Appendix I. Vulnerability Assessment Detailed Methodology

In total four vulnerability assessments were carried out, analyzing roads and bridges affected by sea level rise and storm surge. Each scenario set has a separate vulnerability methodology, but a broad description will help understand the tables below. Each vulnerability index sought to balance both the physical impact of sea level rise (e.g. extent of flooding, height of asset) with social impact indicators (e.g. use level, ridership) using a weighted average.

Road segments were grouped in the GIS environment by each of the analysis categories used in the analysis. For example if a road crosses a municipal boundary it will be split into a separate segment at the boundary. If the road changes functional classification the road was split at the point of that change. Each inundation scenario represented a different segment. As a result any given road could be split into a very large number of segments. For the purposes of the final assessment, these segments were scored by name and municipality. For example all the roads called “Memorial Boulevard” in Providence were scored together. As each analysis variable carried a different score, a way needed to be found to fairly average these scores. This was done with another kind of weighted average. The full inundation length for each road was found in each municipality. The length of each segment was divided by the total length to find the percentage each segment represented of the total. Each segment was then scored individually, and the scores were multiplied by the length percentage. These scores were then summed to reach the final road score.

For each Indicator a numeric assignment was made between one and ten. This could be done in two ways. When staff wanted to describe an indicator that either did or did not exist, the numeric assignment would be either 0 or 10. For example, a road either is (10) or is not (0) an evacuation route. Other characteristics represent more of a continuum, for example the number of trips over a bridge on an average day. In this case assignments were made in such a way that the most impactful characteristics were assigned a 10 while less impactful characteristics received lower scores. In the case of the daily trips over a bridge, high medium and low classes were created based on the number of trips, with the high class receiving an assignment of ten, medium receiving a 7, and the low receiving a 3.

Scenario Sets

	Sea Level Rise	Storm Surge
Road	SLR-RD	Surge-RD
Bridge	SLR-BR	Surge-BR

To create a weighted average, the numeric assignments were multiplied by an assigned weight based on the SPP staff’s professional judgement about which indicators were more impactful in determining the scale of hazard and systemic importance. The weight is, in effect, a percentage used to determine how much the numeric scores contribute to the final score. So for example staff could have chosen to give the evacuation route numeric a weight of 0.5 or 50%. If they had chosen to do so, and a given asset was in fact an evacuation rout (numeric score of 10), then the evacuation rout numeric would have contributed 5 points to the final score. As will be seen below, this was not the weight given to the evacuation route score, the weight of 50% was used for discussion purposes only.

In order to make the scores easier to balance and the equations easier to quality control, staff designed the weighted average so that the hazard scores and the system scores were given an equal weight, and so that the highest score possible is 10. It follows that the highest possible hazard or system score is 5. This balancing is advisable for quality control purposes but is not strictly necessary. If an agency conducting a similar analysis wanted to value the hazard score over the system score, they could easily make the weight of the hazard 60% and the weight of the system 40%, or they could set up the numeric scores such that the highest possible score was 15. The only thing strictly necessary for a weighted average equation to remain coherent is that all the weights sum to 100%.

The indicators, the scoring rubric, and the relative weightings that were used by SPP in the vulnerability assessment are included in the tables below:

Variables Used for Vulnerability Ranking of Roads Affected by Sea Level Rise				
Type	Indicator	Source	Numeric Assignment	Weight
Hazard	Length of Road Innindated at 1 Foot of SLR	RIDOT Roads Layer and STORMTOOLS	0-15 feet = 3, 15-100 feet = 7, 100+ feet = 10	0.5
Hazard	Length of Road Innindated at 3 Feet of SLR	RIDOT Roads Layer and STORMTOOLS	0-100 feet = 3, 100-800 feet = 7, 800+ feet = 10	0.5
Hazard	Length of Road Innindated at 5 Feet of SLR	RIDOT Roads Layer and STORMTOOLS	0-500 feet = 3, 500-1500 feet = 7, 1500+ feet = 10	0.5
Hazard	Length of Road Innindated at 7 Feet of SLR	RIDOT Roads Layer and STORMTOOLS	0-1000 feet = 3, 1000-2000 feet = 7, 2000+ feet = 10	0.5
System	Functional Classification	RIDOT Roads Layer	See Table Below	0.3
System	Intermodal	RIPTA Routes, RIDOT Bike Layer	10	0.1
System	Evacuation Route	RIDOT Evacuation Routes Layer	10	0.1

Variables Used for Vulnerability Ranking of Roads Affected by 100 Year Storm Surge Event Plus Sea Level Rise				
Type	Indicator	Source	Numeric Assignment	Weight
Hazard	Length of Road Innindated With No SLR	RIDOT Roads Layer and STORMTOOLS	0-10 feet = 3, 10-50 feet = 7, 50+ feet = 10	0.5
Hazard	Length of Road Innindated With 1 Foot of SLR	RIDOT Roads Layer and STORMTOOLS	0-15 feet = 3, 15-100 feet = 7, 100+ feet = 10	0.5
Hazard	Length of Road Innindated With 3 Feet of SLR	RIDOT Roads Layer and STORMTOOLS	0-100 feet = 3, 100-800 feet = 7, 800+ feet = 10	0.5
Hazard	Length of Road Innindated With 5 Feet of SLR	RIDOT Roads Layer and STORMTOOLS	0-500 feet = 3, 500-1500 feet = 7, 1500+ feet = 10	0.5
Hazard	Length of Road Innindated With 7 Feet of SLR	RIDOT Roads Layer and STORMTOOLS	0-1000 feet = 3, 1000-2000 feet = 7, 2000+ feet = 10	0.5
System	Functional Classification	RIDOT Roads Layer	See Table Below	0.3
System	Intermodal	RIPTA Routes, RIDOT Bike Layer	10	0.1
System	Evacuation Route	RIDOT Evacuation Routes Layer	10	0.1

Functional Classification	Weight
Interstate	10
Freeways and Expressways	9
Principal Arterial	8
Minor Arterial	6
Major Collector	4
Minor Collector	2
Local	2

Variables Used for Vulnerability Ranking of Bridges Affected by Sea Level Rise				
Type	Indicator	Source	Numeric Assignment	Weight
Hazard	Freeboard Relative to 7 Feet of SLR	RIDOT Bridge Section	0" or less = 10, 0"-14" = 8, 14"-28"= 4, 28"-42" = 2, 42" or greater = 0	0.2
Hazard	Type of Bridged Feature	RIDOT Bridge Section	MHHW=10, Water=0, Land= -5	0.1
Hazard	Bridge Access at 7 Feet of SLR	RISPP, STORMTOOLS, RIDOT Roads Layer	Access Clear = 0, Access Problem = 10	0.2
System	Annual Average Daily Travel	RIDOT Bridge Section	0-1 = 0, 2-5000 = 3, 5000-15000 = 7, 15000+ = 10	0.3
System	Intermodal Facility	RIPTA Routes, RIDOT Bike Layer	10	0.1
System	Evacuation Route	RIDOT Evacuation Routes Layer	10	0.1

Variables Used for Vulnerability Ranking of Bridges Affected by 100 Year Storm Surge Event Plus Sea Level Rise				
Type	Indicator	Source	Numeric Assignment	Weight
Hazard	Freeboard Relative to Surge+7 Feet of SLR	RIDOT Bridge Section	0" or less = 10, 0"-69" = 8, 69"-166"= 4, 166" or greater = 0	0.2
Hazard	Type of Bridged Feature	RIDOT Bridge Section	MHHW=10, Water=0, Land= -5	0.1
Hazard	Bridge Access with Surge+7 Feet of SLR	RISPP, STORMTOOLS, RIDOT Roads Layer	Access Clear = 0, Access Problem = 10	0.2
System	Annual Average Daily Travel	RIDOT Bridge Section	0-1 = 0, 2-5000 = 3, 5000-15000 = 7, 15000+ = 10	0.3
System	Intermodal Facility	RIPTA Routes, RIDOT Bike Layer	10	0.1
System	Evacuation Route	RIDOT Evacuation Routes Layer	10	0.1

An example:

A road is forecast to have 40 linear feet inundated at five feet of sea level rise and 60 at seven feet of sea level rise. The road is not an evacuation rout and does contain an intermodal facility, and is functionally classified as a minor arterial. Since 40+60=100, the segment inundated at five feet of sea level rise (Segment A) will represent 40% of the final score, and the segment inundated at seven feet (Segment B) will represent 60% of the final score. Since Segment A is less than 500 feet in length and is inundated at five feet of sea level rise, it gets a numeric score of 3 with a weight of 0.5 for a hazard score of 1.5. Since Segment B is less than a thousand feet in length and is inundated at 7 feet of sea level rise, it receives a numeric score of 3 with a weight of 0.5 for a hazard score of 1.5. To bring these together, the scores must be multiplied by the length percentage thusly: (1.5*40%)+(1.5*60%)=1.5. Since both segments are not evacuation routes they do not receive any score for that variable. Since both are intermodal facilities, they receive a numeric score of 10 with a weight of 0.1, they each receive an intermodal score of 1. Both segments also share the functional classification of minor arterial, which receives the numeric score of 6 and the weight of 0.3, meaning that each segment receives 1.8 points from its functional classification. The preliminary system score for each segment is therefore the evacuation rout points plus the intermodal points plus the functional classification points, or in this case 0+1+1.8=2.8. To find the final system score, the length percentages are once again used thusly: (2.8*40%)+(2.8*60%)=2.8. Since the weights have already been incorporated into the equations , the hazard score and the system score can now simply by added together to find the final vulnerability score of 1.5+2.8=4.30. These equations can be executed simply using Microsoft excel or any similar spreadsheet based platform.