PIARC International Seminar
“Best Practices for Earthworks and Rural Roads”

CLIMATE CHANGE AND INFRASTRUCTURE

Resilient Measures for Road Risk Reduction and Storm Damage Prevention

Gordon R. Keller, PE, GE
Geotechnical Engineer
GENESEE GEOTECHNICAL
Retired USDA Forest Service
CLIMATE CHANGE

The Problem: CO$_2$ Emissions (Greenhouse Gases)
Climate Change—What can we expect?

• Generally warmer climate
• Cycles of drought and flooding
• More extreme storm events
• More intense rainfall
• More frequent major storms
• Erratic weather patterns
• Unpredictable events
Mitigations in the Transportation Sector

- Modify building codes/standards
- Inventories of critical points/routes
- Improve weather/flood warning systems
- Retrofit structures for larger flows
- Adapt AC and Concrete design for hotter weather
- Use Roads Engineering Best Practices
- Implement road “Stormproofing”
DROUGHTS AND FIRES
Napa, California 2017

Portugal, 2017
Fire Impacts on Roads
FIRE MITIGATIONS

French Fire, Sierra NF

Rock Mattress 6 Years Later

Newly Installed TRM
FREEZING AND ICE DAMS
STORMS WILL HAPPEN!!

The Question is…
• When??
• Where??
“Storm Damage Risk Reduction Guide for Low-Volume Roads”
or

- US Forest Service Climate Change & Transportation Resiliency Guidebook
- RMRS-GTR 375, Chapter 11: Effects of Climate Change on Infrastructure
Figure 10.1—Many geomorphic, hydrologic, and weather-related disturbances can damage roads and other infrastructure. Figure from Strauch et al. (2014).
## Risk Assessment

*Table 1—Risk assessment matrix*

<table>
<thead>
<tr>
<th>Probability of Damage or Loss</th>
<th>Magnitude of Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RISK</td>
</tr>
<tr>
<td></td>
<td>Major</td>
</tr>
<tr>
<td>Very likely</td>
<td>Very high</td>
</tr>
<tr>
<td>Likely</td>
<td>Very high</td>
</tr>
<tr>
<td>Possible</td>
<td>High</td>
</tr>
<tr>
<td>Unlikely</td>
<td>Intermediate</td>
</tr>
</tbody>
</table>

**RISK Summary:**
- Very high: Very likely
- High: Likely
- Intermediate: Possible
- Low: Unlikely
- Very low: Unlikely
Risk Assessment Tools

Measures to Identify Hazards, Minimize Landscape Changes, Reduce Geologic Hazards, and Reduce Infrastructure Damage

- Erosion Prediction Models (WEPP, ERMiT)
- USGS Debris Hazard/Slide Risk Maps
- Road/Structures Inventory Maps
- Road/Facility Damage History
- Watershed Improvement Needs
- Knowledgeable Folks/Problematic Areas
- Critical Road Maintenance Areas
Roads Vulnerability Reduction

Preventative Mitigation Measures
(Stormproofing)

• Having Road Maintenance Current
• Improving Road Surface Drainage
• Having Adequate Cross-Drainage
• Culvert and Channel Cleaning
• Preventing Culvert Diversion
• Increasing Pipe Capacity
• Overflow Protection and Trash Racks
• Low-Water Fords vs Culvert Pipes
Roads Vulnerability Reduction

Preventative Mitigation Measures (Stormproofing)

- Bridge Channel Cleaning & Scour Protection
- Road-Stream Encroachment-Moving Roads
- Good Vegetative Cover (Deep roots)
- Using Soil Bioengineering/Biotechnical Measures
- Gully Control and Prevention
- Local Slope Stabilization Measures
  - Pulling Back Unstable Fills, Deep Patch, Drainage Improvements, Soil Nailing.
Debris Slide Impacts

Don Lindsay, CGS
Debris Slide Prevention and Mitigation

- Preventing Drainage Concentration
- Pulling Back Sliver Fills

- Containment and Deflection Structures

Bill Shelmerdine
Landslide Impacts
Landslide Prevention and Mitigation

• Biotechnical Slope Stabilization Measures

• Deep Rooted Vegetation

• Retaining Structures

• Deep Patch
Flooding and Drainage Issues

- Local Flooding

- Stream Diversion

- Failed Structures and Washouts
Surface Drainage Issues

WATER CONCENTRATION

• Surface Drainage Problems—Erosion, Gullies
- **Surface Drainage Mitigations**
- **PREVENT WATER CONCENTRATION**
  - Improved Surface Drainage
  - Outslope, Inslope, Crown

![Diagram of drainage options](image1)

**Elevate the Road**

**An Entrenched, "Bath Tub" Section**
- Remove organic material and refill with selected borrow or aggregate backfill

**Fill Section**
- Use ditch embankment material to build up roadway

**Tump Pike Section**
- Cap with selected material or aggregate

![Elevated road section](image2)

**Remove Berms**

![Road with berms removed](image3)
Culvert Problems

- **Plugging**

- **Stream Diversion**

  - Sketch of a stream diverted down the road, forming a new channel. M. Furniss

- **Failed Structures**
FLOOD RESISTENT CULVERT DESIGN

- Q50-100 vs Q25

- Span ≥ Bankfull Width

- HW/D ≤ 1.0

**BETTER**
HW/D < 1

**WORSE**
HW/D > 1

HIGH HEADWATER:PIPE DIAMETER RATIO
Culvert Mitigations

- Stream Diversion Prevention

Robbin Stoddard
Culvert Mitigations

- Stream Simulation Structures

Mark Weinhold
Culvert Mitigations

• Drainage Structure Plugging Prevention - Trash Racks

After Fires
From Large Culvert to Ford/Low-Water Crossing
Road-Stream Encroachment

STAY OUT OF HARM’S WAY

- Evaluate Natural Channel Meander Potential

MOVE INFRASTRUCTURE AWAY FROM STREAMS

- Armor Stream Channels near Infrastructure
Bridge Problems

• Obstructions

• Lack of Capacity or Freeboard

• Scour Issues
Bridge Mitigations

Adequate Capacity, Span, and Freeboard
Bridge Mitigations

Scour Prevention/Protection

ABC, GRS Bridge Abutments, Buried Bridges
STARBUCKS FLOODING!!
Figure 10.6 Mapping buffers around streams can be used to identify current roads that are potentially at risk from flooding, and to preclude the placement of new roads in vulnerable locations.

Furniss, Little, Peterson
Figure 1. Map of the watershed which was the source of the debris flow impacting the Yokoji-Zen Mountain Center. The point locations (1-3) are referred to in the text.
Percent change in bankfull flow between historical and future (2080s) time periods for road segments within 90 m (200 feet) of streams.

Jessica Halofsky, et al.
Snowpack vulnerability at winter recreation sites and trails

Jessica Halofsky
Highways in the River Environment: Floodplains, Extreme Events, Risk, and Resilience

Highways in the Coastal Environment: Assessing Extreme Events
"Storm Damage Risk Reduction Guide for Low-Volume Roads"


or


- US Forest Service Climate Change & Transportation Resiliency Guidebook
- RMRS-GTR 375, Chapter 11: Effects of Climate Change on Infrastructure