Gulf Coast Study, Phase 2

Impacts of Climate Change and Variability on Transportation Systems & Infrastructure

Climate and Weather Risk Management Tools and Findings

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58th Annual Transportation Conference, Montgomery, AL
February 9, 2014
Importance of Resilience for FHWA

- Climate change and extreme weather events are disrupting transportation systems across the country
  - Increased temperature
  - More intense precipitation events
  - Sea level rise

- FHWA Goal: Systematic consideration of climate change vulnerability and risk in transportation decision making, at system and project level
FHWA Order 5520: Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events

Issued December 15, 2014
Challenges addressed:

1) Developing climate projections for assessing future transportation vulnerability

2) Screening and assessing vulnerability of a large number of assets

3) Applying engineering principles to develop adaptation options for vulnerable assets
Projections: Challenges

Challenge:

Need data on future environmental conditions:
- Transportation assets have long service lives
- Historical data might not indicate future trends
- Projections from climate models may help inform future trends

Need design thresholds for a range of variables
- Temperature (high temperature, # days per year above 95F)
- Precip (future 24-hr precip levels for 100-year events)
- Coastal conditions (future sea levels, storm surge inundation levels)
Projections: GC2 Solution
Temp, Precip; Storm Surge, Sea Level Rise

- Defined relevant climate variables
- Downscaled temperature and precipitation projections
- Developed storm surge scenarios
- Bracketed range of potential futures
### Excel Spreadsheet Tool

- Downloads Temperature and Precipitation projections
- Processes downscaled climate projections into T, P variables relevant to transportation projects
- Overcomes major need for easy access to climate data
Challenges:

• Need way to prioritize which assets to study for vulnerability

• Need method to quickly determine sensitivity of diverse set of assets to particular climate stressors

• Need procedure to efficiently develop vulnerability “scores” for large number of assets
Using Indicators to Score Vulnerability

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Sensitivity</th>
<th>Adaptive Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>• <strong>Temp</strong>-Days above 95°F</td>
<td>• <strong>Temp</strong> - Pavement binder, traffic (roads)</td>
<td>• <strong>Speed to recover asset</strong> – cost of</td>
</tr>
<tr>
<td>• 24-hour <strong>precipitation</strong></td>
<td>• <strong>Precip</strong> - FEMA flood zones, ponding, surface</td>
<td>improvement (bridges), identified as a</td>
</tr>
<tr>
<td>• <strong>Storm surge</strong> height</td>
<td>permeability (all modes)</td>
<td>priority in emergency planning (rail,</td>
</tr>
<tr>
<td>• <strong>Wind</strong> speed exceeds</td>
<td>• <strong>Storm surge</strong> – Height &amp; condition (bridges),</td>
<td>air, transit)</td>
</tr>
<tr>
<td>threshold above which impacts may</td>
<td>electric signaling &amp; soil type (rail), access</td>
<td>• <strong>Redundancy</strong> - detour length (bridges,</td>
</tr>
<tr>
<td>occur (yes/no)</td>
<td>(transit)</td>
<td>air), number of terminals/runways (air),</td>
</tr>
<tr>
<td>• Inundated by <strong>sea level rise</strong></td>
<td>• <strong>Wind</strong> - Building height, materials, roof</td>
<td>ability to reroute (transit and rail),</td>
</tr>
<tr>
<td>(yes/no)</td>
<td>type; road sign or signal density (road and rail)</td>
<td>rail yard interchange utility (rail)</td>
</tr>
<tr>
<td></td>
<td>• <strong>Sea level rise</strong> – Drainage (air), protection</td>
<td>• <strong>System disruption duration</strong> (climate</td>
</tr>
<tr>
<td></td>
<td>(transit, roads)</td>
<td>variable-specific)</td>
</tr>
</tbody>
</table>
Screening: GC2 Results

- All modes except airports have assets highly vulnerable to sea level rise, storm surge
- Airports and rail vulnerable to extreme heat. Brownouts could affect ports
- Transit has low vulnerability due to flexibility of bus system; pipelines have low vulnerability as most are buried

Example: The Causeway (R10)
- 17-29 ft of storm surge/waves
- Damaged in past, unprotected, low approach, low embankment
- High replacement cost
# Key Vulnerable Facilities

<table>
<thead>
<tr>
<th>Facility</th>
<th>Mode</th>
<th>Primary Vulnerability</th>
<th>Secondary Vulnerability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile Downtown Airport &amp; Airbus assembly facility</td>
<td>Airport</td>
<td>Temp</td>
<td>Storm surge, Precip</td>
</tr>
<tr>
<td>Alabama State Port Authority Docks</td>
<td>Ports</td>
<td>Surge, SLR</td>
<td>Temp, Precip</td>
</tr>
<tr>
<td>Atlantic Marine Mobile Container Terminal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terminal Rail Yard at Alabama State Docks</td>
<td>Rail</td>
<td>Surge, SLR</td>
<td>Temp, Precip Wind Wind</td>
</tr>
<tr>
<td>GM &amp; O Terminal</td>
<td>Transit</td>
<td>Surge, SLR</td>
<td></td>
</tr>
<tr>
<td>I-10 Wallace Tunnel I-10 Bridge Dauphin Island Bridge</td>
<td>Highway</td>
<td>Surge, SLR, Precip, Temp</td>
<td></td>
</tr>
</tbody>
</table>
## Vulnerability Assessment Scoring Tool (VAST)

### Spreadsheet Tool
- Analytical framework for assessing vulnerability
- Guidance on key steps
- "Indicator Libraries" tied to Mobile study

<table>
<thead>
<tr>
<th>Asset ID</th>
<th>Asset Name</th>
<th>Past Experience</th>
<th>My Indicator</th>
<th>My Indicator 2</th>
<th>Scour Criticality</th>
<th>Sensitivity Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>Highway 1</td>
<td>Yes</td>
<td>4</td>
<td>101</td>
<td>2</td>
<td>No Data</td>
</tr>
<tr>
<td>H2</td>
<td>Highway 2</td>
<td>No</td>
<td>2</td>
<td>218</td>
<td>4</td>
<td>No Data</td>
</tr>
<tr>
<td>H3</td>
<td>Highway 3</td>
<td>Yes</td>
<td>4</td>
<td>180</td>
<td>3</td>
<td>12955.5</td>
</tr>
<tr>
<td>H4</td>
<td>Highway 4</td>
<td>No</td>
<td>1</td>
<td>141</td>
<td>2</td>
<td>12955.5</td>
</tr>
<tr>
<td>H5</td>
<td>Highway 5</td>
<td>Unknown</td>
<td>No data</td>
<td>115</td>
<td>2</td>
<td>5171.4</td>
</tr>
<tr>
<td>H6</td>
<td>Highway 6</td>
<td>Yes</td>
<td>4</td>
<td>191</td>
<td>3</td>
<td>9270.3</td>
</tr>
<tr>
<td>H7</td>
<td>Highway 7</td>
<td>No</td>
<td>1</td>
<td>95</td>
<td>2</td>
<td>1.4</td>
</tr>
<tr>
<td>H8</td>
<td>Highway 8</td>
<td>No</td>
<td>1</td>
<td>221</td>
<td>4</td>
<td>9895.6</td>
</tr>
<tr>
<td>H9</td>
<td>Highway 9</td>
<td>No</td>
<td>1</td>
<td>67</td>
<td>2</td>
<td>20.85</td>
</tr>
<tr>
<td>H10</td>
<td>Highway 10</td>
<td>No</td>
<td>1</td>
<td>204</td>
<td>4</td>
<td>9895.6</td>
</tr>
<tr>
<td>H11</td>
<td>Highway 11</td>
<td>Yes</td>
<td>4</td>
<td>136</td>
<td>2</td>
<td>10.4</td>
</tr>
<tr>
<td>H12</td>
<td>Highway 12</td>
<td>No</td>
<td>1</td>
<td>157</td>
<td>3</td>
<td>4892.55</td>
</tr>
<tr>
<td>H13</td>
<td>Highway 13</td>
<td>No</td>
<td>1</td>
<td>144</td>
<td>2</td>
<td>104.3</td>
</tr>
<tr>
<td>H14</td>
<td>Highway 14</td>
<td>Yes</td>
<td>4</td>
<td>114</td>
<td>2</td>
<td>978.51</td>
</tr>
<tr>
<td>H15</td>
<td>Highway 15</td>
<td>No</td>
<td>1</td>
<td>114</td>
<td>2</td>
<td>978.51</td>
</tr>
</tbody>
</table>

*Table shows the assessment of assets with various criteria and scores.*
Screening: GC2 Products
Vulnerability Assessment Scoring Tool (VAST)

View results for...

Generate PDF

Rods Vulnerability Summary

- Low Scenario
  - Temperature Changes
  - Precipitation Changes
  - Storm Surge

- High Scenario
  - Temperature Changes
  - Precipitation Changes
  - Storm Surge

Not Exposed
Low (≥ 1)
Moderate (≥ 2)
High (≥ 3)
Engineering: Challenges

Problems:

• Need analytical process for assessing vulnerability of assets and developing solutions
• Need method for using climate projections to inform traditional engineering design processes
Approximately 3 miles

Airport Blvd.
Culvert at Montlimar Creek

Cochrane-Africatown USA Bridge

I-10 (Wallace) Tunnel

W. Approach Embankment & W. Abutment, Tensaw-Spanish River Bridge

US 90/98 ramp to I-10 eastbound at Exit 30

I-10 (mileposts 24 to 25)

McDuffie Terminal Dock 1
Eleven-Step Adaptation Process

1. Describe the site context
2. Describe the existing or proposed facility
3. Identify environmental factors that may impact infrastructure components
4. Decide on climate scenarios and determine magnitude of changes
5. Assess performance of the existing or proposed facility
6. Develop adaptation option(s)
7. Assess performance of the adaptation options
8. Conduct an economic analysis
9. Evaluate additional decision-making considerations
10. Select a course of action
11. Plan and conduct on-going activities
Pilot Study: Airport Blvd.
Precipitation - Culvert
Precipitation Projections in Mobile

- Precipitation projections are much more variable than temperature projections for Mobile
- Many precipitation variables not projected to change significantly
Hyetographs vs. Hydrographs

Intensity ($i$)

Discharge ($Q$)

Time (t)

24 hours

Design Peak $Q_1$

Design Peak $Q_2$

24 hours
### Step 4: Climate Scenario

<table>
<thead>
<tr>
<th>24-hour Storm Event Return Period</th>
<th>NOAA Baseline (inches)⁴</th>
<th>Observed 1980-2009 (inches)¹</th>
<th>NOAA 90% Upper Conf. Limit²</th>
<th>Wetter Narrative³</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-yr storm</td>
<td>14.9</td>
<td>13.5</td>
<td>18.9</td>
<td>21.0</td>
</tr>
</tbody>
</table>

### Step 5: Assess Facility Performance

![Graph showing Headwater Elevation vs. Flow Rate (cfs)]

- **7845 cfs - 100-yr Wetter**
- **5713 cfs - 25-yr Wetter**
- **4485 cfs - 25-yr NOAA**
- **3045 cfs - 25-yr Observed**

**Notes:**
3. Source: Spreadsheet titled "Precipitation Projection Data from Task 2 for Warmer and Hotter Climate Narratives" supplied by Beth Rodehorst of ICF on June 18th, 2013.
4. **NOTE SOURCE**
Pilot Study: Airport Blvd.
Precipitation - Culvert

Step 8: Conduct Economic Analysis

- Climate Change Scenario
- Storm Event—Year and Intensity (Monte Carlo Simulation)
- Calculate costs (no adaptation)
- Calculate Costs (with adaptation)
- Calculate NPV/BCR of Adaptation option
- Generate Probabilistic Distribution of NPVs/BCRs from All Iterations Run
- Identify Adaptation Options

Optimization of Timing of Adaptation Option (possible future improvement)
Lessons Learned

• 24-hour duration precipitation projections that are available from standard climate models are better suited for larger watersheds such as in the design of large culverts

• Benefit/Cost Analysis using the Monte Carlo process is an effective way to deal with the environmental uncertainties influencing major projects
For More Information

Webinar Series:
Building a Climate Resilient Transportation System

• Tuesdays starting February 10th

• www.fhwa.dot.gov/environment/climate_change/adaptation/webinars/

Virtual Adaptation Framework website:
www.fhwa.dot.gov/environment/adaptationframework

www.fhwa.dot.gov/environment/climate_change/adaptation/
I-10 – Mileposts 24 to 25
Road Alignment Exposure to Storm Surge
I-10 – Mileposts 24 to 25
Road Alignment Exposure to Storm Surge

Step 4: Climate scenario – Coastal storm surge with sea level rise added to most extreme scenario

Step 5: Assess Facility Performance

<table>
<thead>
<tr>
<th>Surge Scenario</th>
<th>Overtop I-10?</th>
<th>Inland Flooding Acre-Feet (Cu.Meters)</th>
<th>Flow Velocities at Tenn. St. &amp; Rail Underpass fps (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hurricane Katrina Base Case Scenario</td>
<td>NO</td>
<td>40 (51,700)</td>
<td>3.4 (1.0)</td>
</tr>
<tr>
<td>Hurricane Katrina Shifted Scenario</td>
<td>YES</td>
<td>1,300 (1,581,000)</td>
<td>6.6 (2.0)</td>
</tr>
<tr>
<td>Hurricane Katrina Shifted + Intensified + Sea Level Rise (SLR) Scenario</td>
<td>YES</td>
<td>2,800 (3,412,000)</td>
<td>6.8 (2.1)</td>
</tr>
</tbody>
</table>

Permissible velocities: Grass: 2 to 4 fps; RR ballast: 3 to 6 fps; Concrete: 18 fps
Lessons Learned

- Roadway embankment breaching is an area with little research data on prediction methods.
- Additional erosion protection should be considered when designing roadway crossings that could be subjected to reverse flow from storm surges.

Step 6: Develop Adaptation Options

- Harden one or more of the underpasses
- Armor I-10 roadway embankment
- Raise the roadway
### Criticality Guidance
- Provides how-to for doing a critical asset inventory

### Sensitivity Matrix
- Details if and how infrastructure types are affected by climate stressors
Using Indicators to Score Vulnerability

- $V = \text{Function of } (E, S, A)$
- Chose indicators to represent exposure, sensitivity, and adaptive capacity
  - Characteristics that could indicate an asset may or may not be vulnerable
  - Averages of indicators drive scoring
  - Weighting is important!
## Engineering: GC2 Solution

### Case Studies Covered Multiple Modes

<table>
<thead>
<tr>
<th>Climate Stressor</th>
<th>Asset Type</th>
<th>Damage Mechanism</th>
<th>Asset Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Culvert</td>
<td>Overtopping</td>
<td>Airport Blvd @ Montlimar Creek</td>
</tr>
<tr>
<td>Sea Level Rise</td>
<td>Bridge</td>
<td>Clearance</td>
<td>Cochrane Africatown USA Bridge</td>
</tr>
<tr>
<td>Sea Level Rise</td>
<td>Slope</td>
<td>Slope erosion</td>
<td>US 90/98 Tensaw Bridge</td>
</tr>
<tr>
<td>Storm Surge</td>
<td>Pier</td>
<td>Waves</td>
<td>McDuffie Coal Terminal, Dock 1</td>
</tr>
<tr>
<td>Storm Surge</td>
<td>Bridge</td>
<td>Waves/Scour</td>
<td>US 90/98 Tensaw Bridge</td>
</tr>
<tr>
<td>Storm Surge</td>
<td>Bridge</td>
<td>Wave forces</td>
<td>Exit 30, EB Ramp I-10 Bayway Brdg</td>
</tr>
<tr>
<td>Storm Surge</td>
<td>Roadway</td>
<td>Flood/erosion</td>
<td>I-10, Between Mileposts 24 and 25</td>
</tr>
<tr>
<td>Storm Surge</td>
<td>Tunnel</td>
<td>Flood</td>
<td>Wallace Tunnel</td>
</tr>
<tr>
<td>Temperature</td>
<td>Pavement</td>
<td>Ruts, Heaves</td>
<td>Generic</td>
</tr>
<tr>
<td>Temperature</td>
<td>Rail</td>
<td>Buckling</td>
<td>Generic</td>
</tr>
<tr>
<td>All</td>
<td>O&amp;M</td>
<td>Wear/tear</td>
<td>Generic</td>
</tr>
</tbody>
</table>