www.gcr1.com/5010web/)		Excellent			1	
						Good			2	
						Fair			3	
						Poor			4	
☐	→	**Surface Treatment**	Runways with groove treatments are better able to handle surface water and precipitation than runways without a surface treatment.	• FAA Airport Master Record Forms 5010-1 & 5010-2 (http://www.gcr1.com/5010web/)		Grooved surface			1	Grooved surfaces perform better under wet conditions.
						No surface treatment			4	
☐	→	**Approach Lights**	LED lights can operate while underwater, but older incandescent lights cannot and would be more sensitive to precipitation changes. Note: LEDs have not been approved for runways by FAA, but can be used on taxiways.	• Interviews/survey/conversations with operations and maintenance staff		100% LED on taxiways			1	LEDs are less sensitive to water than incandescent lights.
						Partial LED on taxiways			2.5	
						100% incandescent			4	
☐	→	**Instrumentation Type**	Some types of instrument landing systems allow for landings in low visibility and poor weather conditions, which reduces the sensitivity of airport operations to bad weather.	• FAA Airport Master Record Forms 5010-1 & 5010-2 (http://www.gcr1.com/5010web/)		Instrument landing system (ILS) or a Precision Approach Radar (PAR)			1	
						Horizontal guidance or area type navigation equipment and has a straight-in type of non-precision instrument approach procedure including radar approaches			3	
						Visual approach procedures, with no straight-in instrument approach procedures and no instrument designation			4	

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Indicators of Transit Assets Sensitivity to Heavy Precipitation

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Precipitation**	Assets that have experienced damage in the past from precipitation events are more likely to be damaged if exposed in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Propensity for Ponding**	If an asset is located at a relatively low elevation compared to surrounding areas, water may tend to "pond" there, causing flooding during heavy precipitation events.	• Analysis of local LiDAR data	Ponding score (median number of neighboring "cells' with Elevation	0 42 = 42 84 = 84 126 = 126 + =	1 2 3 4	Value ranges based on range of ponding scores for assets in Mobile, AL.
☐	→	**Percentage of Impervious Surface**	Assets with greater impermeability to water are more likely to experience issues with flooding and run-off from precipitation.	• Interviews/survey/conversations with operations and maintenance staff	Percent of asset with above average impermeability	0% 25% = 25% 50% = 50% 75% = 75% 100% =	1 2 3 4	In the Gulf Coast Study, used compared asset’s imperviousness to the average impermeability in the City of Mobile (27%). Could also score % impervious surface on its own.
☐	→	**Impaired Access**	Even if the asset itself is unaffected, if structures near the asset are flooded, the ability to access and operate a facility or bus service may be impeded.	• Interviews/survey/conversations with operations and maintenance staff	Access is not impaired by inundation? (Yes/No)	No Yes	1 4	
☐	→	**Ventilation/Tunnel Openings in Flood-Prone Areas**	In areas where underground transit systems are present, water can enter through ventilation systems, tunnel openings, or seep through other openings to the underground system.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐	→	**Flood Protection**	For underground transit, consider whether there are any protective features in place to prevent water from entering the system.	• Interviews/survey/conversations with operations and maintenance staff	Not available			

****The Roads, Bridges and Culverts, and Rail sections may also contain indicators relevant to Transit Assets.****

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Roads Sensitivity to Sea Level Rise (SLR)

		Potential Indicators and Data Sources			Example Scoring Approach			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Tides/SLR**	Roads and bridges that have experienced flooding during extreme high tide events in the past are likely to be some of the first roads impacted by sea level rise.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Flood Protection**	Roads protected by a dike, sea wall, or other structure are less likely to be affected by sea level rise.	• Interviews/survey/conversations with operations and maintenance staff • Visual inspection	Protected? (Yes/No)	Yes No	1 4	
☐	→	**Soil Type**	The susceptibility of soils to erosion, as well as their drainage characteristics and porosity can impact the sensitivity of shoreline infrastructure to sea level rise. In areas where soil is particularly porous, water can actually seep up from the ground, in which case physical protection structures like levees or sea walls may not protect against encroaching waters.	• USDA Web Soil Survey • Local soil type map, soil type GIS layer • Interviews with local stakeholders	Not available			
☐	→	**Nearby Areas Exposed to SLR**	If inundation occurs in adjacent geographical areas, then a "protected" structure may still be inundated as waters come in from other directions.	• Maps, exposure analysis	Not available			

Indicators of Bridges Sensitivity to Sea Level Rise

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Tides/SLR**	Bridges that have experienced flooding during extreme high tide events in the past are likely to be some of the first roads impacted by sea level rise.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Approach Elevation**	Bridge approaches are often the most affected part of the bridge. Approaches that are closer to the water surface are more sensitive to flooding from sea level rise, storm surge, or heavy rain.	• LiDAR data • Asset management system	Approach elevation (feet above water surface)	0 5 = 5 10 = 10 15 = Not a water crossing or > 15 ft. =	4 3 2 1	
☐	→	**Navigational Clearance of Bridge**	Bridges with less clearance above the waterway are more likely to be affected by sea level rise; operational changes may be needed if certain sized vessels no longer have sufficient clearance as sea level rises.	• National Bridge Inventory, Item 39 (Navigation Vertical Clearance)	Navigational Clearance (feet)	0 5 = 6 10 = 11 20 = 21 + =	4 3 2 1	
☐	→	**Bridge Height**	Bridges with less clearance above the waterway are more likely to be at risk of waters reaching the bridge deck.	• LiDAR data • Asset management system	Embankment height (meters)	0 0.5 = 0.5 1.5 = 1.5 2 = 2 + =	4 2 2 1	
☐	→	**Soil Type**	The susceptibility of soils to erosion, as well as their drainage characteristics and porosity can impact the sensitivity of shoreline infrastructure to sea level rise. In areas where soil is particularly porous, water can actually seep up from the ground, in which case physical protection structures like levees or sea walls may not protect against encroaching waters.	• USDA Web Soil Survey • Local soil type map, soil type GIS layer • Interviews with local stakeholders	Not available			
☐	→	**Nearby Areas Exposed to SLR**	If inundation occurs in adjacent geographical areas, then a "protected" structure may still be inundated as waters come in from other directions.	• Maps, exposure analysis	Not available			

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Indicators of Rail Lines Sensitivity to Sea Level Rise

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Tides/SLR**	Rail segments that have experienced flooding during extreme high tide events in the past are likely to be some of the first rail segments impacted by sea level rise.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Drainage System Performance**	Rail segments that have experienced drainage system performance issues are more likely to experience flooding or drainage issues from sea level rise.	• Interviews/survey/conversations with operations and maintenance staff	Performance issues in past? (Yes/No)	No Yes	1 4	
☐	→	**Elevation**	Assets that are elevated above ground level may be shielded from exposure to sea level rise.	• Interviews/survey/conversations with operations and maintenance staff	Elevated? (Yes/No)	Yes No	1 4	
☐	→	**Soil type**	Whether rail assets are sensitive to sea level rise may also depend on the type of soil and substrate of the rail. More porous soils may allow water to more easily infiltrate and destabilize the rail bed, while more compact soils may divert rising waters elsewhere.	• USDA Web Soil Survey • Local soil type map, soil type GIS layer • Interviews with local stakeholders	Not available			
☐	→	**Protection**	Whether a rail asset is protected from sea level rise by other physical or man-made barriers could also be a sensitivity indicator.	• Interviews/survey/conversations with operations and maintenance staff • Visual inspection	Not available			

Indicators of Ports Sensitivity to Sea Level Rise

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Tides/SLR**	Ports that have experienced previous issues with tidal variation are more likely to be sensitive to sea level rise.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Shoreline Protection**	Ports with shoreline protection such as bulkheads or riprap are less sensitive to sea level rise than those without.	• Visual inspection of satellite imagery	Protected? (Yes/No)	Yes No	1 4	
☐	→	**Age of Wharves, Structures**	Older wharves and structures may have been built to lower standards and/or be in poorer condition compared to newer structures, and therefore more susceptible to damage.	• Interviews/survey/conversations with operations and maintenance staff	Age (years)	0 25 = 25 50 = 50 75 = 75 + =	1 2 3 4	
☐	→	**Elevation Relative to Sea Level**	Height of docks and other key port infrastructure, relative to the current sea level could be evaluated. If all of the key infrastructure is currently significantly above high tides, then a certain amount of sea level rise could occur without causing problems for the ports.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐	→	**Height of Drainage Outlets Relative to Sea Level**	Even if sea level rise is not sufficient to inundate a port, if it blocks a drainage outlet, then the port may flood during precipitation events.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐	→	**Floating or Fixed**	Floating docks are less likely to be affected by sea level rise. Deeper waters would actually make it easier for larger vessels to access and work in ports.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐	→	**Type of Operations**	The type operations on ports may change based on changes in sea level.	• Interviews/survey/conversations with operations and maintenance staff	Not available			

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Airports Sensitivity to Sea Level Rise

		Potential Indicators and Data Sources		Example Scoring Approach (used in the Gulf Coast Study)					
	Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**			**Score**	**Notes**
☐ →	**Past Experience with Tides/SLR**	Airports that have experienced flooding during extreme high tide events in the past are likely to be some of the first roads impacted by sea level rise.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No			1	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
					Yes			4	
☐ →	**Height of Drainage Discharge**	If drainage system discharge point is below projected sea level rise, airport would be affected.	• Visual inspection of satellite imagery • Asset management system • Elevation data (NED or LiDAR)		Height of drainage discharge is lower than projected sea level rise for the area			1	
					Height of drainage discharge is higher than projected sea level rise for the area			4	
☐ →	**Drainage System Pipe Condition**	Pipes in poor condition are more likely to cause drainage and chronic flooding issues.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff	Pipe Condition	Excellent			1	
					Good			1	
					Fair			4	
					Poor			4	
☐ →	**Evidence of Blowouts**	Blowouts indicate that joints are failing and/or pipes are collapsing. A higher number of blowouts would therefore indicate a higher sensitivity to future precipitation levels, exacerbated by sea level rise. Blowouts occur when a leak, failure, or collapse in the drainage pipe begins to suck in sediment and creates a depression in the field.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance records	Number of blowouts	0	0	=	1	
					1	2	=	2	
					3	5	=	3	
					5	+	=	4	
☐ →	**Age of Drainage System**	In older drainage systems, joints can fall apart over time. The older the drainage system, the more likely it is to fail during a flooding event.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff	Age (years)	0	25	=	1	
					25	30	=	2	
					30	50	=	3	
					50	+	=	4	
☐ →	**Adjacent to Areas Exposed to Sea Level Rise**	If inundation occurs in adjacent geographical areas, then even protected structures may still be inundated as waters come in from other directions.	• Interviews/survey/conversations with operations and maintenance staff • Maps	Not available					
☐ →	**Access Roads Vulnerable to Sea Level Rise**	An airport itself may not be vulnerable to sea level rise, but the roads that access it could be.	• Interviews/survey/conversations with operations and maintenance staff • Roads vulnerability assessment	Not available					

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Indicators of Transit Assets Sensitivity to Sea Level Rise

	Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
	Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐ →	**Past Experience with Tides/SLR**	Assets that have experienced flooding during extreme high tide events in the past are more likely to experience disruption again in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐ →	**Elevated or Protected above Bare Earth Elevation**	Assets that are elevated or well protected are less likely to be affected during sea level rise events.	• Visual inspection of satellite imagery • Asset management system	Protected or elevated? (Yes/No)	Yes No	1 4	Applies to all assets.
☐ →	**Impaired Access**	Even if the asset itself is unaffected, if structures near the asset are flooded, the ability to access and operate a facility or bus service may be impeded.	• Interviews/survey/conversations with operations and maintenance staff	Access impaired? (Yes/No)	No Yes	1 4	Applies to all assets.
☐ →	**Ventilation/Tunnel Openings in Flood-Prone Areas**	For underground transit, indicators may include the extent to which ventilation or tunnel openings are located in areas thought to be exposed to sea level rise.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐ →	**Flood Protection**	For underground transit, consider whether there are any protective features in place to prevent water from entering the system.	• Interviews/survey/conversations with operations and maintenance staff	Not available			

****The Roads, Bridges and Culverts, and Rail sections may also contain indicators relevant to Transit Assets.****

Indicators of Roads Sensitivity to Storm Surge

	Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
	Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐ →	**Past Experience with Storm Surge**	Road segments that already experience storm surge impacts are more likely to experience damage if exposed again in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐ →	**Flood Protection**	Roads protected by a dike, sea wall, vegetation, or other structure are less likely to be affected by storm surge.	• Interviews/survey/conversations with operations and maintenance staff • Visual inspection		Yes No	1 4	
☐ →	**Elevation of Asset**	The higher the asset is, the less likely it would be inundated and damaged from storm surge.	• National Elevation Dataset (NED) • LiDAR data • Asset management system	Not available			

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Bridges Sensitivity to Storm Surge

	Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)					
	Indicator	Description and Rationale	Potential Data Source(s)	Indicator Unit	Value Range			Score	Notes
☐ →	Past Experience with Storm Surge	Bridge segments that already experience storm surge impacts are more likely to experience damage if exposed again in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No			1	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
					Yes			4	
☐ →	Bridge Height	Bridges with less clearance above the waterway are more likely to experience storm surge heights that reach their deck.	• LiDAR data • Asset management system	Embankment height (meters)	0	0.5	=	4	
					0.5	1.5	=	2	
					1.5	2	=	2	
					2	+	=	1	
☐ →	Navigational Clearance of Bridge	Bridges with less clearance above the waterway are more likely to experience storm surge heights that reach their deck and cause damage.	• National Bridge Inventory, Item 39 (Navigation Vertical Clearance)	Navigational Clearance (feet)	0	5	=	4	
					6	10	=	3	
					11	20	=	2	
					21	+	=	1	
☐ →	Scour Rating	Bridges that have already been identified as having problems with scour are more likely to be damaged during storm surge events.	• National Bridge Inventory, Item 113 (Scour Critical Bridges) • Asset management system		N	Not over waterway		1	
					U	Not evaluated		No data	
					T	Likely low risk		1	
					9	Likely low risk		1	
					8	Stable		2	
					7	Countermeasures in		2	
					6	Not evaluated		No data	
					5	Stable		2	
					4	Stable		3	
					3	Scour critical		4	
					2	Scour critical		4	
					1	Scour critical		4	
					0	Scour critical		4	
					99	Miscoded data		No data	
☐ →	Condition of Bridge Substructure	Bridges that are in poor condition are more likely to be damaged during storm surge events.	• National Bridge Inventory, Item 60 (Substructure Condition Rating)	NBI Score	0	1	=	4	
					2	3	=	3	
					4	6	=	2	
					7	9	=	1	
☐ →	Condition of Bridge Superstructure	Bridges that are in poor condition are more likely to be damaged during storm surge events.	• National Bridge Inventory, Item 59 (Superstructure Condition Rating)	NBI Score	0	1	=	4	
					2	3	=	3	
					4	6	=	2	
					7	9	=	1	
☐ →	Condition of Bridge Deck	Bridges that are in poor condition are more likely to be damaged during storm surge events.	• National Bridge Inventory, Item 58 (Deck Condition Rating)	NBI Score	0	1	=	4	
					2	3	=	3	
					4	6	=	2	
					7	9	=	1	
☐ →	Movable Bridge	Movable bridges can be more susceptible to damage during storm surge events because they have electrical components.	• National Bridge Inventory, Item 43b (Structure Type)		Movable			4	NBI structure types 15, 16, and 17 are considered "movable."
					Not Movable			1	
☐ →	Bridge Age	Older bridges may have deteriorated structures or have experienced more extreme damaging storm surge events, rendering them more sensitive to storm surge events than bridges designed more recently. In addition, changes in sea level and the accumulation of more historical extreme storm events could greatly change the value of the water surface level (e.g., the Q100 water surface level) that an older bridge was originally designed for.	• National Bridge Inventory, Item 27 (Year Built)	Age (years)	0	25	=	1	
					25	50	=	2	
					50	75	=	3	
					75	+	=	4	
☐ →	Approach Elevation	Bridge approaches are often the most affected part of the bridge. Approaches that are not much higher than the water surface are more sensitive to flooding from sea level rise, storm surge, or heavy rain.	• LiDAR data • Asset management system	Approach elevation (feet above water surface)	0	5	=	4	
					5	10	=	3	
					10	15	=	2	
					Not a water crossing or > 15 ft.		=	1	

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☐	→	**Elevation of Asset**	The higher the asset is, the less likely it would be inundated.	• LiDAR data • Asset management system	Not available
☐	→	**Weight of Bridge Deck**	Heavier bridge decks may be less sensitive to damage or displacement from storm surge than lighter bridge decks.	• Asset management system • Engineers in your organizations • Expert judgment from stakeholders	Not available
☐	→	**Bridge Deck Type**	Bridges with decks that are supported may be more sensitive than bridges with decks that are integral parts of the bridge structure.	• Asset management system • Engineers in your organizations • Expert judgment from stakeholders	Not available
☐	→	**Number of Longitudinal Girders**	Longitudinal girders underneath the deck can act as air-trapping pockets, increasing wave action against the deck and increasing the likelihood of damage from storm surge.	• Asset management system • Engineers in your organizations • Expert judgment from stakeholders	Not available

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Rail Lines Sensitivity to Storm Surge

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Storm Surge**	Rail segments that have experienced flooding during storm events in the past are likely to be flooded during future storm events.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Drainage System Performance**	Rail segments that have experienced drainage system performance issues are more likely to experience flooding or drainage issues from sea level rise.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Performance issues in past? (Yes/No)	No Yes	1 4	
☐	→	**Elevation or Protection**	Assets that are protected by seawalls, dikes, vegetation, or that are otherwise elevated above ground level may be shielded from exposure to storm surge.	• National Elevation Dataset (NED) • LiDAR data • Asset management system	Protected? (Yes/No)	Yes No	1 4	
☐	→	**Undercut Track**	Track that crosses underneath major overpasses may have been undercut in order to accommodate larger, double-stacked trains. These areas may be more sensitive to impacts from flooding.	• Satellite imagery	Undercut Track? (Yes/No)	No Yes	1 4	
☐	→	**Ballast Type**	Certain types of ballast anchor the track more firmly than others and may be less sensitive to wash-outs from storm surge.	• Interviews/survey/conversations with operations and maintenance staff		Granite Limestone	1 4	
☐	→	**Soil Type**	Rail that is on soil that is susceptible to erosion or flooding (e.g., in low-lying, marsh areas or areas with fill) may be more sensitive to washouts.	• USDA Web Soil Survey • Local soil type map, soil type GIS layer • Interviews with local stakeholders	On susceptible soil? (Yes/No)	No Yes	1 4	
☐	→	**Electric Signals**	Electric signals may be damaged by exposure to water from flooding during storm surge.	• Interviews/survey/conversations with operations and maintenance staff	Has electric signals? (Yes/No)	No Yes	1 4	
☐	→	**Elevation of Asset**	The higher the asset is, the less likely it would be inundated.	• National Elevation Dataset (NED) • LiDAR data • Asset management system	Not available			
☐	→	**Materials Used in Drainage System**	The materials used in a drainage system can help understand the drainage capacity of a rail asset.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐	→	**Design Capacity of Drainage System**	The design capacity of a drainage system can help understand how well it can divert water from a rail asset.	• Interviews/survey/conversations with operations and maintenance staff	Not available			

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Ports Sensitivity to Storm Surge

	Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
	Indicator	Description and Rationale	Potential Data Source(s)	Indicator Unit	Value Range	Score	Notes
☐ →	Past Experience with Storm Surge	Ports that have experienced damage during past storm events are more likely to be damaged if exposed in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐ →	Shoreline Protection	Ports with protection features such as bulkheads or riprap are less likely to be affected by storm surge.	• Interviews/survey/conversations with operations and maintenance staff • Visual inspection of satellite imagery	Port is armored by a bulkhead, riprap, or other mechanism (Yes/No)	Yes No	1 4	
☐ →	Height of Key Infrastructure	Ports with docks and other infrastructure closer to sea level are more likely to experience damage from storm surge.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Height (feet)	0.0 5.4 = 5.4 10.9 = 10.9 16.3 = 16.3 + =	4 3 2 1	Scoring value ranges based on 0-25%, 25-50%, 50-75%, and 75%+ of the maximum storm surge depth projected for Mobile, 21.7 feet.
☐ →	Age of Wharves, Structures	Certain types of ballast anchor the track more firmly than others and may be less sensitive to wash-outs from storm surge.	• Interviews/survey/conversations with operations and maintenance staff	Age (years)	0 25 = 25 50 = 50 75 = 75 + =	1 2 3 4	
☐ →	Condition	Current condition (ranging from Good to Poor) can be an indicator of how likely an asset is to be damaged by future impacts.	• Interviews/survey/conversations with operations and maintenance staff • Maritime Strategic Development Study Phase III: Inventory of Existing Port Maritime Facilities		Good = Good-Fair = Fair = Poor =	1 2 3 4	
☐ →	Reliance on Electrical Power	Electric signals may be damaged by exposure to water from flooding during storm surge.	• Interviews/survey/conversations with operations and maintenance staff		Not reliant = Partially reliant = Reliant, with backup = Reliant =	1 2 3 4	
☐ →	Materials Handled	If materials handled or stored at the facility are damaged by water or are perishable, they will experience greater negative effects from storm surge.	• Interviews/survey/conversations with operations and maintenance staff		Aluminum Assorted Break bulk Cement Coal Containers Floating equipment Hazardous materials Iron Metal products None Passengers Perishables Petroleum products Piling, slabs, girders Seafood Ship services Stone, sand, gravel Wood products	1 2.5 1 1 3 3 4 4 1 1 1 4 4 2 1 4 4 1 4	
☐ →	Types of Key Infrastructure	Most low-lying infrastructure of some ports may consist of parking lots or metal buildings; storm surge would bring in debris and dirt that would need to be cleaned up, but the infrastructures are unlikely to be significantly damaged. Other ports may have infrastructure or equipment that would be more likely to be damaged to storm surge.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐ →	Location of Key Equipment	The extent to which key equipment is kept in low-lying areas of the ports may indicate the level of damage it could face from storm surge.	• Interviews/survey/conversations with operations and maintenance staff	Not available			

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Airports Sensitivity to Storm Surge

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	Past Experience with Storm Surge	Airports that have experienced damage during past storm events are more likely to be damaged if exposed in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	Foundation Type	Some building foundation types are more likely to withstand storm surge than others. For example, in Mobile, pilings are the strongest foundation type used at airports while footers are less strong.	• Interviews/survey/conversations with operations and maintenance staff		Pilings Footers	1 4	
☐	→	Drainage System Pipe Condition	Pipes in poor condition are more likely to cause drainage and chronic flooding issues.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff	Pipe Condition	Excellent Good Fair Poor	1 1 4 4	
☐	→	Age of Drainage System	In older drainage systems, joints can fall apart over time. The older the drainage system, the more likely it is to fail during a flooding event.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff	Age (years)	0 25 = 25 30 = 30 50 = 50 + =	1 2 3 4	
☐	→	Evidence of Blowouts	Blowouts indicate that joints are failing and/or pipes are collapsing. A higher number of blowouts would therefore indicate a higher sensitivity to future precipitation levels, exacerbated by sea level rise. Blowouts occur when a leak, failure, or collapse in the drainage pipe begins to suck in sediment and creates a	• Interviews/survey/conversations with operations and maintenance staff • Maintenance records	Number of blowouts	0 0 = 1 2 = 3 5 = 5 + =	1 2 3 4	
☐	→	Soil Type	Some soil types may be more susceptible to movement or sliding (e.g., mud or fill is more susceptible to movement than sand"). Therefore, infrastructure built on these more susceptible soil types are more likely to be damaged during storm surge.	• USDA Web Soil Survey • Local soil type map, soil type GIS layer • Interviews with local stakeholders		Sand Mix of sand, mud, or fill Fill Mud	1 2.5 4 4	Fill and mud are relatively more susceptible to movement or sliding than sand.
☐	→	Approach Lights	Water-tight electrical wiring conduit is necessary to resist salt water intrusion damage. LED lights can operate while underwater, but older incandescent lights cannot and would be more sensitive to precipitation changes. Note: LEDs have not been approved for runways by FAA, but can be used on taxiways.	• Interviews/survey/conversations with operations and maintenance staff		100% LED on taxiways Partial LED on taxiways 100% incandescent	1 2.5 4	LEDs are less sensitive to water than incandescent lights.

Indicators of Transit Assets Sensitivity to Storm Surge

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	Past Experience with Storm Surge	Assets that have experienced damage during past storm events are more likely to be damaged if exposed in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	Foundation Type	Certain foundation designs of transit facilities are more vulnerable to structural damage than others.	• Interviews/survey/conversations with operations and maintenance staff		Pilings Footers	1 4	Applies to facilities only.
☐	→	Elevated or Protected above Bare Earth Elevation	Assets that are elevated or well protected are less likely to be affected during storm surge events.	• Interviews/survey/conversations with operations and maintenance staff	Protected or elevated? (Yes/No)	Yes No	1 4	Applies to all assets.
☐	→	Impaired Access	Even if the asset itself is unaffected, if structures near the asset are flooded, the ability to access and operate a facility or bus service may be impeded.	• Interviews/survey/conversations with operations and maintenance staff	Access impaired? (Yes/No)	No Yes	1 4	Applies to all assets.
☐	→	Ventilation/Tunnel Openings in Flood-Prone Areas	For underground transit, indicators may include the extent to which ventilation or tunnel openings are located in areas thought to be exposed to storm surge.	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐	→	Flood Protection	For underground transit, consider whether there are any protective features in place to prevent water from entering the system.	• Interviews/survey/conversations with operations and maintenance staff	Not available			

****The Roads, Bridges and Culverts, and Rail sections may also contain indicators relevant to Transit Assets.****

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Roads Sensitivity to Wind

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Wind**	Assets that have experienced damage due to high winds in the past are more likely to be damaged if exposed in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Roadway Signal Density**	Wind damage to roadway signals and signs can delay traffic significantly and disrupt evacuation and recovery. Roads and bridges with a higher density of road way signs and signal lights may be more prone to this type of damage.	• GIS data • Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Traffic signals per mile	0 1 = 2 5 = 6 9 = 10 + =	1 2 3 4	
☐	→	**Wind Design Speeds**	The wind speed the asset is designed to withstand provides information about how sensitive it may be to high wind speeds. The design speed may serve as a threshold for sensitivity or the higher the design speed, the less sensitive the asset.	• Interviews/survey/conversations with operations and maintenance staff • Engineers • Design standards, manuals	Not available			
☐	→	**Proximity of Trees to Power Lines**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. The proximity of the trees along the road to power lines or could be an indicator of how likely that road is to experience a downed power line.	• GIS analysis • Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Efficacy of Tree Trimming Maintenance**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. The frequency of tree trimming could indicate whether tree branches are likely to be a source of debris.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Building Density**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. The density of buildings could indicate how likely the road segment is to experience debris from that source.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Presence of Overhead Utility Lines**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. The presence or density of overhead utility lines could indicate how likely the road segment is to experience debris from that source.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Sign Support Strength**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. Some signs/signals are built to withstand higher wind speeds than others. The wind stability of nearby signs and signals is thus an indicator of how likely the road segment is to experience debris from those signs and signals.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Height and Size of Road Signs**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. Larger and taller road signs may be more likely to cause damage.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Length of Support Arms**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. Some signs/signals are built to withstand higher wind speeds than others. The wind stability of nearby signs and signals is thus an indicator of how likely the road segment is to experience debris from those signs and signals.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Fixed or Cabled Signals?**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. Some signs/signals are built to withstand higher wind speeds than others. The wind stability of nearby signs and signals is thus an indicator of how likely the road segment is to experience debris from those signs and signals.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Underground or Overhead Power and Utilities?**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. Road segments with underground power lines are less likely to experience wind-related issues.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			

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Indicators of Bridges Sensitivity to Wind

	Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
	Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐ →	**Past Experience with Wind**	Assets that have experienced damage from high winds in the past are more likely to be damaged if exposed in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐ →	**Roadway Signal Density**	Wind damage to roadway signals and signs can delay traffic significantly and disrupt evacuation and recovery. Roads and bridges with a higher density of road way signs and signal lights may be more prone to this type of damage.	• GIS data • Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Traffic signals per mile	0 1 = 2 5 = 6 9 = 10 + =	1 2 3 4	This scoring approach is based off the number of traffic signals per mile of roadway.
☐ →	**Wind Design Speeds**	The wind speed the asset is designed to withstand provides information about how sensitive it may be to high wind speeds. The design speed may serve as a threshold for sensitivity or the higher the design speed, the less sensitive the asset.	• Interviews/survey/conversations with operations and maintenance staff • Engineers • Design standards, manuals	Not available			
☐ →	**Proximity of Trees to Power Lines**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. The proximity of the trees along the road to power lines or could be an indicator of how likely that bridge is to experience a downed power line.	• GIS analysis • Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐ →	**Efficacy of Tree Trimming Maintenance**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. The frequency of tree trimming could indicate whether tree branches are likely to be a source of debris.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐ →	**Building Density**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. The density of buildings could indicate how likely the bridge is to experience debris from this source.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐ →	**Presence of Overhead Utility Lines**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. The presence or density of overhead utility lines could indicate how likely the bridge is to experience debris from that source.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐ →	**Sign Support Strength**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. Some signs/signals are built to withstand higher wind speeds than others. The wind stability of nearby signs and signals is thus an indicator of how likely the bridge is to experience debris from those signs and signals.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐ →	**Height and Size of Road Signs**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. Larger and taller road signs may be more likely to cause damage.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐ →	**Length of Support Arms**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. Some signs/signals are built to withstand higher wind speeds than others. The wind stability of nearby signs and signals is thus an indicator of how likely the bridge is to experience debris from those signs and signals.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐ →	**Fixed or Cabled Signals?**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. Some signs/signals are built to withstand higher wind speeds than others. The wind stability of nearby signs and signals is thus an indicator of how likely the bridge is to experience debris from those signs and signals.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐ →	**Underground or Overhead Power and Utilities?**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and road signs and signals. Road segments with underground power lines are less likely to experience wind-related issues.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Rail Lines Sensitivity to Wind

		Potential Indicators and Data Sources			**Example Scoring Approach (used in the Gulf Coast Study)**			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Wind**	Rail segments that have experienced damage from high winds in the past may be more prone to damage in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Number of Signals/ Signs or Major Crossings**	Rail segments with a number of major crossings are more likely to have signs and signals that could be damaged by wind.	• Satellite imagery	Number of crossings	0 1 = 2 3 = 3 5 = 5 + =	1 2 3 4	
☐	→	**Presence of Aerial Signal Lines**	Aerial signals and lines are sensitive to wind impacts and could be damaged during storms. This, in turn, could cause delays or damage to rail assets.	• Satellite imagery	Signals present? (Yes/No)	No Yes	1 4	
☐	→	**Proximity of Trees to Power Lines**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and rail signs and signals. The proximity of the trees along the rail to power lines or could be an indicator of how likely that rail is to experience a downed power line.	• GIS analysis • Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Efficacy of Tree Trimming Maintenance**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and rail signs and signals. The frequency of tree trimming could indicate whether tree branches are likely to be a source of debris.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Building Density**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and rail signs and signals. The density of buildings could indicate how likely the rail segment is to experience debris from that source.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Presence of Overhead Utility Lines**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and rail signs and signals. The presence or density of overhead utility lines could indicate how likely the rail segment is to experience debris from that source.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Sign Support Strength**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and rail signs and signals. Some signs/signals are built to withstand higher wind speeds than others. The wind stability of nearby signs and signals is thus an indicator of how likely the rail segment is to experience debris from those signs and signals.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Height and Size of Road Signs**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and rail signs and signals. Larger and taller rail signs may be more likely to cause damage.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Length of Support Arms**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and rail signs and signals. Some signs/signals are built to withstand higher wind speeds than others. The wind stability of nearby signs and signals is thus an indicator of how likely the rail segment is to experience debris from those signs and signals.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Fixed or Cabled Signals?**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and rail signs and signals. Some signs/signals are built to withstand higher wind speeds than others. The wind stability of nearby signs and signals is thus an indicator of how likely the rail segment is to experience debris from those signs and signals.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Underground or Overhead Power and Utilities?**	Debris is often the major cause of wind-related damage, including both trees and non-vegetative sources, such as buildings and rail signs and signals. rail segments with underground power lines are less likely to experience wind-related issues.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Ports Sensitivity to Wind

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Wind**	Ports that have experienced damage during past high winds are more likely to be damaged if exposed in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Age of Wharves, Structures**	Older wharves and structures may have been built to lower standards and/or be in poorer condition compared to newer structures, and therefore more susceptible to damage.	• Interviews/survey/conversations with operations and maintenance staff	Age (years)	0 25 = 25 50 = 50 75 = 75 + =	1 2 3 4	
☐	→	**Reliance on Electrical Power**	Ports and port facilities that rely on electrical power to operate will be more sensitive to electricity losses due to widespread weather-related outages including those caused by stress on the grid from high winds.	• Interviews/survey/conversations with operations and maintenance staff		Not reliant Partially reliant Reliant, with backup Reliant	1 2 3 4	
☐	→	**Materials Handled**	If materials handled or stored at the facility are easily damaged by high winds, they will experience greater negative effects from storm-force winds.	• Interviews/survey/conversations with operations and maintenance staff		Aluminum Assorted Break bulk Cement Coal Containers Floating equipment Hazardous materials Iron Metal products None Passengers Perishables Petroleum products Piling, slabs, girders Seafood Ship services Stone, sand, gravel Wood products	1 2.5 1 1 4 2 4 2 1 1 1 4 1 2 1 1 2 3 1	
☐	→	**Wind Design Speeds**	The wind speed a facility is designed to withstand provides information about how sensitive it may be to high wind speeds. The design speed may serve as a threshold for sensitivity or the higher the design speed, the less sensitive the facility	• Interviews/survey/conversations with operations and maintenance staff • Engineers • Design standards, manuals • ASCE wind design standards for structures	Not available			
☐	→	**Port Equipment**	Since debris is often the major cause of wind-related damage, it would be appropriate to consider the extent to which boats, docks, cranes, and other equipment at the port are sufficiently secured during high wind events.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			
☐	→	**Nearby At-Risk Infrastructure**	Identify nearby objects that could potentially cause debris hazards. For example, if there is a lot of at-risk infrastructure nearby, there may be of a chance that some of that infrastructure could come loose and create debris hazards.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records	Not available			

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Airports Sensitivity to Wind

	Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
	Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐ →	**Past Experience with Wind**	Airports that have experienced wind damage in the past are more likely to be damaged if exposed in the future.	• Interviews/survey/conversations with operations and maintenance staff • Maintenance or repair records • Emergency response records	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐ →	**Age of Buildings**	Older buildings are more likely to be built to lower design standards than newer buildings, and therefore more sensitive to damage from wind and other weather.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff	Age (years)	0 25 = 25 30 = 30 50 = 50 + =	1 2 3 4	
☐ →	**Building Material Type**	Some building materials are more likely to be damaged from wind than other materials. For example, metal and wood construction are more sensitive to wind than masonry.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff		Masonry Metal Wood	1 4 4	
☐ →	**Roof Type**	Some roof materials are more likely to be damaged from wind than other materials. For example, flat roofs are more sensitive to wind than pitched roofs.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff		Pitched roof Flat roof	1 4	
☐ →	**Height of Air Traffic Control Tower**	Taller buildings are more sensitive to high winds than shorter ones.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff • Visual inspection	Building height (feet)	0 20 = 20 115 = 115 330 = 330 + =	1 2 3 4	1 building story is approximately 9.5 feet
☐ →	**Height of Hangars**	Taller buildings are more sensitive to high winds than shorter ones.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff • Visual inspection	Building height (feet)	0 20 = 20 115 = 115 330 = 330 + =	1 2 3 4	1 building story is approximately 9.5 feet
☐ →	**Height of Terminals**	Taller buildings are more sensitive to high winds than shorter ones.	• Asset management system • Interviews/survey/conversations with operations and maintenance staff • Visual inspection	Building height (feet)	0 20 = 20 115 = 115 330 = 330 + =	1 2 3 4	1 building story is approximately 9.5 feet
☐ →	**Sheltered by Surrounding Structures**	Buildings that are sheltered (e.g., by surrounding structures or terrain) may be less sensitive to wind.	• Interviews/survey/conversations with operations and maintenance staff	Sheltered? Yes/No	Yes No	1 4	
☐ →	**Wind Design Speeds**	Buildings are designed to withstand certain wind speeds. When those wind speeds are exceeded, the building risks damage. The lower the design speed of the building, the more sensitive that building is to wind speeds, though buildings should not be damaged unless wind speeds exceed their design threshold.	• Interviews/survey/conversations with operations and maintenance staff • ASCE wind design standards for structures	Not available			
☐ →	**Operations**	Winds could affect operations, such as runway orientation (as relates to prevailing wind speeds) or other factors	• Interviews/survey/conversations with operations and maintenance staff	Not available			
☐ →	**Proximity to Potential Projectile Materials**	The proximity of an airport to areas with potential projectile materials (e.g. adjacent properties with commercial building roof ballast) may indicate its sensitivity to damage from debris.	• Interviews/survey/conversations with operations and maintenance staff	Not available			

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Transit Assets Sensitivity to Wind

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Past Experience with Wind**	Transit assets that have experienced wind damage in the past are more likely to be damaged if exposed in the future.	• Interviews/survey/conversations with operations and maintenance staff	Damaged in past? (Yes/No)	No Yes	1 4	Past experience does not necessarily have to be scored based on Yes/No answers. For example, the indicator could be used to track "how many times has the asset experienced damage in the past X years?" and then scored based on those values.
☐	→	**Age of Buildings or Fleet**	Older buildings or buses are more likely to be built to lower design standards than newer ones, and therefore more sensitive to damage from wind and other weather.	• Interviews/survey/conversations with operations and maintenance staff • Asset management system	Age (years)	0 25 = 25 30 = 30 50 = 50 + =	1 2 3 4	Applies to all assets.
☐	→	**Building Material Type**	Some building materials are more likely to be damaged from wind than other materials. For example, metal and wood construction are more sensitive to wind than masonry.	• Interviews/survey/conversations with operations and maintenance staff		Masonry Metal Wood	1 4 4	Applies to facilities only.
☐	→	**Roof Type**	Some roof materials are more likely to be damaged from wind than other materials. For example, flat roofs are more sensitive to wind than pitched roofs.	• Interviews/survey/conversations with operations and maintenance staff		Pitched roof Flat roof	1 4	Applies to facilities only.
☐	→	**Building Height**	Taller buildings are more sensitive to high winds than shorter ones.	• Interviews/survey/conversations with operations and maintenance staff	Building height (feet)	0 20 = 20 115 = 115 330 = 330 + =	1 2 3 4	Applies to facilities only. 1 building story is approximately 9.5 feet
☐	→	**Sheltered by Surrounding Structures**	Assets that are sheltered (e.g., by surrounding structures or terrain) may be less sensitive to wind.	• Interviews/survey/conversations with operations and maintenance staff	Located in areas sheltered by similar structures? (Yes/No)	Yes No	1 2	Applies to all assets.
☐	→	**Wind Design Speeds**	Buildings are designed to withstand certain wind speeds. When those wind speeds are exceeded, the building risks damage. The lower the design speed of the building, the more sensitive that building is to wind speeds, though buildings should not be damaged unless wind speeds exceed their design threshold.	• Interviews/survey/conversations with operations and maintenance staff • ASCE wind design standards for structures	Not available			

****Although it is very difficult to predict damage due to debris, consider any factors that might contribute to the likelihood of debris formation.****
****The Roads, Bridges and Culverts, and Rail sections may also contain indicators relevant to Transit Assets.****

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Roads Adaptive Capacity

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Replacement Cost**	Replacement costs for each asset are used as a rough proxy for the ease in which assets could be repaired or replaced. Resources are assumed to be more easily mobilized for lower cost repairs, and replacement costs may indicate overall complexity, size, and expense of the asset itself.	• Asset management system • National Bridge Inventory, Item 96 (Total Project Cost)	Replacement cost (USD)	0 $1,000,000 = $1,000,000 $10,000,000 = $10,000,000 $100,000,000 = $100,000,000 + =	1 2 3 4	
☐	→	**Detour Length**	Detour length is used as an indicator of redundancy in the system. Segments with longer detour lengths assumed to have less adaptive capacity than segments with shorter detours.	• National Bridge Inventory provides detour length for bridges in the database (Item 19)	Detour length (km)	0 10 = 10 30 = 30 50 = 50 + =	1 2 3 4	
☐	→	**Disruption Duration**	Disruption duration is used to indicate the timeframes necessary to restore service to assets following impacts of each of the variables. Length of time for the disruption to clear is an indicator of how well the system can deal with the climate impact.	• Interviews/survey/conversations with staff • Incident management system		Hours Days Weeks Months	1 2 3 4	
☐	→	**FHWA Roadway Functional Classification**	Functional classification characterizes the type of services roadways are intended to provide (e.g., interstate vs. arterial vs. local). Roadways with a higher functional classification may cause greater system disruptions if damaged.	• Asset management system • GIS analysis	Not available			
☐	→	**Evacuation Route**	Roads designated as evacuation routes could have a greater consequence if damaged (and, thus, lower adaptive capacity).	• Internal agency data/emergency plans • Asset management system • GIS analysis	Not available			
☐	→	**Annual Average Daily Traffic (AADT)**	AADT is the volume of vehicle traffic of a road for a year divided by 365 days. Roadways with higher traffic volumes would affect more drivers/traffic and cause a greater disruption if damaged.	• Agency datasets • Asset management system	Not available			
☐	→	**Historical Repair Cost**	Historical repair costs for each asset are used as a proxy for the ease in which assets could be repaired or replaced in future events. In locations where historical repair costs for specific assets are available, this information might prove to be a more accurate indicator, particularly if those costs could be associated with specific weather events.	• Interviews/survey/conversations with staff • Asset management system • Post-event damage reports	Not available			
☐	→	**Access to Critical Areas**	Roads that provide the only access to critical areas are more significant to the adaptive capacity of the larger response system.	• Maps • Emergency planning department • Stakeholder interviews	Not available			

Indicators of Bridges Adaptive Capacity

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**	**Score**	**Notes**
☐	→	**Replacement Cost**	Replacement costs for each asset are used as a rough proxy for the ease in which assets could be repaired or replaced. Resources are assumed to be more easily mobilized for lower cost repairs, and replacement costs may indicate overall complexity, size, and expense of the asset itself.	• Asset management system • National Bridge Inventory, Item 96 (Total Project Cost)	Replacement cost (USD)	0 $1,000,000 = $1,000,000 $10,000,000 = $10,000,000 $100,000,000 = $100,000,000 + =	1 2 3 4	
☐	→	**Detour Length**	Detour length is used as an indicator of redundancy in the system. Bridges with longer detour lengths assumed to have less adaptive capacity than bridges with shorter detours.	• National Bridge Inventory provides detour length for bridges in the database (Item 19)	Detour length (km)	0 10 = 10 30 = 30 50 = 50 + =	1 2 3 4	The relative burden of a detour can length can vary by location. The example shown is the "bins" for Mobile, AL.
☐	→	**Disruption Duration**	Disruption duration is used to indicate the timeframes necessary to restore service to assets following impacts of each of the variables. Length of time for the disruption to clear is an indicator of how well the system can deal with the climate impact.	• Interviews/survey/conversations with staff • Incident management system		Hours Days Weeks Months	1 2 3 4	

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☐	→	**FHWA Roadway Functional Classification**	Functional classification characterizes the type of services roadways are intended to provide (e.g., interstate vs. arterial vs. local). Bridges carrying roadways with a higher functional classification may cause greater system disruptions if damaged.	• Asset management system • GIS analysis	Not available
☐	→	**Evacuation Route**	Bridges that contain designated evacuation routes could have a greater consequence if damaged (and, thus, lower adaptive capacity).	• Internal agency data/emergency plans • Asset management system • GIS analysis	Not available
☐	→	**Annual Average Daily Traffic (AADT)**	AADT is the volume of vehicle traffic of a road for a year divided by 365 days. Bridges with higher traffic volumes would affect more drivers/traffic and cause a greater disruption if damaged.	• National Bridge Inventory, Item 29--Average Daily Traffic • Agency datasets • Asset management system	Not available
☐	→	**Historical Repair Cost**	Historical repair costs for each asset are used as a proxy for the ease in which assets could be repaired or replaced in future events. In locations where historical repair costs for specific assets are available, this information might prove to be a more accurate indicator, particularly if those costs could be associated with specific weather events.	• Interviews/survey/conversations with staff • Asset management system • Post-event damage reports	Not available
☐	→	**Access to Critical Areas**	Bridges that provide the only access to critical areas are more significant to the adaptive capacity of the larger response system.	• Maps • Emergency planning department • Stakeholder interviews	Not available

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Rail Lines Adaptive Capacity

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)				
		Indicator	**Description and Rationale**	**Potential Data Source(s)**	**Indicator Unit**	**Value Range**		**Score**	**Notes**
☐	→	**Presence of Bridges along Segment**	Bridges are generally more expensive to replace than rail; the speed to recover from damage to bridges along a segment of rail may therefore be longer than segments without bridges.	• Visual inspection of segments	Bridge along segment? (Yes/No)	Yes		4	
						No		1	
☐	→	**Signaling**	Signaling can be expensive and time-intensive to replace.	• Interviews/survey/conversations with staff		Signaled		4	
						Not signaled		1	
☐	→	**Evacuation Plans**	Rail companies with a plan in place are expected to suffer less damage and recover more quickly from storms.	• Interviews/survey/conversations with staff		Plan in place		4	
						No plan		1	
☐	→	**Part of Disaster Relief Recovery Plan**	Rail assets that are part of a larger disaster relief recovery plan may be expedited for return to service.	• Interviews/survey/conversations with staff	Part of a disaster relief recovery plan? (Yes/No)	Yes		4	
						No		1	
☐	→	**Ability to Reroute System**	Systems and segments that can flexibly reroute will be more resilient to damage, track obstructions, and outages.	• Interviews/survey/conversations with staff		Limited	Assets are physically fixed	4	
						Low	Assets are inflexible	3	
						Medium	Assets are somewhat flexible	2	
						High	Assets are highly flexible	1	
☐	→	**Interchange Utility**	This is a yard-specific measure of the interchange between carriers, which is of importance in the ability to transfer all cars within yards.	• Interviews/survey/conversations with staff	Quality of interchange utility	Poor		4	
						Good		1	
☐	→	**Disruption Duration**	Disruption duration is used to indicate the timeframes necessary to restore service to assets following impacts of each of the variables. Length of time for the disruption to clear is an indicator of how well the system can deal with the climate impact.	• Interviews/survey/conversations with staff • Incident management system		Hours		1	
						Days		2	
						Weeks		3	
						Months		4	
☐	→	**Replacement Cost**	Specific replacement cost of assets or specific sub-components could serve as a proxy for how easy that asset would be to repair or replace if damaged.	• Asset management system • Interviews/survey/conversations with staff	Not available				
☐	→	**Number of Rail Lines**	The number of rail lines serving a specific location can capture the redundancy of a system.	• Satellite imagery • Visual inspection	Not available				

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Ports Adaptive Capacity

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)		
		Indicator	**Rationale**	**Potential Data Source(s)**	**Indicator Value**	**Score**	**Notes**
☐	→	**Redundancy within a Facility**	Operational disruptions are less likely to occur if other parts of the same facility can be substituted in the event of minor damage.	• Interviews/survey/conversations with staff	Can easily shift operations within the facility … … Cannot shift operations	1 2 3 4	
☐	→	**Redundancy across Facilities**	Serious operation disruptions are less likely to occur if other facilities can be substituted in the event of major damage.	• Interviews/survey/conversations with staff	Can easily shift operations to another facility … … Cannot shift operations	1 2 3 4	
☐	→	**Disruption Duration**	Disruption duration is used to indicate the timeframes necessary to restore service to assets following impacts of each of the variables. Length of time for the disruption to clear is an indicator of how well the system can deal with the climate impact.	• Interviews/survey/conversations with staff	Hours Days Weeks Months	1 2 3 4	
☐	→	**Availability of Supplies and Repair Equipment**	The extent to which supplies and repair equipment are stockpiled could be an indicator of how quickly ports would be able to recover from damage.	• Interviews/survey/conversations with staff	Not available		
☐	→	**Sharing Equipment across Ports, Agencies**	Agreements with other ports or agencies to share equipment or facilities to maintain operations after a major event could be indicators of adaptive capacity.	• Interviews/survey/conversations with staff	Not available		
☐	→	**Cost of Replacement of Specific Assets**	The replacement cost of specific buildings could be a proxy for the ease of repair and/or cost of replacement.	• Interviews/survey/conversations with staff	Not available		
☐	→	**Historical Cost of Replacement**	In locations where historical repair costs for specific assets are available, this information might prove to be a more accurate indicator of replacement costs of assets, particularly if those costs could be associated with specific weather events.	• Historical repair costs • Interviews/survey/conversations with staff • Government/Community post-event damage reports	Not available		
☐	→	**Usage Statistics**	Usage statistics such as operations, passenger-miles, or cargo volumes can help capture the impact of damage to an asset on the larger transportation system.	• Interviews/survey/conversations with staff	Not available		
☐	→	**Access to Critical Areas**	Whether assets provide the only access to critical areas can help capture the impact of damage to an asset on the larger transportation system.	• Interviews/survey/conversations with staff • Emergency planning department	Not available		
☐	→	**Tourism Costs**	Damage to ports may influence the costs of tourists not being able to visit.	• Interviews/survey/conversations with staff	Not available		
☐	→	**Cost of Disrupted or Increased Shipping Routes**	The cost of disrupted or increased shipping routes can help provide an evaluation of "damage" due to disrupted use of an asset.	• Interviews/survey/conversations with staff	Not available		

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

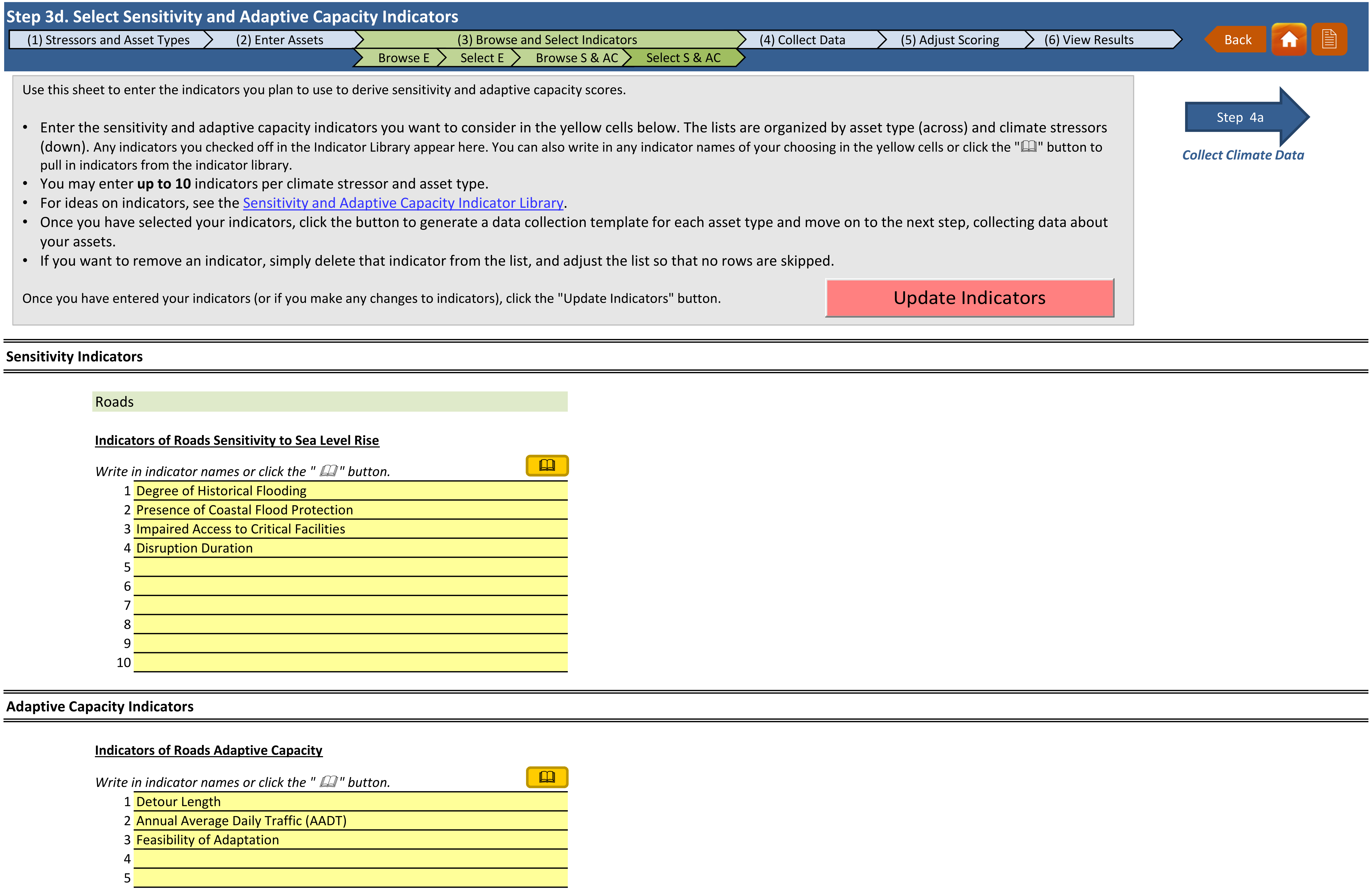
Indicators of Airports Adaptive Capacity

	Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)			
	Indicator	**Rationale**	**Potential Data Source(s)**	**Indicator Value**		**Score**	**Notes**
☐ →	**Special Designation**	If airports are specifically designated as important for emergency response, national security, defense, or support to health facilities, they are more likely to be re-opened quickly after damage.	• Interviews/survey/conversations with staff • Emergency response plans	Designated as a component of the National Defense System or as an emergency supply source (Yes/No)	Yes No	1 4	
☐ →	**Number of Terminals**	The number of terminals at an airport is an indicator of internal redundancy within the airport. Airports with multiple terminals may be able to shift operations to other portions of the airport if a specific terminal or area is damaged.	• Interviews/survey/conversations with staff • Visual inspection • Airport website	Number of terminals	0 1 = 2 2 = 3 3 = 4 + =	4 3 2 1	
☐ →	**Number of Runway Headings**	The number of runway headings at an airport is an indicator of internal redundancy within the airport. If airport has more than one runway facing in direction of prevailing winds, this reduces the chances that planes will have to take off and land in cross winds, reducing delays.	• FAA Airport Master Record Forms 5010-1 & 5010-2 (http://www.gcr1.com/5010web/)	Number of runway headings	2 3 = 4 5 = 6 7 = 7 + =	4 3 2 1	
☐ →	**Distance to Nearest Alternate Airport**	The distance to an airport that has similar characteristics to the given airport is a measure of air service system redundancy.	• FAA National Plan of Integrated Airport Systems (NPIAS) • Maps	Miles to nearest alternate airport	0 30 = 30 60 = 60 120 = 120 + =	1 2 3 4	For the Gulf Coast Study, alternate airport defined as an airport that shared the same service level (primary or cargo), hub type (if primary), cargo level (if applicable), and Airport Reference Code (ARC). ARC refers to the aircraft type and approach speeds that an airport can handle.
☐ →	**Number of Alternate Airports within 120 Miles**	The number of airports that could act as substitutes for the given airport and that are within a 2 hour drive is a measure of system redundancy.	• FAA National Plan of Integrated Airport Systems (NPIAS) • Maps	Number of alternate airports within 120 miles	0 0 1 1 2 2 3 +	4 3 2 1	For the Gulf Coast Study, alternate airport defined as an airport that shared the same service level (primary or cargo), hub type (if primary), cargo level (if applicable), and Airport Reference Code (ARC). ARC refers to the aircraft type and approach speeds that an airport can handle.
☐ →	**Disruption Duration**	Disruption duration is used to indicate the timeframes necessary to restore service to assets following impacts of each of the variables. Length of time for the disruption to clear is an indicator of how well the system can deal with the climate impact.	• Interviews/survey/conversations with staff		Hours Days Weeks Months	1 2 3 4	
☐ →	**Cost of Replacement of Specific Assets**	The replacement cost of specific buildings could be a proxy for the ease of repair and/or cost of replacement.	• Asset management system • Interviews/survey/conversations with staff	Not available			
☐ →	**Historical Cost of Replacement**	In locations where historical repair costs for specific assets are available, this information might prove to be a more accurate indicator of replacement costs of assets, particularly if those costs could be associated with specific weather events.	• Historical repair costs • Interviews/survey/conversations with staff • Government/Community post-event damage reports	Not available			
☐ →	**Usage Statistics**	Usage statistics such as operations, passenger-miles, or cargo volumes can help capture the impact of damage to an asset on the larger transportation system.	• FAA Airport Master Record Forms 5010-1 & 5010-2 (http://www.gcr1.com/5010web/)	Not available			
☐ →	**Access to Critical Areas**	Whether assets provide the only access to critical areas can help capture the impact of damage to an asset on the larger transportation system.	• Interviews/survey/conversations with stakeholders	Not available			
☐ →	**Redundancy in Power Systems**	Airports relay on continuous energy to provide navigation safety for air traffic. Protection of back up engine generators, capacity of their fuel tanks to power critical infrastructure and presence of alternatives such as battery banks would enable airports to function when grid power is unavailable.	• Interviews/survey/conversations with stakeholders	Not available			
☐ →	**Tourism Costs**	Damage to airports may influence the costs of tourists not being able to visit.	• Interviews/survey/conversations with stakeholders • Local tourism office or chamber of commerce	Not available			
☐ →	**Cost of Disrupted or Increased Shipping Routes**	The cost of disrupted or increased shipping routes can help provide an evaluation of "damage" due to disrupted use of an asset.	• Interviews/survey/conversations with staff	Not available			

U.S. DOT Vulnerability Assessment Scoring Tool, Sensitivity and Adaptive Capacity Indicator Library

Indicators of Transit Assets Adaptive Capacity

		Potential Indicators and Data Sources			Example Scoring Approach (used in the Gulf Coast Study)				
		Indicator	**Rationale**	**Potential Data Source(s)**	**Indicator Value**			**Score**	**Notes**
☐	→	**Priority for Assistance**	If a transit asset is designated with USACE priority for assistance after a major weather event, it is more likely to be re-opened quickly after damage.	• Interviews/survey/conversations with staff	On list of priorities? (Yes/No)	Yes		1	
						No		4	
☐	→	**Function of Facility or Asset**	Assets that are difficult to replace or move have lower adaptive capacity than assets that are replaceable or movable.	• Interviews/survey/conversations with staff		Facility or asset serves a unique purpose and would be extremely difficult to replace if damaged		1	
						Facility or asset serves a unique purpose and would be difficult to replace, but temporary emergency measures are available		2	
						The function of the facility or asset is reasonably flexible in that it could be relocated or replaced with moderate or limited disruption to services		3	
						Facility functions and assets are interchangeable and can be replaced if one is damaged with almost no disruption to services		4	
☐	→	**Disruption Duration**	Disruption duration is used to indicate the timeframes necessary to restore service to assets following impacts of each of the variables. Length of time for the disruption to clear is an indicator of how well the system can deal with the climate impact.	• Interviews/survey/conversations with staff		Hours		1	
						Days		2	
						Weeks		3	
						Months		4	
☐	→	**Ability to Reroute**	Assets that are able to reroute or detour easily are more capable of adapting to extreme weather events.	• Interviews/survey/conversations with staff		Limited	Assets are physically fixed	4	
						Low	Assets are inflexible	3	
						Medium	Assets are somewhat flexible	2	
						High	Assets are highly flexible	1	
☐	→	**Ability of Fixed Lines to Reroute**	For transit that runs on fixed lines (such as subways), alternate indicators could consider whether alternative routes and modes can be employed if one line is disrupted. That is, to what extent would buses be able to be quickly deployed to sufficiently fill the gap created if a subway or light rail line became inoperable?	• Interviews/survey/conversations with staff	Not available				
☐	→	**Ability to Reroute around Problem Areas**	If a single station or a single point on the rail is damaged, does the entire line shut down, or can trains be routed around the problem areas?		Not available				
☐	→	**Cost of Replacement of Specific Assets**	The replacement cost of specific buildings could be a proxy for the ease of repair and/or cost of replacement.	• Interviews/survey/conversations with staff	Not available				
☐	→	**Historical Cost of Replacement**	In locations where historical repair costs for specific assets are available, this information might prove to be a more accurate indicator of replacement costs of assets, particularly if those costs could be associated with specific weather events.	• Historical repair costs • Interviews/survey/conversations with staff • Government/Community post-event damage reports	Not available				



Step 3d. Select Sensitivity and Adaptive Capacity Indicators

Use this sheet to enter the indicators you plan to use to derive sensitivity and adaptive capacity scores.

- Enter the sensitivity and adaptive capacity indicators you want to consider in the yellow cells below. The lists are organized by asset type (across) and climate stressors (down). Any indicators you checked off in the Indicator Library appear here. You can also write in any indicator names of your choosing in the yellow cells or click the "📖" button to pull in indicators from the indicator library.
- You may enter **up to 10** indicators per climate stressor and asset type.
- For ideas on indicators, see the Sensitivity and Adaptive Capacity Indicator Library.
- Once you have selected your indicators, click the button to generate a data collection template for each asset type and move on to the next step, collecting data about your assets.
- If you want to remove an indicator, simply delete that indicator from the list, and adjust the list so that no rows are skipped.

Once you have entered your indicators (or if you make any changes to indicators), click the "Update Indicators" button.

Update Indicators

Collect Climate Data

Sensitivity Indicators

Roads

Indicators of Roads Sensitivity to Sea Level Rise

Write in indicator names or click the "📖" button.

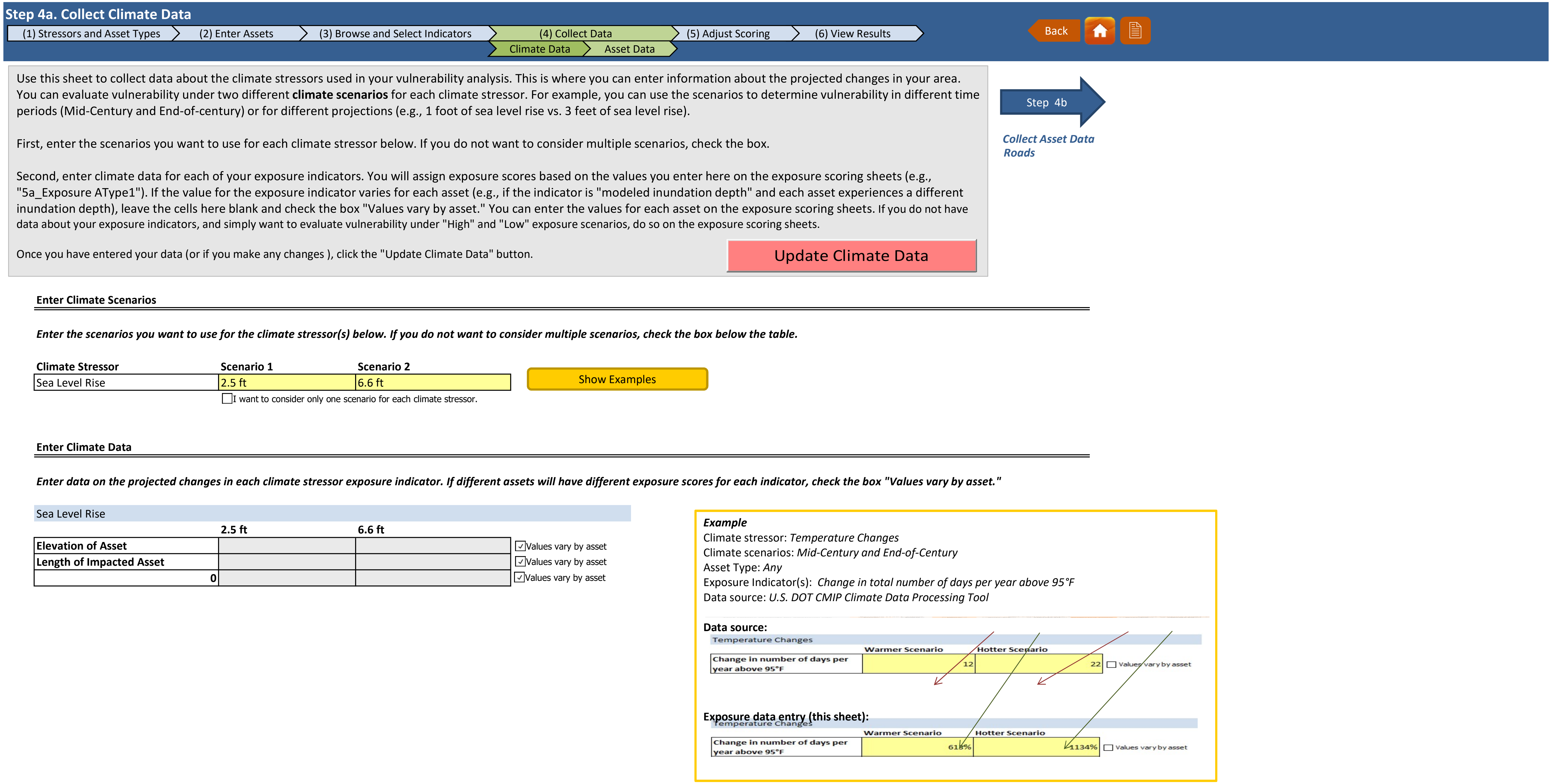
1 Degree of Historical Flooding
2 Presence of Coastal Flood Protection
3 Impaired Access to Critical Facilities
4 Disruption Duration
5
6
7
8
9
10

Adaptive Capacity Indicators

Indicators of Roads Adaptive Capacity

Write in indicator names or click the "📖" button.

1 Detour Length
2 Annual Average Daily Traffic (AADT)
3 Feasibility of Adaptation
4
5



Step 4a. Collect Climate Data

Use this sheet to collect data about the climate stressors used in your vulnerability analysis. This is where you can enter information about the projected changes in your area. You can evaluate vulnerability under two different **climate scenarios** for each climate stressor. For example, you can use the scenarios to determine vulnerability in different time periods (Mid-Century and End-of-century) or for different projections (e.g., 1 foot of sea level rise vs. 3 feet of sea level rise).

First, enter the scenarios you want to use for each climate stressor below. If you do not want to consider multiple scenarios, check the box.

Second, enter climate data for each of your exposure indicators. You will assign exposure scores based on the values you enter here on the exposure scoring sheets (e.g., "5a_Exposure AType1"). If the value for the exposure indicator varies for each asset (e.g., if the indicator is "modeled inundation depth" and each asset experiences a different inundation depth), leave the cells here blank and check the box "Values vary by asset." You can enter the values for each asset on the exposure scoring sheets. If you do not have data about your exposure indicators, and simply want to evaluate vulnerability under "High" and "Low" exposure scenarios, do so on the exposure scoring sheets.

Once you have entered your data (or if you make any changes), click the "Update Climate Data" button.

Enter Climate Scenarios

Enter the scenarios you want to use for the climate stressor(s) below. If you do not want to consider multiple scenarios, check the box below the table.

Climate Stressor	Scenario 1	Scenario 2
Sea Level Rise	2.5 ft	6.6 ft

☐ I want to consider only one scenario for each climate stressor.

Enter Climate Data

Enter data on the projected changes in each climate stressor exposure indicator. If different assets will have different exposure scores for each indicator, check the box "Values vary by asset."

Sea Level Rise

	2.5 ft	6.6 ft	
Elevation of Asset			☑ Values vary by asset
Length of Impacted Asset			☑ Values vary by asset
0			☑ Values vary by asset

Example

Climate stressor: *Temperature Changes*
Climate scenarios: *Mid-Century and End-of-Century*
Asset Type: *Any*
Exposure Indicator(s): *Change in total number of days per year above 95°F*
Data source: *U.S. DOT CMIP Climate Data Processing Tool*

Data source:

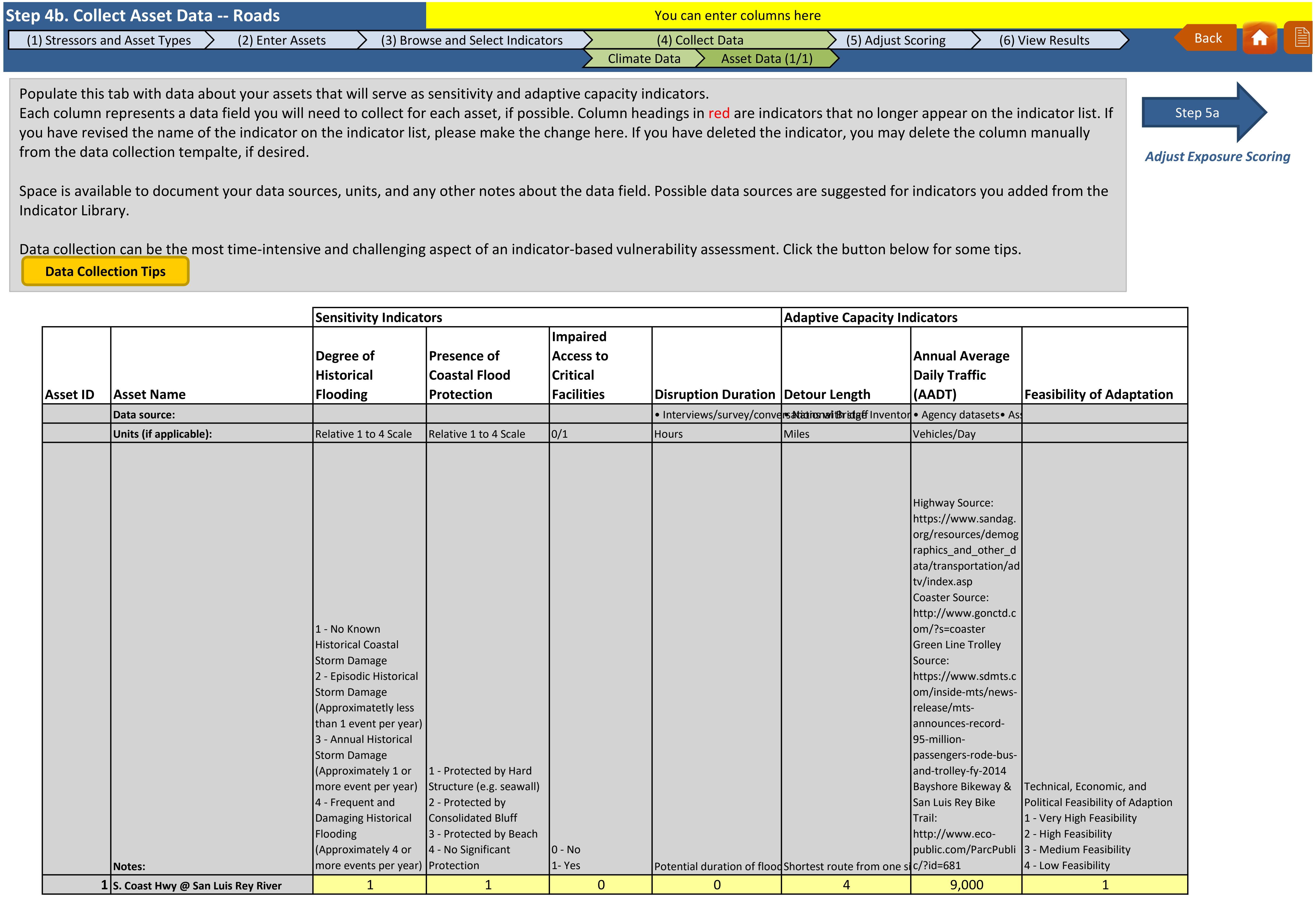
Temperature Changes

	Warmer Scenario	Hotter Scenario	
Change in number of days per year above 95°F	12	22	☐ Values vary by asset

Exposure data entry (this sheet):

Temperature Changes

	Warmer Scenario	Hotter Scenario	
Change in number of days per year above 95°F	618%	1134%	☐ Values vary by asset



Step 4b. Collect Asset Data -- Roads

You can enter columns here

Populate this tab with data about your assets that will serve as sensitivity and adaptive capacity indicators.
Each column represents a data field you will need to collect for each asset, if possible. Column headings in red are indicators that no longer appear on the indicator list. If you have revised the name of the indicator on the indicator list, please make the change here. If you have deleted the indicator, you may delete the column manually from the data collection tempalte, if desired.

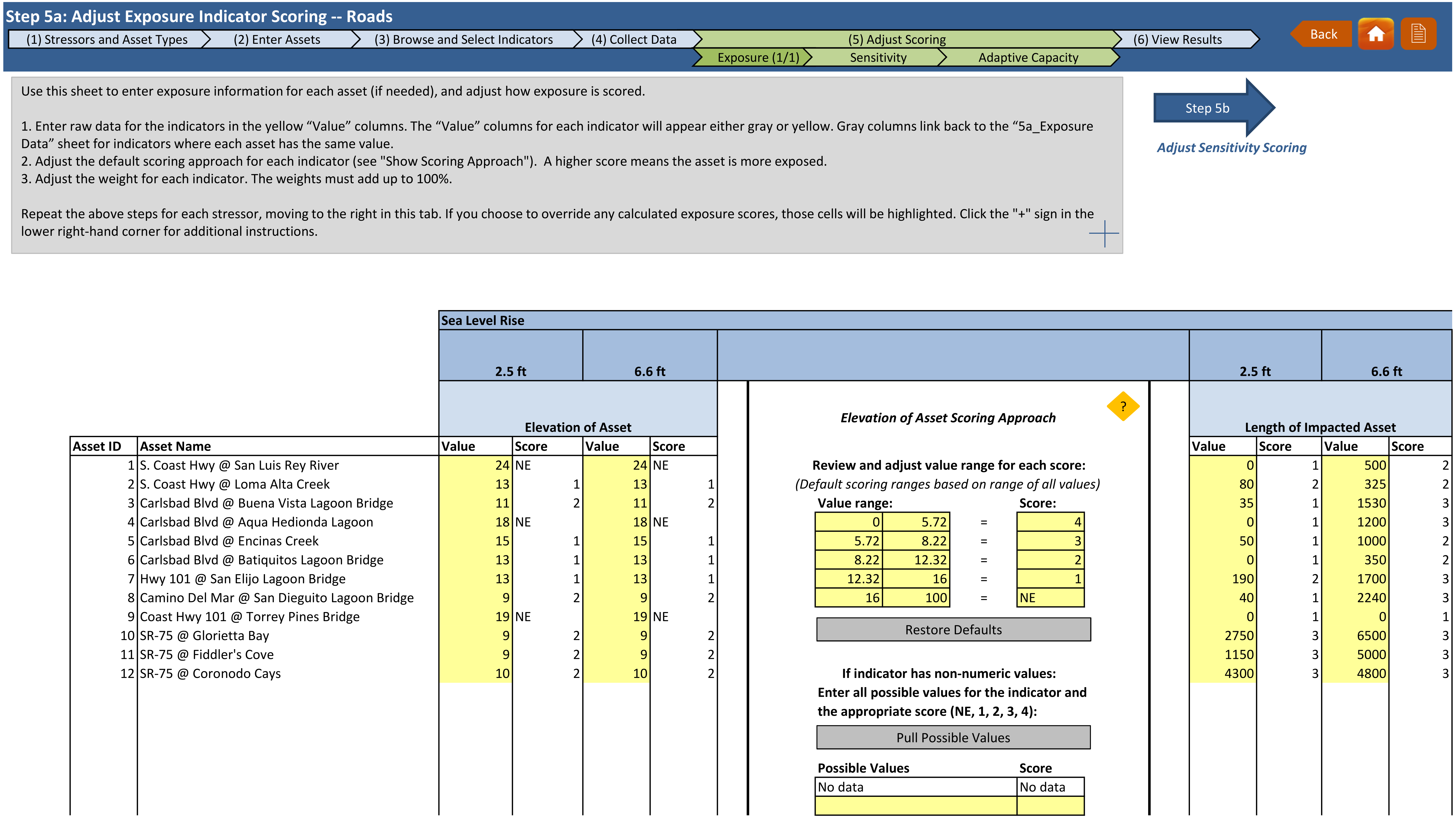
Space is available to document your data sources, units, and any other notes about the data field. Possible data sources are suggested for indicators you added from the Indicator Library.

Data collection can be the most time-intensive and challenging aspect of an indicator-based vulnerability assessment. Click the button below for some tips.

Adjust Exposure Scoring

		Sensitivity Indicators				Adaptive Capacity Indicators		
Asset ID	**Asset Name**	**Degree of Historical Flooding**	**Presence of Coastal Flood Protection**	**Impaired Access to Critical Facilities**	**Disruption Duration**	**Detour Length**	**Annual Average Daily Traffic (AADT)**	**Feasibility of Adaptation**
	Data source:				• Interviews/survey/conversations with staff	• National Bridge Inventor	• Agency datasets• As	
	Units (if applicable):	Relative 1 to 4 Scale	Relative 1 to 4 Scale	0/1	Hours	Miles	Vehicles/Day	
	Notes:	1 - No Known Historical Coastal Storm Damage 2 - Episodic Historical Storm Damage (Approximatetly less than 1 event per year) 3 - Annual Historical Storm Damage (Approximately 1 or more event per year) 4 - Frequent and Damaging Historical Flooding (Approximately 4 or more events per year)	1 - Protected by Hard Structure (e.g. seawall) 2 - Protected by Consolidated Bluff 3 - Protected by Beach 4 - No Significant Protection	0 - No 1- Yes	Potential duration of flooc	Shortest route from one si	Highway Source: https://www.sandag.org/resources/demographics_and_other_data/transportation/adtv/index.asp Coaster Source: http://www.gonctd.com/?s=coaster Green Line Trolley Source: https://www.sdmts.com/inside-mts/news-release/mts-announces-record-95-million-passengers-rode-bus-and-trolley-fy-2014 Bayshore Bikeway & San Luis Rey Bike Trail: http://www.eco-public.com/ParcPublic/?id=681	Technical, Economic, and Political Feasibility of Adaption 1 - Very High Feasibility 2 - High Feasibility 3 - Medium Feasibility 4 - Low Feasibility
1	**S. Coast Hwy @ San Luis Rey River**	1	1	0	0	4	9,000	1

2	S. Coast Hwy @ Loma Alta Creek	3	1	0	24	1.84	16,918	3
3	Carlsbad Blvd @ Buena Vista Lagoon Bri	3	1	1	12	8.5	19,400	3
4	Carlsbad Blvd @ Aqua Hedionda Lagoon	1	1	1	4	2.3	20,894	4
5	Carlsbad Blvd @ Encinas Creek	4	4	1	12	8.4	19,167	3
6	Carlsbad Blvd @ Batiquitos Lagoon Bridg	2	3	1	4	3.12	19,167	3
7	Hwy 101 @ San Elijo Lagoon Bridge	3	3	1	4	4.12	20,682	2
8	Camino Del Mar @ San Dieguito Lagoon	2	1	1	4	5.87	18,500	2
9	Coast Hwy 101 @ Torrey Pines Bridge	2	1	1	4	8.83	19,600	3
10	SR-75 @ Glorietta Bay	2	1	1	4	20.5	22,800	3
11	SR-75 @ Fiddler's Cove	2	1	1	4	20.5	22,800	3
12	SR-75 @ Coronodo Cays	2	1	1	4	20.5	22,800	3



Step 5a: Adjust Exposure Indicator Scoring -- Roads

Use this sheet to enter exposure information for each asset (if needed), and adjust how exposure is scored.

1. Enter raw data for the indicators in the yellow “Value” columns. The “Value” columns for each indicator will appear either gray or yellow. Gray columns link back to the “5a_Exposure Data” sheet for indicators where each asset has the same value.
2. Adjust the default scoring approach for each indicator (see "Show Scoring Approach"). A higher score means the asset is more exposed.
3. Adjust the weight for each indicator. The weights must add up to 100%.

Repeat the above steps for each stressor, moving to the right in this tab. If you choose to override any calculated exposure scores, those cells will be highlighted. Click the "+" sign in the lower right-hand corner for additional instructions.

		Sea Level Rise							
		2.5 ft		6.6 ft		2.5 ft		6.6 ft	
		Elevation of Asset				Length of Impacted Asset			
Asset ID	Asset Name	Value	Score	Value	Score	Value	Score	Value	Score
1	S. Coast Hwy @ San Luis Rey River	24	NE	24	NE	0	1	500	2
2	S. Coast Hwy @ Loma Alta Creek	13	1	13	1	80	2	325	2
3	Carlsbad Blvd @ Buena Vista Lagoon Bridge	11	2	11	2	35	1	1530	3
4	Carlsbad Blvd @ Aqua Hedionda Lagoon	18	NE	18	NE	0	1	1200	3
5	Carlsbad Blvd @ Encinas Creek	15	1	15	1	50	1	1000	2
6	Carlsbad Blvd @ Batiquitos Lagoon Bridge	13	1	13	1	0	1	350	2
7	Hwy 101 @ San Elijo Lagoon Bridge	13	1	13	1	190	2	1700	3
8	Camino Del Mar @ San Dieguito Lagoon Bridge	9	2	9	2	40	1	2240	3
9	Coast Hwy 101 @ Torrey Pines Bridge	19	NE	19	NE	0	1	0	1
10	SR-75 @ Glorietta Bay	9	2	9	2	2750	3	6500	3
11	SR-75 @ Fiddler's Cove	9	2	9	2	1150	3	5000	3
12	SR-75 @ Coronodo Cays	10	2	10	2	4300	3	4800	3

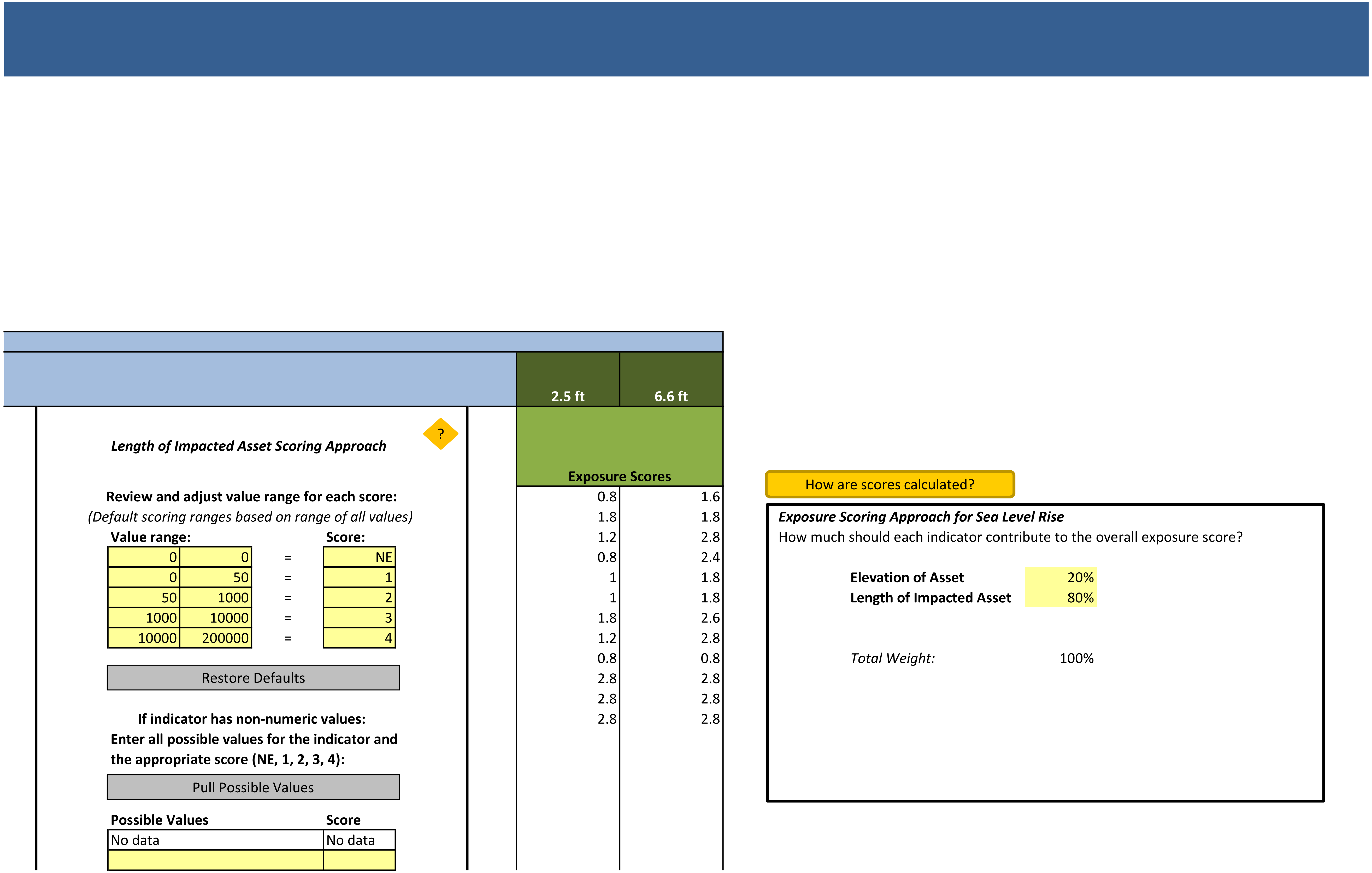
Elevation of Asset Scoring Approach

Review and adjust value range for each score:
(Default scoring ranges based on range of all values)

Value range:			Score:
0	5.72	=	4
5.72	8.22	=	3
8.22	12.32	=	2
12.32	16	=	1
16	100	=	NE

If indicator has non-numeric values:
Enter all possible values for the indicator and the appropriate score (NE, 1, 2, 3, 4):

Possible Values	Score
No data	No data



Length of Impacted Asset Scoring Approach

Review and adjust value range for each score:

(Default scoring ranges based on range of all values)

Value range:			Score:
0	0	=	NE
0	50	=	1
50	1000	=	2
1000	10000	=	3
10000	200000	=	4

If indicator has non-numeric values:

Enter all possible values for the indicator and the appropriate score (NE, 1, 2, 3, 4):

Possible Values	Score
No data	No data

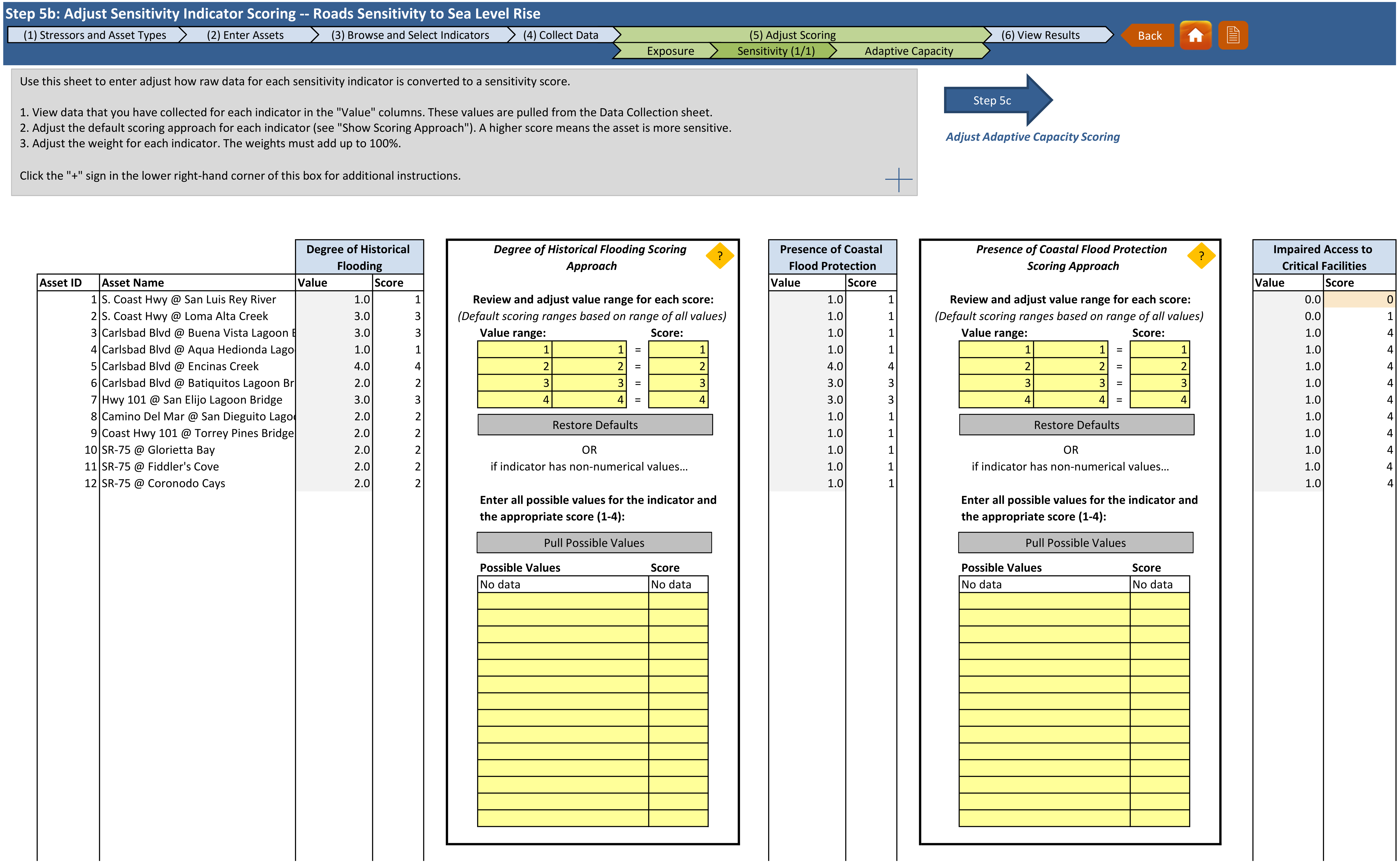
Exposure Scores

2.5 ft	6.6 ft
0.8	1.6
1.8	1.8
1.2	2.8
0.8	2.4
1	1.8
1	1.8
1.8	2.6
1.2	2.8
0.8	0.8
2.8	2.8
2.8	2.8
2.8	2.8

Exposure Scoring Approach for Sea Level Rise

How much should each indicator contribute to the overall exposure score?

Elevation of Asset	20%
Length of Impacted Asset	80%
Total Weight:	100%



Step 5b: Adjust Sensitivity Indicator Scoring -- Roads Sensitivity to Sea Level Rise

Use this sheet to enter adjust how raw data for each sensitivity indicator is converted to a sensitivity score.

1. View data that you have collected for each indicator in the "Value" columns. These values are pulled from the Data Collection sheet.
2. Adjust the default scoring approach for each indicator (see "Show Scoring Approach"). A higher score means the asset is more sensitive.
3. Adjust the weight for each indicator. The weights must add up to 100%.

Click the "+" sign in the lower right-hand corner of this box for additional instructions.

		Degree of Historical Flooding		Presence of Coastal Flood Protection		Impaired Access to Critical Facilities	
Asset ID	**Asset Name**	**Value**	**Score**	**Value**	**Score**	**Value**	**Score**
1	S. Coast Hwy @ San Luis Rey River	1.0	1	1.0	1	0.0	0
2	S. Coast Hwy @ Loma Alta Creek	3.0	3	1.0	1	0.0	1
3	Carlsbad Blvd @ Buena Vista Lagoon	3.0	3	1.0	1	1.0	4
4	Carlsbad Blvd @ Aqua Hedionda Lago	1.0	1	1.0	1	1.0	4
5	Carlsbad Blvd @ Encinas Creek	4.0	4	4.0	4	1.0	4
6	Carlsbad Blvd @ Batiquitos Lagoon Br	2.0	2	3.0	3	1.0	4
7	Hwy 101 @ San Elijo Lagoon Bridge	3.0	3	3.0	3	1.0	4
8	Camino Del Mar @ San Dieguito Lago	2.0	2	1.0	1	1.0	4
9	Coast Hwy 101 @ Torrey Pines Bridge	2.0	2	1.0	1	1.0	4
10	SR-75 @ Glorietta Bay	2.0	2	1.0	1	1.0	4
11	SR-75 @ Fiddler's Cove	2.0	2	1.0	1	1.0	4
12	SR-75 @ Coronodo Cays	2.0	2	1.0	1	1.0	4

Degree of Historical Flooding Scoring Approach

Review and adjust value range for each score:

(Default scoring ranges based on range of all values)

Value range:			**Score:**
1	1	=	1
2	2	=	2
3	3	=	3
4	4	=	4

Restore Defaults

OR

if indicator has non-numerical values...

Enter all possible values for the indicator and the appropriate score (1-4):

Pull Possible Values

Possible Values	**Score**
No data	No data

Presence of Coastal Flood Protection Scoring Approach

Review and adjust value range for each score:

(Default scoring ranges based on range of all values)

Value range:			**Score:**
1	1	=	1
2	2	=	2
3	3	=	3
4	4	=	4

Restore Defaults

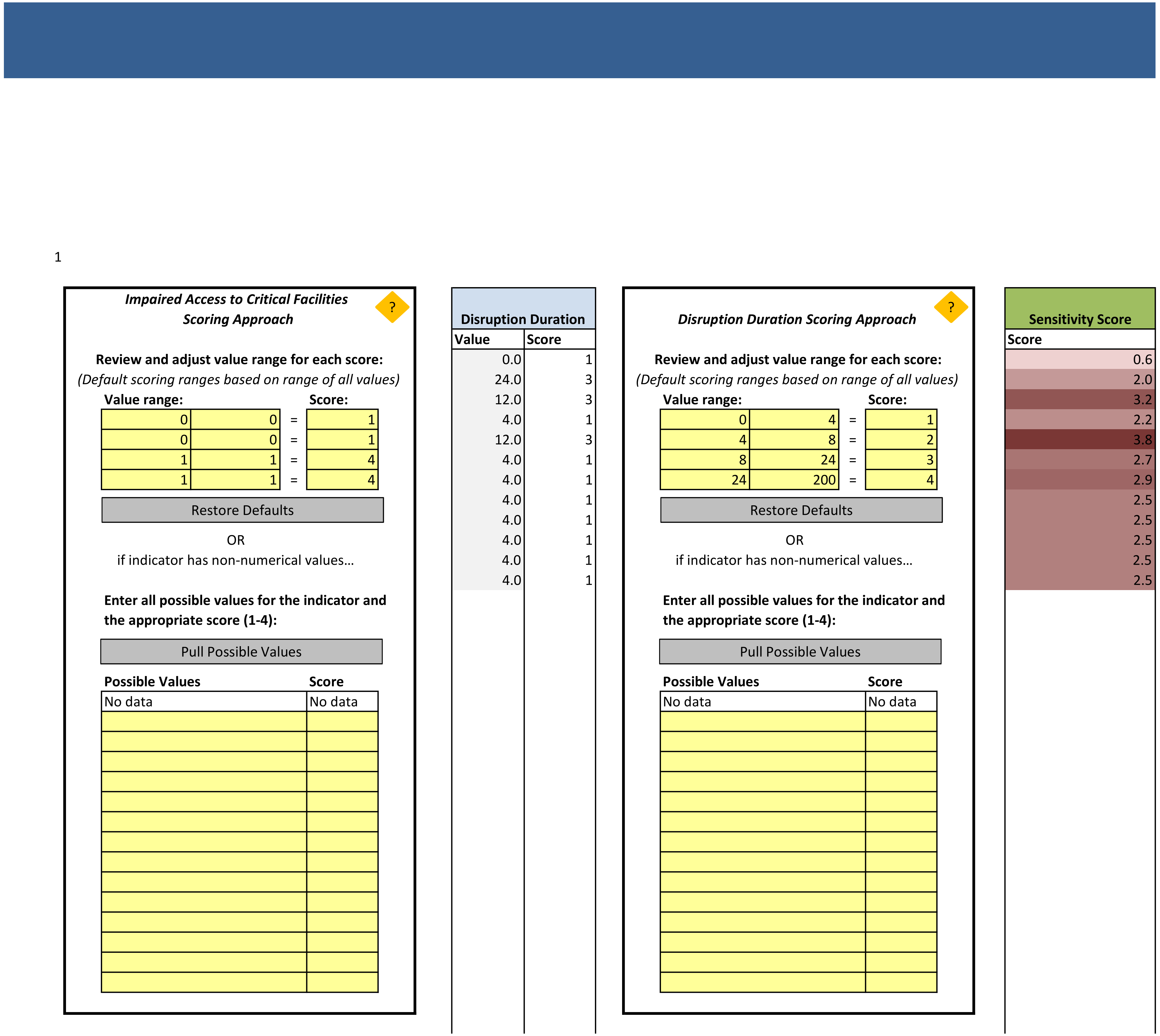
OR

if indicator has non-numerical values...

Enter all possible values for the indicator and the appropriate score (1-4):

Pull Possible Values

Possible Values	**Score**
No data	No data



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Impaired Access to Critical Facilities Scoring Approach

?

Review and adjust value range for each score:
(Default scoring ranges based on range of all values)

Value range:			**Score:**
0	0	=	1
0	0	=	1
1	1	=	4
1	1	=	4

Restore Defaults

OR

if indicator has non-numerical values...

Enter all possible values for the indicator and the appropriate score (1-4):

Pull Possible Values

Possible Values	**Score**
No data	No data

Disruption Duration	
Value	**Score**
0.0	1
24.0	3
12.0	3
4.0	1
12.0	3
4.0	1
4.0	1
4.0	1
4.0	1
4.0	1
4.0	1
4.0	1

Disruption Duration Scoring Approach

?

Review and adjust value range for each score:
(Default scoring ranges based on range of all values)

Value range:			**Score:**
0	4	=	1
4	8	=	2
8	24	=	3
24	200	=	4

Restore Defaults

OR

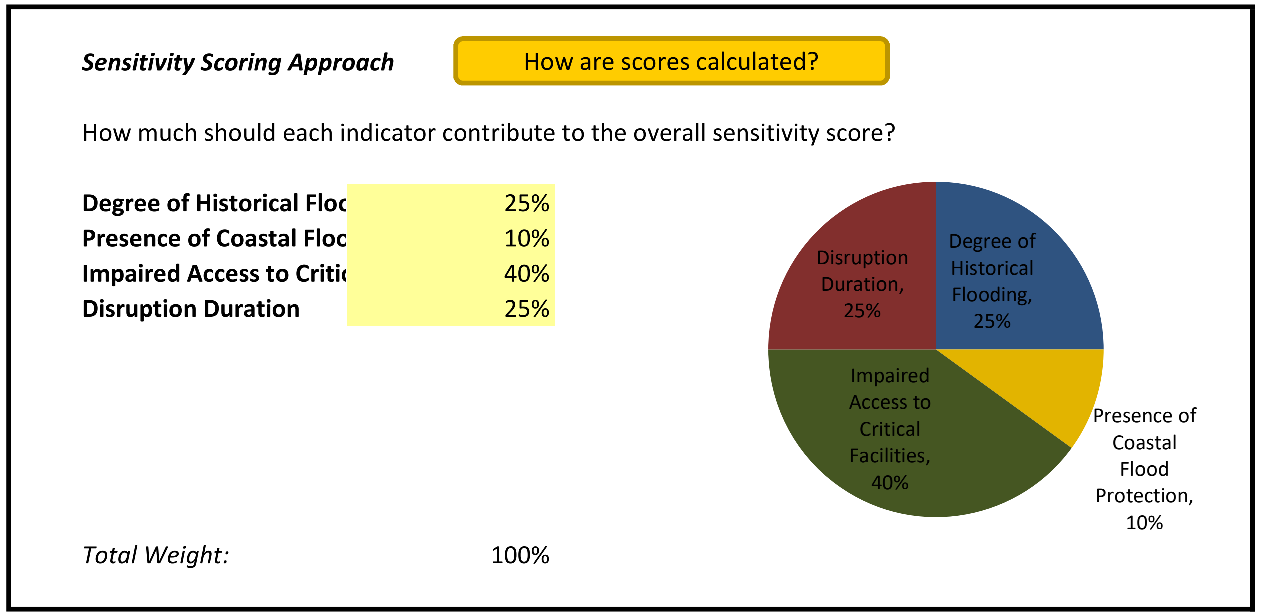
if indicator has non-numerical values...

Enter all possible values for the indicator and the appropriate score (1-4):

Pull Possible Values

Possible Values	**Score**
No data	No data

Sensitivity Score
Score
0.6
2.0
3.2
2.2
3.8
2.7
2.9
2.5
2.5
2.5
2.5
2.5

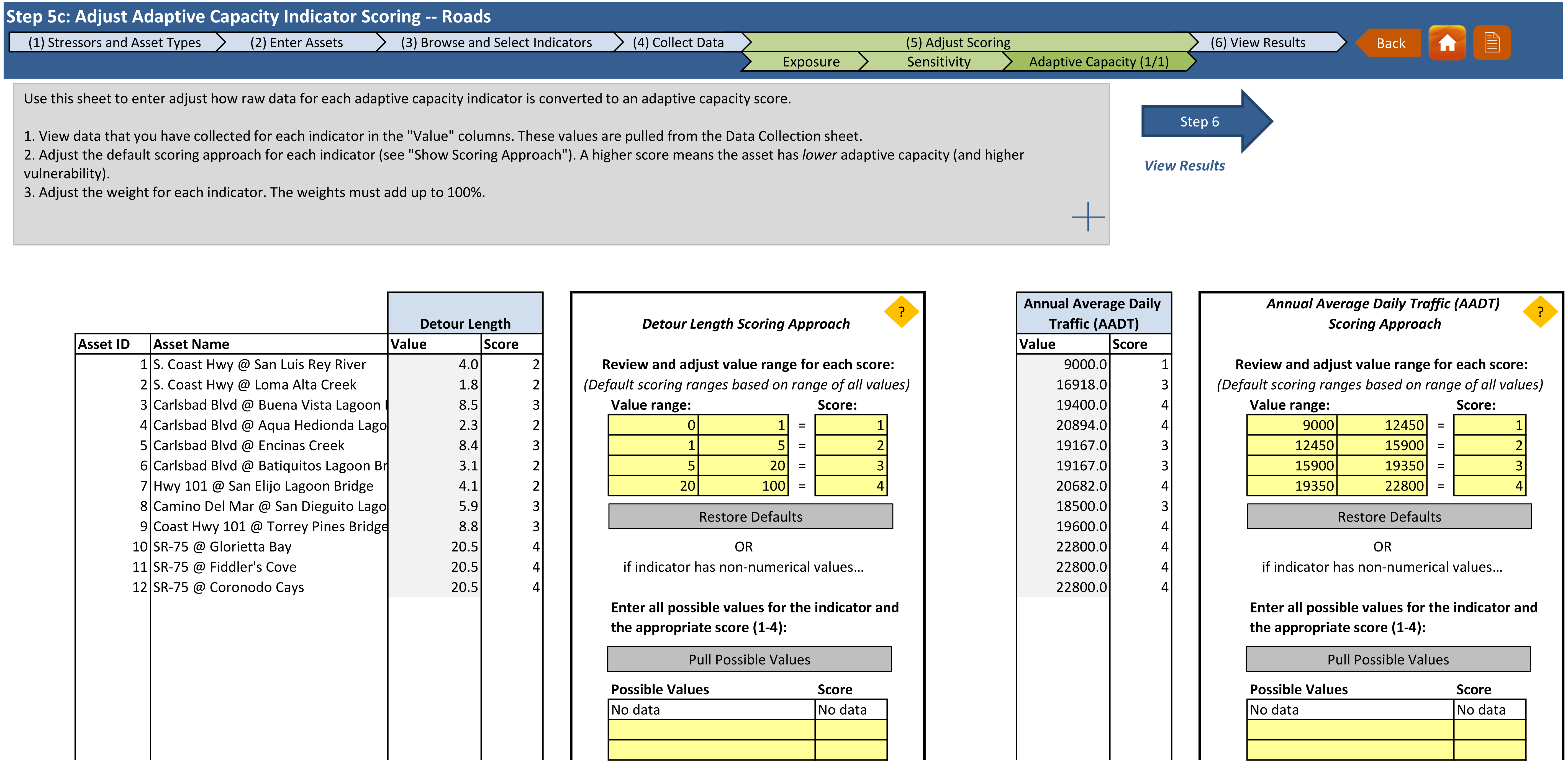


Sensitivity Scoring Approach

How much should each indicator contribute to the overall sensitivity score?

Degree of Historical Floc	25%
Presence of Coastal Floc	10%
Impaired Access to Critic	40%
Disruption Duration	25%

Total Weight: 100%



Step 5c: Adjust Adaptive Capacity Indicator Scoring -- Roads

Use this sheet to enter adjust how raw data for each adaptive capacity indicator is converted to an adaptive capacity score.

1. View data that you have collected for each indicator in the "Value" columns. These values are pulled from the Data Collection sheet.
2. Adjust the default scoring approach for each indicator (see "Show Scoring Approach"). A higher score means the asset has *lower* adaptive capacity (and higher vulnerability).
3. Adjust the weight for each indicator. The weights must add up to 100%.

		Detour Length	
Asset ID	**Asset Name**	**Value**	**Score**
1	S. Coast Hwy @ San Luis Rey River	4.0	2
2	S. Coast Hwy @ Loma Alta Creek	1.8	2
3	Carlsbad Blvd @ Buena Vista Lagoon	8.5	3
4	Carlsbad Blvd @ Aqua Hedionda Lago	2.3	2
5	Carlsbad Blvd @ Encinas Creek	8.4	3
6	Carlsbad Blvd @ Batiquitos Lagoon Br	3.1	2
7	Hwy 101 @ San Elijo Lagoon Bridge	4.1	2
8	Camino Del Mar @ San Dieguito Lago	5.9	3
9	Coast Hwy 101 @ Torrey Pines Bridge	8.8	3
10	SR-75 @ Glorietta Bay	20.5	4
11	SR-75 @ Fiddler's Cove	20.5	4
12	SR-75 @ Coronodo Cays	20.5	4

Detour Length Scoring Approach

Review and adjust value range for each score:
(Default scoring ranges based on range of all values)

Value range:			**Score:**
0	1	=	1
1	5	=	2
5	20	=	3
20	100	=	4

OR

if indicator has non-numerical values...

Enter all possible values for the indicator and the appropriate score (1-4):

Possible Values	**Score**
No data	No data

Annual Average Daily Traffic (AADT)	
Value	**Score**
9000.0	1
16918.0	3
19400.0	4
20894.0	4
19167.0	3
19167.0	3
20682.0	4
18500.0	3
19600.0	4
22800.0	4
22800.0	4
22800.0	4

Annual Average Daily Traffic (AADT) Scoring Approach

Review and adjust value range for each score:
(Default scoring ranges based on range of all values)

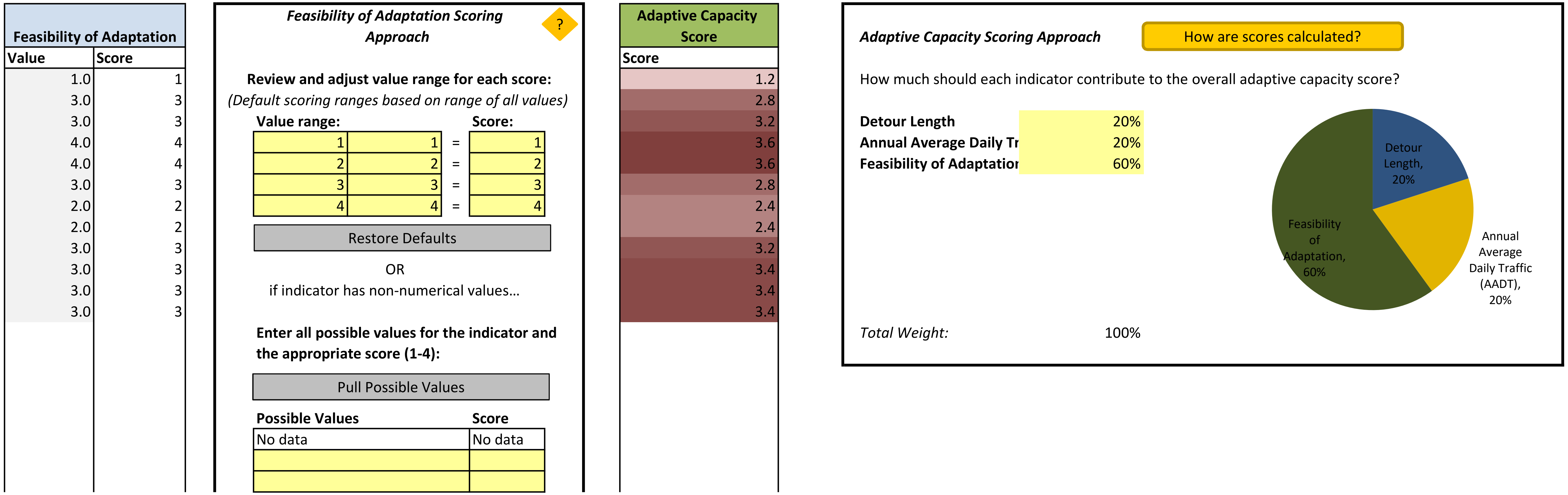
Value range:			**Score:**
9000	12450	=	1
12450	15900	=	2
15900	19350	=	3
19350	22800	=	4

OR

if indicator has non-numerical values...

Enter all possible values for the indicator and the appropriate score (1-4):

Possible Values	**Score**
No data	No data



Feasibility of Adaptation	
Value	Score
1.0	1
3.0	3
3.0	3
4.0	4
4.0	4
3.0	3
2.0	2
2.0	2
3.0	3
3.0	3
3.0	3
3.0	3

Feasibility of Adaptation Scoring Approach

Review and adjust value range for each score:

(Default scoring ranges based on range of all values)

Value range:			Score:
1	1	=	1
2	2	=	2
3	3	=	3
4	4	=	4

OR

if indicator has non-numerical values…

Enter all possible values for the indicator and the appropriate score (1-4):

Possible Values	Score
No data	No data

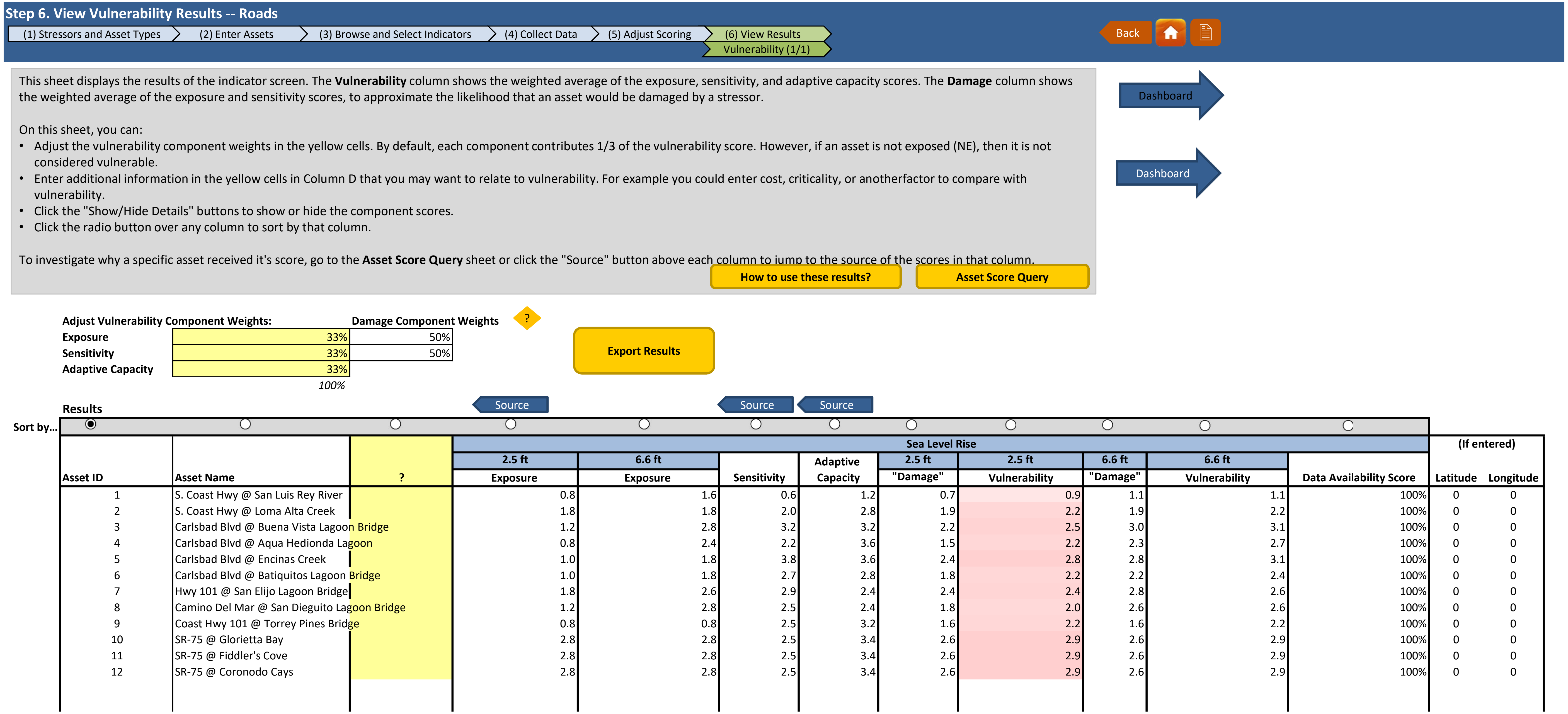
Adaptive Capacity Score
Score
1.2
2.8
3.2
3.6
3.6
2.8
2.4
2.4
3.2
3.4
3.4
3.4

Adaptive Capacity Scoring Approach

How much should each indicator contribute to the overall adaptive capacity score?

Detour Length	20%
Annual Average Daily Tr	20%
Feasibility of Adaptatior	60%

Total Weight: 100%



This sheet displays the results of the indicator screen. The **Vulnerability** column shows the weighted average of the exposure, sensitivity, and adaptive capacity scores. The **Damage** column shows the weighted average of the exposure and sensitivity scores, to approximate the likelihood that an asset would be damaged by a stressor.

On this sheet, you can:

- Adjust the vulnerability component weights in the yellow cells. By default, each component contributes 1/3 of the vulnerability score. However, if an asset is not exposed (NE), then it is not considered vulnerable.
- Enter additional information in the yellow cells in Column D that you may want to relate to vulnerability. For example you could enter cost, criticality, or anotherfactor to compare with vulnerability.
- Click the "Show/Hide Details" buttons to show or hide the component scores.
- Click the radio button over any column to sort by that column.

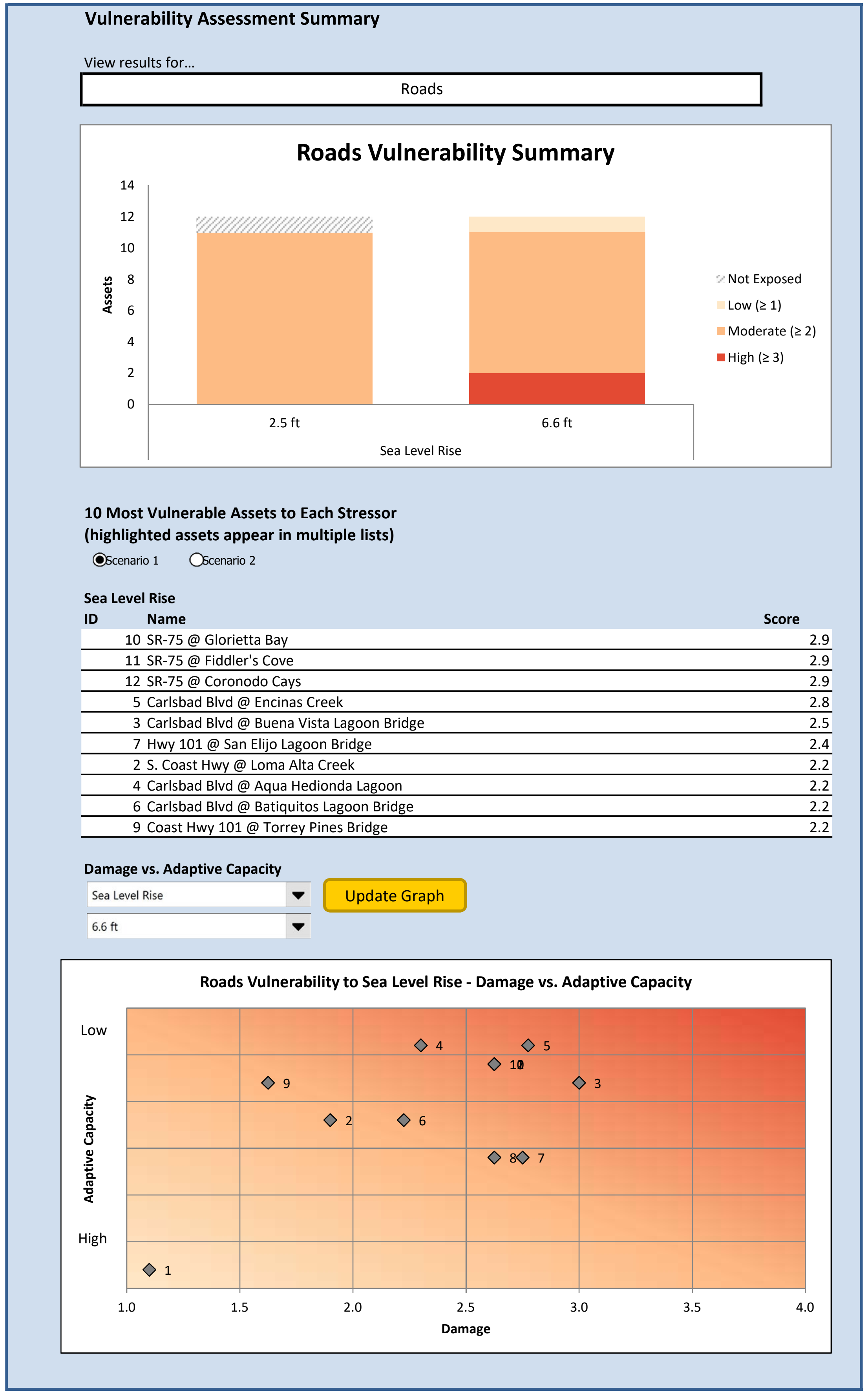
To investigate why a specific asset received it's score, go to the **Asset Score Query** sheet or click the "Source" button above each column to jump to the source of the scores in that column.

Adjust Vulnerability Component Weights:		Damage Component Weights
Exposure	33%	50%
Sensitivity	33%	50%
Adaptive Capacity	33%	
	100%	

Results

Sort by...

●	○	○	○	○	○	○	○	○	○	○	○		
			Sea Level Rise									(If entered)	
			2.5 ft	6.6 ft		Adaptive	2.5 ft	2.5 ft	6.6 ft	6.6 ft			
Asset ID	Asset Name	?	Exposure	Exposure	Sensitivity	Capacity	"Damage"	Vulnerability	"Damage"	Vulnerability	Data Availability Score	Latitude	Longitude
1	S. Coast Hwy @ San Luis Rey River		0.8	1.6	0.6	1.2	0.7	0.9	1.1	1.1	100%	0	0
2	S. Coast Hwy @ Loma Alta Creek		1.8	1.8	2.0	2.8	1.9	2.2	1.9	2.2	100%	0	0
3	Carlsbad Blvd @ Buena Vista Lagoon Bridge		1.2	2.8	3.2	3.2	2.2	2.5	3.0	3.1	100%	0	0
4	Carlsbad Blvd @ Aqua Hedionda Lagoon		0.8	2.4	2.2	3.6	1.5	2.2	2.3	2.7	100%	0	0
5	Carlsbad Blvd @ Encinas Creek		1.0	1.8	3.8	3.6	2.4	2.8	2.8	3.1	100%	0	0
6	Carlsbad Blvd @ Batiquitos Lagoon Bridge		1.0	1.8	2.7	2.8	1.8	2.2	2.2	2.4	100%	0	0
7	Hwy 101 @ San Elijo Lagoon Bridge		1.8	2.6	2.9	2.4	2.4	2.4	2.8	2.6	100%	0	0
8	Camino Del Mar @ San Dieguito Lagoon Bridge		1.2	2.8	2.5	2.4	1.8	2.0	2.6	2.6	100%	0	0
9	Coast Hwy 101 @ Torrey Pines Bridge		0.8	0.8	2.5	3.2	1.6	2.2	1.6	2.2	100%	0	0
10	SR-75 @ Glorietta Bay		2.8	2.8	2.5	3.4	2.6	2.9	2.6	2.9	100%	0	0
11	SR-75 @ Fiddler's Cove		2.8	2.8	2.5	3.4	2.6	2.9	2.6	2.9	100%	0	0
12	SR-75 @ Coronodo Cays		2.8	2.8	2.5	3.4	2.6	2.9	2.6	2.9	100%	0	0



Vulnerability Assessment Summary

View results for...

Roads

10 Most Vulnerable Assets to Each Stressor (highlighted assets appear in multiple lists)

● Scenario 1 ○ Scenario 2

Sea Level Rise

ID	Name	Score
10	SR-75 @ Glorietta Bay	2.9
11	SR-75 @ Fiddler's Cove	2.9
12	SR-75 @ Coronodo Cays	2.9
5	Carlsbad Blvd @ Encinas Creek	2.8
3	Carlsbad Blvd @ Buena Vista Lagoon Bridge	2.5
7	Hwy 101 @ San Elijo Lagoon Bridge	2.4
2	S. Coast Hwy @ Loma Alta Creek	2.2
4	Carlsbad Blvd @ Aqua Hedionda Lagoon	2.2
6	Carlsbad Blvd @ Batiquitos Lagoon Bridge	2.2
9	Coast Hwy 101 @ Torrey Pines Bridge	2.2

Damage vs. Adaptive Capacity

Sea Level Rise

6.6 ft

APPENDIX D: SANDAG POLICY UPDATES (PAGES D-1 – D-22)

Regional Sea Level Rise Adaptation Guidance for Transportation Infrastructure

Task 2.1 – Recommendations for how to update individual policy documents to reflect updated statewide guidance regarding climate change and sea level rise adaptation.

The following table summarizes policies and recommendations in the left column and describes recommendations for proposed updates given SANDAG projects and the best available science in the right column.

Shoreline Preservation Strategy for the San Diego Region (Strategy or SPS, 1993)

Policies and Recommendations	Updates
Overall Policies	
A. The Strategy should provide a cooperative, coordinated, and long-range preservation program for the region's shoreline.	Long-range preservation program required to incorporate sea level rise (SLR) considerations, and monitoring results from the first two Regional Beach Sand Projects (RBSPs).
B. The Strategy should consider the full range of shoreline management tactics, with emphasis on beachfilling to preserve and enhance the environmental quality, recreational capacity, and property protection benefits of the region's shoreline.	Emphasis should be on trigger-based adaptation, e.g., measured tides at Scripps Pier (NOAA Station ID: 9410230 - La Jolla, CA), so that adaptation actions can be phased over time in response to SLR. Beachfilling can be the primary near-term action, and if sea level rises as predicted, then sand can be increased in volume, and potentially supplemented by sand retention measures for mid-term action. Specific updates to Figure 2 showing Potential Shoreline Management Tactics are needed based on best available science and policy understanding: a. Change "C. Reduce Sand Losses to submarine canyons and offshore sand deposits:" with bullet underneath to Using coarse-grained sand (< 0.5 mm) for nourishment to maximize beach widening effects (delete existing bullets), as appropriate given potential beach habitat effects as determined by monitoring. b. Under "E. Regulate Shoreline Land Use and Development by:" update with additional policies in CCC's Draft Residential Guidance, e.g., prepare an adaptation plan, managed retreat program, align LCPs with LHMPs, etc. and delete sand mining (no longer an issue). Make it clear that tactics would be developed through LCP/A process and reflect specific conditions in each jurisdiction. Potentially add action of conveying sand from local reservoirs upstream of dams to the coast to offset historical sand trapping and downstream deficits.

Policies and Recommendations	Updates
C. Structural and mechanical management tactics to stabilize beaches, reduce sand losses, and redistribute sand along the shoreline should be evaluated as complements to the regional beachfilling program and implemented where they have a positive impact on cost-effectiveness. Tactics which mimic natural processes should be preferred when they are equal in cost-effectiveness to other approaches.	Consider supplementing beach nourishment with sand retention strategies. Initially, consider implementing a pilot project with one or more sand retention strategies coupled with beach nourishment and monitoring to document results. If ocean water levels rise as expected based on Scripps Pier publicly available monitoring data, then this could then be followed by a dedicated project of more strategic sand retention combined with nourishment to widen and hold beaches.
D. The Strategy should provide planning estimates of the amount, placement, timing, cost and sources of beachfill, and describe the process for implementation decisions.	See Beachbuilding Recommendations below. Beach nourishment recommendations from 1993 should be updated based on an updated conditions assessment of the coast and past SANDAG accomplishments. For example, the 1993 SPS recommended up to 30 million cubic yards (mcy) of sand be placed along the region's coast. Since that time, SANDAG has placed 3.3 mcy of sand, while other projects have placed 0.5 mcy of sand, for a total of 3 mcy of sand. Therefore, the region may need 27 mcy of sand to accomplish the original goals. Based on SANDAG monitoring data beginning in 1996, current beach width and volume is comparable, or has increased, relative to 1996 conditions and coastal erosion has also not accelerated since 1996. As a result, the 27 mcy of sand needed to accomplish the original goal may still be valid. As sea levels rise, the amount of sand needed should be increased to account for corresponding shoreline retreat in accordance with the "Bruun Rule."
E. Policies and actions to promote the availability of offshore, coastal and upland sources of sand for beachfilling and natural beach replenishment should be developed.	Significant progress has been made to promote offshore, coastal, and upland sand sources. Actions implemented to date include: 1. Investigate offshore sand sources and identify potential source sites, quantifying their volumes, areas, depths, and sand quality. 2. Implement SCOUP programs regionwide. 3. Cessation of upstream sand mining by sand and gravel companies. Action to remove sand from behind reservoirs and convey it downstream to the coast should be explored in the future.

Policies and Recommendations	Updates
F. The Strategy should provide technical information to assist coordinated and consistent approaches to local level management tactics, including regulation of shoreline land use and development, and property protection measures such as artificial dunes, seawalls, and revetments.	Technical information needed includes: 1. Biological habitat data are needed to sensitively design and construct projects. A database should be developed to store data developed by separate projects and agencies into one storehouse available to the public, like the Nearshore Habitat Inventory completed in 2001 by SANDAG and the State Coastal Conservancy. 2. Monitoring data of ocean tides and long-term data on SLR trends over time. 3. Physical monitoring of shoreline width and sand volume data per the SANDAG Regional Beach Monitoring Program. 4. Inventories of beach nourishment projects with quantities, placement sites, and sand quality data. 5. Inventory of shoreline protective devices such as seawalls and revetments, and living shorelines using updated imagery, Google Earth, and California Coastal Records Project.
G. The Strategy should evaluate local, state, and federal policies and regulations and recommend changes to support the other policies and objectives.	SCOUP permitting programs to streamline the permit process, and regional physical and biological monitoring to reduce the burden on individual cities should be considered.
H. The Strategy should be based on the best available scientific data and analysis, and on sound engineering principles.	Policy updates should be consistent with the CCC sea level policy guidance and all recent SANDAG and local nourishment projects.

Policies and Recommendations	Updates
Beachbuilding Recommendations	
Silver Strand Littoral Cell (Silver Strand State Beach to the border) 1. Initial volume of sand needed for beach building could be up to 3 mcy and cost up to $15M; maintaining beach could require up to 90,000 cy/yr at a cost of $500,000/yr; economic benefits from property protection and recreation exceed costs of the beach building and maintenance within 10 years. Major sources of sand include offshore borrow sites near Imperial Beach (estimated 32 mcy) and near Silver Strand Beach (estimated 348 mcy). 2. Determine the feasibility and cost effectiveness of capturing sand at the northern end of the cell near Zuniga jetty, and backpassing it to the southern portion of the cell where beaches are narrower. [paraphrased]	1. Update for existing conditions based on lessons learned from RBSP I/II - initial volume and costs, annual maintenance, borrow sites. For example, since 1995 there has been 1.19 mcy total of sand placed in the Silver Strand Littoral Cell from 9 projects. Therefore, the remaining need may be reduced to 1.9 mcy. However, monitoring done by SANDAG since 1996 should be used to confirm or update the initial volume needed and maintenance volumes, along with monitoring of ocean water levels at Scripps Pier, with estimates being modified upward over time in response to rising water levels. Also, the cost of placing 1 cy of sand at I.B. by SANDAG is approximately $18 based on current practice, so the cost of placing 3 mcy needs to be updated to $54M. Major sources of sand off I.B. have not been confirmed to be suitable. SANDAG investigated sites off the Tijuana River, I.B. and Silver Strand, and off Zuniga jetty. Additional offshore borrow site investigations should occur to identify any suitable sand near I.B. The reason that the cost to nourish I.B. is so high is because the sand comes from offshore of Mission Beach and that is an 18-mile haul. It would be ideal to place smaller volumes of sand at a time, but because the sand comes from such a distance, it is cost-prohibitive to place sand more frequently in smaller amounts. Thus, due to sand source questions, the feasibility of beachbuilding as a mid-term SLR adaptation strategy is questionable. Any sand placement effort at I.B. needs to include legal protection for SANDAG due to the lawsuit filed by homeowners against the City, SANDAG, and its contractors post-2012. 2. Backpassing sand from Zuniga Jetty may be feasible and could still be considered, but thus far the only mechanical effort similar to this was a failure due to maintenance by the owner that was not performed. The infrastructure is costly. Therefore, SANDAG has learned that offshore dredging is more cost-effective and should continue that approach.

Policies and Recommendations	Updates
Mission Bay Littoral Cell 1. Evaluate the limiting effects on beach attendance from overcrowding on the beach, and from parking and access problems, for Ocean, Mission, and Pacific Beaches and determine the feasibility and cost effectiveness of beach building and maintenance programs to meet recreational needs. If it is determined that recreational beach use will increase and parking and access can accommodate additional beach users, initial volume of sand needed for beach building could be 0.5-6.2 mcy and cost up to $31M; maintaining beach could require up to 5,000 cy/yr at a cost of $25,000/yr; economic benefits from increased recreation use exceed costs of the beach building and maintenance within first year. Major sources of sand include offshore borrow site off Mission Beach (estimated 192 mcy). 2. Determine the feasibility and cost effectiveness of capturing sand at the southern end of Mission Beach near the San Diego River jetty, and backpassing it to the north and south where beaches are narrower. [paraphrased]	1. The sand volume needed can be related to recreational demand, but it may also be needed to protect shoreline development from damage. SANDAG placed 151,000 cy at M.B. in 2001, and the USACE placed 450,000 cy there in 2010. Therefore, 601,000 cy has been placed since the SPS was adopted in 1993. Theoretically, the M.B. Littoral Cell may only need between 0 cy and 600,000 cy. These beaches have proven to be very stable with little narrowing and retreat. In addition, SANDAG has found up to 60 mcy of sand available at the offshore M.B. borrow site, and while there is no reason to believe that total is less, more investigation to confirm this. As a result of the wide beach and large, proximal sand source, beachbuilding is likely a feasible, cost-effective mid- and long-term SLR adaptation strategy for M.B. However, the needed volume should be updated to account for SLR and the corresponding shoreline retreat. Costs should also be updated based on SANDAG monitoring, and projections of SLR, with estimates being modified upward over time in response to rising water levels. 2. Sand backpassing may be feasible, but is subject to the same concerns expressed for the Silver Strand Littoral Cell (Zuniga Jetty). However, the suitability of sand near Mission Jetty is better than sand near Zuniga Jetty, so the effort may be worth risking.

Policies and Recommendations	Updates
Oceanside Littoral Cell (Oceanside Harbor to La Jolla) 1. Initial volume of sand needed for beach building could be up to 25 mcy and cost up to $126M; maintaining beach could require up to 320,000 cy/yr at a cost of $1.6M/yr; economic benefits from property protection and recreation exceed costs of the beach building and maintenance within 2 years. Major sources of sand include 8 offshore borrow sites (estimated 112 mcy). 2. Determine the feasibility and cost effectiveness of capturing sand before it is lost down Scripps and La Jolla Submarine Canyon, and backpassing it to upcoast areas with narrow beaches. 3. Determine the feasibility and cost effectiveness of capturing sand before it moves offshore of Oceanside Harbor, and bypassing it to downcoast areas with narrow beaches. [paraphrased]	1. This cell received up to 6.16 mcy in nourishment since the SPS was adopted by multiple projects. Therefore, its need may have been reduced to roughly 20 mcy. The cost needs to be updated to approximately $12.50 per cy (though costs vary by proximity to the sand source), such that 25 mcy would cost approximately $313M based on SANDAG's project experience. The volume of sand needs to be recalculated based on results of SANDAG physical monitoring and sea level data from Scripps Pier, with estimates being modified upward over time in response to rising water levels. In addition, offshore borrow sites need to be investigated to identify additional sites to SO-5 off Del Mar. Several candidates exist near Oceanside. The Oceanside Littoral Cell includes both narrow, bluff-backed beaches (e.g., Encinitas) and wider, river valley beaches (e.g., Del Mar sand spit). The feasibility of beachbuilding as a mid-term SLR adaptation strategy varies in these different geomorphic units. Beachbuilding is more sustainable in wider, river valley settings, whereas in narrow, bluff-backed beaches retention strategies may be needed in order to sustain sand volumes during this timeframe. As sea levels continue to rise, additional strategies such as managed retreat may be needed along bluff-backed beaches in the Oceanside Littoral Cell because these areas do not naturally hold significant volumes of sand, evidenced by the fact that this stretch of the San Diego shoreline has historically been a critical erosion area. 2. Sand capture upcoast of canyons seems to be infeasible compared to the cost and effectiveness of nourishment. More effective might be removal of sand behind upstream dams (e.g., Lake Hodges). 3. Sand bypassing at Oceanside Harbor may be feasible, but the initial USACE pilot project proved to be too maintenance-heavy for successful results. It may be preferable to place a dredge (ideally already located nearby as part of a separate project) in the littoral zone north of the harbor and pump this material back into the littoral cell to the south.

Policies and Recommendations	Updates
Regionwide Recommendations	
1. Develop guidelines for the acceptable composition of beachfill material from all sand sources ...	This was done in SCOUP (2006), in part, but it was focused on upland, not ocean, sediment so a SCOUP update may be needed to address both sources. SANDAG developed guidelines for offshore sand as part of their two RBSPs that may be sufficient.
2. Develop technical information regarding the issues of shoreline land use and protective structures for use by local jurisdictions. The information should include a discussion of the use of setbacks from beaches and seacliffs and beach building over the use of seawalls and revetments to protect property, and the adverse impacts of protective structures on beaches and ways to mitigate these impacts … The technical information should provide for local flexibility in implementation based on local conditions and existing commitments.	Same as Policy F. Additionally, sand retention should be added as another method to build beaches where they may not normally occur.
3. Review harbor, bay and lagoon dredging proposals to ensure that appropriate dredge material is incorporated in the beach building and maintenance programs recommended for each littoral cell ...	This was done in the CRSMP (2009) - see Table 7 for typical quantities and timing of existing sediment sources, including harbor, bay and lagoon projects.
4. Review of water storage and reservoir studies and projects to encourage consideration of using beach compatible sediment from these sources as beachfill ...	This was done in the CRSMP (2009) - see Table 7 for typical quantities and timing of existing sediment sources, including water storage and reservoir projects.
5. Determine the feasibility and cost effectiveness of encouraging the placement of beach compatible material from land development grading at the region’s beaches. Develop regional guidelines for use by local jurisdictions in using this source of sand in the beach building and maintenance programs recommended for each littoral cell, if feasible and cost effective.	This was done through local SCOUPs. All cities have SCOUPs, except Del Mar and San Diego. SCOUP permits need to be updated periodically. SCOUP cost-effectiveness should be updated based on the newer monitoring requirements for biology being required by the CCC. As previously recommended, the region may wish to initiate biological monitoring to supplement the existing physical monitoring and to share the cost among multiple jurisdictions rather than individual cities.

Policies and Recommendations	Updates
6. Pursue the evolving legal interpretation of the "public trust doctrine" as it applies to beach sand for use in implementing recommendations 3, 4, and 5 ...	The concept of "sand rights" similar to "water rights" could be explored. While the Coastal Act requires consideration of impacts to local sand supply, there are projects outside of the coastal zone where a similar assessment is not conducted. A theory of sand rights would require that new projects, e.g., dams and sand/gravel mining, be designed and existing projects be reevaluated to mitigate interference with the system which transports sand to the beach. This theory of sand as a public resource to be protected would provide a legal basis for funding sand replenishment through fees, taxes and assessments.
7. Develop guidelines for the use of temporary methods of protecting shoreline property from storm damage, such as improved storm warning programs, the use of sand bags, and the use of temporary sand berms, for use by appropriate state, federal, and local agencies.	Sand bags are not feasible due to their lack of durability. Temporary winter sand dikes are effective and are used at multiple cities, e.g., Encinitas, Del Mar, and San Diego (Mission Beach and Ocean Beach)
8. Determine the feasibility and cost effectiveness of using beach compatible dredge material from lagoon and estuary enhancement in the region's beach building and maintenance program, as enhancement projects are planned. Incorporate sand from lagoon and estuary enhancement projects in the beach building and maintenance programs recommended for each littoral cell, if feasible and cost effective.	This was done for the Batiquitos Lagoon, San Dieguito Lagoon, and San Elijo Lagoon as part of the restoration projects. The remaining lagoon restoration to occur are at Buena Vista and Los Penasquitos Lagoons and this work will be done as part of those efforts.
9. Determine the feasibility and cost effectiveness of transporting sand from reservoirs, riverbeds (including commercial sandpits) and debris basins to the region's beaches ...	This still needs to be done. Traditional ideas may be expensive, inefficient, and environmentally impacting. New, creative ideas are needed to explore this.
10. Develop guidelines for land use planning, regulation, and development which encourage the continued contribution of sand to the region's beaches from natural sources … These guidelines should be coordinated with other land use planning programs and policies in the region such as open space planning efforts, and should be used by appropriate state, federal, and local agencies.	Guidelines developed at the local level (e.g., through Local Coastal Programs) should require surplus sand to go to the beach. However, the cost to permit, monitor, and mitigate small sand projects is cost-prohibitive. According to Encinitas who has a model SCOUP (2005), the cost threshold of what size sand project was cost effective was 40,000 cy and larger. It is important to update this analysis.

Policies and Recommendations	Updates
11. Determine the capacity of local transportation and parking facilities to accommodate increases in recreational beach use be provided for by the beach building and maintenance programs recommended for each littoral cell ...	No longer relevant.
12. Design and carry out a regional shoreline monitoring program to evaluate the effectiveness of the recommended actions. a. A minimum, low cost monitoring program would involve aerial photo measurements of beach width annually or semi-annually … B. A more effective monitoring program with more frequent beach width measurements and periodic measurements of littoral zone beach profiles should be pursued ...	This has been done. The existing physical monitoring program has provided critical data. As previously discussed, a biological monitoring program is needed to accompany it and provide a holistic picture of the environment.
13. An annual “State of the Region’s Beaches” report should be prepared by SANDAG to describe progress made in implementing the Strategy and identify problem areas that need emphasis.	This still needs to be done (see example from Newport Beach prepared by Moffatt & Nichol). Regional shoreline monitoring would be used to explain the trends in the shoreline position, the beach width, and the shorezone volumes over time. The report would then discuss the condition of the shoreline, its trends, and likely future condition. That information will be used to identify future actions to accomplish SANDAG’s goals from SPS.

Policies and Recommendations	Updates
Financing Recommendations	
1. Traditional state and federal funding sources such as the State Department of Boating and Waterways, the Coastal Conservancy and State Board Act grants and loans, and federal assistance through the U.S. Army Corps of Engineers should continue to be pursued by organizations implementing the Shoreline Preservation Strategy. Special sources of state and federal funds that may become available from time to time … should be pursued … It is anticipated that state and federal funds will cover only a portion of the total financing needs.	Currently, California State Park's Division of Boating and Waterways is an important funding source with its Beach Restoration and Erosion Control Programs. Although the USACE has projects in Encinitas/Solana Beach, the politics of obtaining federal funding make it a less reliable source. Local funds are needed and some cities haves Transient Occupancy Taxes (TOT) for beach nourishment that have been very useful as matches for funding from the State for RBSP projects.
2. The financing program should be developed on a regional basis to ensure equity and to build understanding and support ... It should take into account the cost incurred by cities to provide beach related functions such as lifeguard services, maintenance, insurance, etc.	RBSP I/II were funded by the Division of Boating and Waterways (85%) and local cities (15% based on length of shoreline per city (proportional).
3. The financing program should be designed to consider the high front end costs of beachbuilding and should be flexible to allow for the setting of priorities where program needs exceed funds available, and to incorporate new sources of financing as they become available. It should recognize that a major portion of the needed funds will have to come from local and regional sources.	Recommendations 3-7 describe financing program that is flexible, paid for, in part, by shoreline property owners, visitors, and locals. This financing program does not exist now and should be explored as a potential adaptation strategy as part of this project.

Policies and Recommendations	Updates
4. Shoreline property in the areas of the region where the beach building and maintenance programs are focused will receive major beach benefits from the program results, both directly from property protection and indirectly in terms of property value. A financing mechanism which includes shoreline property for an equitable share of the needed funds should be considered ...	This was used for determining the proportional funding required of each City to share the cost of each RBSP.
5. It is estimated that visitors to San Diego County account for about 20% of the region's beach users. A financing mechanism which collects an equitable share of the needed funds from visitors should be considered. Transient occupancy taxes are one source for these funds.	TOT taxes are in place in most cities and could be used to finance beach nourishment.

Policies and Recommendations	Updates
6. San Diego County residents and businesses benefit substantially from living close to the region's shoreline … A financing mechanism which targets residents for an equitable share of funds should be considered. a. There are several potential financing mechanisms that can be used to collect funds from residents. They include assessment district(s), a parcel tax, an increase in the local sales tax and an increase in property tax. b. A regional impact fee on new development for its fair share of costs could be considered. c. Creation of utility by local agencies which could charge for shore and beach services could be considered ...	Measure A was on the 2016 ballot as a half-cent sales tax which could be utilized for road repairs, transit improvements, traffic relief, safety and water quality improvements, and beach sand nourishment, among other projects. Measure A did not receive the two-thirds of votes necessary to pass.
7. Financing of the Shoreline Preservation Strategy should be coordinated with other Open Space and Natural Resource Financing needs and programs through the Regional Growth Management Strategy being developed by SANDAG. The SANDAG Regional Revenues Advisory Committee and Open Space Citizens Advisory Committee should include financing of the Shoreline Preservation Strategy in their work.	Measure A was on the 2016 ballot as a half-cent sales tax which could be utilized for road repairs, transit improvements, traffic relief, safety and water quality improvements, and beach sand nourishment, among other projects. Measure A did not receive the two-thirds of votes necessary to pass.
8. The first priority for use of public funds should be for protection, preservation, and enhancement of publicly owned resources.	Yes, this is still applicable.

Policies and Recommendations	Updates
Institutional Recommendations	
1. The Shoreline Erosion Committee and SANDAG should continue to coordinate shoreline preservation activities for the region, including the design studies and implementation of the beach building and maintenance programs for the region's shoreline problem areas.	The existing system works well and future actions can be taken to ensure SANDAG has legal protection for beachbuilding projects.
2. Financing and the cooperative institutional arrangements that may be needed to work to implement the Strategy should be developed through the cooperative work of the SANDAG Open Space Citizens Advisory Committee, Regional Revenues Advisory Committee, and the Shoreline Erosion Committee.	See Financing Recommendation 7.
3. Local jurisdictions and state and federal agencies will be responsible for a number of implementation actions, as specified in the recommendations. Some of these actions will need to be implemented locally through amendments to Local Coastal Programs (LCPs), General Plans, and ordinances ...	
4. The interjurisdictional nature of the recommended beach building and maintenance programs, and the significant amount of funds to be raised and expended to carry these programs out, could require additional cooperative intergovernmental arrangements for implementation ...The most appropriate types of intergovernmental arrangements will depend to some extent on the financing mechanism chosen ...	Yes, still applicable.

Policies and Recommendations	Updates
Implementation Recommendations	
1. The implementation of the Shoreline Preservation Strategy should provide for flexibility and latitude ...	And include updates for SLR projections and existing shoreline and habitat conditions.
2. The following implementation steps, and timing and cost estimates, illustrate major decisions and work tasks involved in implementing the Shoreline Preservation Strategy: a. Approval/Support of Strategy b. Scope of Work and Costs for Beach Building Design Studies c. Agreement to Fund and Carry Out Design Studies (Local Jurisdictions, State & Federal Agencies) d. Complete Engineering, Economic and Environmental Design Studies e. Agreement to Fund and Carry Out Shoreline Management Program (Local Jurisdictions, State & Federal Agencies) f. Fund and Implement Projects [paraphrased]	Periodically re-evaluate the individual actions in the SPS with the current science of SLR to determine effectiveness, cost effectiveness, and environmental sensitivity. Add sand retention strategies. Add public information sharing and collaboration strategies identified in this project.

Regional Sea Level Rise Adaptation Guidance for Transportation Infrastructure

Task 2.1 – Recommendations for how to update individual policy documents to reflect updated statewide guidance regarding climate change and sea level rise adaptation.

The following table summarizes policies and recommendations in the left column and describes recommendations for proposed updates given SANDAG projects and the best available science in the right column.

Regional Beach Sand Retention Strategy (SRS 2001)

- Sand retention strategies are recognized in the Shoreline Preservation Strategy (SPS 1993) as one of a number of tactics that can be used to complement the placement of sand on the region's beaches. Sand retention has the potential to increase the cost effectiveness of beach replenishment activities, and may even help to reduce potential environmental effects of beach filling by protecting sensitive resources such as reefs and lagoons from sedimentation, and possibly providing new habitat areas.

Policies and Recommendations	Updates
Economic analysis indicates that, based solely on a life cycle cost analysis, a sand retention strategy incorporating artificial sand retention structures appears warranted along the more erosive beaches in San Diego County. Conversely, such structures do not appear to be economically justified in more stable beach locations. This conclusion is based on costs, and does not quantitatively consider relative benefits between alternative strategies. Although the benefits of a wider beach are inherently included since the analysis is based on retaining the same amount of beach area, benefits not included are habitat enhancement (and detriment) and surfing enhancement (vs. loss of swimming beach).	Sea level rise (SLR) was not factored into the analysis, e.g., concept designs. SLR would affect the designs by requiring any retention structures to be higher to maintain their effectiveness during future higher water levels. Since the elevation of the structures would have to be higher, the footprints would have to be larger, increasing the cost of the structures. A structure should last approximately 100 years, so a retention structure would have to be adaptable and be able to be elevated and enlarged over time with sea level rise. Since the amount of sand needed for nourishment will increase over time, the cost savings and increased effectiveness from sand retention devices could be helpful to achieve the SPS (1993) goal of adding approximately 30 million cubic yards (mcy) of sand to the beaches and to increase shoreline resilience in the face of sea level rise.

Table 2-5 summarizes the sand retention strategies considered foreach city, based upon input from each city as well as the results of the needs/constraints/opportunities assessment.	Sand retention strategies considered for each city are dated. It would be helpful to contact city staff to see if there is still interest in these strategies or if others are preferred (e.g., groin, breakwater, or reef) and in what locations. For example, Carlsbad was willing to do a pilot project at South Carlsbad just north of Encinas Creek mouth, and it's unclear if this is still the case.
Artificial sand retention reefs were generally identified as the measure of choice. Given the limited knowledge and performance data for this type of structure in Southern California, efforts should be focused on expanding this knowledge base. Specific recommendations include: 1. Closely track performance of the Narrowneck Reef developments in Australia. 2. Augment findings of this study with the recently initiated study of sand retention reefs sponsored by the California Coastal Conservancy. 3. Update findings of this study with monitoring data from the Regional Beach Sand Project now underway. 4. Initiate a detailed measurement program of the physical features of existing natural sand retention reefs followed by physical model studies of any proposed artificial sand retention reef. 5. Construct a prototype sand retention reef in Southern California before full Implementation … A detailed shoreline monitoring program would be an essential element of this prototype-scale pilot study to assess both performance and impacts ...	These recommendations have not yet been implemented. Several of them are feasible to complete with existing data. The recommendations that can be done with existing data are: 1. Closely track performance of the Narrowneck Reef developments in Australia. 2. Augment with findings of the Case Studies of Natural Shoreline Infrastructure in Coastal California (Judge, J., et al. 2017), sponsored by the California Coastal Conservancy. 3. Update findings of this study with monitoring data from the previously completed Regional Beach Sand Projects
A prototype-scale pilot study of groin performance could also be considered in Oceanside. The temporary groin should be removable, and possibly adjustable. Detailed monitoring would be a critical element of project implementation, particularly due to the concerns regarding downcoast impacts.	Similar to the update above, it would be helpful to follow-up regarding the City of Oceanside's interest in this study. Oceanside lost interest in this, but may wish to revisit it considering the narrow beach throughout the City with the exception of Harbor Beach.

Regional Sea Level Rise Adaptation Guidance for Transportation Infrastructure

Task 2.1 – Recommendations for how to update individual policy documents to reflect updated statewide guidance regarding climate change and sea level rise adaptation.

The following table summarizes policies and recommendations in the left column and describes recommendations for proposed updates given SANDAG projects and the best available science in the right column.

Sand Compatibility and Opportunistic Use Program (SCOUP 2006)

This report presents a SCOUP Plan for implementing opportunistic beach replenishment (less than 150,000 cubic yards, cy) on a regional basis.

Policies and Recommendations	Updates
The SCOUP Plan identifies the following consistent with Coastal Sediment Management Workgroup (CSMW) objectives: Jurisdictional regulatory agencies, required permits and informational needs; • Specific considerations needed to establish and rank potential receiver sites within the littoral cell or other regional area; • Types of anthropogenic activities that could produce viable potential sources of sediment if located within an economic distance of the receiver site; • Testing protocols, criteria and checklists required to assess potential physical, chemical and biological impacts associated with the use of opportunistic materials, as well as establish compatibility between potential sediment sources and the approved receiver site(s); • Project design considerations including maximum volume, placement techniques, placement rates and location (typically based on biological or recreational concerns), and transportation methods/impacts (often associated with disturbance of nearby residents and economic considerations); • Biological and physical monitoring concerns and testing needed before, during and after project construction, as well as reporting requirements; • Description of user steps required to successfully implement a regional opportunistic program, including additional informational needs and project design considerations when using less-than-optimum source sands; and • Specific examples of ways to increase public education and awareness.	SCOUPs establish a process approved by regulatory agencies for environmentally-responsible use of opportunistic materials to nourish a pre-established receiver site(s) when those materials become available. Use of opportunistic material helps to offset the sediment deficient and can occur between less frequent, larger Regional Beach Sand Projects (RBSP). While the document doesn't mention sea level rise (SLR), SLR doesn't affect the regulatory processes and criteria establishing appropriateness and compatibility of potential sources with receiver sites. SCOUPs will become an increasingly important tool to implement beach nourishment in response to SLR. As such, it would be useful to evaluate if less stringent SCOUP requirements, e.g., placing sand in larger volumes, with a larger grain size distribution, or more frequently, could facilitate use of opportunistic materials for beach nourishment while still avoiding impacts. Monitoring data obtained through permitted SCOUPs, RBSP I/II, and San Elijo Lagoon Restoration nourishments could be used for this evaluation. Since the existing SCOUP requirements were, in large part, developed to avoid impacts to intertidal and reef resources, if biological monitoring were conducted to supplement the existing regional physical monitoring it would provide valuable information to evaluate if less stringent SCOUP requirements sufficiently avoid impacts. SCOUP permits are typically five years and applying for extensions every five years is time-consuming. It would be more cost-effective for local governments to be able to apply for 10-year SCOUP permits from regulatory agencies like the California Coastal Commission. Finally, it may be useful for local governments in Mission and San Diego Bays, i.e., San Diego, Coronado, National City and Chula Vista, to develop SCOUPs as a sea level rise adaptation strategy.

The SCOUP Plan presents a pilot project in the Oceanside littoral cell as an example of implementation. The pilot study identified the most appropriate receiver site to be South Oceanside Beach. The pilot SCOUP program proposes: • The maximum quantity of sediment to be placed at the receiver site over any calendar year is 150,000 cy (but the first two years should be limited to 20,000 cy for information gathering purposes). • Nourishment activities will be restricted during grunion runs, and particularly high beach-use times, such as major holidays. Minimal impacts to natural resources are expected at South Oceanside Beach. • Up to 100% of the total sand volume can be placed during the fall/winter seasons, but no more than one-third of the total volume should be placed during the spring/summer seasons (to reduce impacts to recreational beach use and biology from construction and turbidity); • Project design includes direct placement of optimum materials in a surface layer (berm) on the beach, and placement at the surfzone for less-than-optimum sands (with 15-45% fines content); • Monitoring of nourishment activities to identify turbidity and potential effects to biological resources, beach profiles, and recreation; and • That permits be pursued by City of Oceanside that has jurisdiction over the selected receiver site.	As discussed above, the criteria regarding the allowed sand quantities and thresholds is based on biological constraints, such that SLR doesn't affect the ability to implement beach nourishment per the listed parameters.

Regional Sea Level Rise Adaptation Guidance for Transportation Infrastructure

Task 2.1 – Recommendations for how to update individual policy documents to reflect updated statewide guidance regarding climate change and sea level rise adaptation.

The following table summarizes policies and recommendations in the left column and describes recommendations for proposed updates given SANDAG projects and the best available science in the right column.

Coastal Regional Sediment Management Plan (CRSMP 2009)

The purpose of the CRSMP was to:

- Facilitate solutions to beach erosion affecting infrastructure, recreation, public safety, public coastal access, and habitat, and address sea level rise (SLR);
- Fulfill the statewide sediment management strategy of the California Coastal Sediment Management Workgroup (CSMW) within the region; and
- Enable SANDAG to implement their vision (SPS 1993) and establish a process to address beach erosion through effective management of sediment resources throughout the region.

Policies and Recommendations	Updates
Solutions	
Approx. 60 presently-known sediment source sites, including various types of upland sources, coastal wetlands and harbors, and sands located offshore.	The CRSMP acknowledges that SANDAG may need to reconsider the CRSMP on a five- to ten-year basis to keep the plan current. Updates to Table 7 are needed to reflect current sediment source sites.
27 sites along the coast from Oceanside to Imperial Beach, documented to be eroding or with a deficit of sediment, have been identified to be of concern to state, federal, or local agencies.	Updates to Table 12 are needed based on monitoring data and the Coastal Sediment Management Workgroup database (Beach Erosion Concern Areas).

Solutions presented within this CRSM Plan are targeted to address the effects of sea level rise at the critical receiver sites discussed herein. Other solutions, such as managed retreat, may be feasible and appropriate at other locations along the coastline.	Two Management Alternatives are presented for the addition of new sediment at receiver sites to counteract the effects of the reduced natural sediment supply (400,000 cubic yards per year or cy/yr). Management Alternative One involves nourishment only (1,000,000 cy/yr), while Management Alternative Two involves nourishment (500,000 cy/yr) and installation of sediment management devices to retain more sediment over time. Both Management Alternatives assume that new sediment from outside the littoral cell will come from opportunistic programs and/or from offshore sand dredging. Updates to these Management Alternatives (and Tables 13, 14, and 15) comparing the amount of sediment placed over time within each littoral cell against the target rate needed to meet the regional goal of adding approximately 30 million cubic yards (mcy) of sand to the beaches (SPS 1993) are needed in light of sea level rise. See recommended updates related to the SPS (1993) for consideration of nourishment sand volumes, costs, etc. needed in the near-term (0-1.5 ft. SLR), mid-term (1.5-3 ft. SLR), and long-term (3-5.5 ft. SLR). See recommended updates related to SRS (2001) related to design, cost, adaptability, etc. of sand retention structures.
Data gaps	
Effects of appropriate sediment management devices on reducing future nourishment quantities, the time-frame to accomplish the 30 mcy goal for the region, and the ability to adjust to sea level rise need to be determined … Update the Shoreline Preservation Strategy to include new information from the Regional Beach Sand Projects, and advances in science and technology since its adoption.	This policy analysis review is a first step in addressing this data gap.
Appropriate proportional placement scenarios for lagoon and harbor maintenance need to be developed through evaluation of the most recent longshore sediment transport data from Scripps Institution of Oceanography's (SIO's) Coastal Data Information Program (CDIP)	This is still needed along with projections about how longshore sediment transport may change over the next 20 to 50 years, e.g., if transport is predicted to be more from the south, then it will affect optimal sand placement locations.
Quantification of the risk to sensitive hard-bottom areas from sedimentation relative to sediment placement volume or frequency is necessary	This is still needed. Lessons learned from monitoring of other projects such as the first RBSP, the San Elijo Lagoon Restoration Project beach nourishment, and future Broad Beach Restoration may inform this process.

Evaluation of actual project performance as compared to model predictions will improve the models for future use	This hasn’t been done because given limited resources the focus of the Regional Beach Sand Projects (RBSP I/II) has been getting sand to the beach. Since RBSP is a “shovel ready” sea level rise adaptation strategy, it may be possible to apply for funding to conduct this work.
Utilize data from pilot projects such as the Tijuana Estuary Sediment Fate and Transport Science Study	The Tijuana River Demonstration Project was conducted in 2008 and 2009 between the mouth of the Tijuana River, California, and the U.S.-Mexico international border. This project utilized over 40,000 cy of sediment from a debris basin within Border Field State Park that consisted of approximately 40 percent fine-grained sediment by mass. This sediment was placed directly within the intertidal sandy beach over an interval of several weeks. It was observed to disperse quickly in nearshore waters but was strongly influenced by surf zone currents, which delivered sediment more than (0.6 miles up- and downcoast from the emplacement site). Sedimentation in the project area was limited to a zone immediately within and offshore of the project site, and the majority of sediment moved far offshore of the project site in response to waves and currents. This project showed that sand with a high proportion of silts and clays, referred as less than optimal sand in the SCOUP document (2006), did not harm the nearshore habitat, e.g., cause excessive turbidity. Therefore, loosening of the restrictions on grain size may be warranted on a case-by-case basis to allow for nourishment with less than optimal sand, which would increase the number of potential sand sources and beach nourishment opportunities using opportunistic material. It would be valuable to conduct another similar pilot project with a research institution such as U.S. Geological Survey or Scripps Institution of Oceanography in the Oceanside Littoral Cell to apply findings to that portion of the region.

APPENDIX E

Potential Sea Level Rise Adaptation Strategies

Category	Asset (north to south)	SLR Scenario				Potential Adaptation Strategies
		2.5 ft Inundation	*2.5 ft Flooding*	*6.6 ft Inundation*	*6.6 ft Flooding*	
Roadways	Hwy 101 @ San Luis Rey River				X	1. Protect (e.g., increase bridge abutment rock level) 2. Accommodate (e.g., elevate bridge and roadway) 3. Retreat (e.g., reduce number of lanes and divert traffic to less vulnerable roadway). Complete roadway retreat may face prohibitive complications.
	Hwy 101 @ Loma Alta Creek		X		X	1. Protect (e.g., increase bridge abutment rock level) 2. Accommodate (e.g., elevate bridge and roadway) 3. Retreat (e.g., reduce number of lanes and divert traffic to less vulnerable roadway). Complete roadway retreat may face prohibitive complications.
	I-5 @ Buena Vista Lagoon Bridge				X	This bridge will be replaced as part of future phases of the NCC Program and will be assessed using the best available sea level rise science and guidance.
	Carlsbad Blvd @ Buena Vista Lagoon Bridge			X	X	1. Landward relocation of public assets 2. Dune or wetland restoration 3. Beach nourishment 4. Sand retention with nourishment 5. Elevating structures 6. Coastal armoring Item 5 applies best to this asset. (Moffatt & Nichol 2017a)
	Carlsbad Blvd @ Las Encinas Creek		X	X	X	1. Close one lane of southbound Carlsbad Blvd 2. Retreat all traffic to northbound Carlsbad Blvd 3. Raise existing revetment 4. Construct seawall 5. Beach nourishment 6. Winter sand dikes 7. Nearshore reef 8. Elevate southbound roadway on causeway 9. Hybrid of the above alternatives (Moffatt & Nichol 2017b)
	Carlsbad Blvd @ Batiquitos Lagoon Bridge			X	X	1. Landward relocation of public assets 2. Dune or wetland restoration 3. Beach nourishment 4. Sand retention with nourishment 5. Elevating structures 6. Coastal armoring Item 5 applies best to this asset. (Moffatt & Nichol 2017b)
	Hwy 101 @ San Elijo Lagoon Bridge		X		X	San Elijo Lagoon Bridge: 1. Seismic retrofit required of bridge in short term. Long-term would be bridge replacement with higher and longer bridge. Hwy 101 at Cardiff State Beach north parking lot: 1. Short-term protection with cobble berm 2. Long-term protection with raised parking lot and seawall (Moffatt & Nichol 2018) Hwy 101 at Cardiff State Beach south of the Chart House: 1. Cardiff Living Shoreline Project constructed Spring 2019 to increase coastal protection for Hwy 101.
	I-5 @ San Dieguito Lagoon Bridge		X		X	This bridge is in the process of being replaced as part of Phase 1 of the NCC Program and sea level rise is not expected to pose any risk to the proposed bridge (analyzed up to 66 in. of sea level rise with a fluvial flood).
	Camino Del Mar @ San Dieguito Lagoon Bridge		X		X	City of Del Mar is in the process of replacing the bridge, which will require sea level rise analysis.
	I-5 @ Carmel Valley Creek Bridge		X		X	This bridge will be replaced as part of future phases of the NCC Program and will be assessed using the best available science sea level rise science and guidance.

Potential Sea Level Rise Adaptation Strategies

Category	Asset (north to south)	SLR Scenario				Potential Adaptation Strategies
		2.5 ft Inundation	*2.5 ft Flooding*	*6.6 ft Inundation*	*6.6 ft Flooding*	
Active Transportation Program (ATP)	San Luis Rey Bike Path	X		X	X	1. Protect (e.g., separate trail from lagoon by a levee) 2. Accommodate (e.g., flood-proof the trail so disruption is only temporary or elevate on boardwalk) 3. Retreat (e.g., relocate trail to the roadside)
	San Dieguito River Park Trail	X	X	X	X	1. River channel dredging 2. Reservoir management 3. Levees 4. Elevate structures 5. Relocate public infrastructure (ESA 2018)
	Trans County Trail	X	X	X	X	1. Protect (e.g., separate trail from lagoon by a levee) 2. Accommodate (e.g., flood-proof the trail so disruption is only temporary or elevate on boardwalk) 3. Retreat (e.g., relocate trail to the roadside)
Transit	Railroad @ Buena Vista Lagoon Bridge		X		X	This bridge will be replaced as part of future phases of the NCC Program and will be assessed using the best available science sea level rise science and guidance. 1. Landward relocation of public assets 2. Dune or wetland restoration 3. Beach nourishment 4. Sand retention with nourishment 5. Elevating structures 6. Coastal armoring Item 5 applies best to this asset. (Moffatt & Nichol 2017a)
	Railroad @ San Dieguito Lagoon (South Abutment)		X	X	X	This bridge will be replaced as part of future phases of the NCC Program and will be assessed using the best available science sea level rise science and guidance.
	COASTER @ Del Mar Bluffs		X		X	SANDAG is currently working to stabilize the Del Mar Bluffs. Previous Phases 1, 2, and 3 of stabilizing the Del Mar Bluffs were completed in 2003, 2007, and 2009. Future improvements to this area may involve a tunnel or trench to remove the tracks from the bluffs. Future track replacements will be assessed using the best available science sea level rise science and guidance.
	COASTER @ Los Peñasquitos Lagoon		X		X	Improvements to these railway bridges are pending a final decision on whether a trench or tunnel is built in the City of Del Mar, noted above, and will be assessed using the best available science sea level rise science and guidance.
Roadways	SR-75		X	X	X	For the Imperial Beach: 1. Hardening and armoring of the entire Imperial Beach coastline 2. Managed retreat or phased relocation 3. "Business-as-usual" sand nourishment 4. Hybrid dune and cobble approach 5. Five groins with associated sand nourishment (Revell Coastal 2016) It is anticipated that improvements to this facility would be coordinated with other proposed adaptation projects for transportation facilities surrounding the San Diego Bay. These improvements would likely require a coordinated effort between the appropriate bayfront cities, Port of San Diego, MTS, Caltrans, and SANDAG.

Potential Sea Level Rise Adaptation Strategies

Category	Asset (north to south)	SLR Scenario				Potential Adaptation Strategies
		2.5 ft Inundation	*2.5 ft Flooding*	*6.6 ft Inundation*	*6.6 ft Flooding*	
Active Transportation Program (ATP)	Ocean Beach Bike Path				X	1. Protect (e.g., levees or raised revetment) 2. Accommodate (e.g., elevate on boardwalk) 3. Retreat (e.g., relocate bike path inland) The Ocean Beach Bike Path is elevated higher than much of downtown Ocean Beach. Therefore, significant City of San Diego planning is anticipated to address Ocean Beach vulnerabilities.
	N Harbor Drive Bike Path		X	X	X	1. Protect (e.g., raised seawall/bulkhead to keep water out) 2. Accommodate (e.g., bike path elevated with fill, essentially creating a levee) 3. Retreat (e.g., relocate bike path away from waterfront) The Embarcadero Bike Path and N Harbor Drive Bike Path will be among the first land-based assets flooded in downtown City of San Diego and will likely be part of city-wide adaptation planning. It is anticipated that improvements to this facility would be coordinated with other proposed adaptation projects for transportation facilities surrounding the San Diego Bay. These improvements would likely require a coordinated effort between the appropriate bayfront cities, Port of San Diego, MTS, Caltrans, and SANDAG.
	Embarcadero Bike Path	X	X	X	X	1. Protect (e.g., raised seawall/bulkhead to keep water out) 2. Accommodate (e.g., bike path elevated with fill, essentially creating a levee) 3. Retreat (e.g., relocate bike path away from waterfront) The Embarcadero Bike Path and N Harbor Drive Bike Path will be among the first land-based assets flooded in downtown City of San Diego and will likely be part of city-wide adaptation planning. It is anticipated that improvements to this facility would be coordinated with other proposed adaptation projects for transportation facilities surrounding the San Diego Bay. These improvements would likely require a coordinated effort between the appropriate bayfront cities, Port of San Diego, MTS, Caltrans, and SANDAG.
	Sweetwater Loop & River Trail	X	X	X	X	1. Protect (e.g., separate trail from river with flood-proof wall) 2. Accommodate (e.g., elevate above I-5) 3. Retreat (e.g., relocate inland) The vulnerability for this trail stems from the low-point under I-5. Due to the infeasibility of raising I-5 in order to raise the trail, the Sweetwater Loop trail could be maintained as a floodable asset. It is anticipated that improvements to this facility would be coordinated with other proposed adaptation projects for transportation facilities surrounding the San Diego Bay. These improvements would likely require a coordinated effort between the appropriate bayfront cities, Port of San Diego, MTS, Caltrans, and SANDAG.
	Bayshore Bikeway	X	X	X	X	For the Imperial Beach: 1. Elevate critical roads including the Bayshore bike path. 2. Amend the City of Imperial Beach's Capital Improvement Plan to add addition (Revell Coastal 2016) It is anticipated that improvements to this facility would be coordinated with other proposed adaptation projects for transportation facilities surrounding the San Diego Bay. These improvements would likely require a coordinated effort between the appropriate bayfront cities, Port of San Diego, MTS, Caltrans, and SANDAG.
Transit	Railroad & Green Line Trolley @ Downtown		X	X	X	Blue Line, Orange Line, and Green Line Trolley flooding is anticipated to occur simultaneously with or after flooding of other City of San Diego critical assets such as the Convention Center and Naval port infrastructure. Trolley line sea level rise adaptation is anticipated to be folded into a greater downtown sea level rise adaptation effort. Adaptation strategies for the trolley lines are, therefore, recommendations for coordination and joint sea level rise planning between MTS, the bayfront cities, and SANDAG.
	Orange Line Trolley @ Downtown			X	X	
	Blue Line Trolley @ Downtown			X	X	
	Blue Line Trolley @ North National City		X	X	X	