NATIONAL ACADEMIES *Sciences Engineering Medicine*

TRB TRANSPORTATION RESEARCH BOARD

# TRB Webinar: Climate-Resilient, Low-Volume Road Design and Management

*August 7, 2023*

*1:00 – 2:30 PM*


NOVEMBER 2022 UPDATE

# PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

***The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.***

ENGINEERING RCEP REGISTERED CONTINUING EDUCATION PROGRAM

# Purpose Statement

This webinar will present useful and practical climate adaptation measures that road designers and managers can implement to help “stormproof” roads and reduce the risk of climate-induced damage. Presenters will share key measures for road maintenance, drainage design, slope stabilization, and debris flow mitigation to prevent or minimize damage from fires and storms.

# Learning Objectives

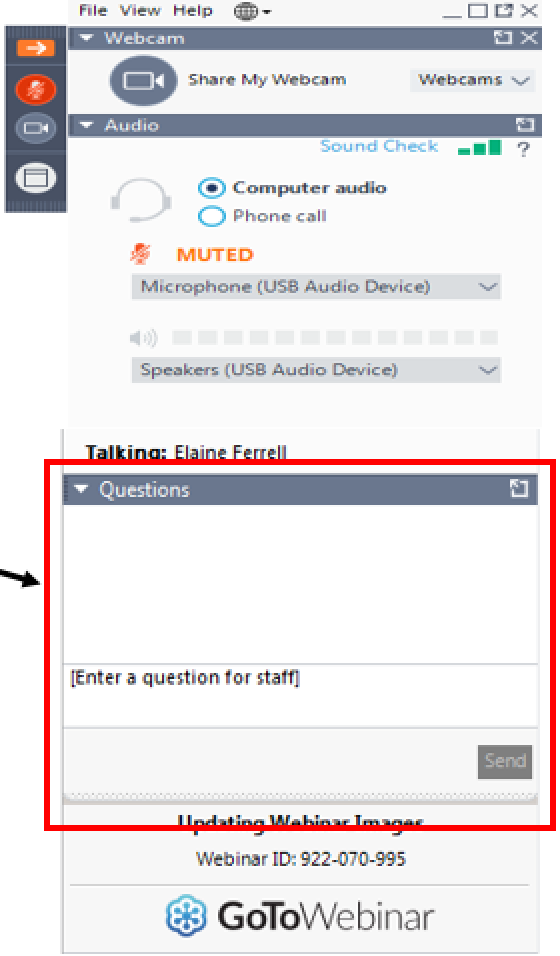
At the end of this webinar, you will be able to:

(1) Utilize a variety of tools or design measures, particularly related to drainage, to prevent storm damage to roads

(2) Implement damage prevention measures and fire-flood-debris flow mechanisms

# Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



# Today's presenters

**Laura Fay**
*Western Transportation Institute*
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MONTANA STATE UNIVERSITY
Western Transportation Institute

**Donald Lindsay**
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California Department of Conservation
California Geological Survey

**Gordon Keller**
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# CLIMATE RESILIENT LOW-VOLUME ROAD DESIGN AND MANAGEMENT

**Transportation Research Board Webinar**

**August 7, 2023**



**Gordon R. Keller PE, GE**
**Geotechnical Engineer**
gordonrkeller@gmail.com

# 2017 OROVILLE DAM SPILLWAY

-190,000 CFS MAX FLOW
-200,000 PEOPLE EVACUATED
- $$ 1.1 BILLION SPILLWAY REPAIRS

# 2018 CAMP FIRE, PARADISE


- 150,000 ACRES BURNED
- 19,000 BUILDINGS DESTROYED
- 85 LIVES LOST
- INSURED LOSSES $7.5-10 BILLION

MONTPELIER,
VERMONT
JUNE 4, 2023

MONTPELIER
JULY 11, 2023


GETTY IMAGES

# Sierra Nevada Climate Change Vulnerability Assessment and Adaptation Strategy for Infrastructure and Recreation




*A partnership among the U.S. Forest Service Region 5, Office of Sustainability and Climate, Pacific Northwest and Southwest Research Stations, and University of Washington*

**PLUS**

**Storm Damage Repair Work on several US ERFO events and in Central America, India, and Nepal**

# INFRASTRUCTURE AT RISK on California's National Forests

- ROADS- 31,300 Miles
- TRAILS- 12,500 Miles
- BRIDGES- 800
- FACILITIES- 6,500 Buildings
- DAMS- 208
- Numerous Culverts, Campgrounds, Water Systems, Communication Towers, Etc.

## There are things we can do!!
## (Improved Design Standards; Conservative, Cost-Effective Designs; Apply BMPs)

# KEY ADAPTATION AREAS

- ROAD MAINTENANCE
- ROAD LOCATION
- ROAD SURFACING
- CULVERTS
- BRIDGES AND FORDS
- SLOPE TREATMENTS
- EROSION CONTROL

# ROAD MAINTENANCE
## Prevent Water Concentration


V.Barandino

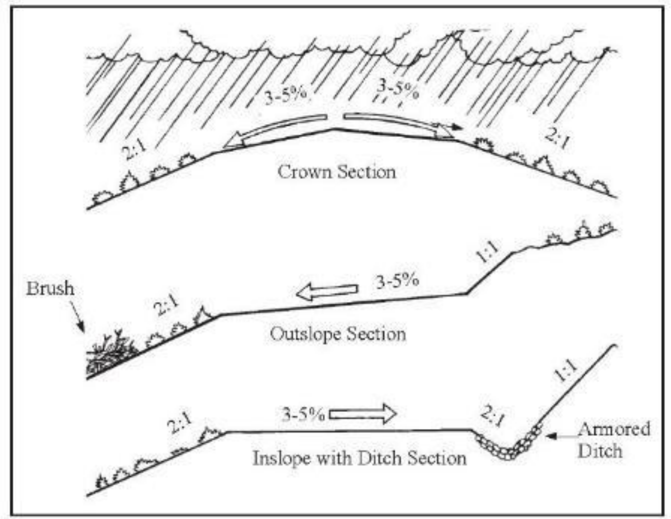
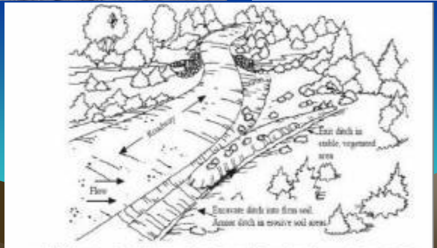
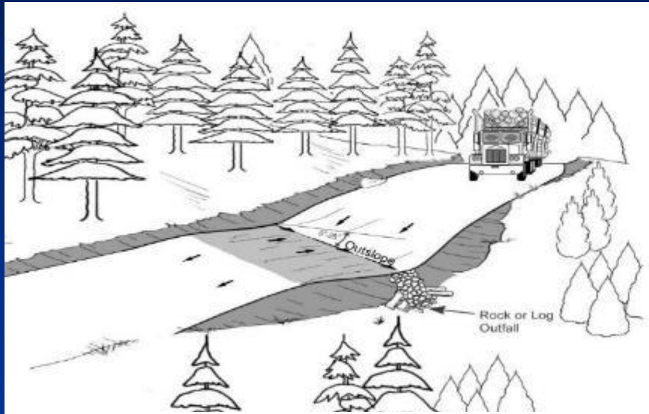


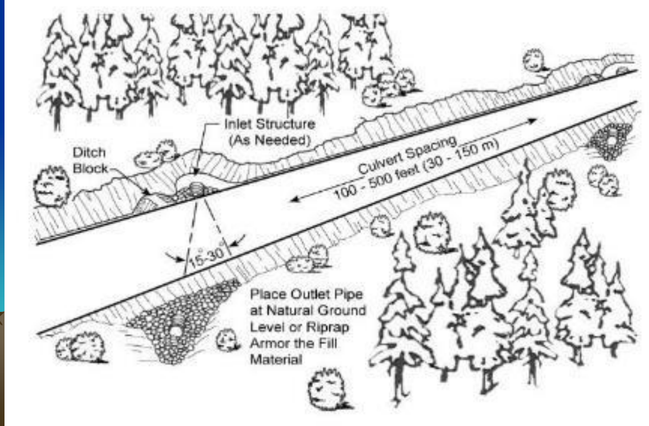

**Figure 7.1 Typical road surface drainage options.**




**a. Ditch Layout and Leadoff** *(Adapted from Wisconsin's Forestry Best Management Practices for Water Quality, 1995)*

# ROAD DESIGN & MAINTENANCE
## Disperse Water Rapidly



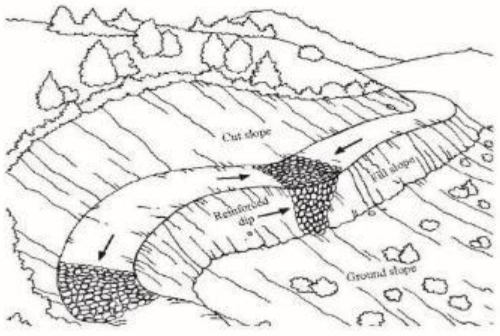
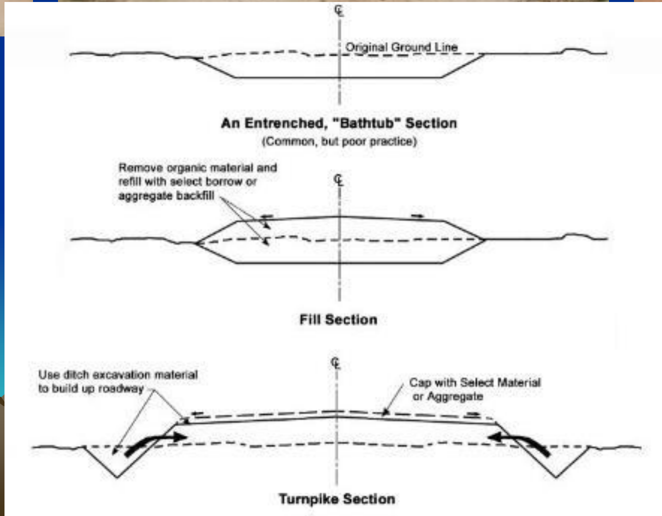




Figure 7-6 Basic Road Surface Drainage with Outsloping, Rolling Grades, and Reinforced Dips.

# ROAD MAINTENANCE
## Prevent Water Concentration


POOR




GOOD!

# ROAD MAINTENANCE
## Increase standard cross-drain size
## (24-36 Inch vs 12-18 Inch)
## Small Pipes Plug Easily!

# MULTIPLE SMALL PIPES ALSO PLUG EASILY



# ROAD LOCATION
# Avoid Channel Migration Zones



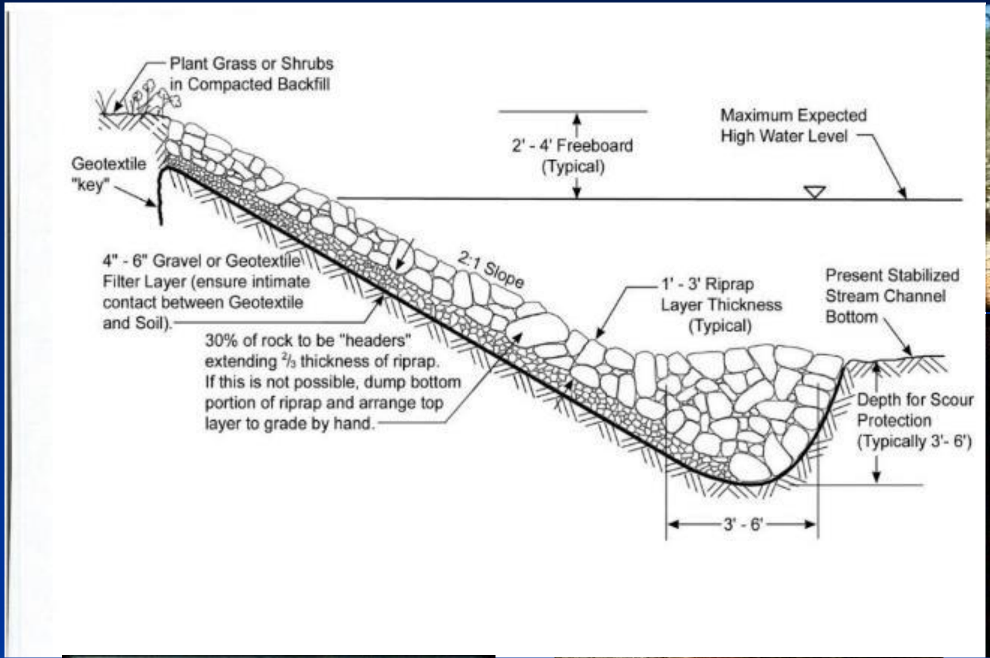
# ROAD LOCATION
# 1. Move the Road
# 2. Armor Streambanks-Redirect Flow





# RIPRAP ARMORING


# RIPRAP ARMORING DESIGN




# GABION ARMORING PROBLEMS

# ROAD SURFACING
## Armor the Road Surface


# ROAD SURFACING
## Armor the Road—Many Options



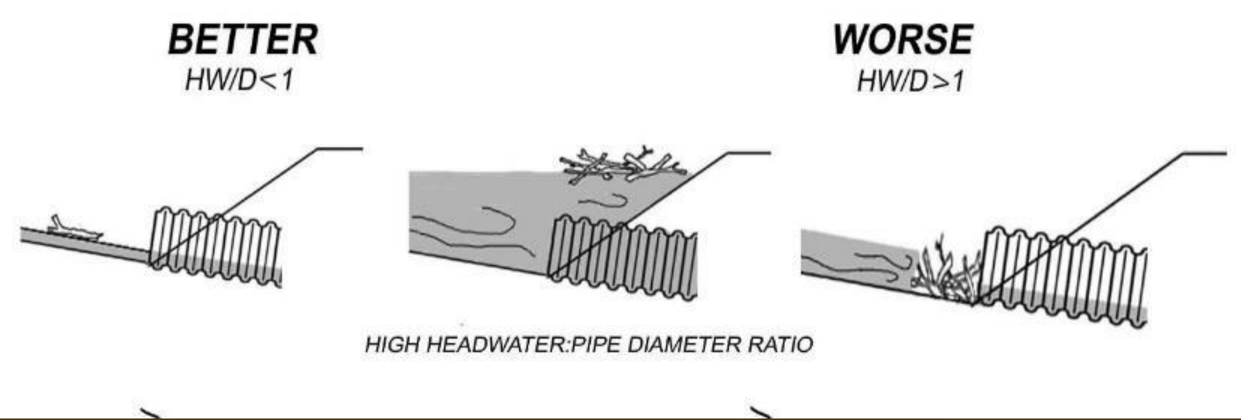


# CULVERTS
# Increase Capacity, Improve Design

-Q50-100  vs Q25

-Width ≥ Bankfull Width

-HW/D ≤ 1.0



# RESILIENT CULVERTS
# Increase Capacity—How Much??

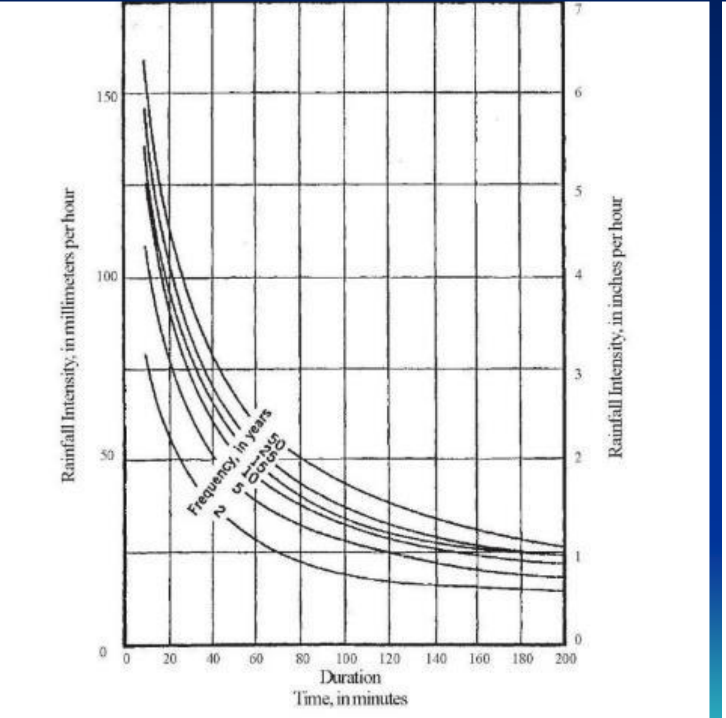
Increase Design Flow by 20-30 percent

Increase Recurrence Interval Q100 vs Q25 (from USGS regression equations)

Increase Frequency on IDF Curve – 100 vs 50 yr curve with Corresponding Increased Rainfall Intensity (i)

Temperature Scaling to adjust rainfall intensity (i)

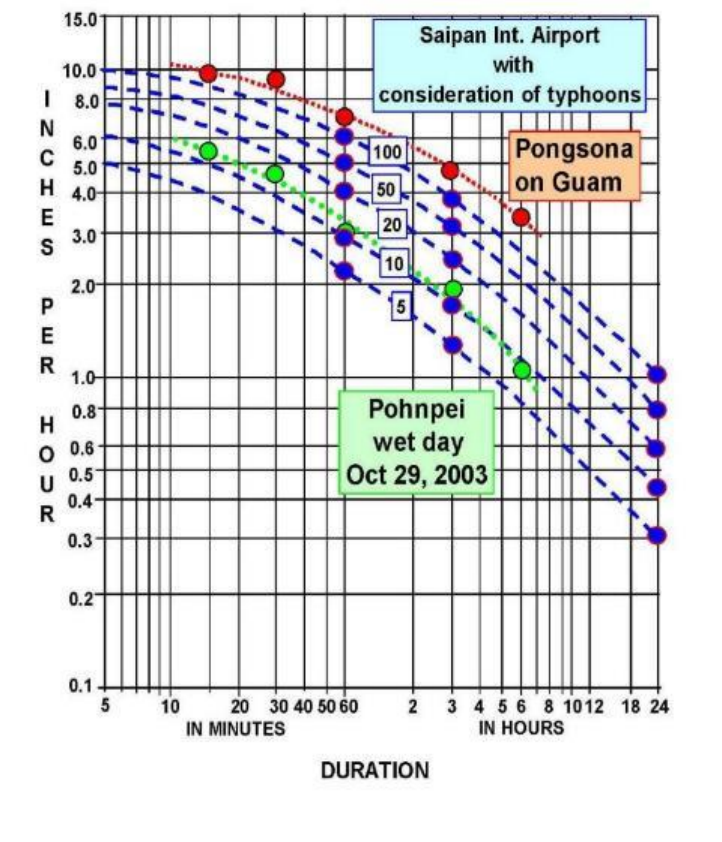
# Typical IDF




Note: Common Maximum Intensity Values for 25-50 Year Frequency of Events:

- Jungle Areas: 200-400 mm/hr
- Deserts: 50-100 mm/hr
- Most Areas (Semi-Arid, Mountains, Coastal Areas): 100-250 mm/hr

# Western Pacific IDF

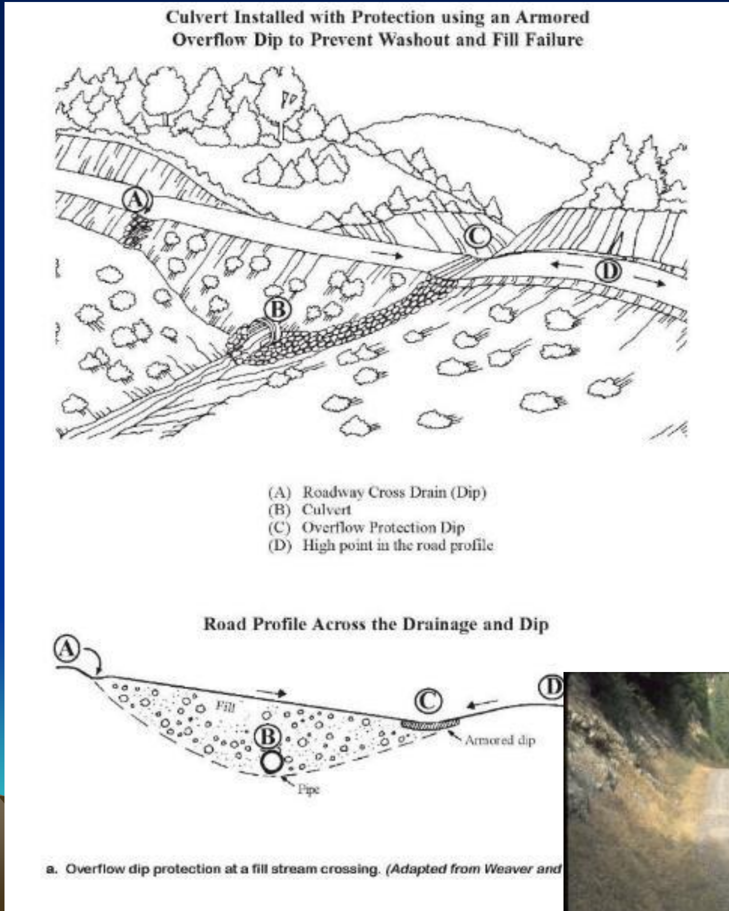


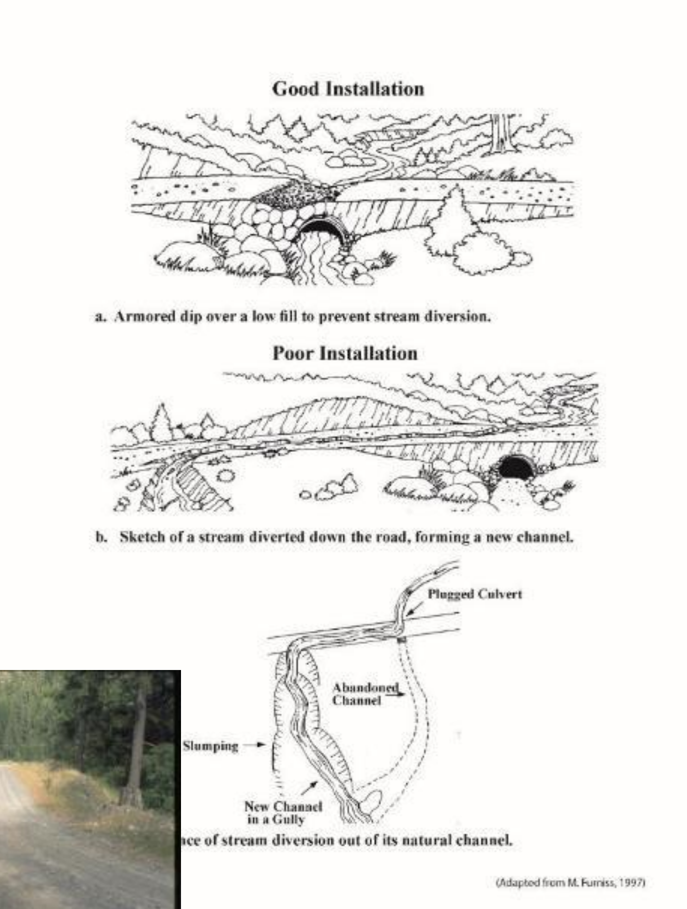
# CULVERTS
## Stream Diversion

Don Lindsay

R. Stoddard

# Stream Diversion Prevention Dips




# CULVERTS
# Plugging Problems
## In Mountains, 85 % of culvert failures are from plugging


# CULVERTS
## Prevent Plugging with Added Trash Racks

V. Barandino

BEFORE

AFTE
R

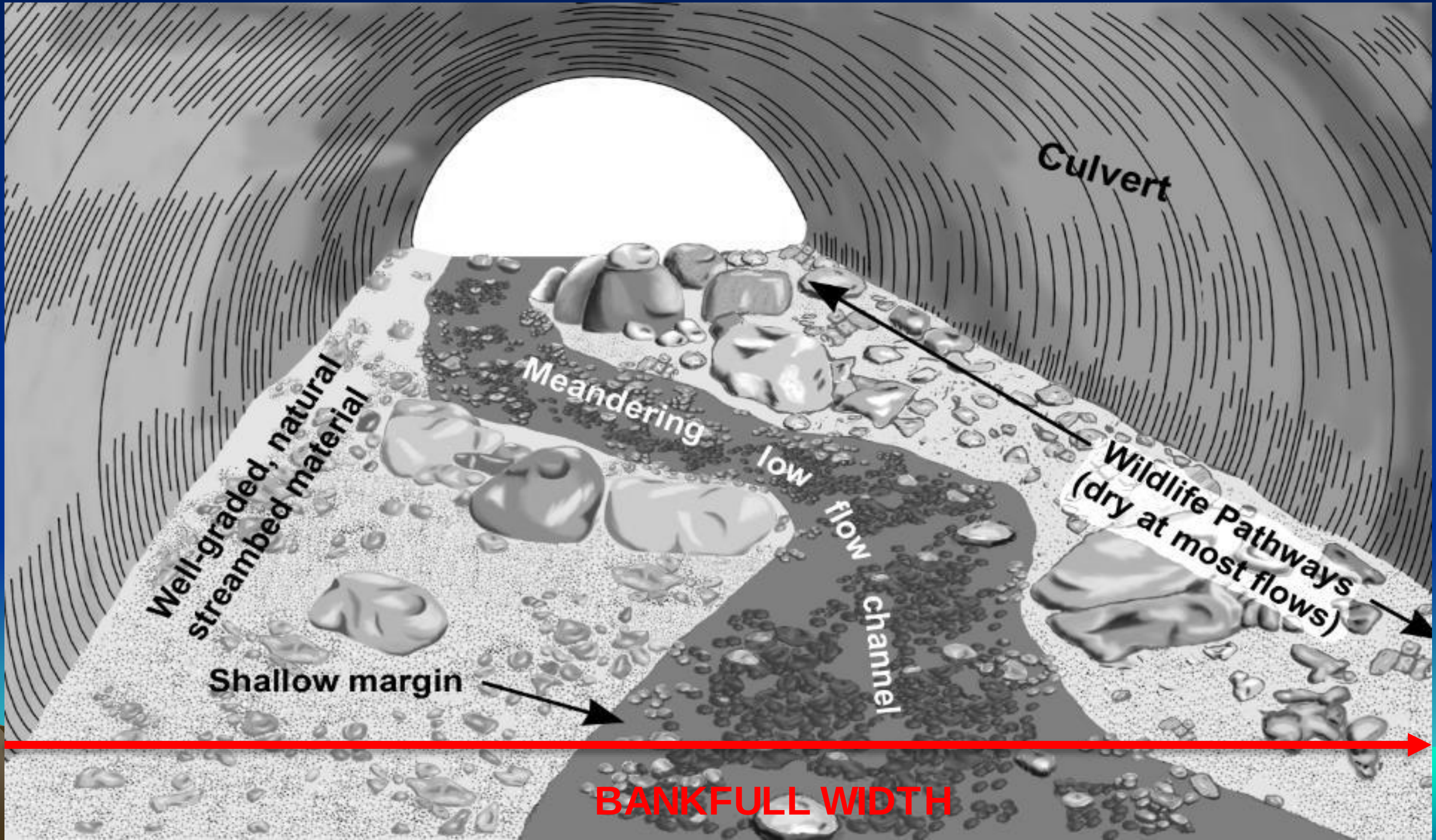
# CULVERTS
# After fires with mobilized sediments—Add Riser Trash Racks

# DAMAGED CULVERTS
# Less Capacity-More Risk

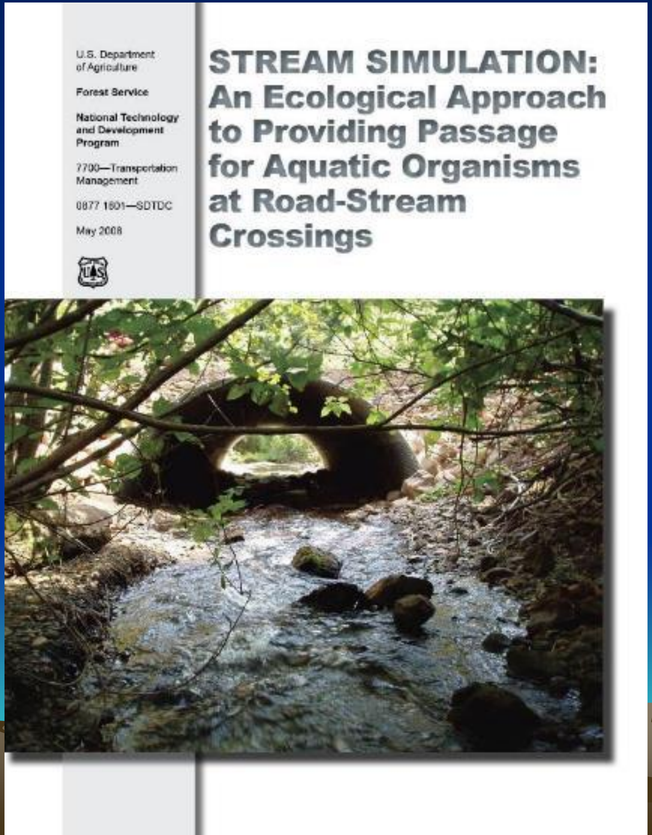
# CULVERTS
# Use Stream Simulation Concepts



# CULVERTS
# Use Stream Simulation Concepts



# CULVERTS
# Stream Simulation





Penn State CDGRS

# CULVERT COSTS
## Stream Simulation

Stream Simulation culverts generally cost more initially

Life cycle costs are often equal or less

Culvert passes larger flows = less damage or replacement/repair

Less problems with debris = less maintenance

Less need for armoring

# BRIDGE ISSUES

- **Obstructions**


- **Lack of Capacity**

- **Scour Issues**

# "Scary" Bridges

# BRIDGES
# Remove Debris/Trees in Channel

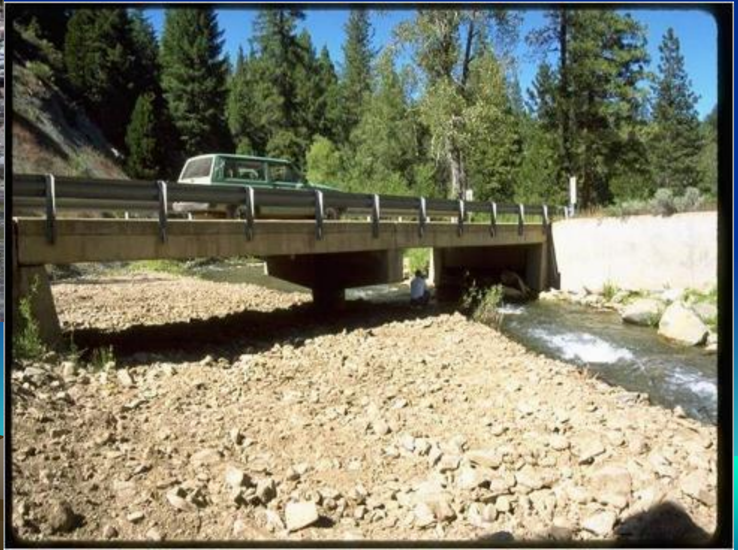
# BRIDGES
# Maintain Capacity and Freeboard





-- Alan Yamada, USFS --

# BRIDGES
## Aggradation--
## Remove the Deposited Sediment!

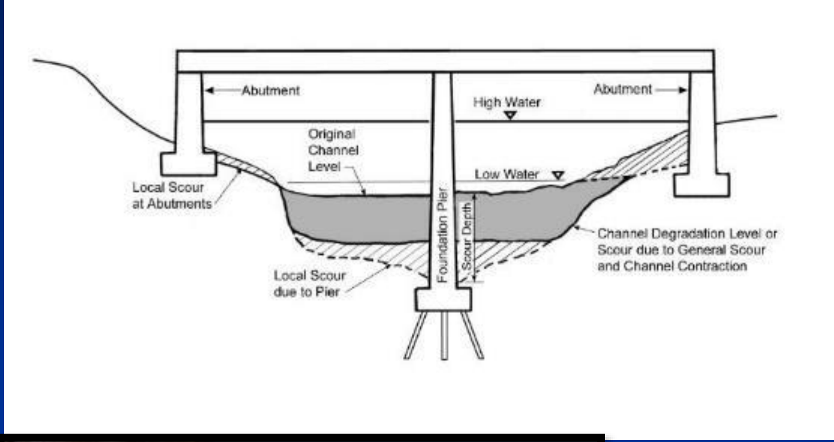



# BRIDGES
## Scour





# BRIDGES
# Use Scour Protection





# BRIDGE REPLACEMENT
# ABC-Accelerated Bridge Construction

Justin Dahlberg,
Iowa State U.
Bridge Eng. Center


**Precast Concrete Beams/Units**

# GRS Abutments


# Buried Bridges

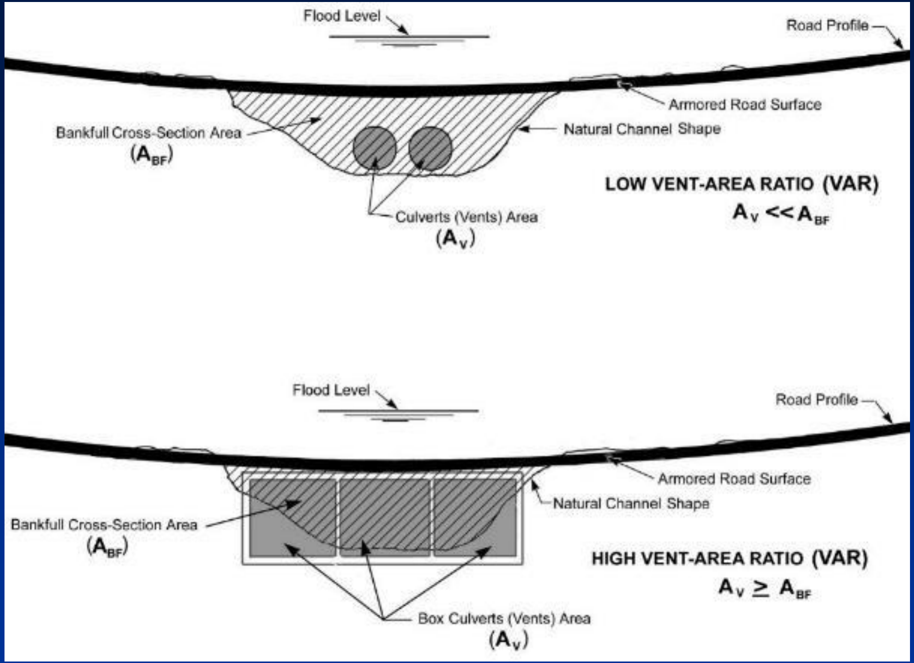
# FORDS or LOW-WATER CROSSINGS


# Where to Use a Low-Water Crossing

- **Flashy Flows/High Flow Fluctuation
- Low Traffic Use
- Delays are Acceptable/Non-critical Route
- Broad/Flat Channels (Slightly Entrenched)
- **Debris Prone Channels
- Grade Control Structures/Barriers
- $$$-Least Expensive Alternative

# FORDS or LOW-WATER CROSSINGS

## Small Pipes Plug Easily




**LOW VAR**

**HIGH VAR (Better!)**



# FORDS or LOW-WATER CROSSINGS

10 Foot Diameter Pipe
"Plugged"

Finally, a Vented Ford!

# SLOPE INSTABILITY

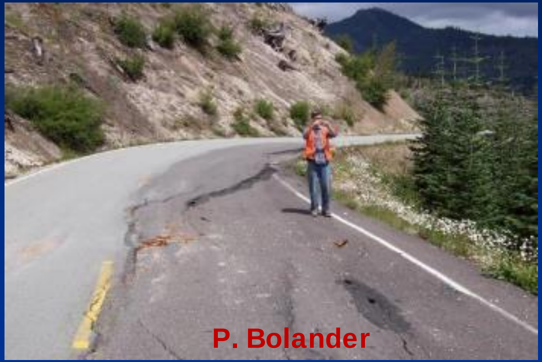


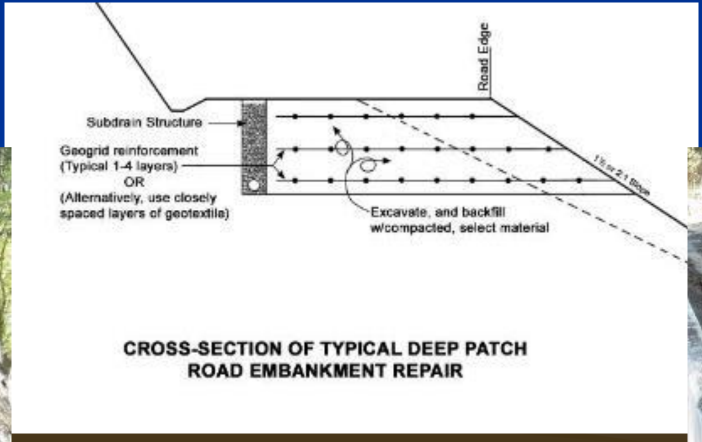

# SLOPE TREATMENTS
# MSE/GRS Walls/Buttresses






# SLOPE TREATMENTS
# Deep Patch Shoulder Reinforcement




# SLOPE TREATMENTS

## Problems with Shallow-Rooted Vegetation

# SLOPE TREATMENTS
# Vegetative Protection

**Deep-Rooted Vegetation**


**Soil Bio-Engineering**

WB

-- Robbin Sotir --


# SLOPE TREATMENTS
# Debris Flow Damage

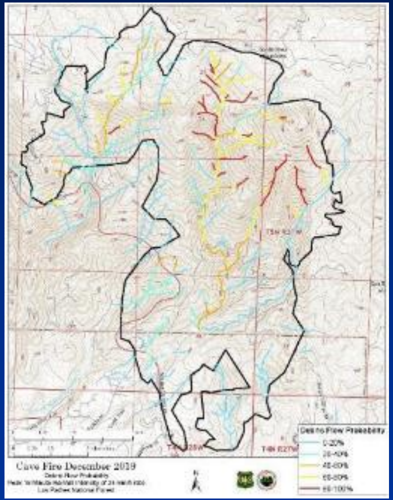

A. King

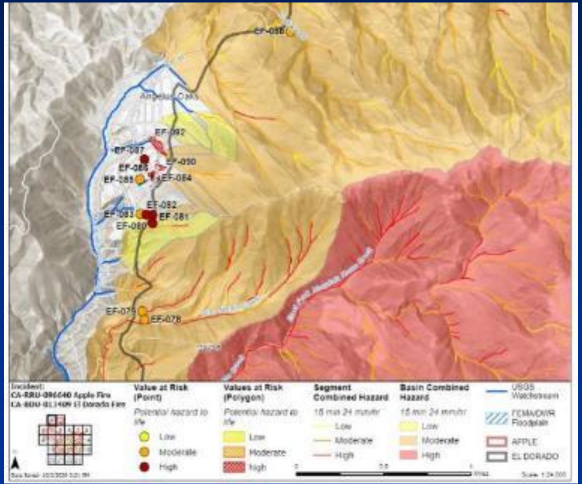

Y. Schwartz


CalTrans


Don Lindsay, CGS

# SLOPE TREATMENTS
# Debris Flow Protection





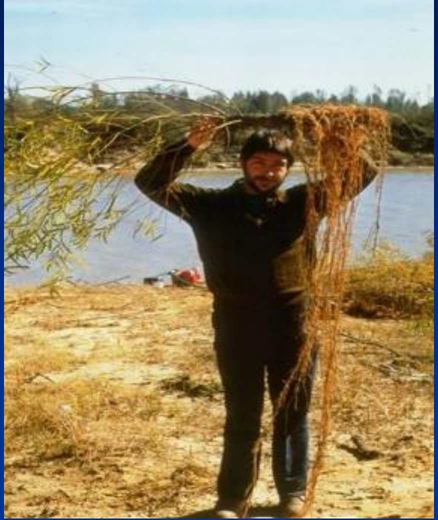
# SLOPE TREATMENTS
# Debris Flow Protection


# EROSION CONTROL
## Drainage Control and Ground Cover

### Control of Water

### Ground Cover

# EROSION CONTROL
# Deep Rooted Vegetation, Nets, RECP




# INFRASTRUCTURE ASSESSMENT AND RISK

- Have good asset inventories
- Form an interdisciplinary team
- Identify the assets at risk
- Examine site data and history
- Study relevant climate data/stressors
- Study relevant hydrology projections
- Conduct risk assessment
- Rank asset vulnerability
- Prioritize needed work

**INFORMATION SOURCES**

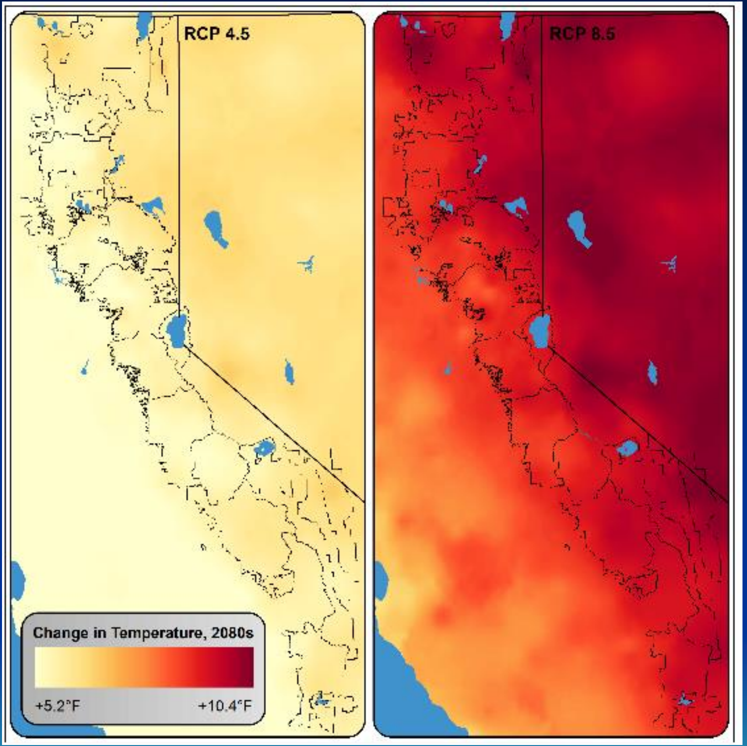
-USFS- Transportation Resiliency Guidebook, Appendix B
-FHWA- Adaptation Decision-Making Assessment Process (ADAP)
-CANADA-Public Infrastructure Engineering Vulnerability Committee

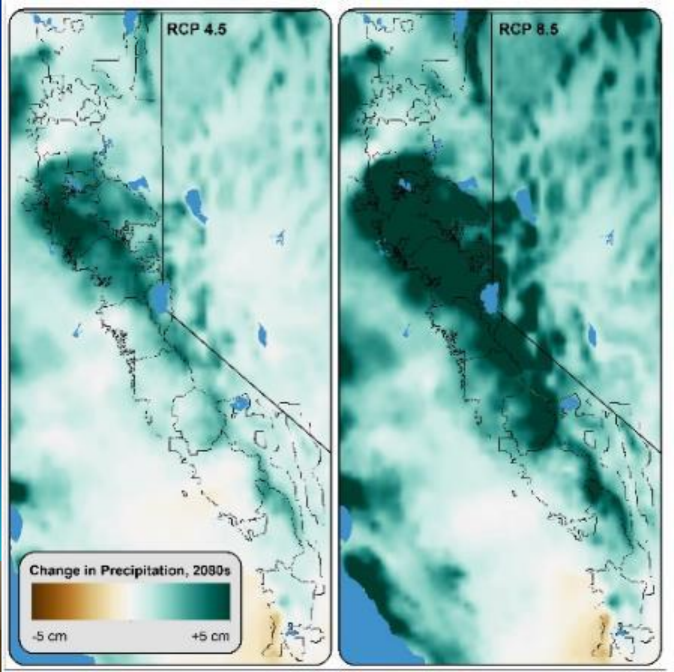
# Risk Assessment

*Table 1—Risk assessment matrix*

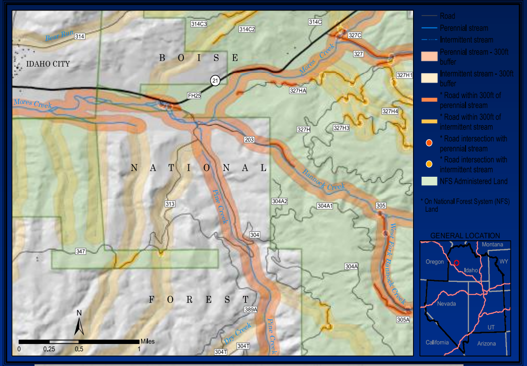
| Probability of Damage or Loss | Magnitude of Consequences | | |
|---|---|---|---|
| | RISK | | |
| | Major | Moderate | Minor |
| Very likely | Very high | Very high | Low |
| Likely | Very high | High | Low |
| Possible | High | Intermediate | Low |
| Unlikely | Intermediate | Low | Very low |

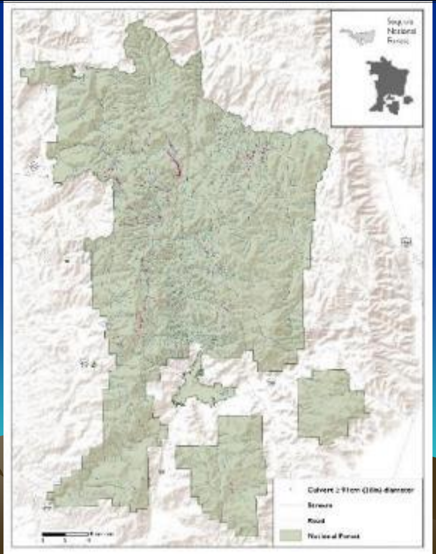
# TOOLS/PRODUCTS

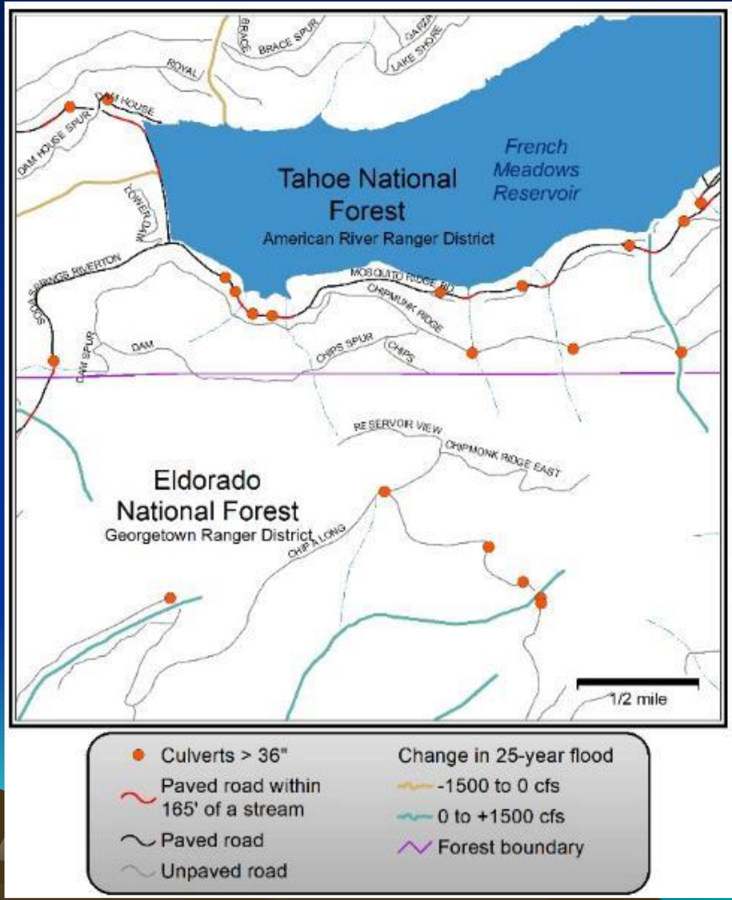


# TOOLS/PRODUCTS





# KEY REFERENCES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Storm damage risk reduction guide for low-volume roads (Keller and Ketcheson 2015).. Online: http://www.fs.fed.us/t-d/pubs/pdfpubs/pdf12771814/pdf12771814dpi100.pdf

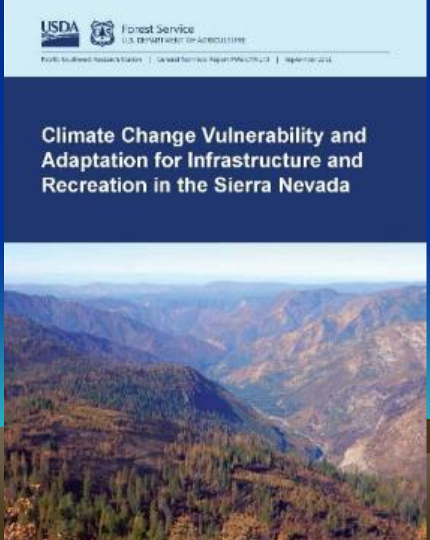
Synthesis of approaches for addressing resilience in project development (FHWA-HEP-17-082, 2017). https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/synthesis/index.cfm

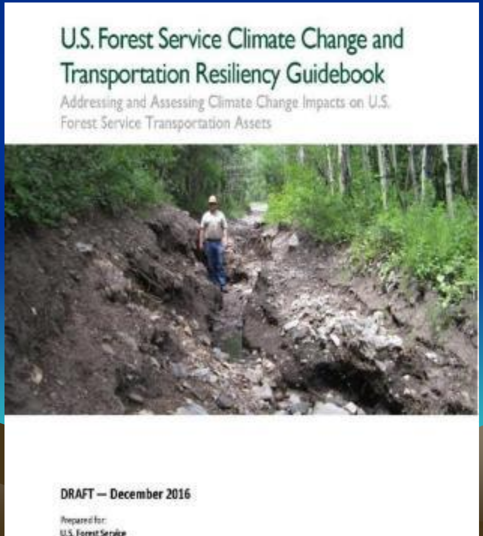
**Storm Damage Risk Reduction Guide for Low-Volume Roads**

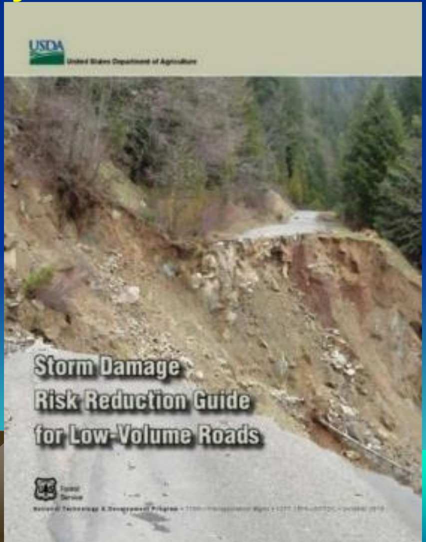
http://www.fs.fed.us/td/pubs/pdfpubs/pdf12771814/pdf12771814dpi100.pdf

**US Forest Service Climate Change & Transportation Resiliency Guidebook**

**PSW-GTR 272, Chapter 4: Infrastructure Vulnerability**



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# Fire, Floods, and Debris Flow Impacts to Roads

**Don Lindsay, PG, CEG, PE, GE**

Supervising Engineering Geologist and Geotechnical Engineer

**California Geological Survey**

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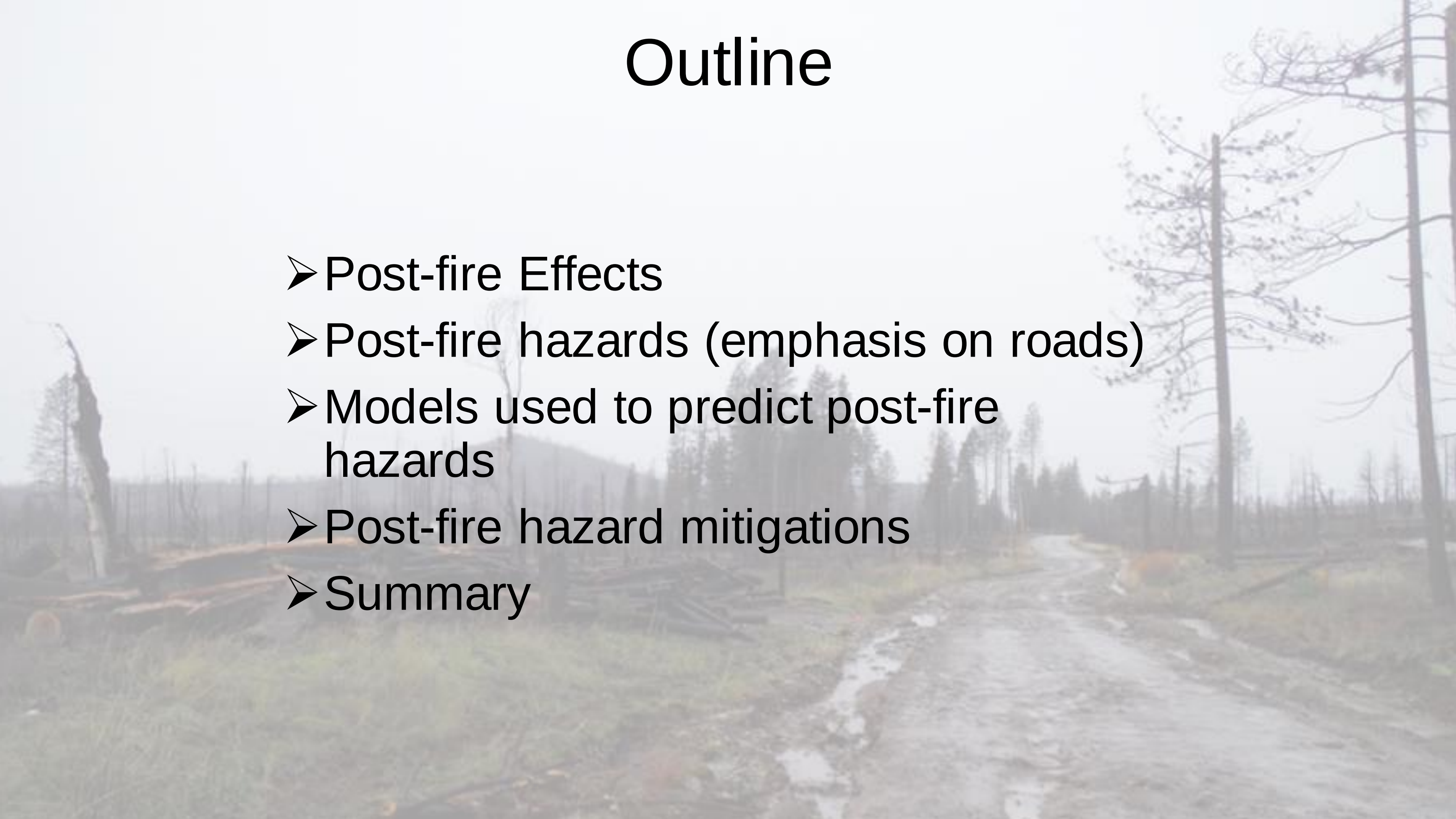


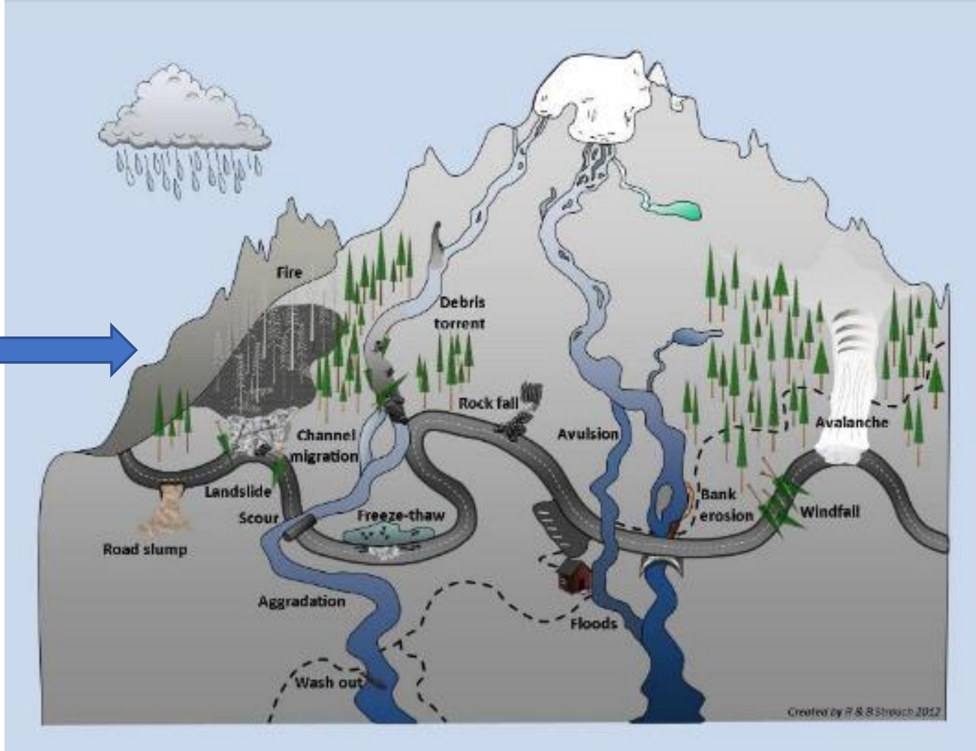
# Outline

- Post-fire Effects
- Post-fire hazards (emphasis on roads)
- Models used to predict post-fire hazards
- Post-fire hazard mitigations
- Summary

# Post-fire Effects → Post-fire Hazards

**Table 11**—Changes in hydrologic processes caused by wildfires (Neary and others 2005).

| Hydrologic process | Type of change | Specific effect |
|---|---|---|
| Interception | Reduced | Moisture storage smaller<br>Greater runoff in small storms<br>Increased water yield |
| Litter and duff storage of water | Reduced | Less water stored<br>Overland flow increased |
| Transpiration | Temporary elimination | Streamflow increased<br>Soil moisture increased |
| Infiltration | Reduced | Overland flow increased<br>Stormflow increased |
| Stream flow | Changed | Increased in most ecosystems<br>Decreased in snow systems<br>Decreased on fog-drip systems |
| Baseflow | Changed | Decreased (less infiltration)<br>Increased (less evaporation)<br>Summer low flows (+ and –) |
| Stormflow | Increased | Volume greater<br>Peakflows larger<br>Time to peakflow shorter<br>Flashflood frequency greater<br>Flood levels higher<br>Stream erosive power increased |
| Snow accumulation | Changed | Fires <10 ac, increased snowpack<br>Fires >10 ac, decreased snowpack<br>Snowmelt rates increased<br>Evaporation and sublimation greater |

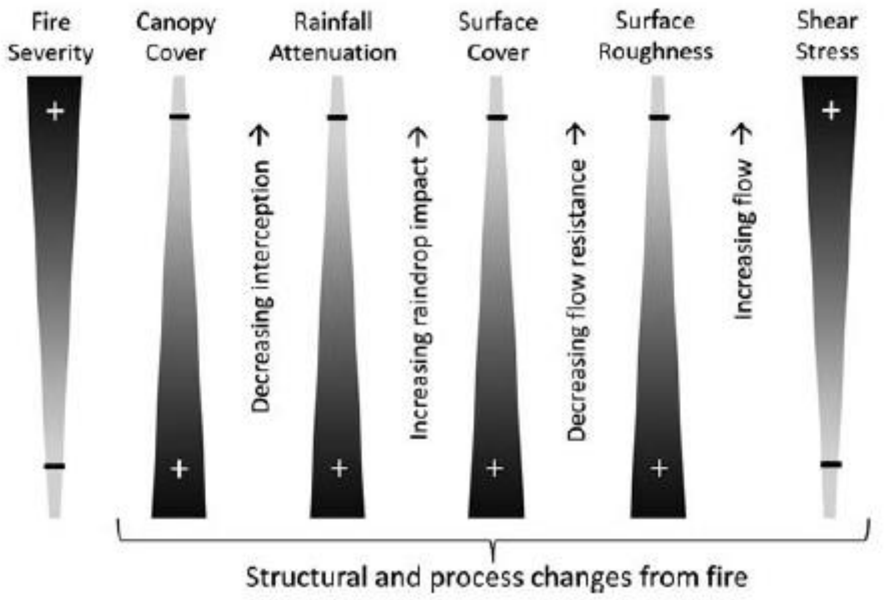



Source: Strauch et al. 2014

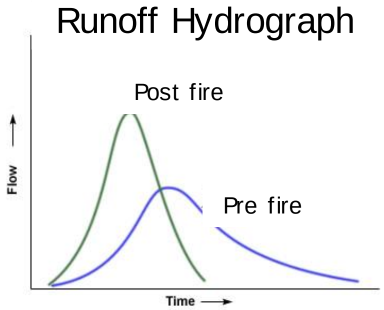
# Post-fire Hazards Related to Roads

- Flood Flows
- Erosion-induced Debris Flows
- Landsliding
- Direct impacts to combustible structures

# Post-fire flood flows




Adapted from Hyde et al., 2014




# Post-fire flood flows

Function of:

- Peak short-term (e.g., 15-minute) rainfall intensity
- Watershed size
- Percent moderate and high soil burn severity
- Time since the fire (most common in first 3 years following fire)
- Evaluability of sediment and debris that can be entrained.

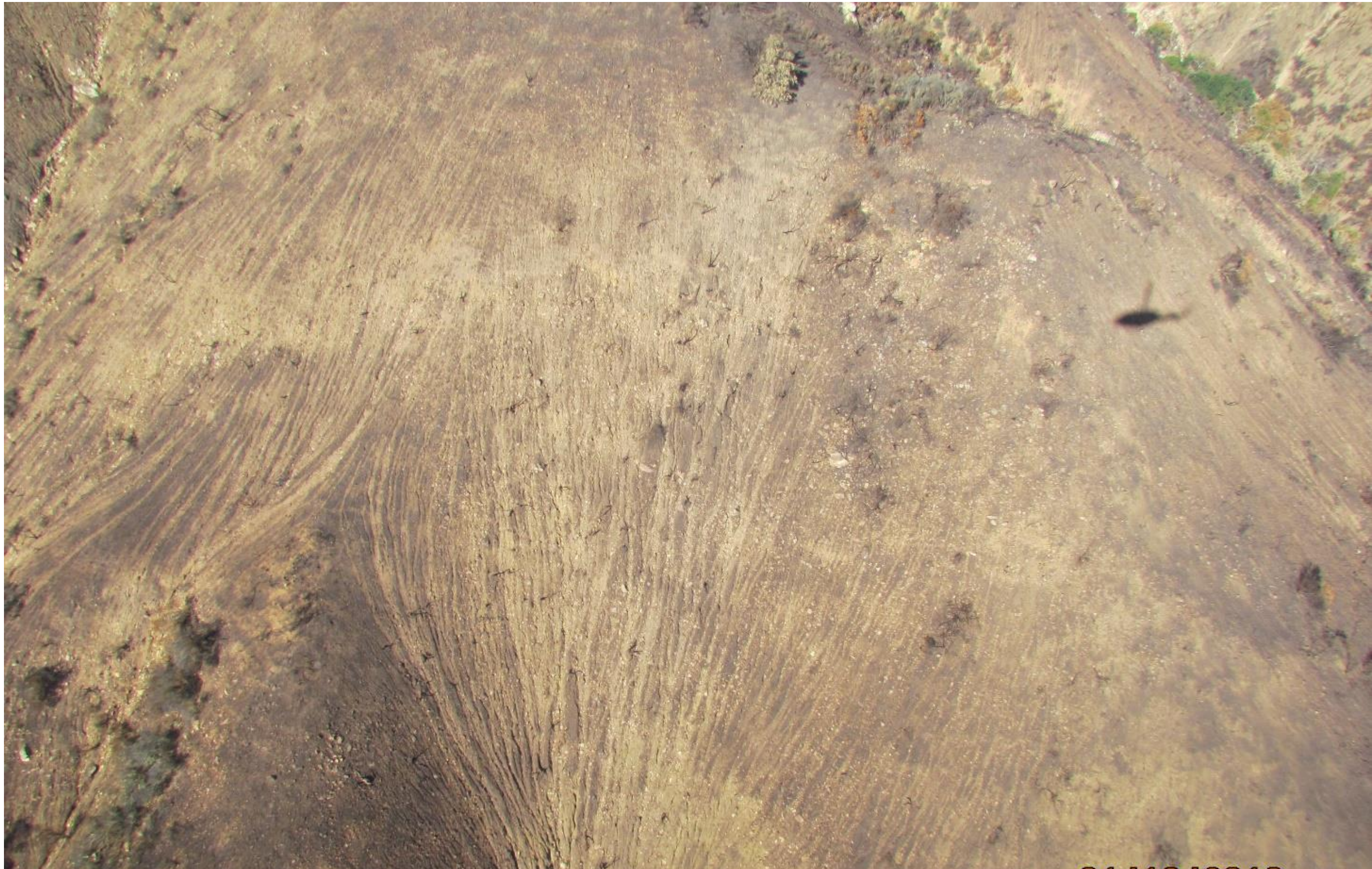
Commonly result in:

- Plugged/Overtopped crossing structures
- Scour and deposition
- Bank failure
- Avulsion

# Post-fire Runoff/Erosion-induced Debris Flows

Initiated by short durations of high-intensity rain. Due to lack of interception, surface roughness, and infiltration limiting conditions, runoff is rapid and develops quickly into overland flow.

Rills initiate within first order draws and become concentrated.



Channelized flow scours low-order channels, bulking flows and building momentum.

Flows bulk to the point where they reach debris flow concentrations (~≥50% by volume) having the consistency of wet concrete.

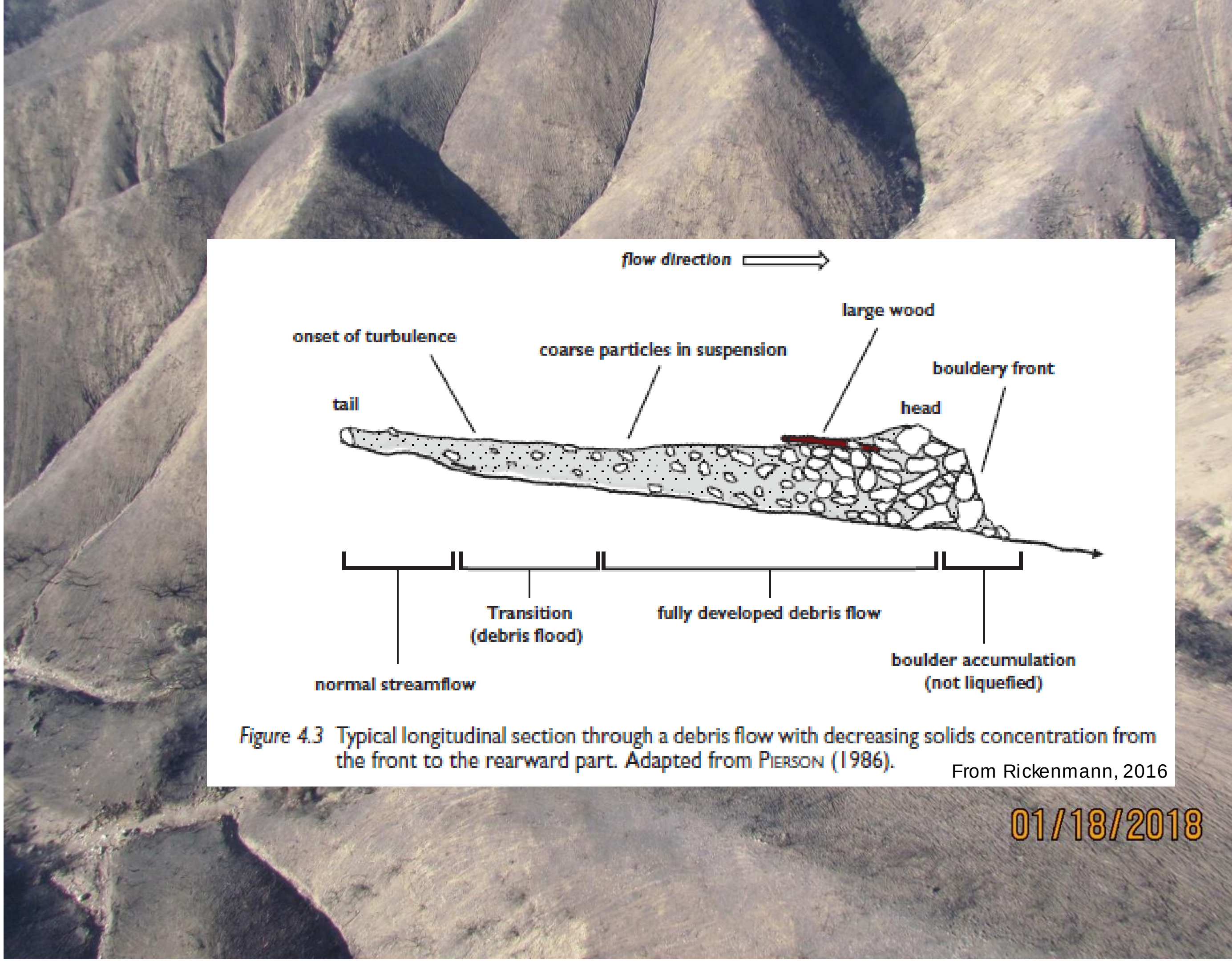
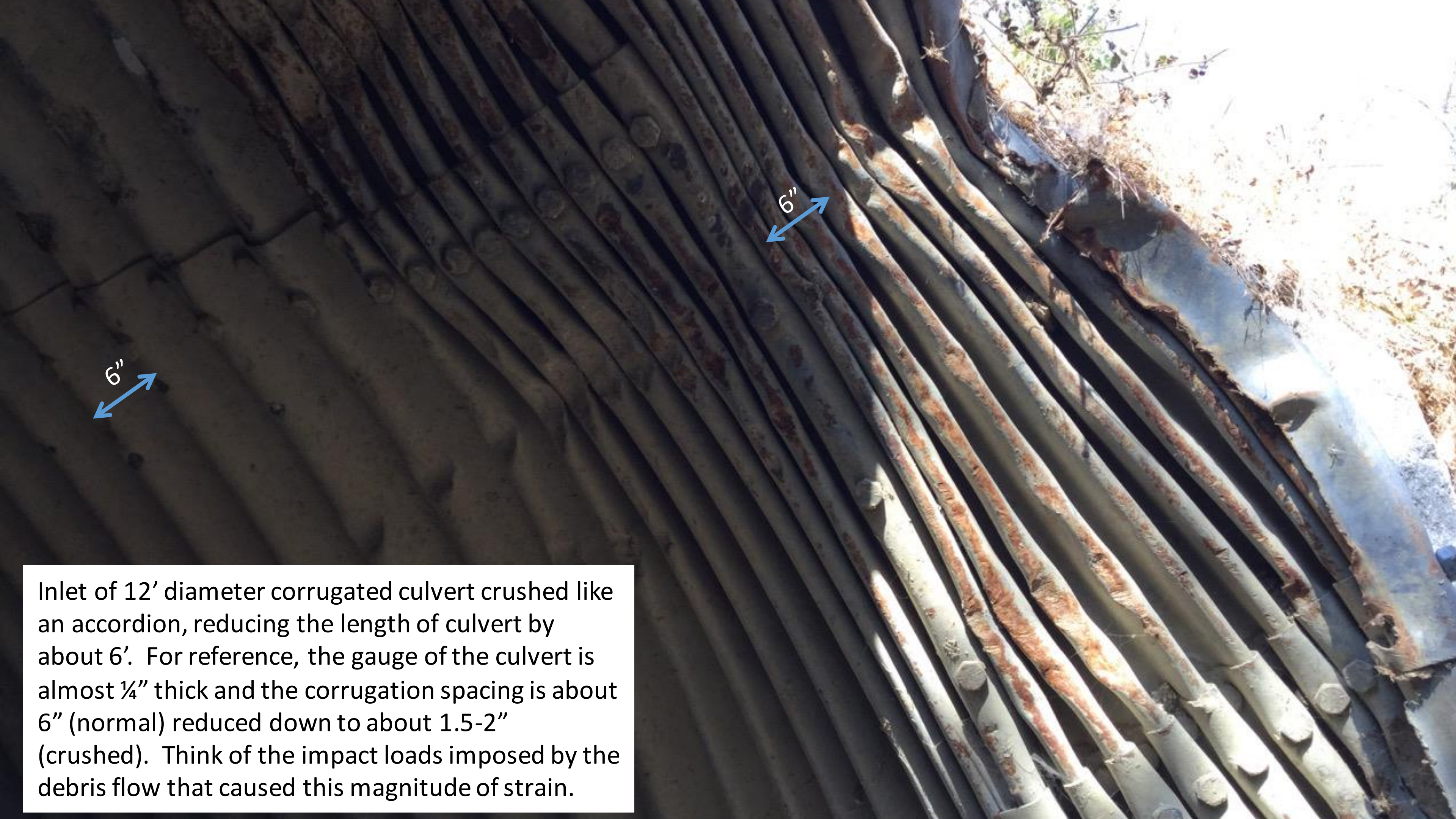



*Figure 4.3* Typical longitudinal section through a debris flow with decreasing solids concentration from the front to the rearward part. Adapted from Pierson (1986).

From Rickenmann, 2016

Due to their high kinetic energy caused be fast moving, dense, viscous fluids, debris flows are very damaging to road infrastructure.




Inlet of 12' diameter corrugated culvert crushed like an accordion, reducing the length of culvert by about 6'. For reference, the gauge of the culvert is almost ¼" thick and the corrugation spacing is about 6" (normal) reduced down to about 1.5-2" (crushed). Think of the impact loads imposed by the debris flow that caused this magnitude of strain.

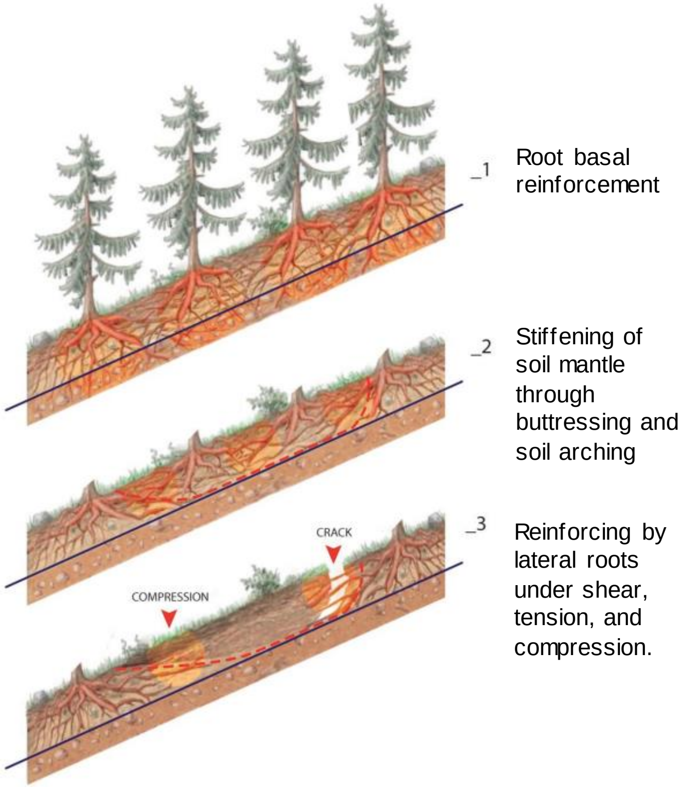


Dixie Fire, June 12th, 2022,
Debris Flow that blocked Hwy 70

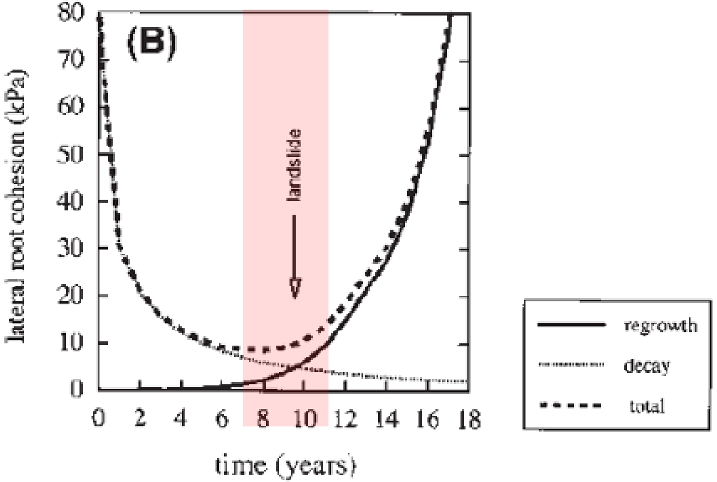
# Post-fire debris flows

- Most common in the first 2 years after fire, but can occur 2-5 years after fire.
- Commonly triggered by heavy rainfall over short durations.
- Less sensitive to antecedent soil moisture.
- Can move faster than floods in steep, confined channel reaches and slower than floods in low-gradient channel reaches.
- Can dramatically alter channel morphology in a short period of time through scour, avulsion, and deposition.

# Post-fire Landslide

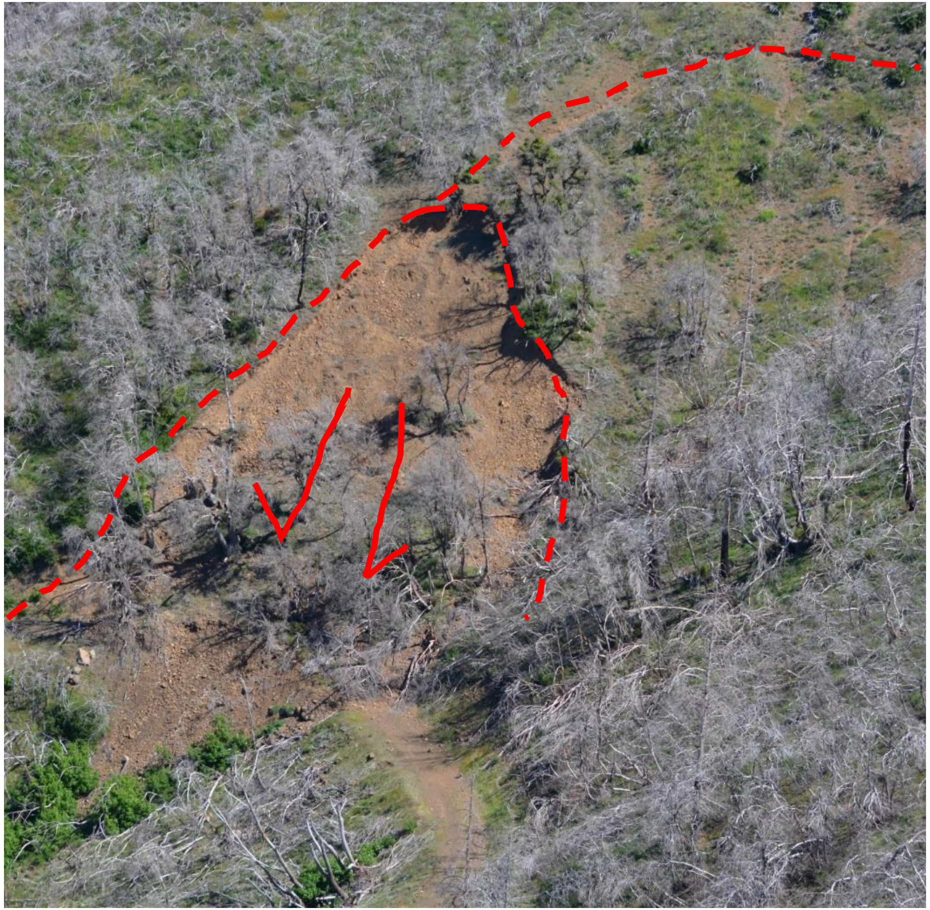



Three types of mechanisms of root reinforcement (adapted from Giadrossich et al, 2013)

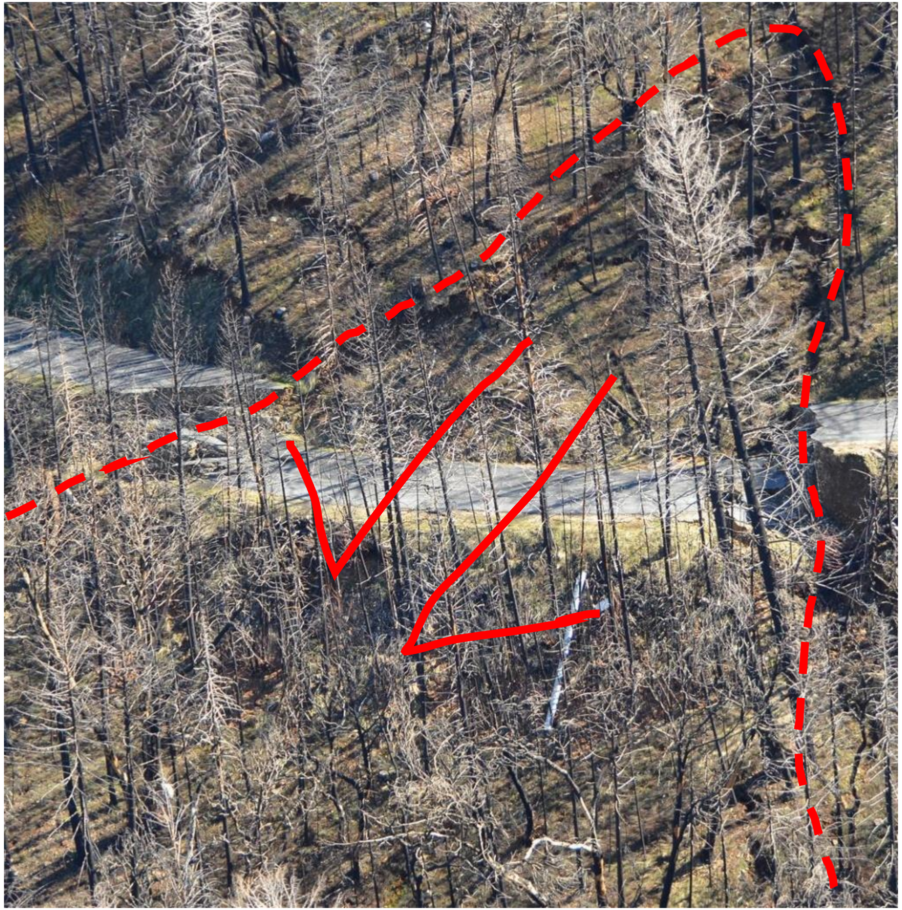



Plot of lateral root cohesion vs time since harvest (adapted from Roering, 2001)

- Minimum root cohesion reached ~7-11 years post fire for Oregon conifer forests and ~3-6 years for southern California chaparral.



2017 translational landslide within 2012 Bagley Fire, CA



2017 translational landslide within 2013 King Fire, CA

# Direct impacts of combustible structures

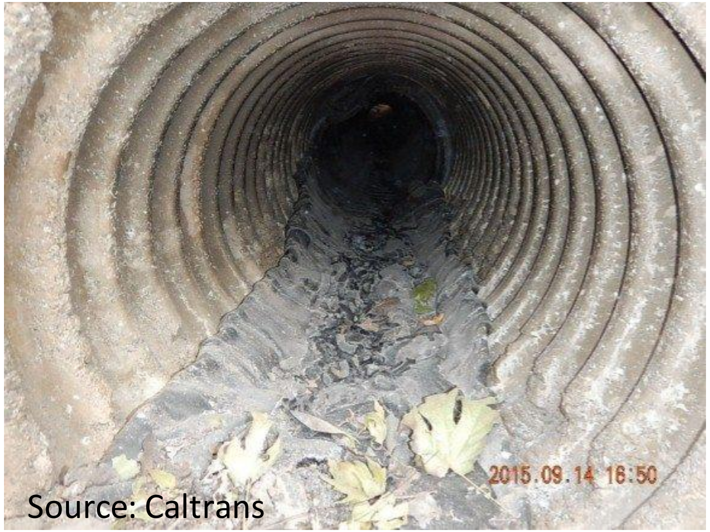
- Structures that are flammable will be damaged.
- Wood soldier pile walls
- Geosynthetic wrapped-face walls
- Wood bridge decks
- Galvanized metal (less of a concern, but still degrades more rapidly after being subjected to high heat)

**Table 2-22. Physical Resistance of Various Pipe Types** (Zhao et al. 1998)

| Type of Resistance | Pipe | | | |
|---|---|---|---|---|
| | Concrete | Corrugated Steel | HDPE | PVC |
| **Abrasion resistance** | Low | Low | High, 2 and 3 times more resistant than PVC and steel pipe, respectively | High |
| **Fire resistance** | High | Most coatings used for corrosion protection are flammable | Flammable | Flammable with lower flammability rating than HDPE |
| **Freeze-thaw resistance** | See note | — | — | — |

*Note*: It is not certain whether concrete culvert pipe is subjected to freeze-thaw damage. Testing is required to clarify this.

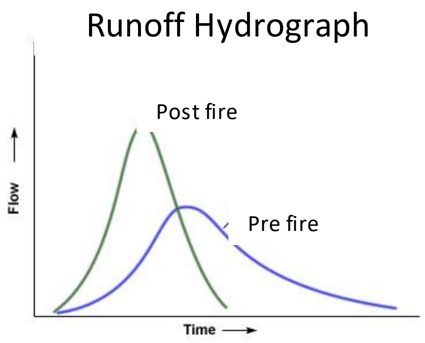
- Caltrans, and many other state DOTs, discourage the use of plastic pipe (HDPE and PVC) and bituminous or plastic coatings in fire hazard areas.
- Recommends consideration of nonflammable materials or modification of the plastic pipe in situations where high fire potential conditions exist.




Source: Caltrans

# Post-fire Flood Flow Models

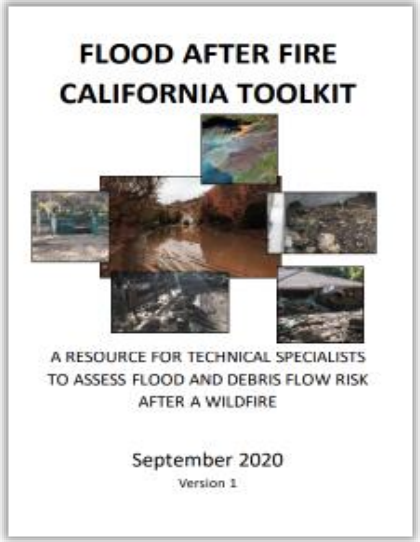
- Rainfall/runoff modeling (Curve Number method; Green-Ampt/Kinematic Wave method) (Kenoshita et al. 2014)
- Increasing the runoff coefficient, C, and decreasing the time of concentration, Tc, (Rational method; Moody, 2012; Kean et al. 2016).
- Applying a flow multiplier to pre-fire flows based on empirical data related to soil burn severity to account for increased runoff and sediment bulking


| Return Interval | Typical factors |
|---|---|
| 2-year | 1.5 to 10 |
| 5-year | 1.5 to 8 |
| 10-year | 1.3 to 6 |
| 25- to 50-year | 1.1 to 5 |
| 100-year | 1.1 to 3 |

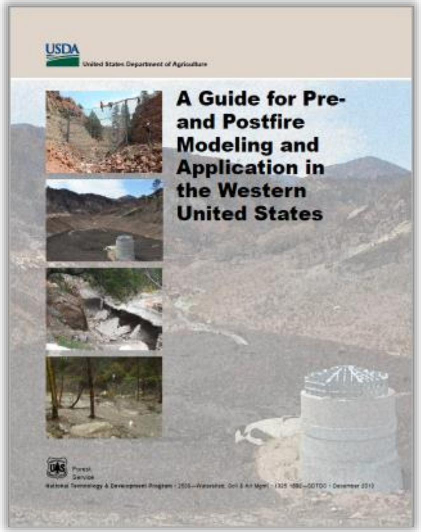
Recent research indicates a potential for higher multipliers

# Post-Fire Flood Flow References

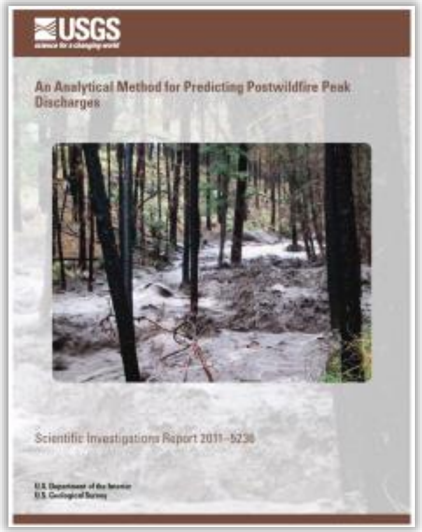



https://www.iwr.usace.army.mil/Silver-Jackets/State-Teams/California/Flood-After-Fire-California-Toolkit/


Foltz et al. 2008

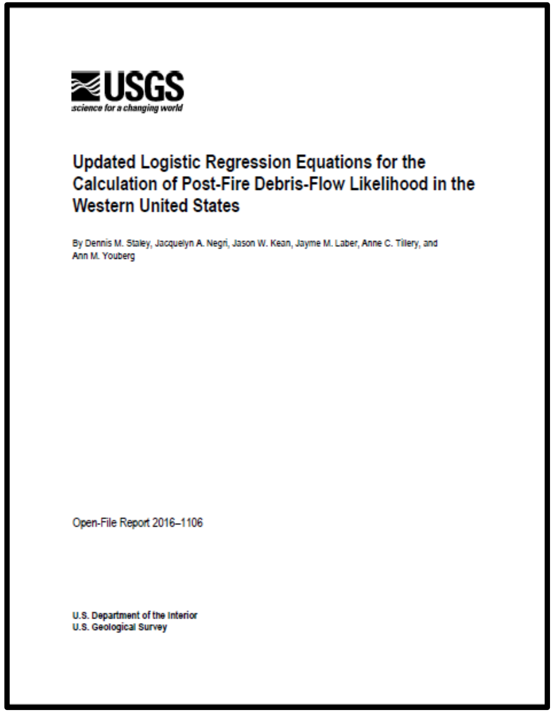



Kenoshita et al. 2014




Moody, 2012

# Primary Models Used for Post-fire Debris-Flow Hazards



USGS
science for a changing world

Updated Logistic Regression Equations for the Calculation of Post-Fire Debris-Flow Likelihood in the Western United States

By Dennis M. Staley, Jacquelyn A. Negri, Jason W. Kean, Jayme M. Laber, Anne C. Tillery, and Ann M. Youberg

Open-File Report 2016–1106

U.S. Department of the Interior
U.S. Geological Survey

(Staley et al., 2016)

Engineering Geology 176 (2014) 45–56

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

Empirical models for predicting volumes of sediment deposited by debris flows and sediment-laden floods in the transverse ranges of southern California

Joseph E. Gartner [a,*], Susan H. Cannon [a], Paul M. Santi [b]

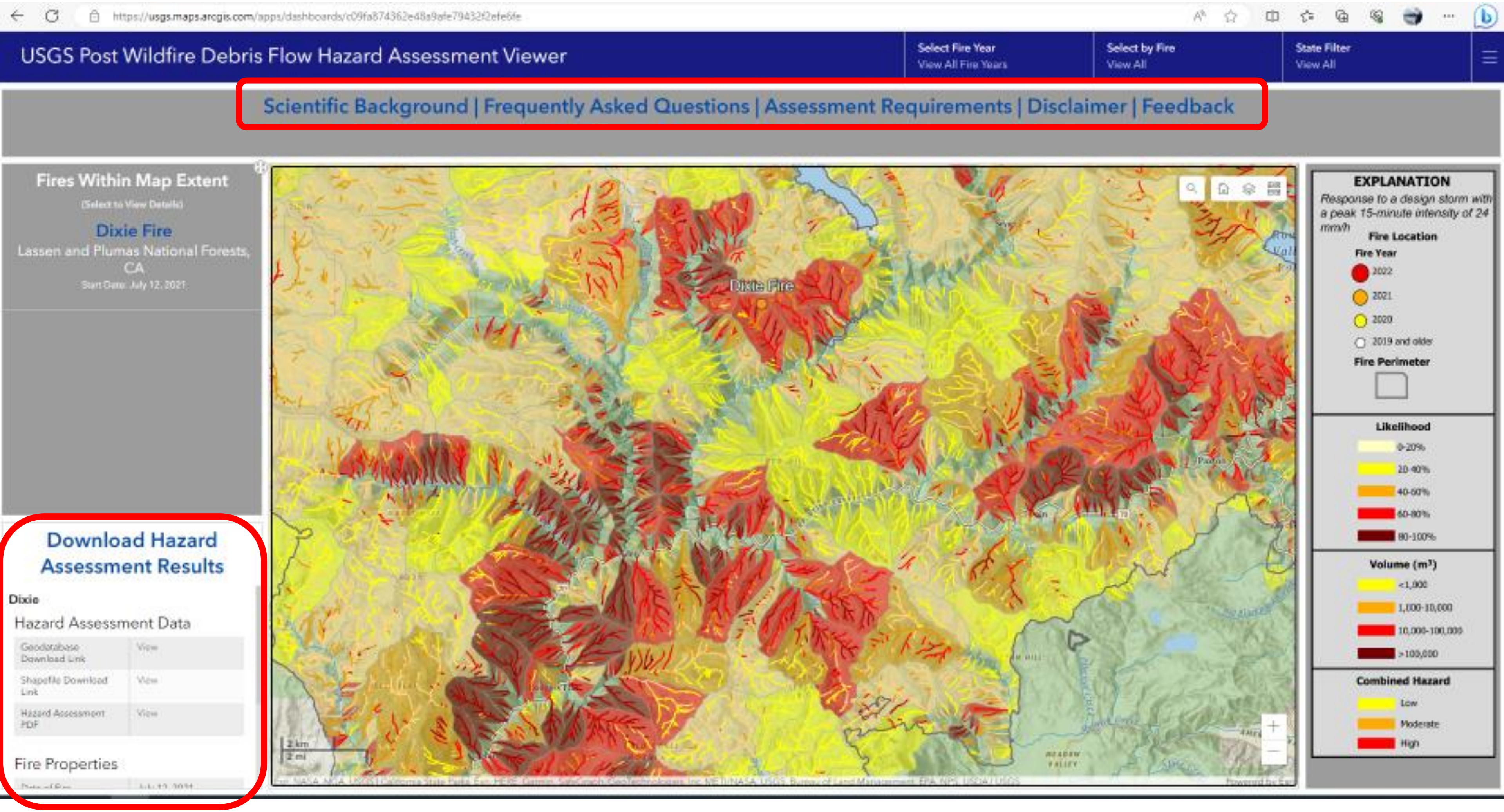
ARTICLE INFO

ABSTRACT

Published by Elsevier B.V.

1. Introduction and background

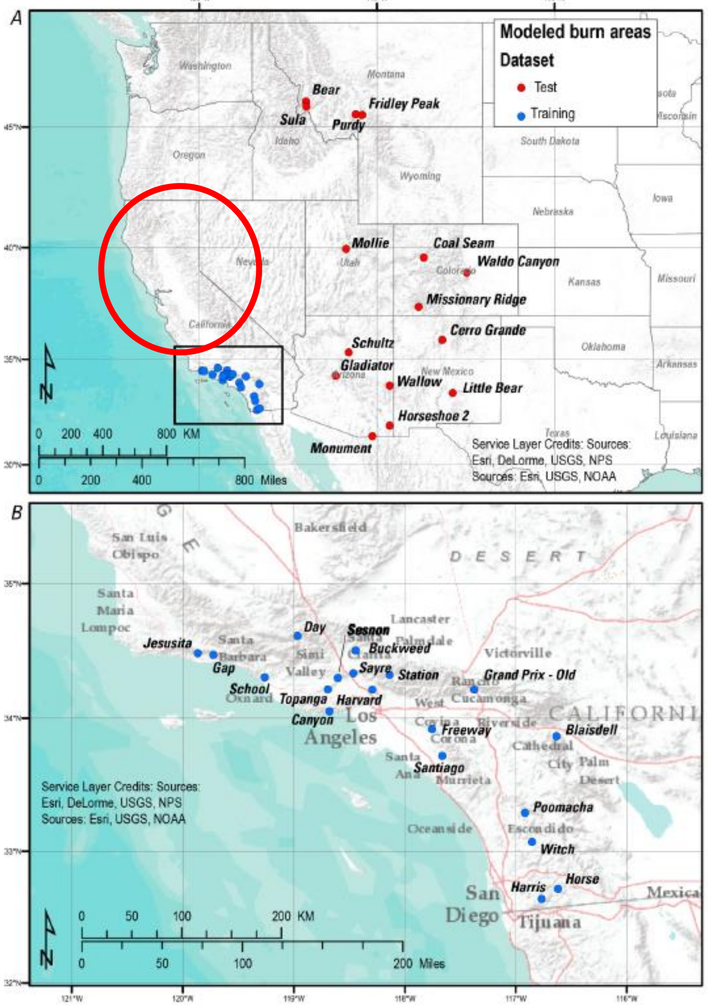
(Gartner et al., 2014)


https://usgs.maps.arcgis.com/apps/dashboards/c09fa874362e48a9afe79432f2efe6fe
USGS Post Wildfire Debris Flow Hazard Assessment Viewer
Select Fire Year
View All Fire Years
Select by Fire
View All
State Filter
View All
Scientific Background | Frequently Asked Questions | Assessment Requirements | Disclaimer | Feedback
Fires Within Map Extent
(Select to View Details)
Dixie Fire
Lassen and Plumas National Forests, CA
Start Date: July 12, 2021
Download Hazard Assessment Results
Dixie
Hazard Assessment Data
Geodatabase Download Link
View
Shapefile Download Link
View
Hazard Assessment PDF
View
Fire Properties
Dixie Fire
EXPLANATION
Response to a design storm with a peak 15-minute intensity of 24 mm/h
Fire Location
Fire Year
2022
2021
2020
2019 and older
Fire Perimeter
Likelihood
0-20%
20-40%
40-60%
60-80%
80-100%
Volume (m³)
<1,000
1,000-10,000
10,000-100,000
>100,000
Combined Hazard
Low
Moderate
High
2 km
2 mi

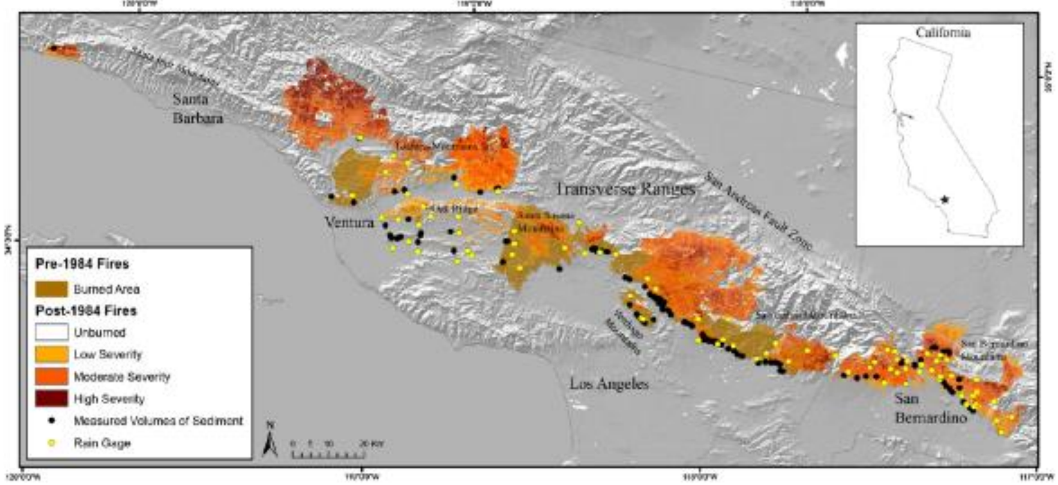
# Model Conundrum:

- Relying on the models in areas outside of southern California?

Staley et al, 2016




Gartner et al, 2014



# Post-fire Landslide Models

**Empirical Models**

- Antecedent rainfall
- Rainfall intensity
- Rainfall duration
- Slope morphologic, geologic, ecologic parameters
- Probability
- Examples: logistic regression models

**Physics-based Models**

- Limit equilibrium models
- Topography
- Soil depth
- Porewater pressures
- Geotechnical parameters of soil
- Examples: SHALSTAB, SINMAP, TRIGRS

# Common Post-Fire Mitigations

Common Post-fire Response:

- Plugged and overtopped culverts
- Flow diversion/avulsion associated with crossings and poorly-drained roads
- Burnt Structures

Common Treatments:

- Monitor and maintain
- Revise culvert design
- Deflection structures
- Debris racks and nets
- Rock-armored crossings
- Low-water crossings
- Free-spanning crossings
- Non-flammable structures

# Monitoring and Maintain

- Early warning
- Perform frequent monitoring during and after storm events
- Maintain as needed to keep road and crossing structures free-draining.

# Revise culverted crossing design

- Increase the size of culvert.
- Reduce the number of barrels - one large culvert performs better than multiple smaller culverts.
- Use more efficient inlet structures (e.g. non-projecting, mitered, flared inlet, headwall, etc.)
- Use inlet structures with redundant entrances (e.g. standpipe)

# Deflection structures

- Commonly used to direct flow away from critical infrastructure, or direct overtopping flows back into the channels.
- Common types of deflections structures include:
  - K rail
  - HESCO barrier
  - Muscle wall
  - Earthen berm

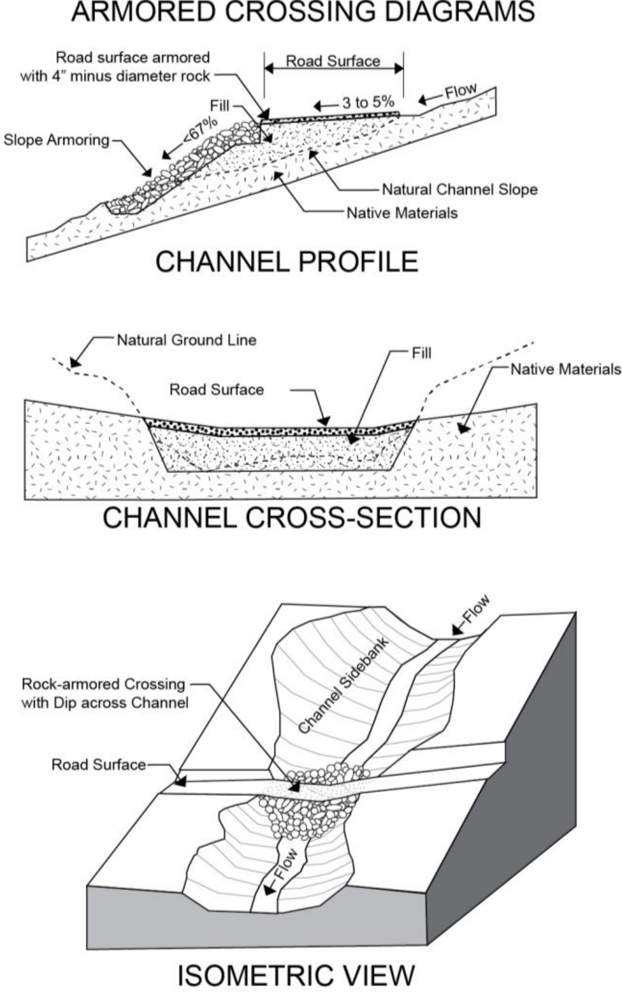
# Debris racks (aka debris fences, grizzlies, straining structures)

- Often used to prevent culvert openings and bridge clearances from becoming plugged.
- Design considerations include the design magnitude or volume of flow, likely flow path, size and gradation of the debris, potential impact forces, and probable storage angle.
- Must be designed to allow normal water flow and stream bedload to pass, but restrain oversized material and debris.
- General rule of thumb for the design of the opening is 1.5 to 2 times the maximum diameter of the boulders (VanDine, 1996)

Images: J. Grim, NRCS, before and after 1st major post-fire winter storm event (1993 Kinneloa Fire in S. CA)

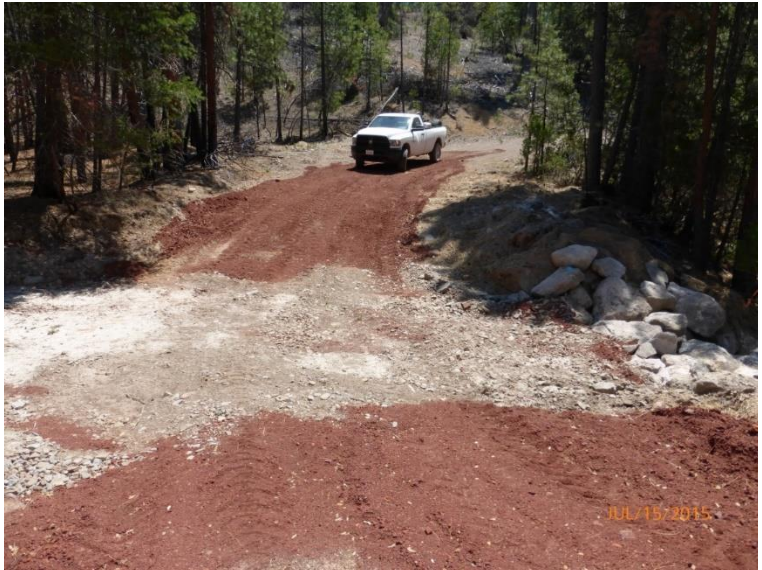
# Lessons Learned
# Debris Racks

- Must be constructed to withstand anticipated hydrodynamic loads plus loads imposed by equipment during cleaning.
- Must be located to maximize the volume of material that can be stored before being overtopped.
- Must be installed where access for heavy equipment is provided for maintenance.
- Debris nets generally plug with small-diameter material that would otherwise be able to pass.
- Debris nets should be placed off the channel bed to allow normal flows to pass, but not so high that they won’t restrain the boulder front of passing debris flows.
- Streambanks along the margins of debris racks should be armored against concentrated flows that can develop as debris builds in front of the structure.




# Rock-armored Crossings

- Commonly used on forest roads
- Rock armor is appropriately sized, keyed, and sufficiently thick to resist anticipated flows.
- Running surface is constructed with sacrificial, small-diameter rock or articulated concrete block mats.


JUL/15/2015

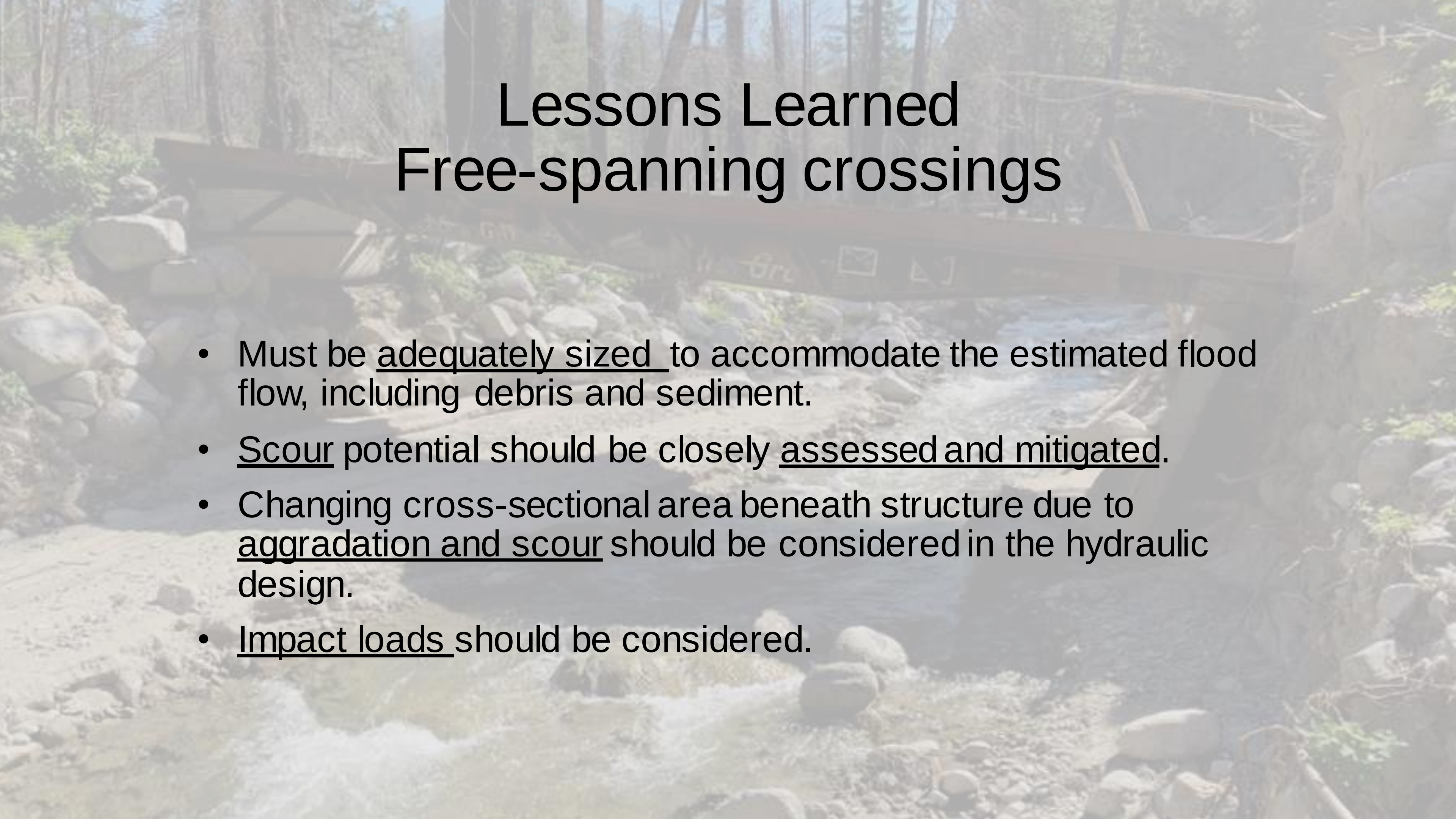
# Lessons Learned
# Rock-armored crossings

- Inspect the shape of the road prism and the outfall structure to determine if it is adequately sized to accommodate the estimated flood flow, including debris and sediment loads.
- Inspect the proposed rock size and placement detailing (i.e. keyway, thickness, and lateral extent) and determine if it would resist mobilization.
- To mitigate winnowing of fines through coarse outside layer of rock, place either an inner layer of well-graded rock (backing filter layer) or geotextile filter fabric.

# Low-water crossings

# Free-spanning crossings

- Installing a free-spanning structure with adequate capacity to convey the anticipated flows plus associated debris can be the most straightforward solution.
- Initial costs of construction can be high, but the cost/benefit ratio often improves with time.



# Lessons Learned
# Free-spanning crossings

- Must be adequately sized to accommodate the estimated flood flow, including debris and sediment.
- Scour potential should be closely assessed and mitigated.
- Changing cross-sectional area beneath structure due to aggradation and scour should be considered in the hydraulic design.
- Impact loads should be considered.

# Summary

- Post-fire hazards generally include increased flow, debris and sediment loading, rockfall, and landslide activity.
- Current models used to predict post-fire hazards require considerable professional judgment before applying.
- Road crossing structures are at the highest threat, particularly culverted crossings due to sediment and debris plugging.
- Solutions to mitigate post-fire impacts range in cost and complexity and require careful consideration before implementing. Examples include:
  - Monitoring and maintenance
  - Deflection structures
  - Upsizing culverts
  - Debris barriers
  - Consider free-spanning or low-water crossing structures in areas prone to excessive post-fire runoff and sediment and debris loading.

# Questions?

# Today’s presenters

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**Gordon Keller**
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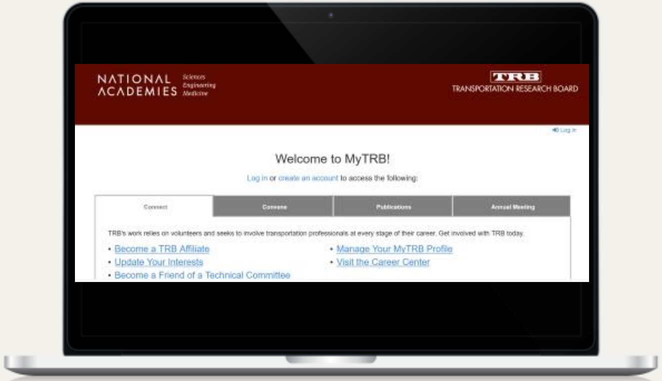


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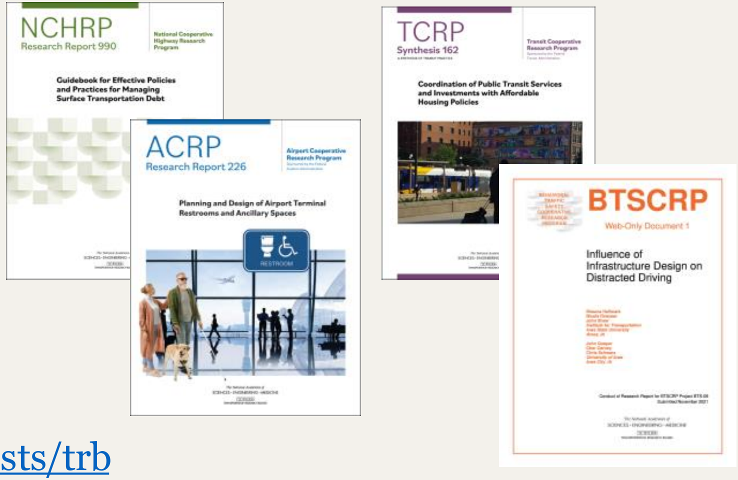


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