America’s Climate Choices
Adaptation – A Challenge to the Transportation Industry

November 3, 2010
TRB Webinar
H. G. Schwartz, Jr.
Major Factors Affecting Climate

**Human Activities**
- Long-lived greenhouse gases
  - Ozone
- Stratospheric water vapor
- Surface reflectivity
  - Direct effect
  - Cloud reflective effect
- Land use
- Soot (black carbon) on snow

**Total natural influences** (solar output)

**Total net** (human activities)
MITIGATION

Measures to reduce Greenhouse Gas emissions:

- Underground sequestration
- Reduced use of fossil fuels
- Geo-engineering of the troposphere
ADAPTATION

Natural or man-made adjustments or actions to accommodate or reduce the adverse consequences of climate change
BASIC TENETS

- Global warming is occurring and climate changes are unlikely to unfold gradually.
- Historical weather and climate patterns may no longer be a reliable planning guide.
- Impacts will affect all U.S. regions and all transportation modes.
- Climate changes will require significant changes in planning, design, operation, and maintenance of the transportation infrastructure.
- Today’s investment decisions will affect how well the infrastructure adapts to climate change far into the future.
WEATHER VS CLIMATE

- Weather is what we experience at any point in time
- Climate is the long-term average weather
CLIMATE CHANGES OF RELEVANCE FOR TRANSPORTATION OVER THE NEXT 50-100 YEARS

- Rising sea levels (virtually certain)
- Increases in very hot days and heat waves (very likely)
- Increases in Arctic temperatures (virtually certain)
- Increases in intense precipitation events (very likely)
- Increases in hurricane intensity (likely)
Gulf Coast Study
Highways Vulnerable to Relative SLR

4 Feet of Sea Level Rise

Source: Cambridge Systematics analysis of U.S. DOT Data.
Hurricane Katrina Damage to Highway 90 at Bay St. Louis, MS

Gulf Coast Study
Highways Vulnerable to Relative SLR

23 Feet of Sea Level Rise

Source: Cambridge Systematics analysis of U.S. DOT Data.
Gulf Coast Study
At 23 foot storm surge

- 64% of Interstate highway miles
- 57% of arterials
- 41% of freight rail lines
- 99% of ports
- 29 airports

Are flooded!
SEA LEVEL RISE
(virtually certain)

- Inundation of roads, rail lines, and runways in coastal areas
- Flooding of tunnels and low lying infrastructure
- Erosion of bridge supports
- Changes needed in harbors and ports
- More severe storm surges requiring evacuation
- Destruction of barrier islands
Lower Emissions Scenario
Projected Temperature Change (°F)
from 1961-1979 Baseline

Mid-Century
(2040-2059 average)

End-of-Century
(2080-2099 average)
Higher Emissions Scenario
Projected Temperature Change (°F)
from 1961-1979 Baseline

Mid-Century
(2040-2059 average)

End-of-Century
(2080-2099 average)
INCREASED HEAT WAVES
(very likely)

- Thermal expansion – bridges and pavements
- Pavement integrity
- Rail track deformations
- Lift-off limits at hot weather airports
- Lower water levels in Great Lakes
- Droughts → brush and forest fires
- Limitations on hours of construction
Observed and Projected Temperature Rise in Alaska
Projected Coastal Erosion, 2007 to 2027
Newtok, western Alaska
INCREASE IN ARCTIC WARMING (virtually certain)

- Thawing of permafrost – subsidence of highways, rail beds, pipelines, and runways
- Shorter season for ice roads
- Sea ice retreat → erosion
- 10-20% increase in infrastructure maintenance costs
- Ice-free Northwest Passage
- Longer ocean transport season
Increases in Very Heavy Precipitation
1958 to 2007
INCREASE IN INTENSE PRECIPITATION (very likely)

- Increase in intense precipitation events
- Traffic disruptions
- Increase in airline delays due to convective weather
- Localized flooding of roadways, rail lines, runways
- Major flooding on inland rivers
- Scouring of pipeline supports and bridge foundations
STRONGER HURRICANES (likely)

- Interruptions to air service
- More frequent and costly evacuations
- Greater probability of infrastructure failures
- Failure of bridge decks
- Damage to ports and harbors
- 7 of 10 largest ports are on Gulf Coast
- Thousands of oil platforms along Gulf Coast
RISK ANALYSIS

- Hazards of concern
- Vulnerable transportation assets
- Potential consequences
- Probability of occurrence

Risk = probability × consequence
UNCERTAINTY OF CLIMATE SCIENCE

- Natural variations
- Level of GHG emissions
- Response of earth’s ecosystem
ISSUE OF SCALE

Global

Continental

Regional

Local

Confidence

Level
Climate change will be characterized by more frequent, more intense weather events.

1:100 year → 1:20 year
MULTIPLE STRESSES

- Climate change is but one stress
- Environmental
- Economic
- Social
- Institutional
ADAPTATION PLANNING PROCESS

1. Identify current and future climate changes relevant to the system
2. Assess the vulnerabilities and risk to the system
3. Develop an adaptation strategy using risk-based approach
4. Identify opportunities for co-benefits and synergies across sectors
5. Implement adaptation options
6. Monitor and re-evaluate implemented adaptation options
NYC RISK MATRIX

Magnitude of consequence of impact on infrastructure

Likelihood of impact on infrastructure occurring during asset’s useful life

- Low
- Medium
- High
- Very High

- Develop Strategies
- Evaluate Further/Develop Strategies
- Watch
NYC PRIORITIZATION MATRIX

Funding Needed to implement adaptation strategy
DEVELOPING AN ADAPTATION STRATEGY

- Pertinent climate change impacts
- Identify vulnerable assets
- Develop alternative strategies
- Evaluate risk
- Consider co-benefits and adverse impacts
- Cost-effectiveness and timeliness
SEA LEVEL RISE ADAPTATION

- Dikes and levees
- Elevate critical infrastructure
- Move or abandon coastal systems
- Incentives to reduce development
- Good evacuation routes
ADAPTATION TO HEAT WAVES

- New heat resistant materials
- Replacement of expansion joints
- Longer runways
- Redesign rails to reduce stresses
- More night time construction
ADAPTATION TO MORE INTENSE STORMS

- Revise FEMA flood plain maps
- Update return frequency curves
- Revise design standards for hydraulic structures
- Protect vulnerable structures
- Restrict development in flood plains
- Storm retention basins
ADAPTATION TO STRONGER HURRICANES

- Move critical infrastructure inland
- More robust and resilient structures
- Design for greater storm surges, farther inland
- Strengthen port and harbor facilities
- Surge barriers on critical rivers
ADAPTATION IN THE ARCTIC

- Identify areas with permafrost thawing
- New designs for construction on less stable soils
- Dikes and levees
- Move at-risk communities
REFERENCES

America’s Climate Choices: Adapting to the Impact of Climate Change
National Research Council, 2010

The National Research Council
TRB Special Report 290

Adaptation to the Impacts of Climate Change on Transportation
Henry G. Schwartz, Jr
The Bridge, Volume 40, Number 3, Fall 2010
References

Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study Phase 1
www.climatescience.gov

Global Climate Change Impacts in the United States,
www.globalchange.gov/usimpacts
Adapting Transportation Systems to Changes in Climate.....Incorporating Risk and Uncertainty into Decision Making

Michael D. Meyer, P.E.
F. R. Dickerson Professor of Civil Engineering
Georgia Institute of Technology
Climate Adaptation Planning

Identify critical performance measures

Identify critical assets in the network

Identify predominant climate change trends and factors for region

Identify impact of these changes on local environmental conditions

Identify vulnerabilities of highway system to these changing conditions

Conduct risk appraisal of vulnerabilities and environmental changes

Identify trigger levels

Assess feasibility and cost effectiveness of adaptation strategies

Asset A
Asset B
Asset C
Asset X
Network Functions

Identify affected highway agency functions

Change design standards
Change operating strategies
Change maintenance practices
Change construction practices
Etc.

Identify critical performance measures
Climate Adaptation Planning

1. Identify critical performance measures
2. Identify critical assets in the network
3. Identify predominant climate change trends and factors for region
4. Identify impact of these changes on local environmental conditions
5. Identify vulnerabilities of highway system to these changing conditions
6. Conduct risk appraisal of vulnerabilities and environmental changes
7. Identify trigger levels
8. Assess feasibility and cost effectiveness of adaptation strategies

Network Functions

- Identify affected highway agency functions
- Change design standards
- Change operating strategies
- Change maintenance practices
- Change construction practices
- Etc.
Ensembles, November 2009. *Climate Change and Its Impacts at Seasonal, Decadal and Centennial Timescales*, Met Office Hadley Centre, Exeter, UK.
Probability of Occurrence

Ensembles, November 2009. Climate Change and Its Impacts at Seasonal, Decadal and Centennial Timescales, Met Office Hadley Centre, Exeter, UK.
Risk Rating: Victoria

Table 9: Risk Rating Matrix

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Insignificant</th>
<th>Minor</th>
<th>Moderate</th>
<th>Major</th>
<th>Catastrophic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>A (almost certain)</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>B (likely)</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>E</td>
</tr>
<tr>
<td>C (moderate)</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>E</td>
</tr>
<tr>
<td>D (unlikely)</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>E (very unlikely)</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
</tr>
</tbody>
</table>

E - Extreme risk, requiring immediate action.
H - High risk issue requiring detailed research and planning at senior management level.
M - Moderate risk issue requiring change to design standards and maintenance of assets.
L - Low risk issue requiring action through routine maintenance of assets.

Figure 4.1 Cascade of uncertainties in climate change prediction. The dashed line encompasses the climate simulation segment of the cascade (from Giorgi 2005).
Figure 4.3 Carbon dioxide emissions from 1970-2100 using the SRES scenario storylines and uncertainty quantification. In red is the A1 scenario, in pink the A2, in green the B1 and in blue the B2 (van Vuuren et al. 2007).
Figure 3.6 Additional water required (in intervals in Ml/d) in order to maintain levels of service by the 2030s in the East Suffolk and Essex Water Resource Zone under the water company’s demand projection as a function of regional climate response uncertainty (represented by summer precipitation change in the horizontal from a 25% increase to a 50% decrease) and climate impacts uncertainty (represented by hydrological modelling uncertainty in the vertical from -50% to 50%).
Physical processes such as:
-- Wave runup
-- Settlement
-- Degradation
-- Super elevation
-- etc.

Physical processes such as:
--Wave runup
--Settlement
--Degradation
--Super elevation
--etc.

Figure 3.5 Flexible design, anticipating imaginable surprises

**TABLE 1 Environmental Factors and Related Impacts: Temperature**

<table>
<thead>
<tr>
<th>Environmental Factor</th>
<th>Facility</th>
<th>Possible Effect</th>
<th>Cause</th>
<th>Formula Index Nos.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Rise</td>
<td>Roadway Foundation</td>
<td></td>
<td></td>
<td>401, 407</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roadway Pavement</td>
<td>Asphalt strength decrease</td>
<td>Loss of viscosity</td>
<td>404, 406</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Concrete pavement heaving</td>
<td>Thermal expansion</td>
<td>406, 407</td>
</tr>
<tr>
<td></td>
<td>Roadside Slopes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roadside Planting</td>
<td>Species death or migration</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bridge - Water Crossing</td>
<td>Structural damage</td>
<td>Thermal expansion</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Bridge - Roadway Crossing</td>
<td>Structural damage</td>
<td>Thermal expansion</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Culvert</td>
<td>Flooding</td>
<td>Snowmelt</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Storm Sewerage</td>
<td>Flooding</td>
<td>Snowmelt</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Open Channel</td>
<td>Flooding</td>
<td>Snowmelt</td>
<td></td>
</tr>
<tr>
<td>Temperature Fall</td>
<td>Roadway Foundation</td>
<td>Foundation weakening</td>
<td>Freeze/thaw cycle frequency increase</td>
<td>401, 403, 404, 405, 406</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roadway Pavement</td>
<td>Pavement base and surface failure</td>
<td>Freeze/thaw cycle frequency increase</td>
<td>401, 407</td>
</tr>
<tr>
<td></td>
<td>Roadside Slopes</td>
<td>Slope stability decrease</td>
<td>Freeze/thaw cycle frequency increase</td>
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<td></td>
<td>Roadside Planting</td>
<td>Species death or migration</td>
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<td></td>
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<tr>
<td></td>
<td>Bridge - Water Crossing</td>
<td>Structural damage</td>
<td>Ice load</td>
<td>201</td>
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<tr>
<td></td>
<td>Bridge - Roadway Crossing</td>
<td>Foundation weakening</td>
<td>Thermal contraction</td>
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<tr>
<td></td>
<td>Culvert</td>
<td>Structural damage</td>
<td>Ice load</td>
<td>100-108</td>
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<tr>
<td></td>
<td>Storm Sewerage</td>
<td>Capacity reduction</td>
<td>Ice blockage</td>
<td>100-108</td>
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<tr>
<td></td>
<td>Open Channel</td>
<td>Capacity reduction</td>
<td>Icing</td>
<td>100-108</td>
</tr>
</tbody>
</table>
For example........

<table>
<thead>
<tr>
<th>Formula Index No.</th>
<th>Formula</th>
<th>Formula Name</th>
<th>Affected Variable</th>
<th>Range Under Existing Conditions</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>$Q = CiA$</td>
<td>Rational</td>
<td>$i$</td>
<td>0.3-1.2 in/hr (10%, 1 hour storm) 0.4-1.8 in/hr (1%, 1 hour storm)</td>
<td>Ground cover imperviousness factor probably will increase depending on location due to erosion caused by increased flow.</td>
</tr>
<tr>
<td>101</td>
<td>$t_c = \frac{0.93L^{0.6}N^{0.6}}{t^{0.4}S^{0.3}}$</td>
<td>Time of Concentration (Kinematic Wave)</td>
<td>$N$</td>
<td>0.011 – 0.80</td>
<td>Manning's overland flow roughness coefficient expected to decrease due to erosion caused by increased flow. Changes will depend on location.</td>
</tr>
<tr>
<td>102</td>
<td>$V = \frac{1.49}{n} R^{0.667} S^{0.5}$</td>
<td>Manning's equation for open channel flow</td>
<td>$n$</td>
<td>0.01 – 0.20</td>
<td>Roughness coefficient for excavated, dredged or natural channels. Expected to decrease due to increased channeling due to increased flow volumes.</td>
</tr>
<tr>
<td>104</td>
<td>$Q = aA^{b_1}S^{b_2}$</td>
<td>Regional regression equations</td>
<td>$a,b_1,b_2$</td>
<td>-</td>
<td>Based on historical recorded levels of gaged streams in region. With increased precipitation, historical records will no longer reflect current flows.</td>
</tr>
</tbody>
</table>

Keller, Jake A.; Armstrong, Amit; Flood, Michael; Meyer, Michael D, AN APPROACH TO ADDRESSING THE IMPACTS OF CLIMATE VARIABILITY ON ROADWAY AND BRIDGE DESIGN, paper to be presented at the Annual Meeting of TRB, Jan. 2011.
<table>
<thead>
<tr>
<th>Frameworks for decision making under uncertainty</th>
<th>Uncertainty assessment methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top-down approaches</td>
<td></td>
</tr>
<tr>
<td>• Prevention Principle</td>
<td>c</td>
</tr>
<tr>
<td>• IPCC approach</td>
<td>key</td>
</tr>
<tr>
<td>• Risk approaches</td>
<td>key</td>
</tr>
<tr>
<td>Bottom-up approaches</td>
<td></td>
</tr>
<tr>
<td>• Precautionary Principle</td>
<td>c</td>
</tr>
<tr>
<td>• Engineering safety margin</td>
<td>c</td>
</tr>
<tr>
<td>• Anticipating design</td>
<td>c</td>
</tr>
<tr>
<td>• Resilience</td>
<td>key</td>
</tr>
<tr>
<td>• Adaptive management</td>
<td>c</td>
</tr>
<tr>
<td>Mixed and alternative approaches</td>
<td></td>
</tr>
<tr>
<td>• Human development approaches</td>
<td>c</td>
</tr>
<tr>
<td>• Adaptation Policy Framework</td>
<td>key</td>
</tr>
<tr>
<td>• Robust decision making</td>
<td>key</td>
</tr>
</tbody>
</table>

| Table 5.2 Match and mismatch between Frameworks for decision making under uncertainty and methods for uncertainty assessment. Key = method of key importance; c=complementary method; mm=mismatch (between the type of uncertainty information that the assessment method yields and the type of uncertainty information that the decision framework needs). Shaded cells are combinations that to our opinion go well hand in hand. |
Vulnerability and Its Components

Exposure

Sensitivity

Potential Impact

Adaptive Capacity

Vulnerability

Other Countries

England

Climate Change Effects and Impacts Assessment
A Guidance Manual for Local Government in New Zealand
2nd Edition

May 2008

New Zealand
Highways Agency Approach

1. Define 'Objectives' and 'Decision making criteria'

2. Identify 'Climatic Trends' affecting Highways Agency

3. Identify Highways Agency 'Vulnerabilities'

4. 'Risk Appraisal'

5. 'Options Analysis' to address each vulnerability

6. Develop and implement 'Adaptation Action Plans' for each vulnerability

7. 'Adaptation Programme Review'

'Research', 'Monitoring' or periodic review

Confirm alignment
<table>
<thead>
<tr>
<th>Risk screening (Tier 1)</th>
<th>Qualitative and quantitative risk assessment (Tier 2 and 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Checklists</td>
<td>Uncertainty Radial</td>
</tr>
<tr>
<td>Brainstorming</td>
<td>Fault/Event Trees</td>
</tr>
<tr>
<td>Problem Mapping Tools</td>
<td>Decision and Probability Trees</td>
</tr>
<tr>
<td>Process Influence Diagrams</td>
<td>Expert Judgement and Elicitation</td>
</tr>
<tr>
<td>Consultation Exercises</td>
<td>Scenario Analysis</td>
</tr>
<tr>
<td>Fault/Event Trees</td>
<td>Climate Change Scenarios</td>
</tr>
<tr>
<td>Expert Judgement and Elicitation</td>
<td>Cross-Impact Analysis</td>
</tr>
<tr>
<td>Scenario Analysis</td>
<td>Monte Carlo Techniques</td>
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<tr>
<td>Climate Change Scenarios</td>
<td>Modelling Tools: Process Response Models</td>
</tr>
<tr>
<td>Cross-Impact Analysis</td>
<td>Statistical Models</td>
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<tr>
<td>Deliberate Imprecision</td>
<td>Development and use of Specific Sophisticated Modelling Tools</td>
</tr>
<tr>
<td>Pedigree Analysis</td>
<td>Climate Typing</td>
</tr>
<tr>
<td></td>
<td>Downscaling</td>
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<tr>
<td></td>
<td>Bayesian Methods</td>
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<td></td>
<td>Markov Chain Modelling</td>
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<tr>
<td></td>
<td>Interval Analysis</td>
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</tbody>
</table>
Criteria for Risk Appraisal

- Uncertainty
- Rate of Climate Change
- Extent of Disruption
- Severity of Disruption
## Uncertainty

<table>
<thead>
<tr>
<th>Uncertainty Level — Climate Change Predictions</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>H</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Medium</td>
<td>H</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Low</td>
<td>M</td>
<td>L</td>
<td>L</td>
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</tbody>
</table>
England’s Highway Agency

<table>
<thead>
<tr>
<th>Primary Climatic Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in average temperatures</td>
</tr>
<tr>
<td>Increase in maximum temperatures</td>
</tr>
<tr>
<td>Increase in winter rainfall</td>
</tr>
<tr>
<td>Reduction in summer rainfall</td>
</tr>
<tr>
<td>More extreme rainfall events</td>
</tr>
<tr>
<td>Reduction in snowfall</td>
</tr>
<tr>
<td>Increased wind speed for worst gales</td>
</tr>
<tr>
<td>Sea level rise</td>
</tr>
</tbody>
</table>
England’s Highway Agency

<table>
<thead>
<tr>
<th>Secondary Climatic Change Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longer growing season</td>
</tr>
<tr>
<td>Reduction in soil moisture</td>
</tr>
<tr>
<td>Change in groundwater level</td>
</tr>
<tr>
<td>Flooding</td>
</tr>
<tr>
<td>Reduction in fog days in winter</td>
</tr>
<tr>
<td>Reduction in icy days in winter</td>
</tr>
<tr>
<td>Frequency of extreme storm surges</td>
</tr>
</tbody>
</table>
## Extent of Disruption

<table>
<thead>
<tr>
<th>Score</th>
<th>Criterion Extent of Network Affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>&gt; 80% of network/users affected, or any specific highly strategic routes/locations</td>
</tr>
<tr>
<td>Medium</td>
<td>20-80% of network/users affected</td>
</tr>
<tr>
<td>Low</td>
<td>&lt; 20% of network/users affected</td>
</tr>
</tbody>
</table>
Assign 3, 2 and 1 to high, medium and low

Then…….

Highly disruptive, time-critical with high confidence vulnerabilities…..

(rate of climate change) x (extent of disruption) x (severity of disruption) x (4 – [uncertainty]) divided by 81
# Highways Agency High-level Climate-related Risks to Corporate Objectives

<table>
<thead>
<tr>
<th>Risk</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced asset condition and safety</td>
<td>Assets deteriorate more quickly due to changes in average climatic conditions, assets are more badly damaged as a result of more extreme climatic events.</td>
</tr>
<tr>
<td>Reduced network availability and/or functionality</td>
<td>Need for restrictions on the network to maintain safety, increased need for roadworks</td>
</tr>
<tr>
<td>Increased costs to maintain a safe, serviceable network</td>
<td>Construction/maintenance/repairs/renewal required more often; more extensive efforts required; new (more expensive) solutions required</td>
</tr>
<tr>
<td>Increased safety risk to road workers</td>
<td>Increased risk to construction and maintenance workers and traffic officers as a result of the need to work on the network more often and during extreme events</td>
</tr>
<tr>
<td>Increased program and quality risks due to required changes in construction activities</td>
<td>More onerous design requirements; new technical solutions with higher uncertainty affecting project programs and/or quality</td>
</tr>
<tr>
<td>Internal operational procedures not appropriate</td>
<td>Effects of climate change require new ways of working; changed or new business processes/skills/competencies</td>
</tr>
<tr>
<td>Increased business management costs</td>
<td>Need for more staff, more frequent (expensive) incidents to pay for; need for more research</td>
</tr>
</tbody>
</table>
Options for the treatment of risks:

- Future-proofing of designs
- Retro-fit solutions
- Developing contingency plans
- Updating operating procedures
- Monitoring
- Research
Proactive Strategies to Flood Risk

• Preventing flooding by improving the rainfall capture and storage capacity of a catchment (e.g. by enhancing or mimicking the water storage capacity of the soil);

• Increasing conveyance capacity to disperse floodwaters;

• Creating policies to maintain existing levels of service which incorporate climate change factors at the time of repairs or upgrades;

Proactive Strategies to Flood Risk, cont’d

• Establishing physical protection measures, e.g. building stop-banks;

• Managing the effects of flooding by removing at-risk land use such as infrastructure and the built environment in floodplains; and

• Managing the expectations of communities in flood-prone areas to expect and cope with flood events.

In summary,........