Flash Flood Vulnerability and Climate Adaptation Pilot Project

Philip Schaffner
Office of Transportation System Management
Minnesota Department of Transportation
MnDOT’s 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
Project Roles and Responsibilities

Consultant: PARSONS BRINCKERHOFF
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 \textit{vulnerability} in the transportation context is a function of a transportation system’s \textit{exposure} to climate effects, \textit{sensitivity} to climate effects, and \textit{adaptive capacity}.” (Vulnerability Framework)

- \textbf{Exposure} - whether the asset or system is located in an area experiencing direct impacts of climate change
- \textbf{Sensitivity} - how the asset or system fares when exposed to an impact
- \textbf{Adaptive capacity} - the systems’ ability to adjust or cope with existing climate variability or future climate impacts
Systemwide 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
Criteria Weighting
Example: Culverts

Sensitivity
- Culvert Condition Rating 25%
- Channel Condition Rating 15%

% change in design flow for overtopping 60%

Adaptive Capacity
- AADT 35%
- HCADT 25%
- Flow Control Regime 5%
- Detour Length 35%

Exposure
- Previous Flood Issues 35%
- Stream Velocity 20%
- % Drainage Area Urban 15%
- % Drainage Area not Lakes/Wetlands 10%
- % Drainage Area Forest 10%
- Belt Width to Span Length Ratio 10%

Overall, the criteria for sensitivity include:
- 25% for Culvert Condition Rating
- 15% for Channel Condition Rating

The exposure criteria are weighted as:
- 35% for Previous Flood Issues
- 20% for Stream Velocity
- 15% for % Drainage Area Urban
- 10% for % Drainage Area not Lakes/Wetlands
- 10% for % Drainage Area Forest
- 10% for Belt Width to Span Length Ratio
## Number of Assets Scored

<table>
<thead>
<tr>
<th></th>
<th>Bridges</th>
<th>Large Culverts</th>
<th>Pipes</th>
<th>Roads Paralleling Streams (segments)</th>
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<tbody>
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<td>920</td>
<td>62</td>
<td>1,819</td>
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</table>
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.
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Facility Level Adaptation Assessments
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
MN 61 Silver Creek Culvert
Adaptation Analysis Case Study 1
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 Facility
Existing Hydrology

- Drainage Area: 19.65 mi²
- Precipitation and Discharge:

<table>
<thead>
<tr>
<th>24-hour Storm Event Return Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-yr storm</td>
</tr>
<tr>
<td>(in)</td>
</tr>
<tr>
<td>2.48</td>
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</table>

<table>
<thead>
<tr>
<th>24-hour Storm Event Return Period</th>
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<tr>
<td>2-yr storm</td>
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<tr>
<td>(cfs)</td>
</tr>
<tr>
<td>769</td>
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</tbody>
</table>
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 Climate Conditions

<table>
<thead>
<tr>
<th>24-Hr Storm Return Period</th>
<th>Atlas 14 Precip. Depth (in)</th>
<th>Low Scenario Precipitation Depth (in)</th>
<th>Medium Scenario Precipitation Depth (in)</th>
<th>High Scenario Precipitation Depth (in)</th>
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<tbody>
<tr>
<td></td>
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<td>2040</td>
<td>2070</td>
<td>2100</td>
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<tr>
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<td>5.05</td>
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<tr>
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<td>5.73</td>
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<tr>
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<td>6.31</td>
<td>6.55</td>
<td>6.68</td>
<td>6.74</td>
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Data from SimCLIM
## Projected Hydrologic Conditions

<table>
<thead>
<tr>
<th>24-Hr Storm Return Period</th>
<th>Existing Discharges (cfs)</th>
<th>Low Scenario Discharges (cfs)</th>
<th>Medium Scenario Discharges (cfs)</th>
<th>High Scenario Discharges (cfs)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>2100</td>
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<td>2100</td>
<td>2100</td>
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<tr>
<td>2-yr storm</td>
<td>770</td>
<td>1,120</td>
<td>1,230</td>
<td>1,550</td>
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<td>3,390</td>
<td>3,670</td>
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<td>4,170</td>
<td>4,500</td>
<td>5,480</td>
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<td>5,000</td>
<td>5,420</td>
<td>6,610</td>
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<td>500-yr storm</td>
<td>6,090</td>
<td>7,150</td>
<td>7,800</td>
<td>9,630</td>
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</table>
Adaptation Options

• 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:

<table>
<thead>
<tr>
<th></th>
<th>Car</th>
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<th>Total</th>
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<tbody>
<tr>
<td>Operating Costs</td>
<td>$40,176</td>
<td>$11,520</td>
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<td>Travel Time</td>
<td>$78,624</td>
<td>$9,555</td>
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<td>Total</td>
<td>$118,800</td>
<td>$21,075</td>
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For Each Adaptation Option

Adaptation Option 1 Depth Damage Function

Depth

$0

$500,000

$1,000,000

$1,500,000

$2,000,000

$2,500,000

$3,000,000

Embankment erosion starts

Overtopping starts

With Social Costs

Without Social Costs
For Each Adaptation Option for 3 time periods

Adaptation Option 1: Depth Probabilities (2056-2085)
COAST Model

Option 1 Depth Probabilities (2020-2055)

- Option 1 Depth Damage Function
  - With Social Costs
  - Without Social Costs

Depth Probabilities (2020-2055)
- Low Scenario
- Medium Scenario
- High Scenario

Option 1 Depth Damage Function
- Construction Cost
## Cost Effectiveness: Silver Creak

### Without Social Costs

<table>
<thead>
<tr>
<th>Cumulative Cost (Present Value)</th>
<th>Base case</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>$0</td>
<td>$200,000</td>
<td>$400,000</td>
<td>$600,000</td>
</tr>
<tr>
<td>Med</td>
<td>$800,000</td>
<td>$600,000</td>
<td>$1,000,000</td>
<td>$1,200,000</td>
</tr>
<tr>
<td>High</td>
<td>$1,400,000</td>
<td>$1,200,000</td>
<td>$1,400,000</td>
<td>$1,400,000</td>
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</table>

### With Social Costs

<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>$0</td>
<td>$200,000</td>
<td>$400,000</td>
<td>$600,000</td>
</tr>
<tr>
<td>Med</td>
<td>$800,000</td>
<td>$600,000</td>
<td>$1,000,000</td>
<td>$1,200,000</td>
</tr>
<tr>
<td>High</td>
<td>$1,400,000</td>
<td>$1,200,000</td>
<td>$1,400,000</td>
<td>$1,400,000</td>
</tr>
</tbody>
</table>

**Cost Effectiveness**

- **Without Social Costs**
  - Base case: $0
  - Option 1: $200,000
  - Option 2: $400,000
  - Option 3: $600,000

- **With Social Costs**
  - Base case: $0
  - Option 1: $200,000
  - Option 2: $400,000
  - Option 3: $600,000
US 63 Spring Valley Culvert
Adaptation Analysis Case Study 2
District 6 – Spring Valley Creek

- Culvert 5722
- Crosses Spring Valley Creek
- US 63 – connects Rochester to Cedar Rapids
- AADT 5,700
- Detour: 0.6 miles
Existing Facility
Existing Hydrology

- Drainage Area: 13.94 mi²
- Precipitation and Discharge:

<table>
<thead>
<tr>
<th>24-hour Storm Event Return Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-yr storm</td>
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<tr>
<td>-----------</td>
</tr>
<tr>
<td>(in)</td>
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<td>2.79</td>
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<tr>
<td>2-yr storm</td>
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<tr>
<td>----------</td>
</tr>
<tr>
<td>(cfs)</td>
</tr>
<tr>
<td>851.5</td>
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</table>
Performance of Existing Facility

• Currently Overtopped by 10-year Storm

• Prone to nuisance flooding due to
  – Undersized conveyance area of culverts
  – Low lying roadway profile

• Performance decreases under all future climate projections
# Projected Climate Conditions

<table>
<thead>
<tr>
<th>24-Hr Storm Return Period</th>
<th>Atlas 14 Precip. Depth (in)</th>
<th>Low Scenario Precipitation Depth (in)</th>
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<tr>
<td></td>
<td>2040</td>
<td>2070</td>
<td>2100</td>
<td>2040</td>
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<tr>
<td>2-yr storm</td>
<td>2.79</td>
<td>2.80</td>
<td>2.81</td>
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<td>7.90</td>
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<td>10.97</td>
<td>11.05</td>
<td>11.10</td>
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## Projected Hydrologic Conditions

<table>
<thead>
<tr>
<th>24-Hr Storm Return Period</th>
<th>Existing Discharge (cfs)</th>
<th>Low Scenario Discharges (cfs)</th>
<th>Medium Scenario Discharges (cfs)</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>2040</td>
<td>2070</td>
<td>2100</td>
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<tr>
<td>2-yr storm</td>
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<td>980</td>
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<td>1480</td>
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<td>1540</td>
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<td>6160</td>
<td>6490</td>
<td>6630</td>
<td>6700</td>
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Adaptation Options

• Base: Replace in-kind
  – Construct cost: $460,000

• Option 1: Add 2 6’x10’ culvert cells to existing design
  – Construction cost: $690,000

• Option 2: same as option 1 + floodplain enhancement
  – Construction cost: $1,130,000

• Option 3: Replace Culvert three span 84-foot long bridge
  – Construction cost: $4,210,000
Cost Effectiveness: Spring Valley

Without Social Costs

<table>
<thead>
<tr>
<th>Cumulative Cost (Present Value)</th>
<th>Low</th>
<th>Med</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>1,500,000</td>
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<td>2,500,000</td>
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<tr>
<td>Option 1</td>
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<td>2,000,000</td>
<td>2,500,000</td>
</tr>
<tr>
<td>Option 2</td>
<td>1,500,000</td>
<td>2,000,000</td>
<td>2,500,000</td>
</tr>
<tr>
<td>Option 3</td>
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With Social Costs

<table>
<thead>
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<th>Med</th>
<th>High</th>
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<tbody>
<tr>
<td>Base case</td>
<td>1,500,000</td>
<td>2,000,000</td>
<td>2,500,000</td>
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<td>Option 1</td>
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<td>2,500,000</td>
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<td>Option 2</td>
<td>1,500,000</td>
<td>2,000,000</td>
<td>2,500,000</td>
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<td>Option 3</td>
<td>1,500,000</td>
<td>2,000,000</td>
<td>2,500,000</td>
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Conceptual Adaptation Screening Framework

- Silver Creek
- Spring Valley

- Perform Well Under Current Conditions
- Perform Poorly
- Significant Alteration
- Small Improvements
- No Adaptation Needed
Assets currently performing poorly compared to design storm with high social costs (AADT > 10,000 and/or detour > 20 mi)

<table>
<thead>
<tr>
<th>Asset Type</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridges</td>
<td>31</td>
</tr>
<tr>
<td>Culverts</td>
<td>6</td>
</tr>
<tr>
<td>Pipes</td>
<td>129</td>
</tr>
<tr>
<td>Road Segments</td>
<td>2</td>
</tr>
</tbody>
</table>
Assets currently performing poorly compared to design storm with high social costs (AADT > 10,000 and/or detour > 20 mi)
Next Steps

- Complete assessments in other districts and/or other types of “assets” (i.e. slopes)
- Support efforts to improve downscaling techniques and availability
- Incorporate considerations of risk into ongoing culvert and bridge improvement programs
- Incorporate scores into asset management databases and the asset management plan
QUESTIONS?

www.mndot.gov/climate/pilotproject.html

Project Contact:
Philip Schaffner
Policy Planning Director
MnDOT Office of Transportation System Management
philip.schaffner@state.mn.us
651-366-3743