Infrastructure Vulnerability in a Changing Climate

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DEPARTMENT OF TRANSPORTATION

Office of Sustainability and Public Health

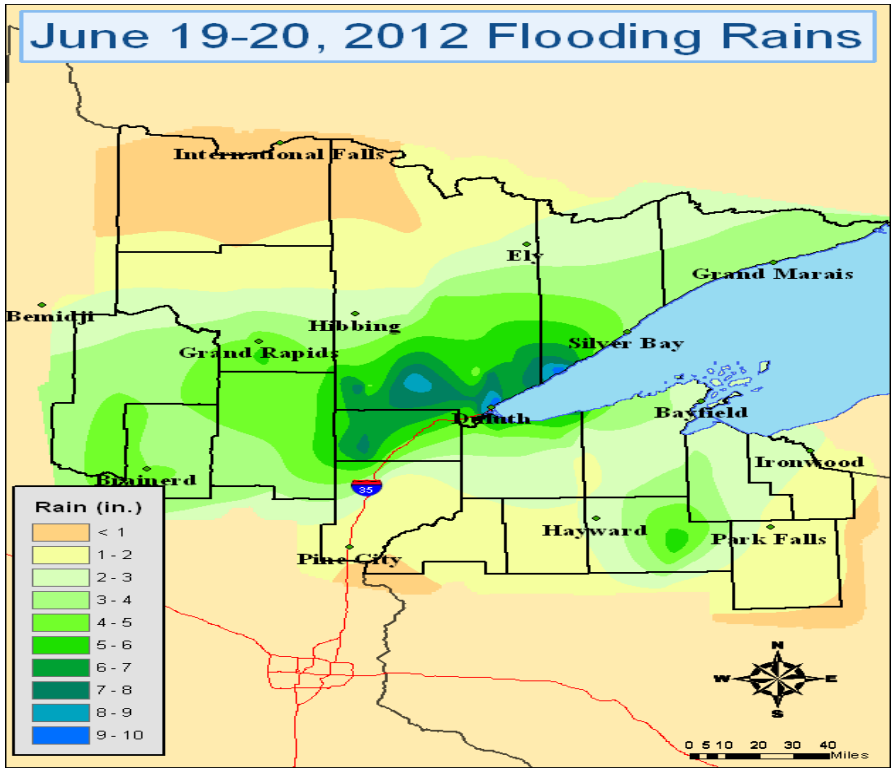
Metric	Target	Results
Sector Level Total annual GHG emissions generated by Minnesota's transportation system	29,500,000 tons CO_2e	41,842,898 tons CO_2e 2018
State Highway Construction Total annual GHG emissions from the fuel and materials used to construct MnDOT projects	252,500 metric tons CO_2e	228,245 metric tons CO_2e 2017
MnDOT GHG Emissions -		
Facilities Total annual GHG emissions generated from energy used by MnDOT-owned facilities	21,800 metric tons CO_2e	27,012 metric tons CO_2e 2018
Fleet Total annual GHG emissions generated from fuel used by the MnDOT-owned fleet	26,500 metric tons CO_2e	43,028 metric tons CO_2e 2018

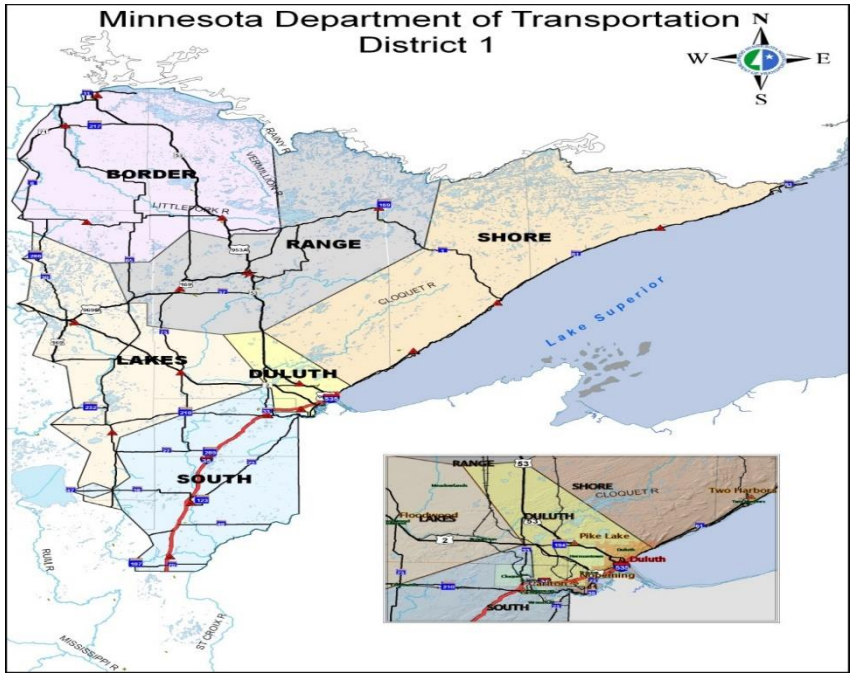
Climate Change and Transportation

- Warmer
- Wetter

Example:

- Change in freeze/thaw cycles?
- Increase in salt use?





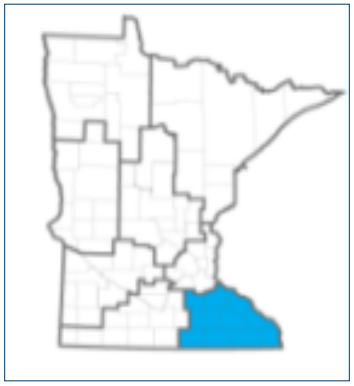
Vulnerability Pilot Project

Objectives

- Better understand the trunk highway network's risk from flash flooding
- Identify cost-effective options to improve the network's resiliency
- Support MnDOT's asset management planning
- Provide feedback to FHWA on the Draft Framework

Pilot Project Overview

- Phase 1: System-wide vulnerability assessment
  - High-level screen of trunk highway network in Districts 1 & 6

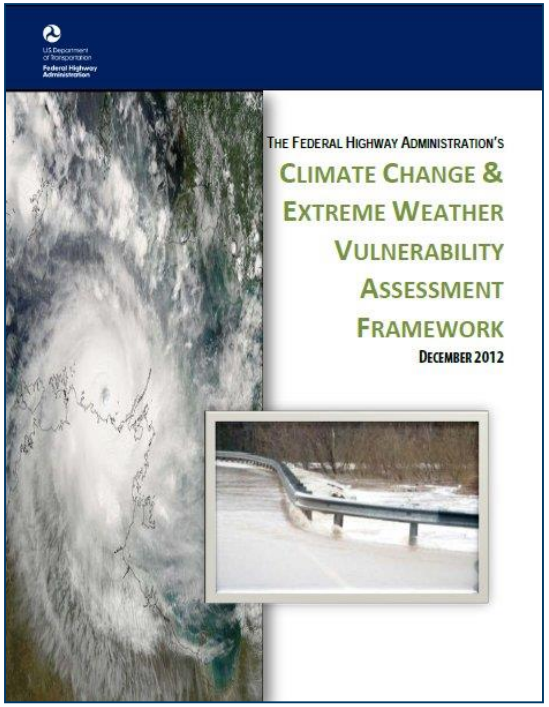


- Phase 2: Facility-level adaptation analysis
  - Two high risk facilities (one in each district)

Defining Vulnerability

"Climate change ***vulnerability*** in the transportation context is a function of a transportation system's *exposure* to climate effects, *sensitivity* to climate effects, and *adaptive capacity*."
(Vulnerability Framework)

- ***Exposure*** – whether the asset or system is located in an area experiencing direct impacts of climate change
- ***Sensitivity*** - how the asset or system fares when exposed to an impact
- ***Adaptive capacity*** - the systems' ability to adjust or cope with existing climate variability or future climate impacts



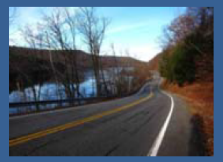
System wide Vulnerability Assessment Approach

Identify Assets of Interest


Bridges


Large culverts


Pipes


Roads paralleling floodplains

Calculate the Vulnerability Scores for Each Asset

Sensitivity

- Capacity to handle higher flows
  - % change in peak design flow required for overtopping (based on StreamStats)
- Asset condition
  - Pavement condition (roads)
  - Scour rating (bridges)
  - Substructure condition (bridges)
  - Channel condition (bridges and large culverts)
  - Culvert condition (large culverts)
  - Pipe condition (pipes)

Exposure

- Stream velocity
- Previous flooding issues
- Belt width to span length ratio (bridges, large culverts, pipes)
- Belt width to floodplain width ratio (roads)
- % of total roadway length parallel to the floodplain at risk of erosion from the stream channel (roads)
- % forest land cover in drainage area (bridges, large culverts, pipes)
- % of drainage area not covered by lakes & wetlands (storage capacity)
- % urban land cover in drainage area

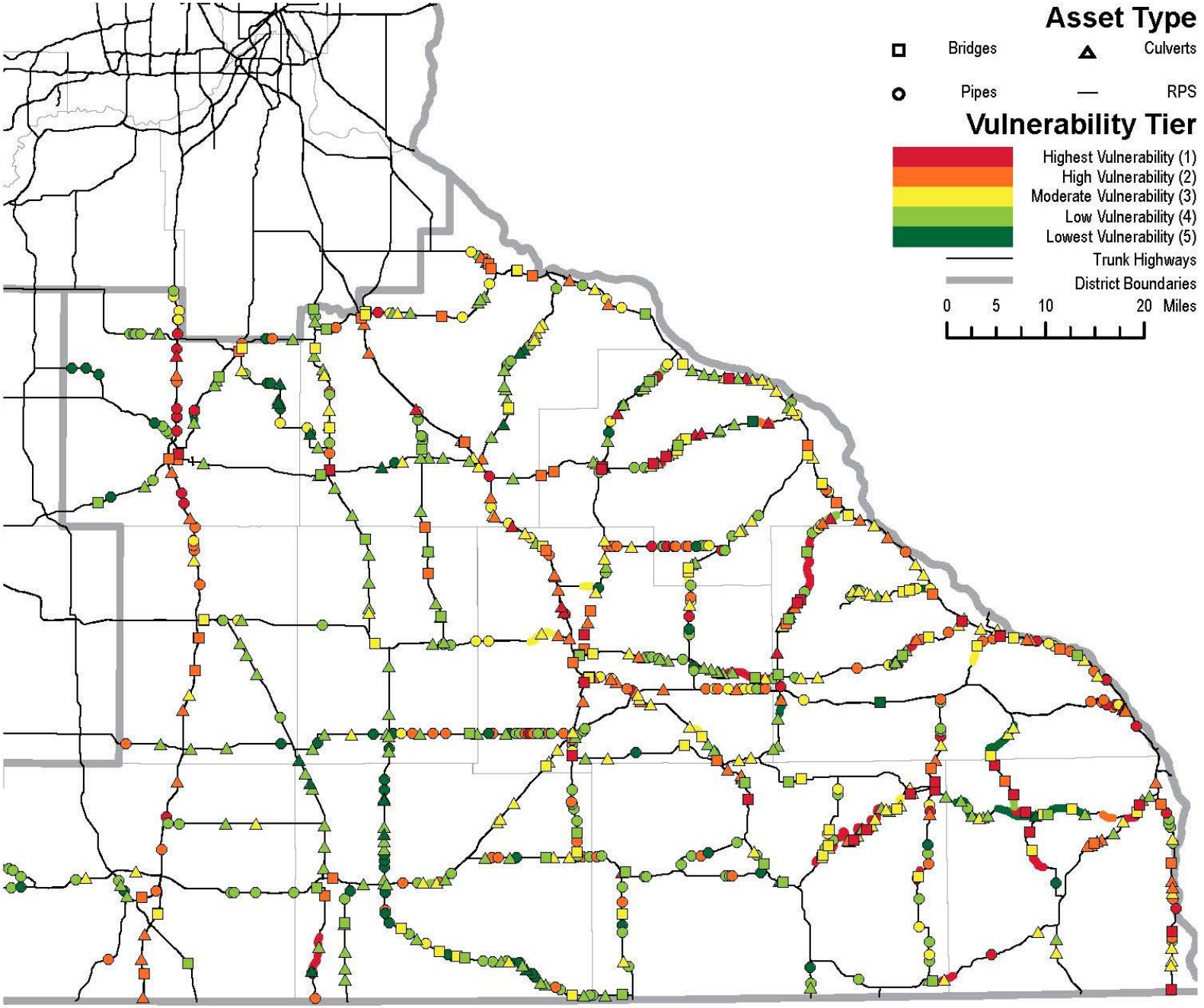
Adaptive Capacity

- Average annual daily traffic (AADT)
- Heavy commercial average daily traffic (HCADT)
- Detour length
- Flow control regime (bridges, large culverts, and pipes)

Rank Flood Vulnerabilities by District

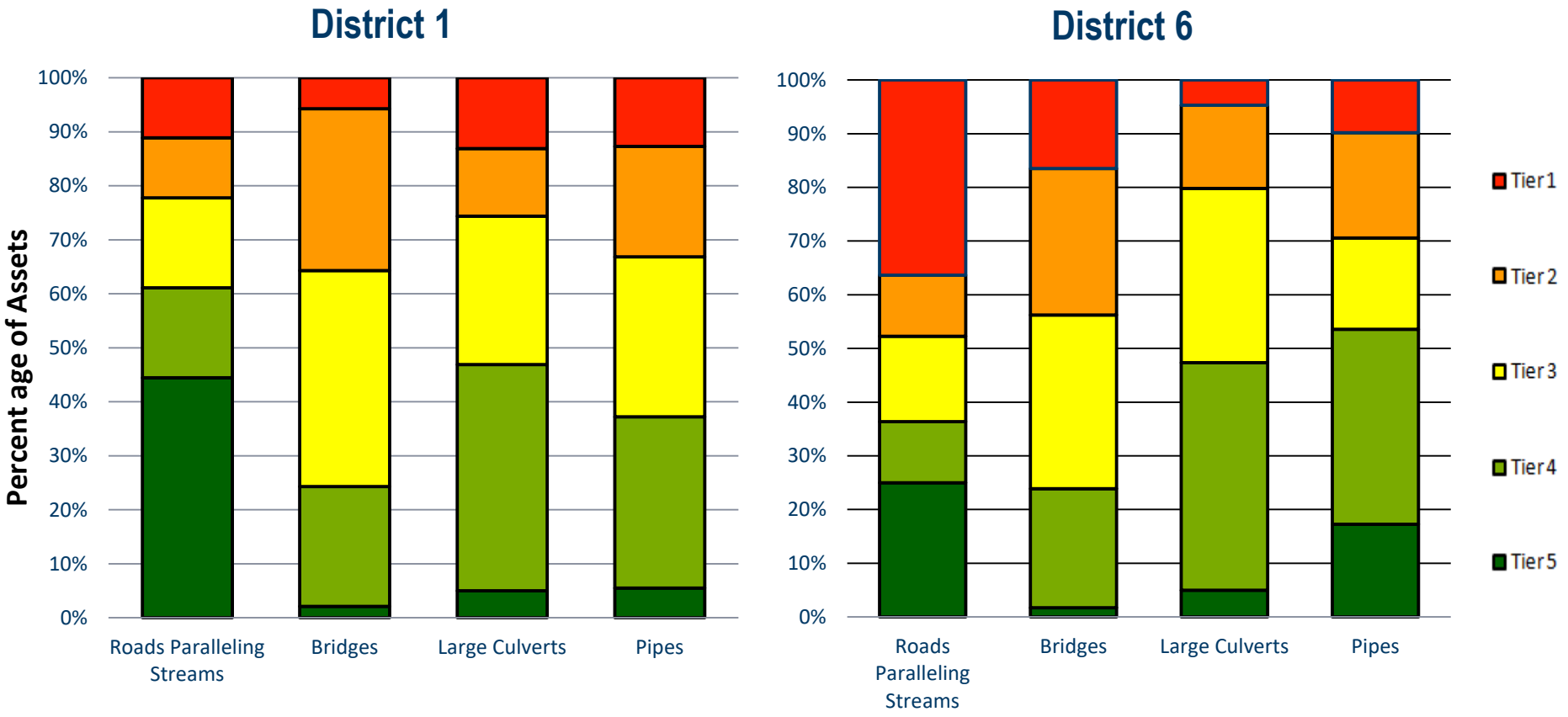
Number of Assets Scored

	Bridges	Large Culverts	Pipes	Roads Paralleling Streams (segments)	Total
District 1	140	160	543	18	**861**
District 6	176	361	377	44	**958**
Total	**316**	**521**	**920**	**62**	**1,819**



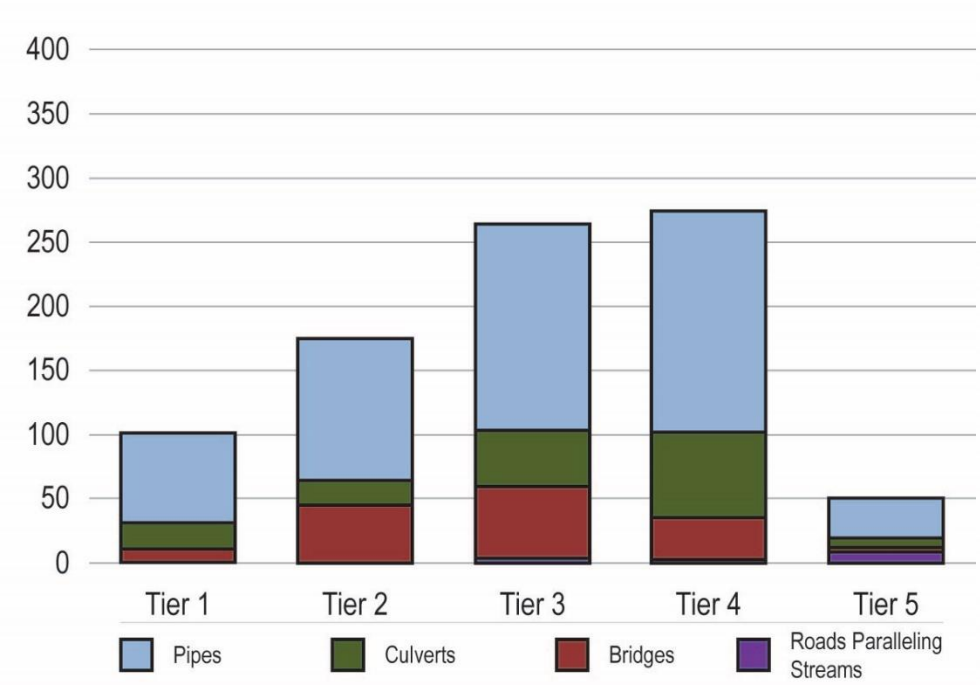
Highly vulnerable (Tier 1 and 2) assets are not necessarily in imminent danger of flooding, nor are lower vulnerability assets immune from flooding. Values are indicators of relative vulnerability compared with other assets in the same district.

Vulnerability By Asset Type

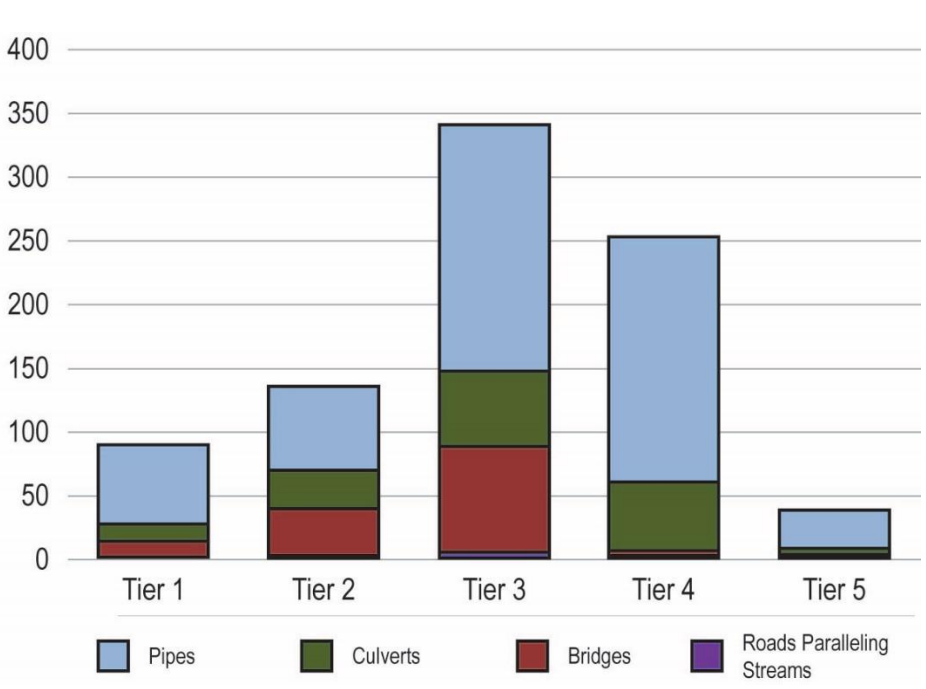


Vulnerability By Asset Type: District 1

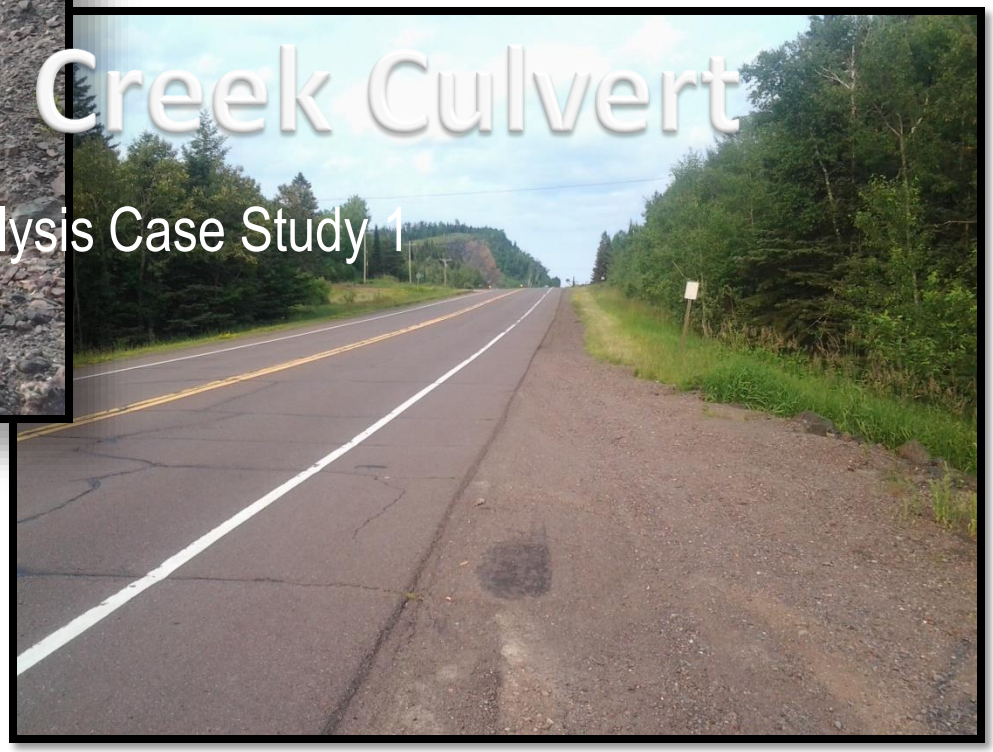
Exposure, Sensitivity & Adaptive Capacity



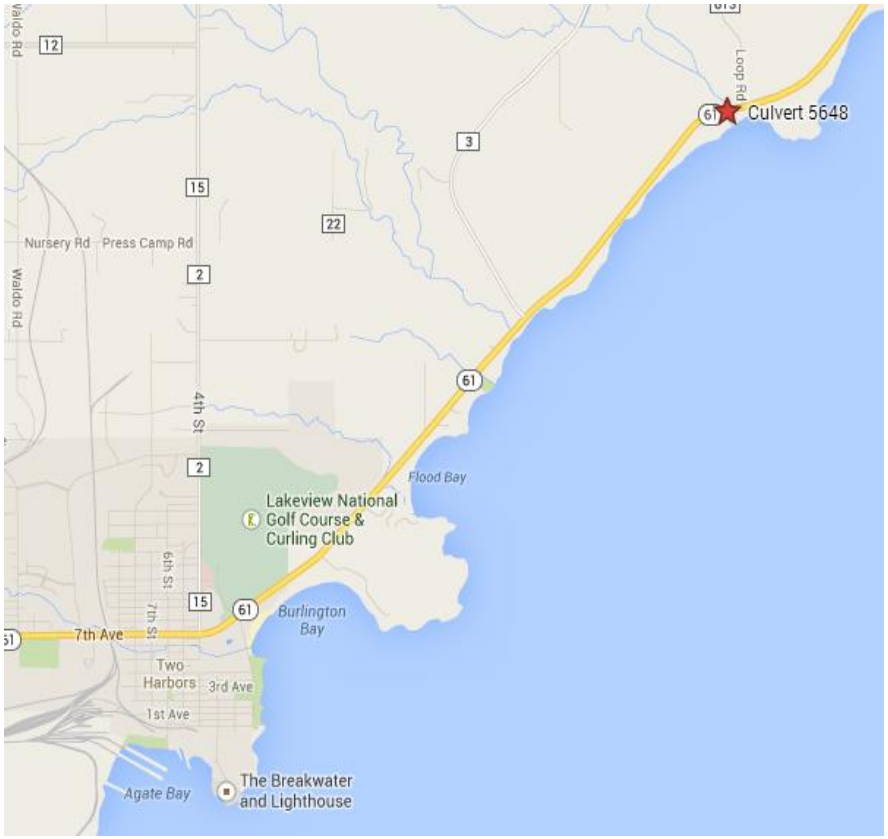
Just Exposure & Sensitivity



Phase 2: Existing Facility

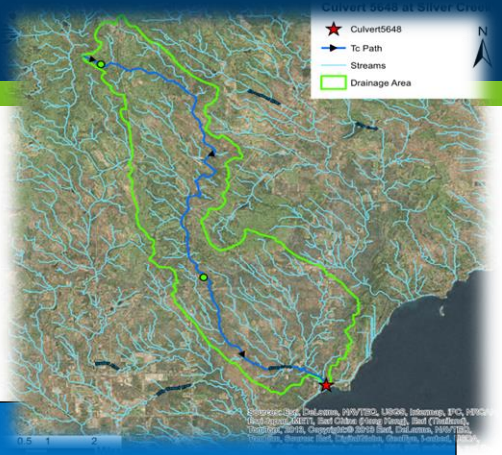


District 1 – Silver Creek



- Culvert 5648
- Crosses Silver Creek
- MN 61- Parallel to Lake Superior from Duluth up to Canadian Border
- AADT: 5,900
- Detour Length: 24 miles

Existing Hydrology



- Drainage Area: 19.65 mi^2
- Precipitation and Discharge:

24-hour Storm Event Return Period						
2-yr storm	5-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm
(in)	(in)	(in)	(in)	(in)	(in)	(in)
2.48	3.26	3.89	4.80	5.53	6.31	8.26

24-hour Storm Event Return Period						
2-yr storm	5-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm
(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
769	1354	1879	2693	3373	4136	6085

Performance of Existing Facility

- Currently system is functioning well when compared to design storm conditions
  - Does not overtop at the current 50-year storm
- Performance decreases under future climate projections

Projected Hydrologic Conditions

24-Hr Storm Return Period	Existing Discharges (cfs)	Low Scenario Discharges (cfs) 2100	Medium Scenario Discharges (cfs) 2100	High Scenario Discharges (cfs) 2100
2-yr storm	770	1,120	1,230	1,550
5-yr storm	1,350	1,830	2,000	2,460
10-yr storm	1,880	2,450	2,660	3,250
25-yr storm	2,690	3,390	3,670	4,460
50-yr storm	3,370	**4,170**	4,500	5,480
100-yr storm	**4,140**	5,000	5,420	6,610
500-yr storm	6,090	7,150	7,800	9,630

Adaptation Options Analysis

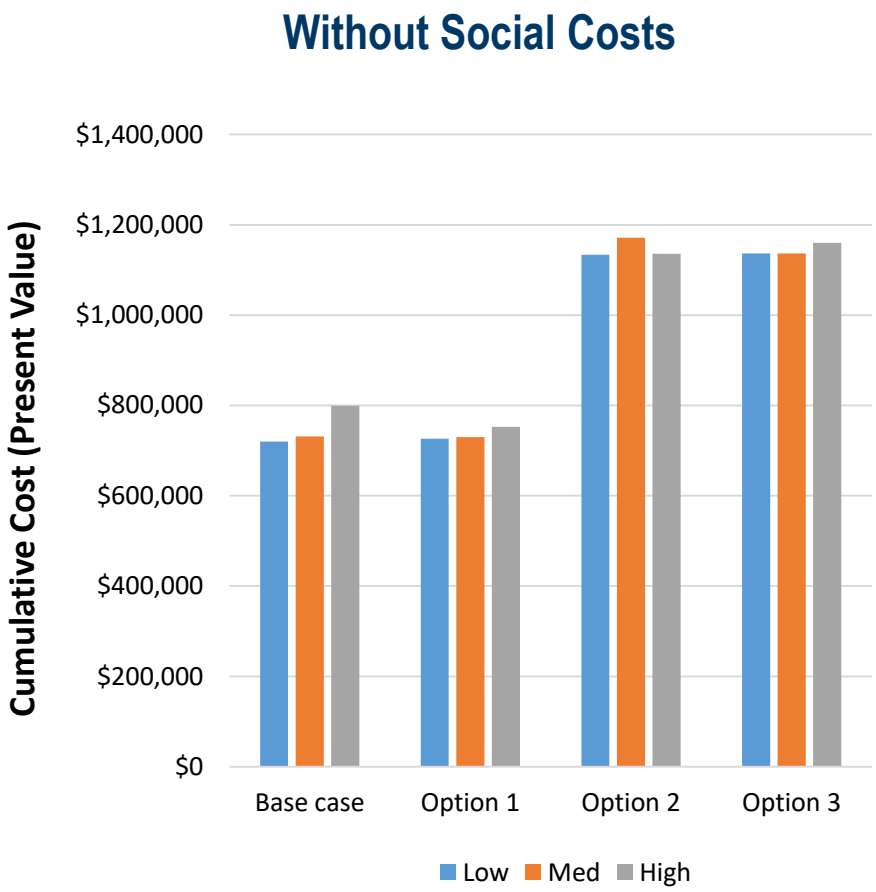
- Base: Replace in-kind
  - Construct cost: $710,000
- Option 1: Increase culvert to 16’ X 14’
  - Construction cost: $770,000
- Option 2: Replace Culvert with a 35’ span bridge
  - Construction cost: $1,130,000
- Option 3: Replace Culvert with a 40’ span bridge
  - Construction cost: $1,210,000

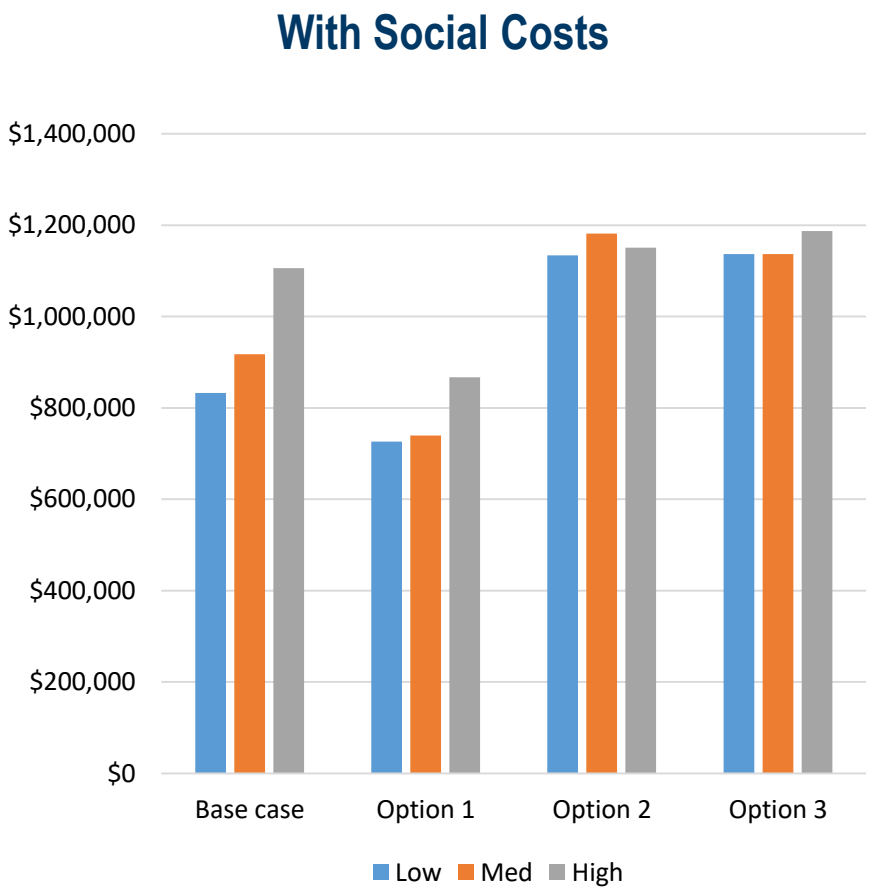
Benefit-Cost Assumptions

- Analysis period: 2020 - 2100
- Discount rate: 2.0%
- Safety Cost: $80,000
- Detour Cost Per Day:

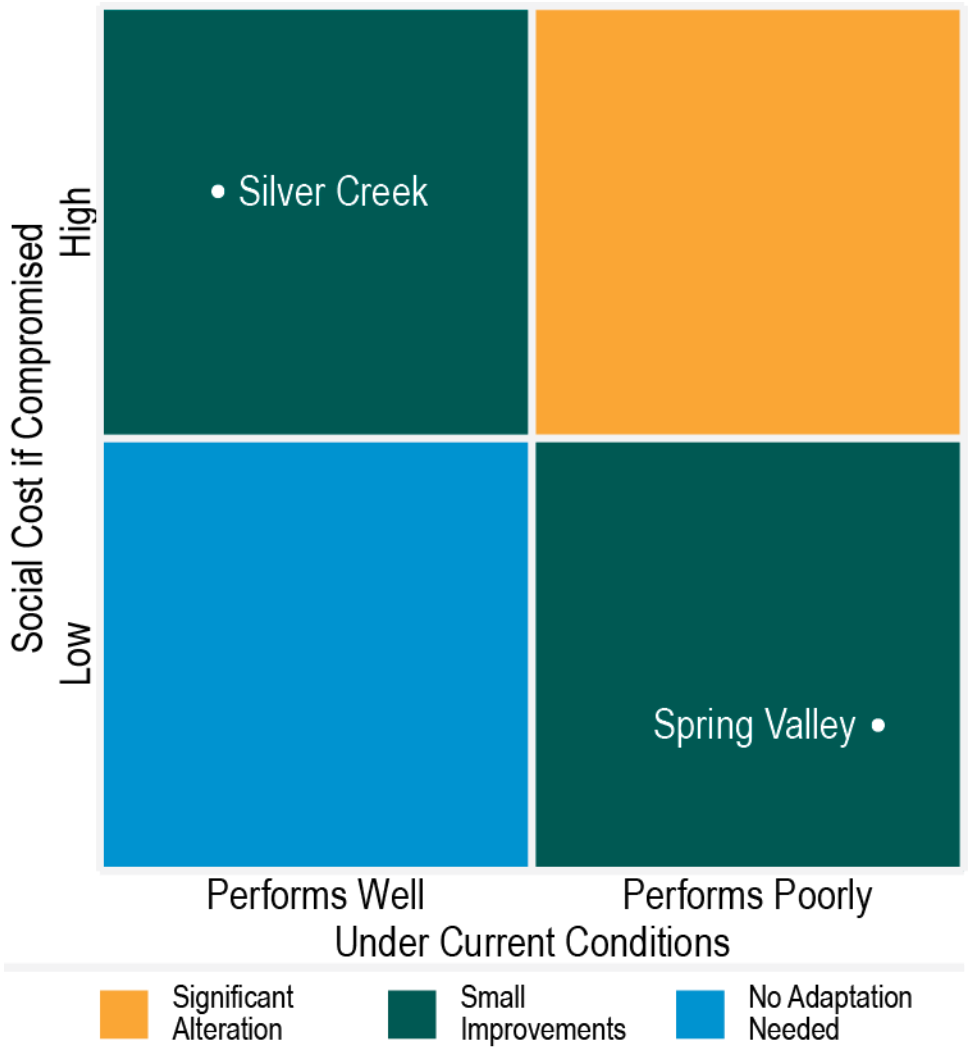
	Car	Truck	Total
Operating Costs	$40,176	$11,520	$51,696
Travel Time	$78,624	$9,555	$88,179
Total	$118,800	$21,075	$139,875

Cost Effectiveness: Silver Creek

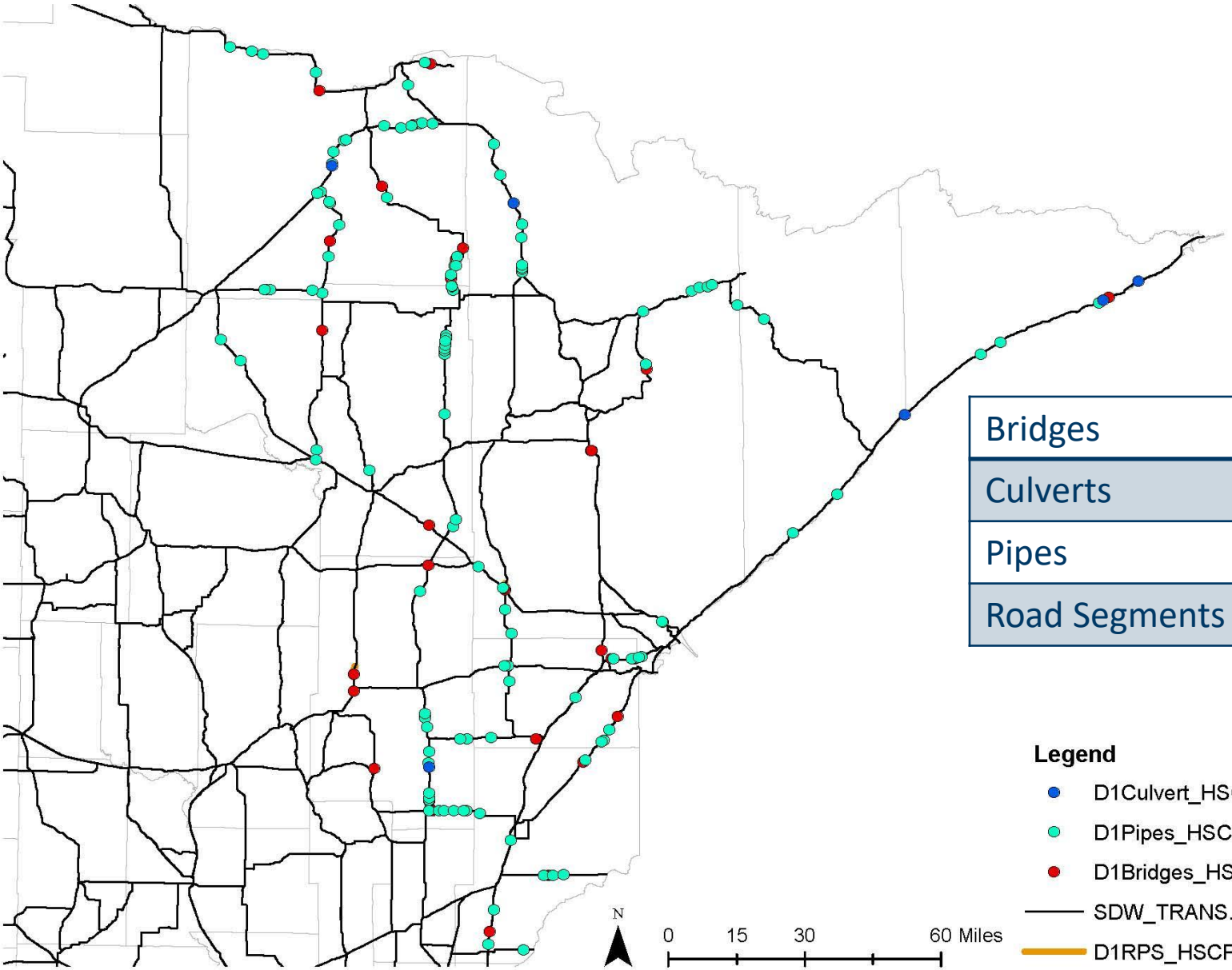




Conceptual Adaptation Screening Framework



Assets currently performing poorly compared to design storm with high social costs (AADT ≥ 10,000 and/or detour ≥ 20 mi)



Bridges	31
Culverts	6
Pipes	129
Road Segments	2

Adaptation Options

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  - Construct cost: $710,000
- Option 1: Increase culvert to 16’ X 14’
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Resilience and Fish Passage

- New Aquatic Organism Passage guidance
- “What’s good for the fish is good for the climate”

Peter Leete (2013)

Natural substrate on the bottom of the stream and adequate water depth demonstrate that this culvert provides AOP by connecting the upstream and downstream reaches of this stream.

Extreme Flood Vulnerability Assessment

- Identify hydrological regions
- Identify asset samples
- Select climate model and predict future depths on daily maximums
- Validate methodology
- Incorporate into asset management software (BRIM/TAMS)
- Incorporate costs into analysis

Building Resilience and Looking Forward

Drafting Resilience Report

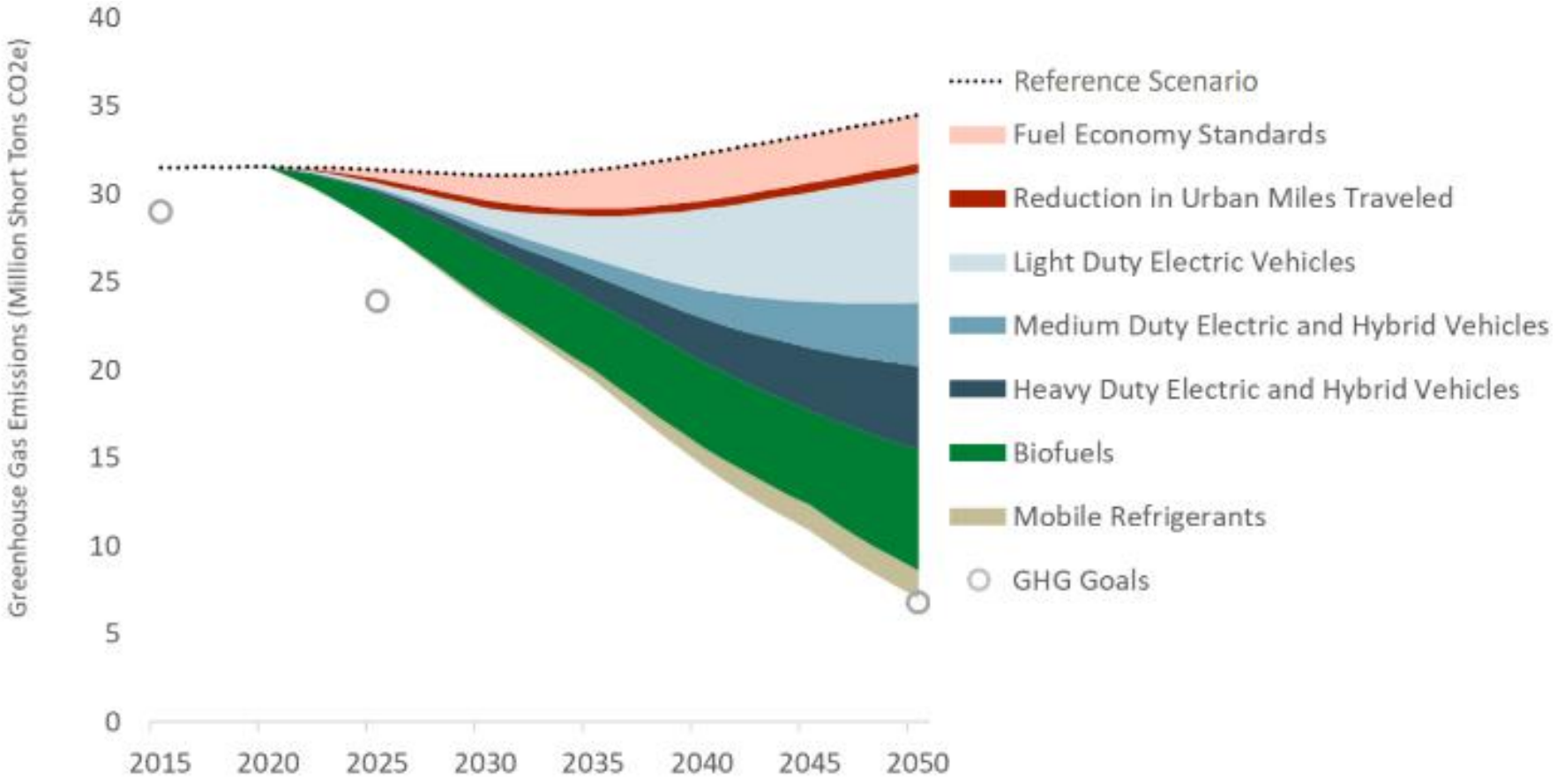
- Compiling current MnDOT practices that build resilience
- Reviewing best practices from other state DOTs
- Analyzing gaps and opportunities for MnDOT to further build resilience

Example:

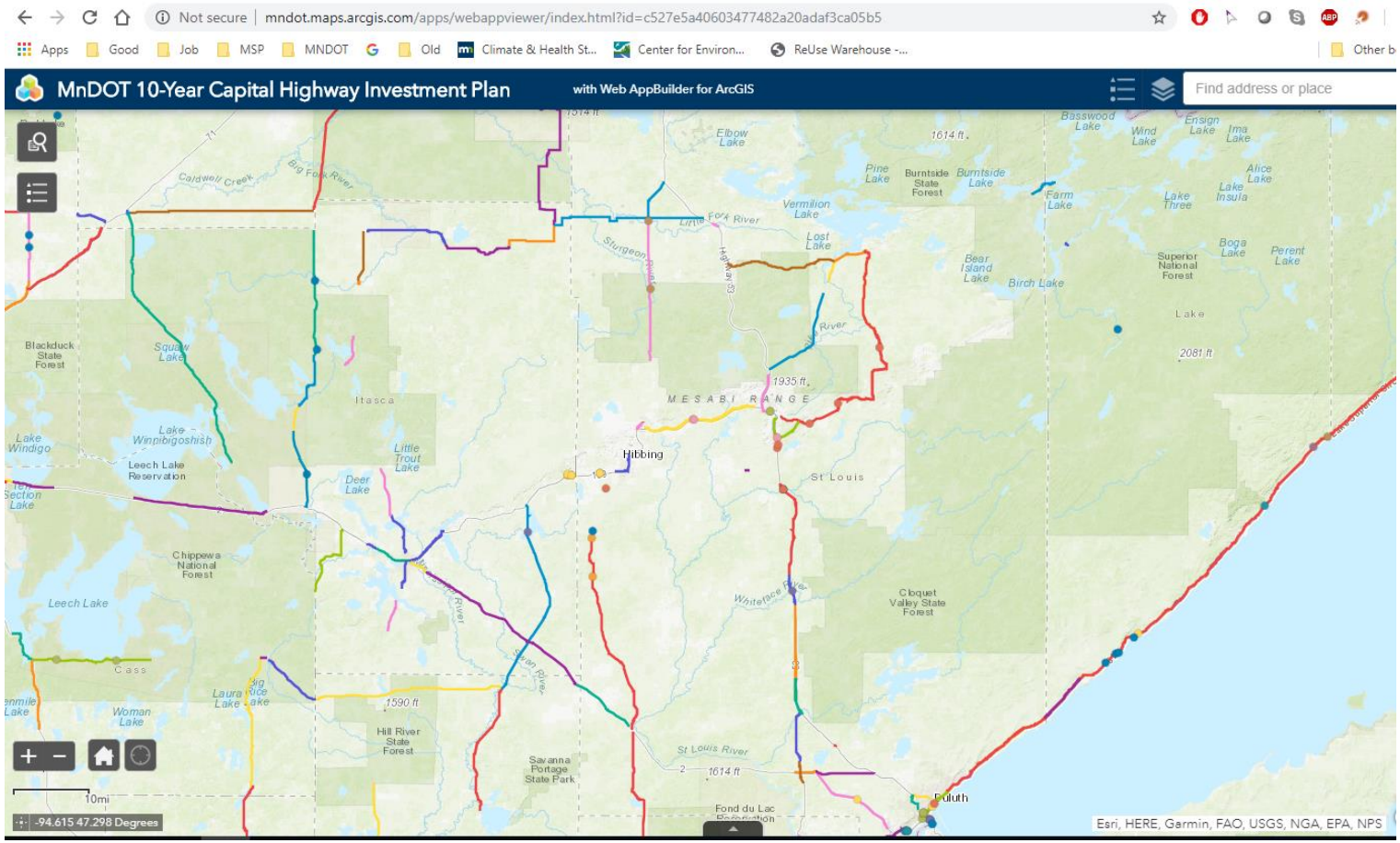
- RFP to study on changes in Freeze/Thaw cycles in Minnesota

Pathways Forward

- Releasing our Pathways to Decarbonization for Transportation study soon



Local MnDOT Projects



www.dot.state.mn.us/planning/10yearplan/

Questions?

Contact Info

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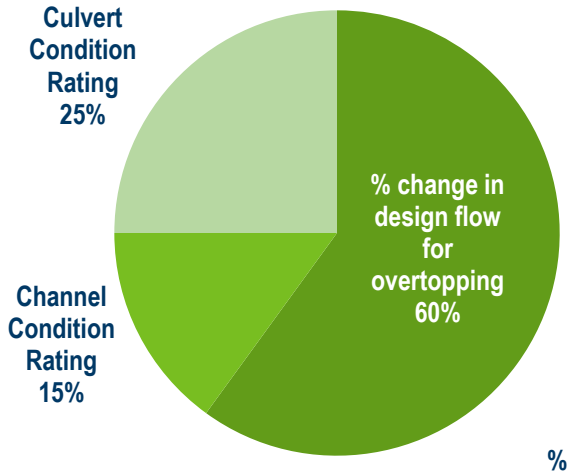
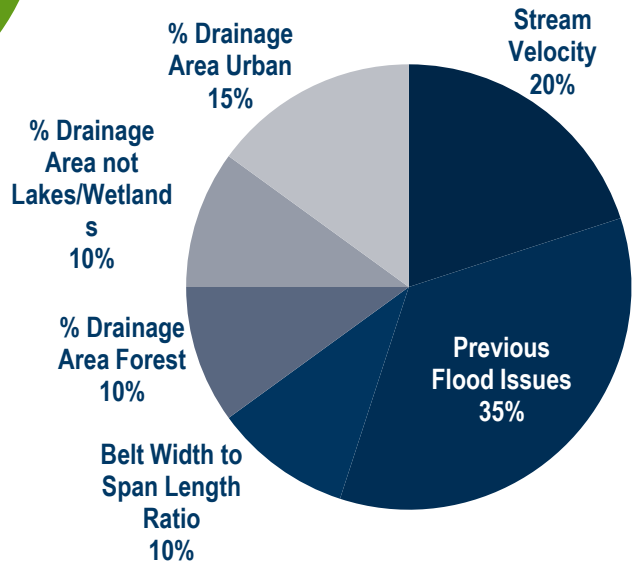
Criteria Weighting

Example: Culverts

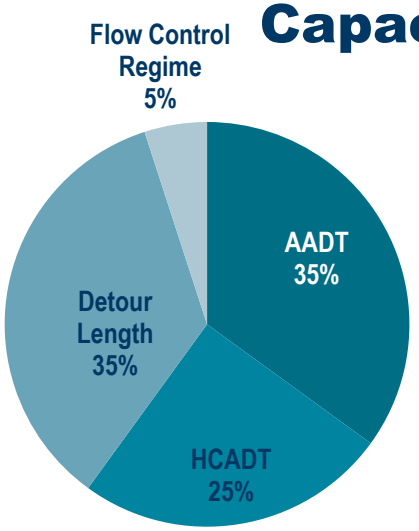
Sensitivity



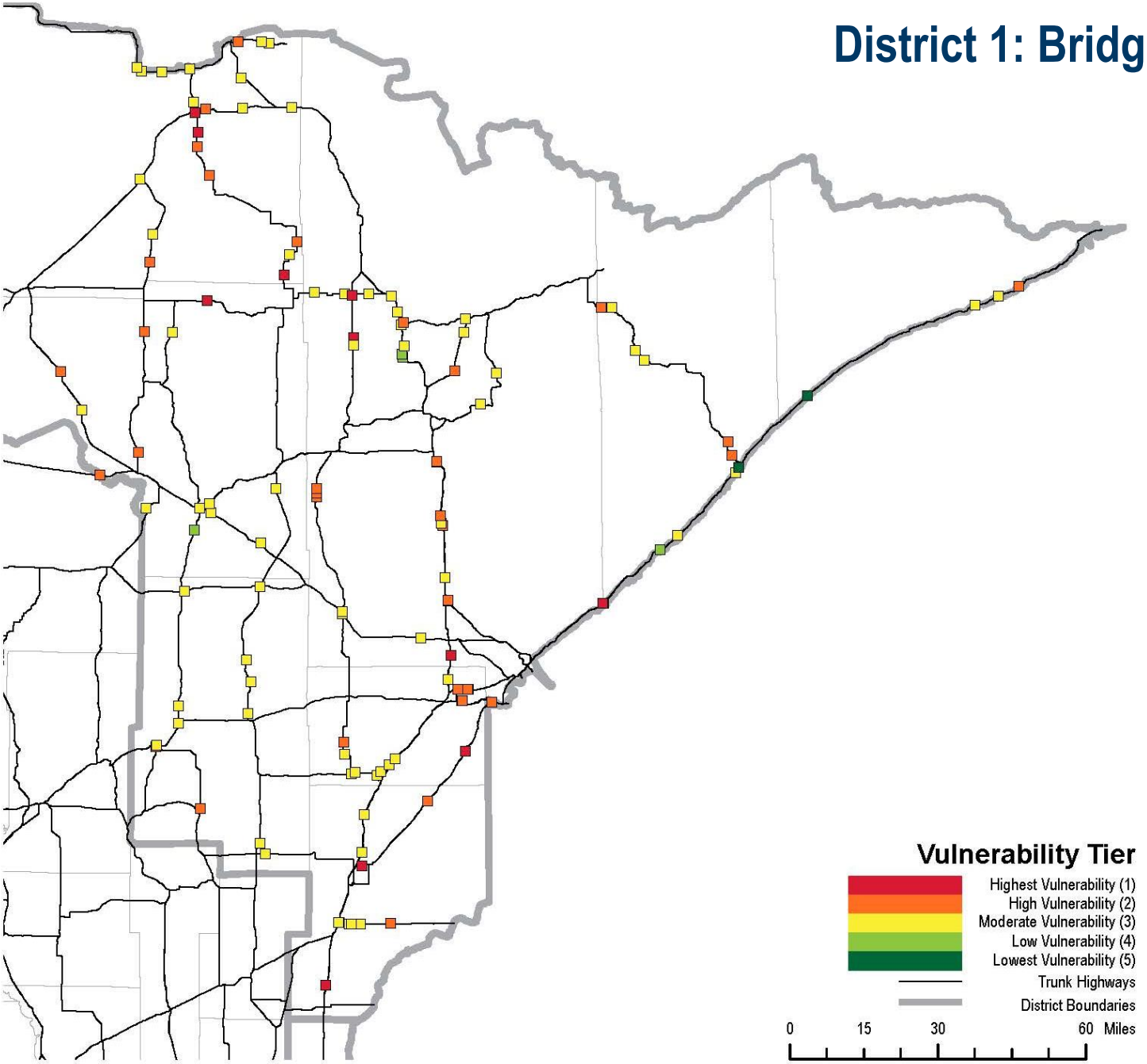
Exposure



Adaptive Capacity

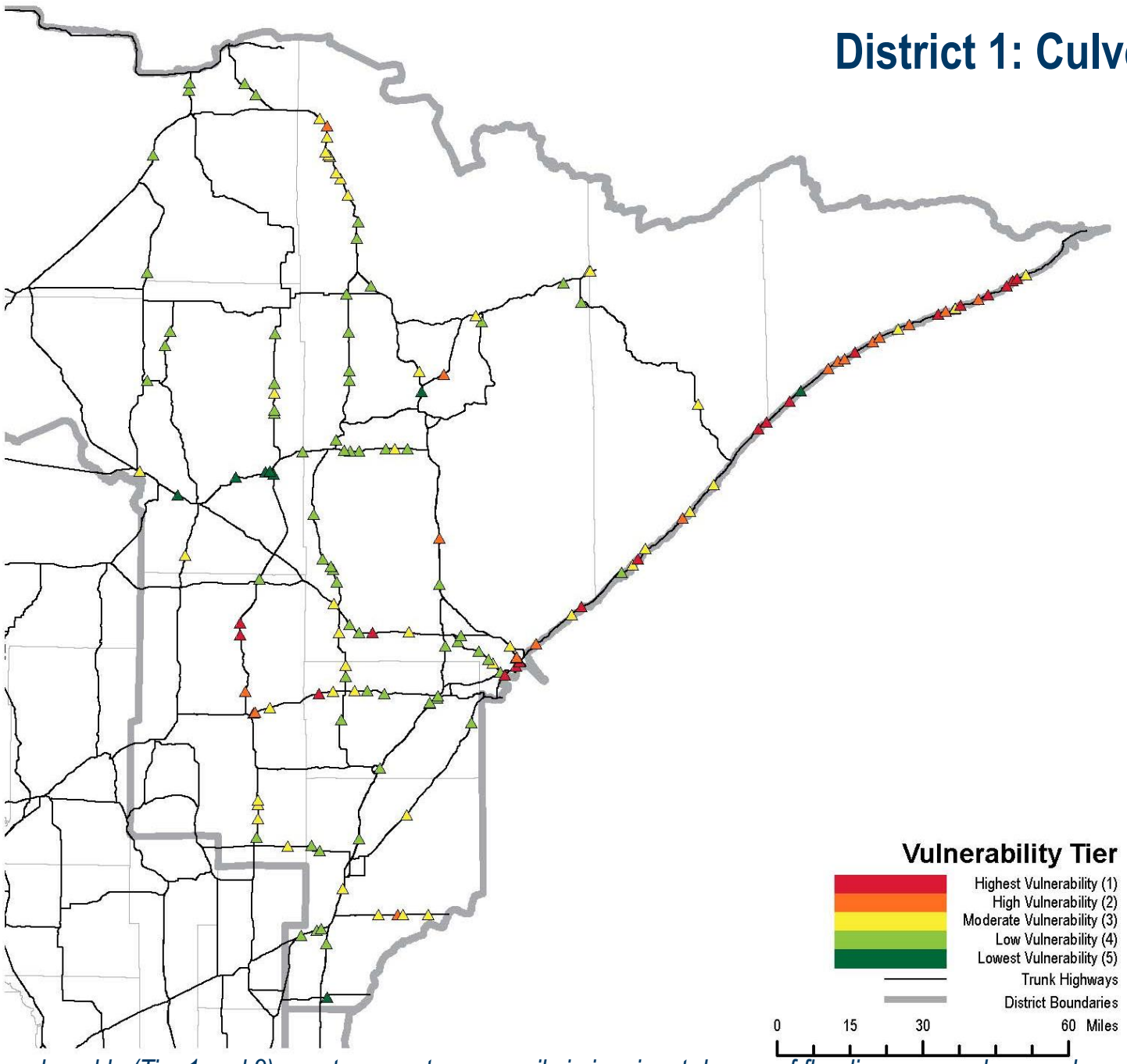


District 1: Bridges



Highly vulnerable (Tier 1 and 2) assets are not necessarily in imminent danger of flooding, nor are lower vulnerability assets immune from flooding. Values are indicators of relative vulnerability compared with other assets in the same district.

District 1: Culverts



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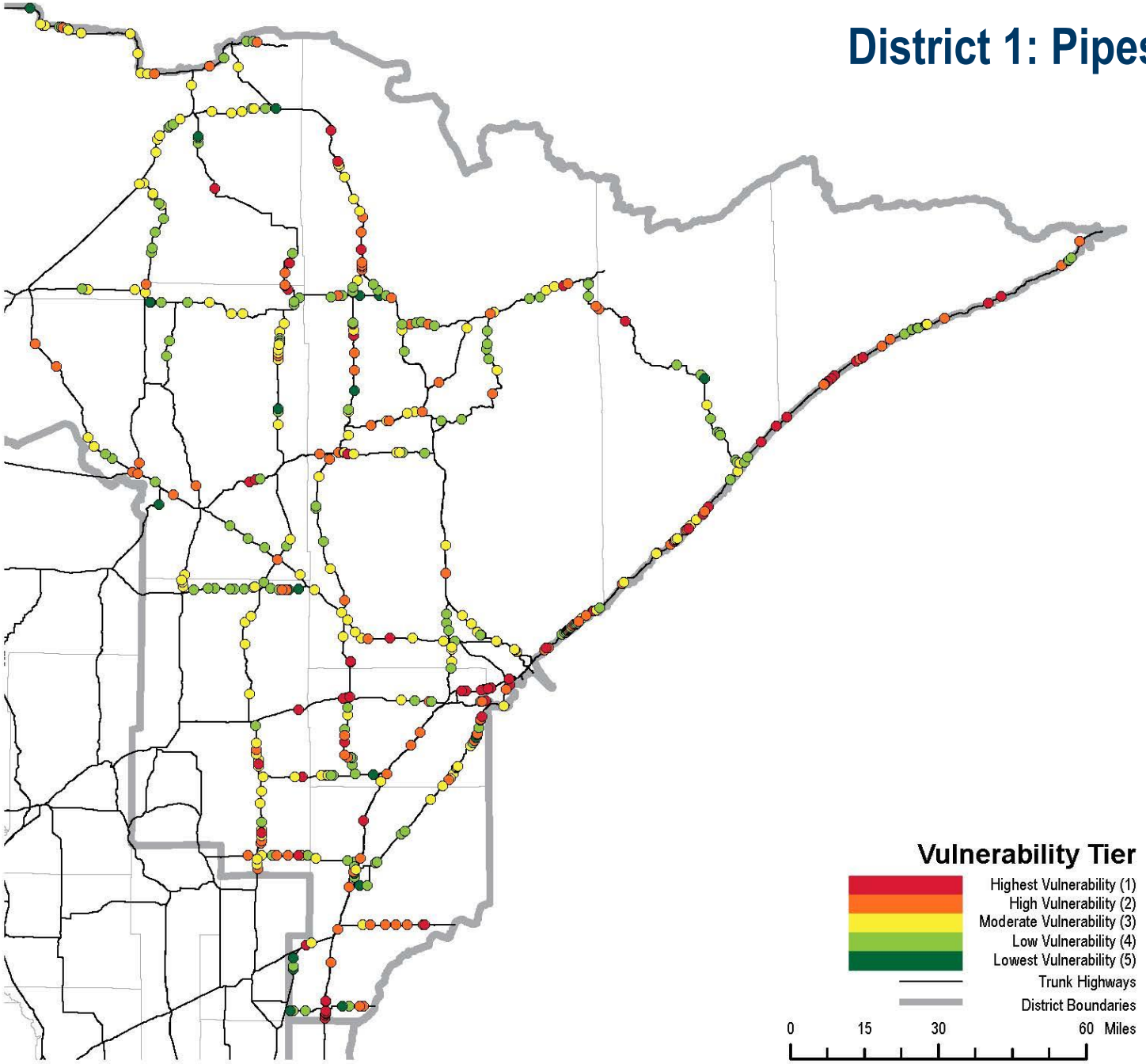
District 1: Pipes



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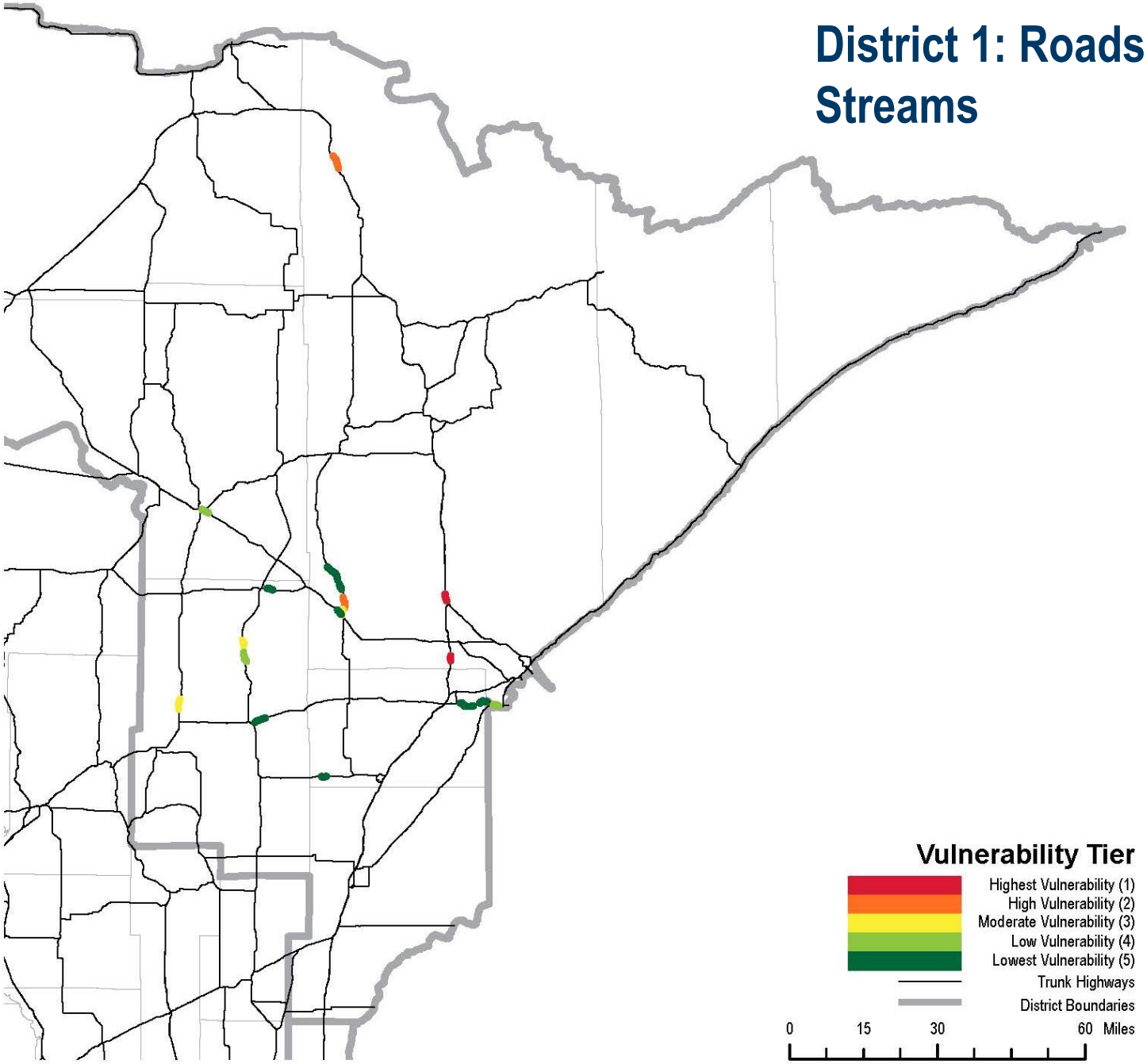
District 1: Roads Paralleling Streams



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Adaptation Assessment General Approach

1. Describe the site context
2. Describe the facility
3. Identify climate stressors
   - Heavy precipitation
4. Develop climate scenarios (Low*, Medium, High)
5. Assess performance of the facility
6. Identify adaptation options
   - Meet MnDOT 50-year clearance guidance
   - Meet FEMA 100-yr floodplain impact regulations
7. Assess performance of the adaptation options
8. Conduct an economic analysis
9. Evaluate additional considerations
10. Select a course of action
11. Plan and conduct ongoing activities

**we used IPCC RCP4.5 for the low, which used to be called a medium scenario*

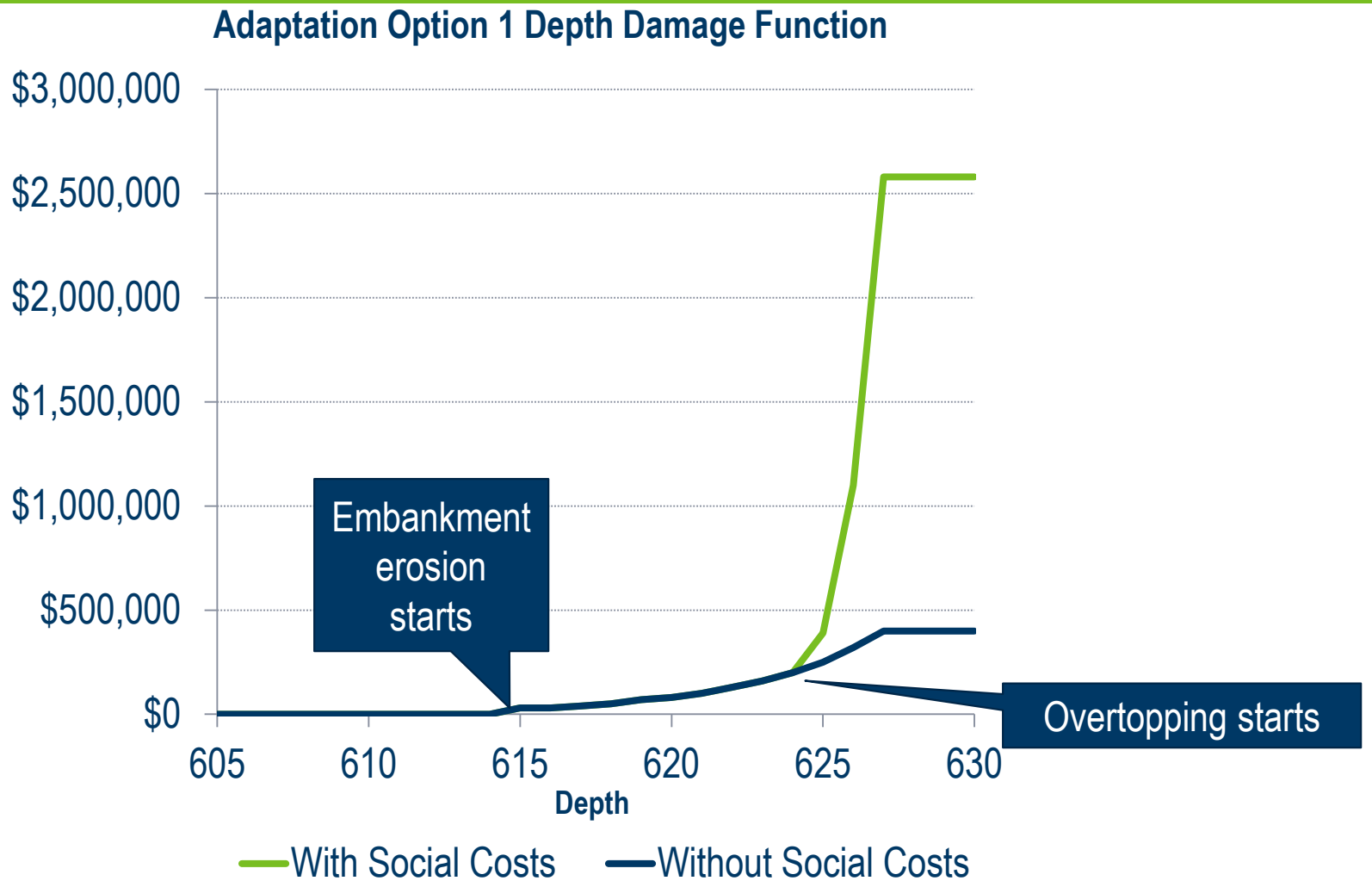

Silver
Creek

Projected Climate Conditions

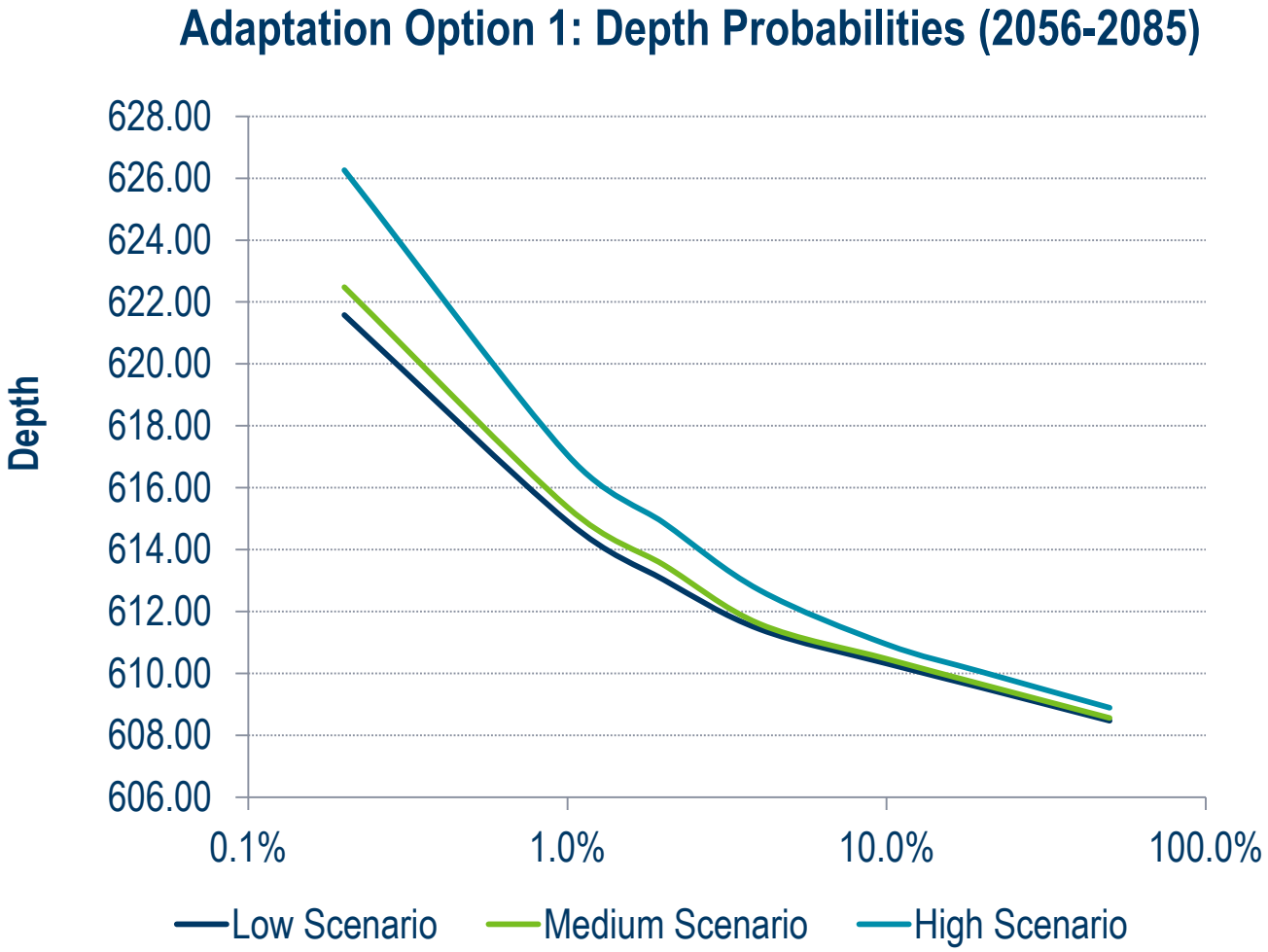
24-Hr Storm Return Period	Atlas 14 Precip. Depth (in)	Low Scenario Precipitation Depth (in)			Medium Scenario Precipitation Depth (in)			High Scenario Precipitation Depth (in)		
		2040	2070	2100	2040	2070	2100	2040	2070	2100
2-yr storm	2.48	2.56	2.60	2.62	2.59	2.67	2.75	2.69	2.91	3.12
5-yr storm	3.26	3.36	3.42	3.44	3.41	3.51	3.62	3.54	3.83	4.12
10-yr storm	3.89	4.02	4.08	4.11	4.08	4.20	4.33	4.24	4.60	4.95
25-yr storm	4.8	4.96	5.05	5.09	5.04	5.21	5.38	5.26	5.73	6.19
50-yr storm	5.53	5.73	5.84	5.89	5.83	6.02	6.23	6.08	6.66	7.22
100-yr storm	6.31	6.55	6.68	6.74	6.67	6.91	7.16	6.98	7.68	8.36
500-yr storm	8.26	8.63	8.83	8.92	8.81	9.17	9.56	9.28	10.35	11.39

Data from SimCLIM

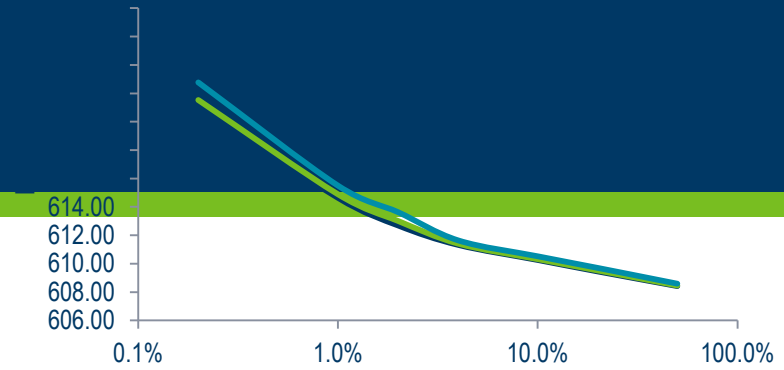
For Each Adaptation Option

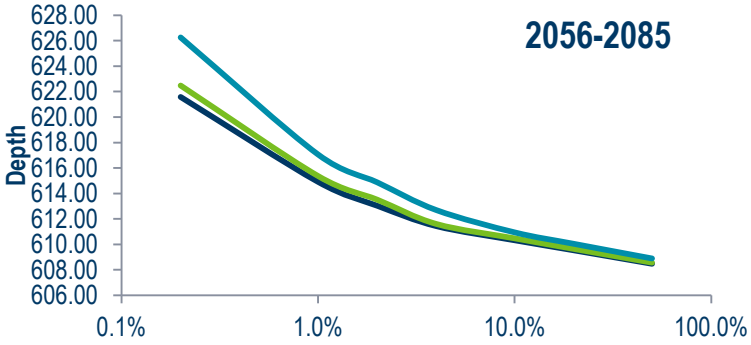


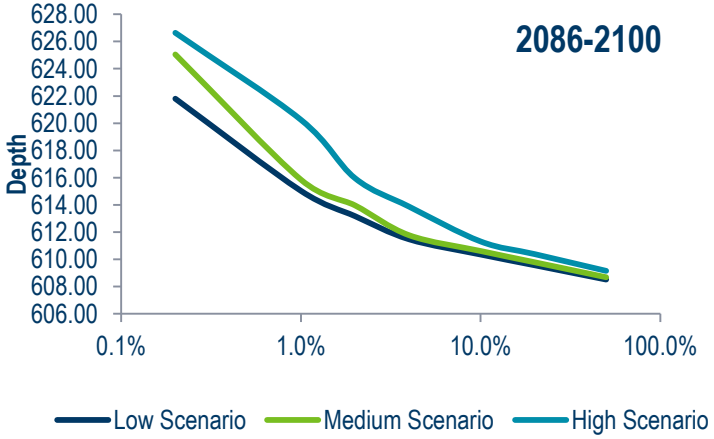
For Each Adaptation Option for 3 time periods

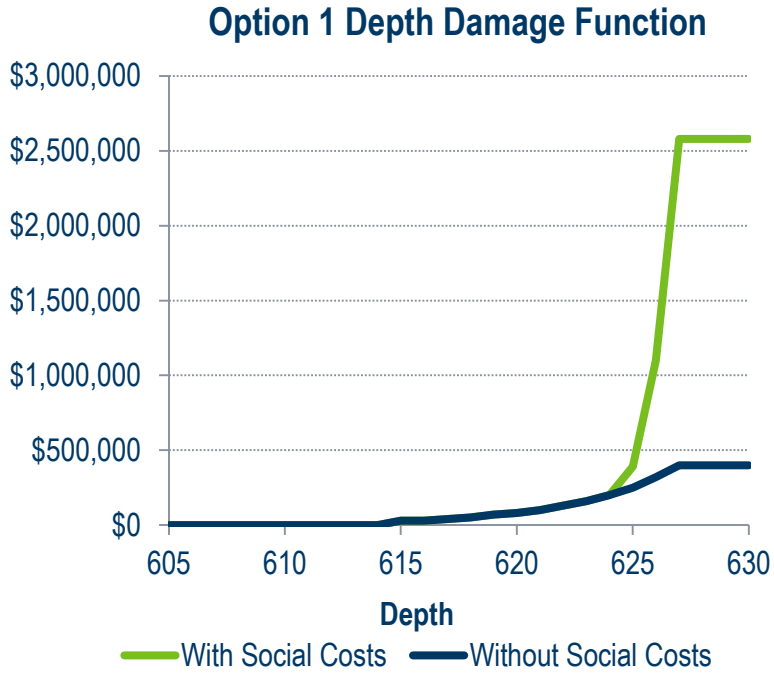


COAST Mode



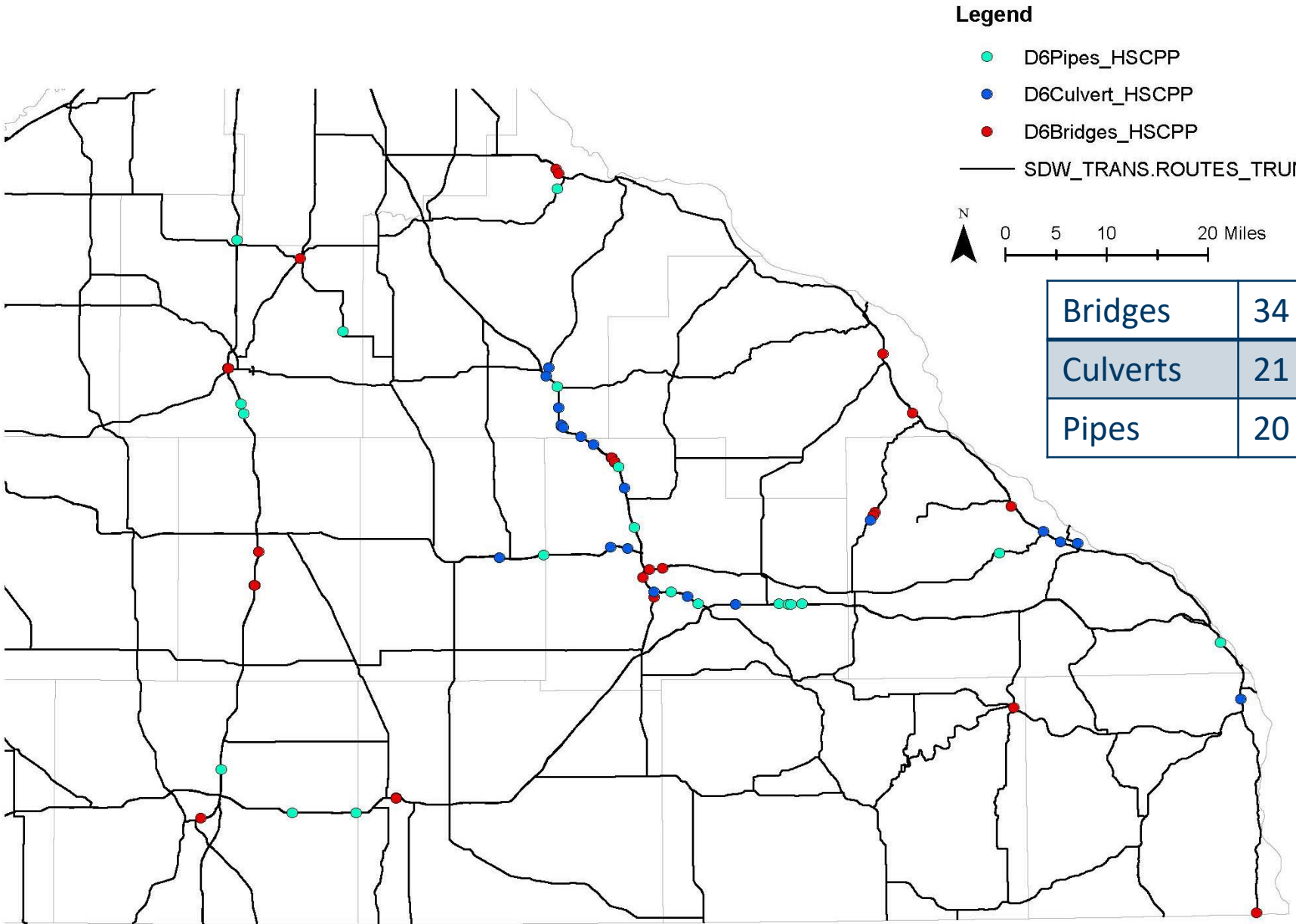






Construction Cost

Assets currently performing poorly compared to design storm with high social costs (AADT ≥ 10,000 and/or detour ≥ 20 mi)



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Culverts	21
Pipes	20