CLIMATE RESILIENT LOW-VOLUME ROADS ENGINEERING

38th Annual North Central Region LTAP Conference
October 23-25, Sioux Falls, SD

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

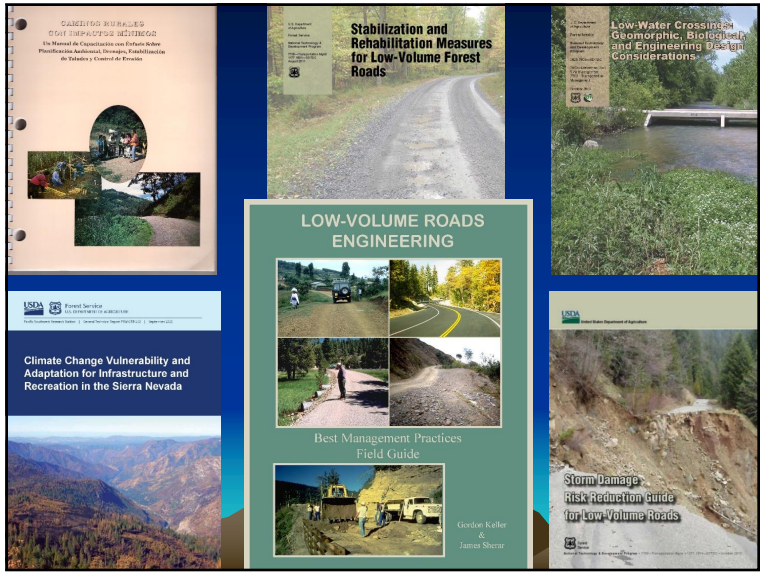
1

2

USDA Forest Service

- 190,000,000 Acres of Land
- 155 National Forests
  - Most Forests have 3-6 Districts
- More than 375,000 Miles Of Roads
  - 7% Paved
  - 18% Surfaced with Aggregate
  - 75% Native Soil Surfacing
- Responsible for Forest and Watershed Management

3



4

SOME KEY POINTS

- Apply the Basics and BMPs.
- Be Smart- Use Appropriate, Innovative Technology.
- Protect Roads Against Storms.
- People are Like Gold--Precious! Get Them and Keep Them.
- Use Specialists when Needed.
- Find Useful References on Topics.

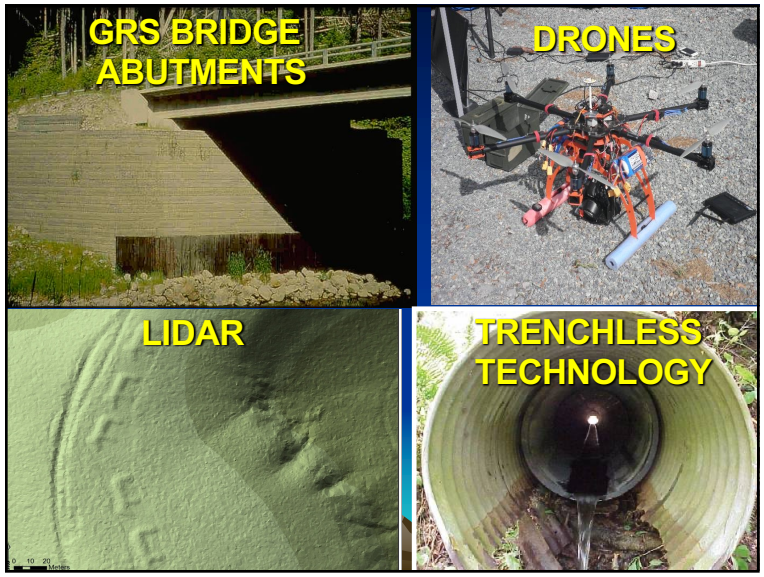
6

7

ENVIRONMENTAL PROTECTION

8

9


GRS BRIDGE ABUTMENTS
DRONES
LIDAR
TRENCHLESS TECHNOLOGY

10


CLIMATE VARIABILITY AND RESILIENCE
2017 OROVILLE DAM SPILLWAY
-190,000 CFS MAX FLOW
-200,000 PEOPLE EVACUATED
- $$ 1.1 BILLION SPILLWAY REPAIRS

11


2018 CAMP FIRE, PARADISE
Paradise Inn
-150,000 ACRES BURNED
-19,000 BUILDINGS DESTROYED
-85 LIVES LOST
-INSURED LOSSES $7.5-10 BILLION

12


MONTPELIER, VERMONT
JUNE 4, 2023
MONTPELIER
JULY 11, 2023
GETTY IMAGES

13

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

14

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

15

ROAD MAINTENANCE
Prevent Water Concentration

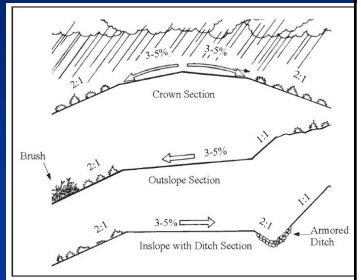


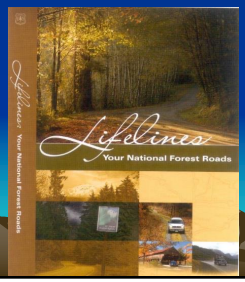
Figure 7.1 Typical road surface drainage options.

16

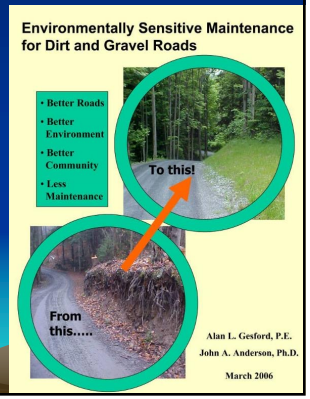
17

Road Maintenance Guides

Video Titles
Forest Roads and the Environment
Reading the Traveled Way
Reading Beyond the Traveled Way
Smoothing and Reshaping the Traveled Way
Maintaining the Ditch and Surface
Cross Drains



Develop a field guide with
Penn State U, Penn DOT, EPA



18

DRAINAGE, DRAINAGE, DRAINAGE

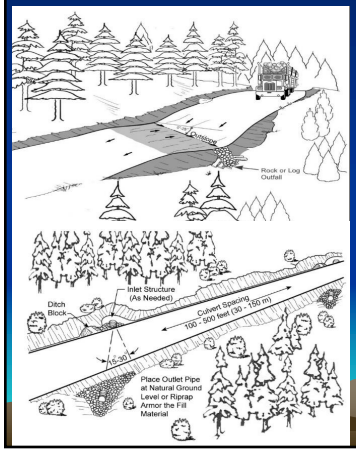
"SEEPAGE, DRAINAGE AND FLOW NETS"
1967
CALTRANS, USACE, DWR

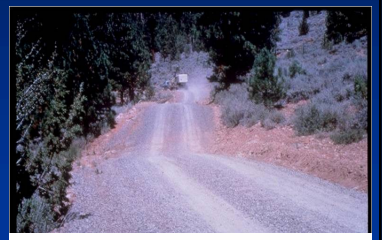
"Seepage analysis and control are among the most important problems faced by Civil Engineers"

"Drainage inadequacies and omissions are causing some of the most serious civil engineering failures of our time"
Harry R. Cedergren

19

ROAD DESIGN & MAINTENANCE
Disperse Water Rapidly





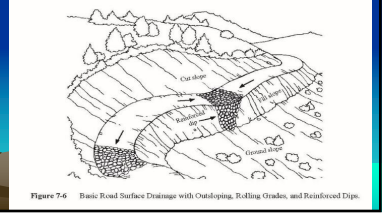
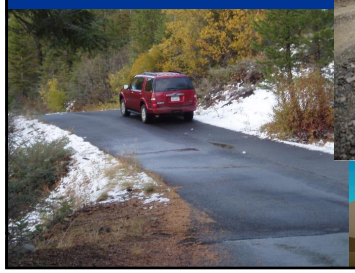


Figure 7-6 Basic Road Surface Drainage with Outsloping, Rolling Grades, and Reinforced Dips.

20

Rolling Dips
(Broad Based Dips)



21

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

23

24

MULTIPLE SMALL PIPES ALSO PLUG EASILY

25

ROAD LOCATION
Avoid Channel Migration Zones

26

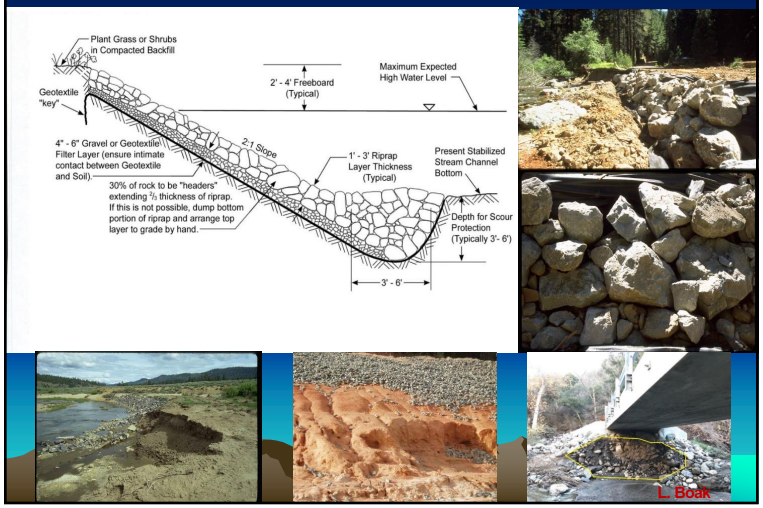
ROAD LOCATION
1. Move the Road
2. Armor Streambanks-Redirect Flow

27

RIPRAP ARMORING

28

RIPRAP ARMORING DESIGN



29

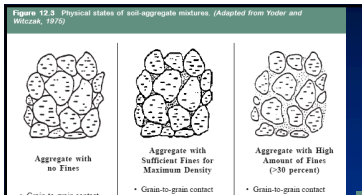
GABION ARMORING PROBLEMS

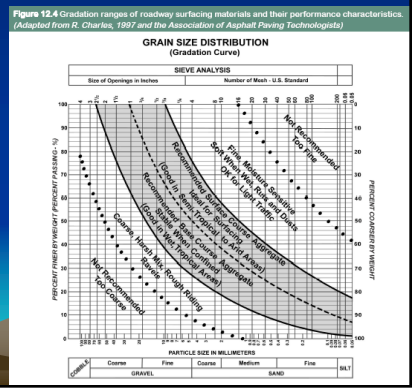
30

ROAD SURFACING
Armor the Road Surface



31





32

33

ROAD SURFACING
Armor the Road—Many Options

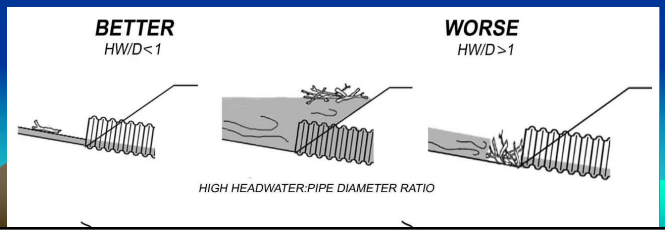
34

CULVERTS
Increase Capacity, Improve Design

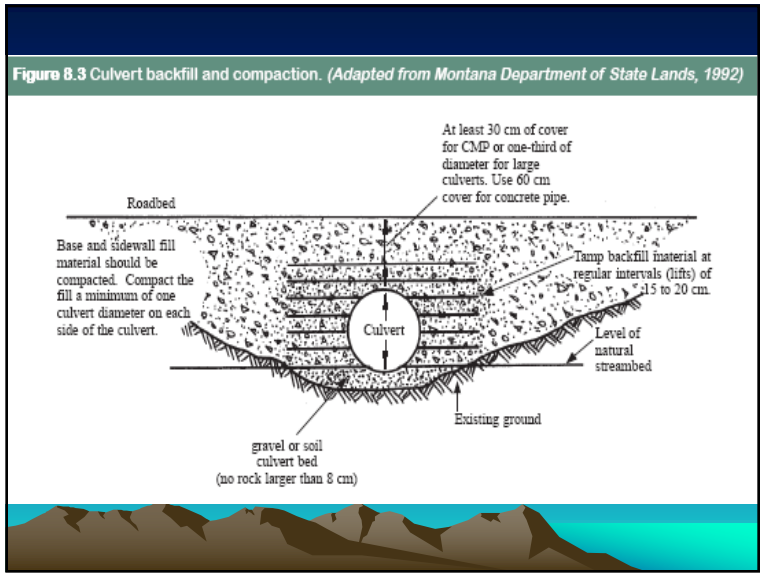
- Q50-100 vs Q25

- Width ≥ Bankfull Width

- HW/D ≤ 1.0



35



36

FLOW DETERMINATION METHODS

- United States Geological Survey (USGS) Regression Equations & StreamStats
- Local Guaging Data
- High Water/Bankfull Marks
- Rational Method (for Small Watersheds)
- Other Methods -Corps of Engineers -HEC
  -Natural Resources Conservation Service -TR-55
  -Federal Highway Administration, AASHTO, State methods, etc.

37

FLOW DETERMINATION

- Compare a Couple Methods
- Consider Weather Variations and Period of Record
- What About Changes in the Watershed?
- Don't Forget About
  - Bulking
  - Sediment
  - Debris

...And then...Climate Change

38

RESILIENT CULVERTS
Increase Capacity—How Much??

Increase Design Flow by 20-30 percent

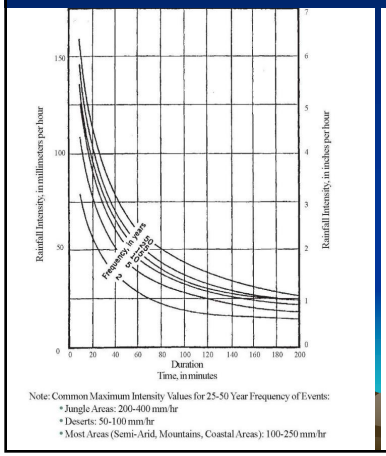
Increase Recurrence Interval Q100 vs Q25 (from USGS regression equations)

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

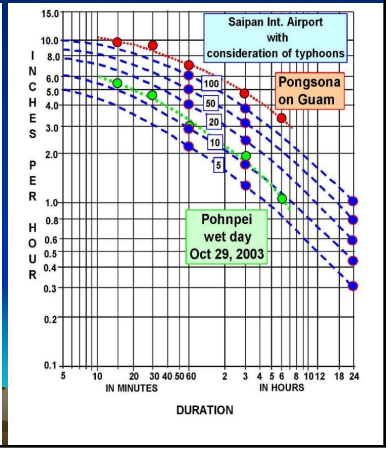
Temperature Scaling to adjust rainfall intensity (i)

39

Typical IDF



Western Pacific IDF

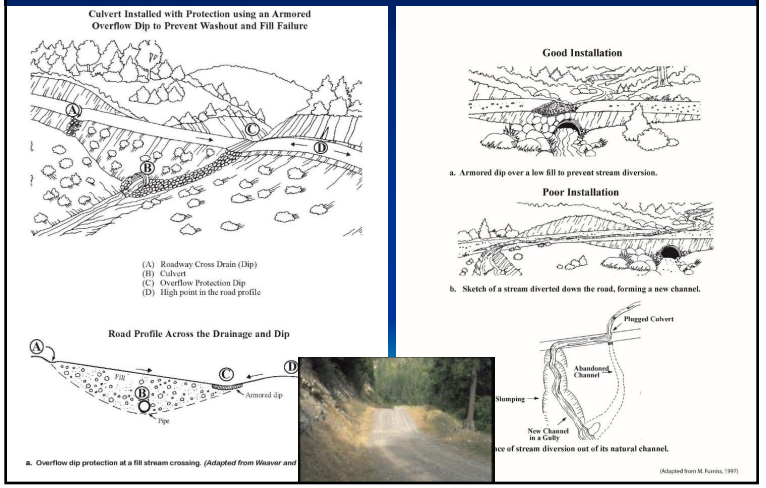


40

CULVERTS
Stream Diversion

41

Stream Diversion Prevention Dips



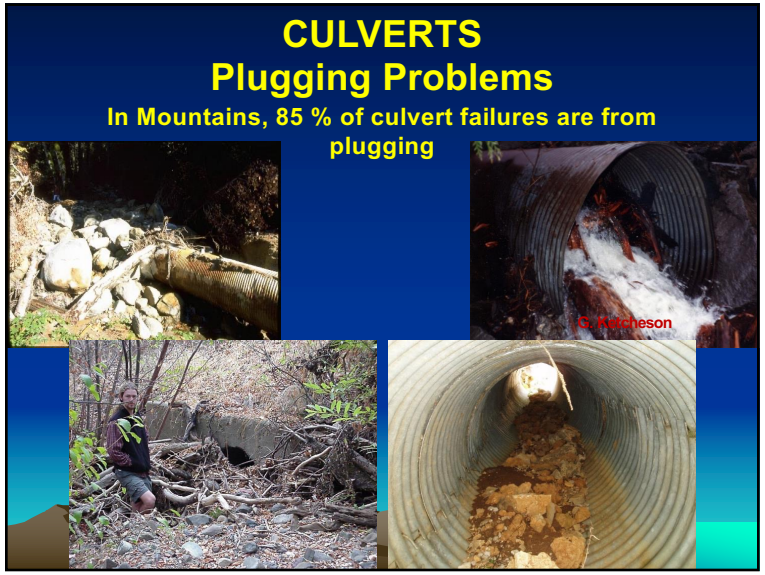
42


Stream Diversion Prevention Dip
1
PLUGGED CULVERT
2
3
4-NEW DIP

43


Diversion Prevention Fill Armor

44


CULVERTS
Plugging Problems
In Mountains, 85 % of culvert failures are from plugging
G. Kitcheson

45


CULVERTS
Prevent Plugging with Added Trash Racks
BEFORE
AFTER
V. Barendino

46

47

CULVERTS
After fires with mobilized sediments—Add Riser Trash Racks

48

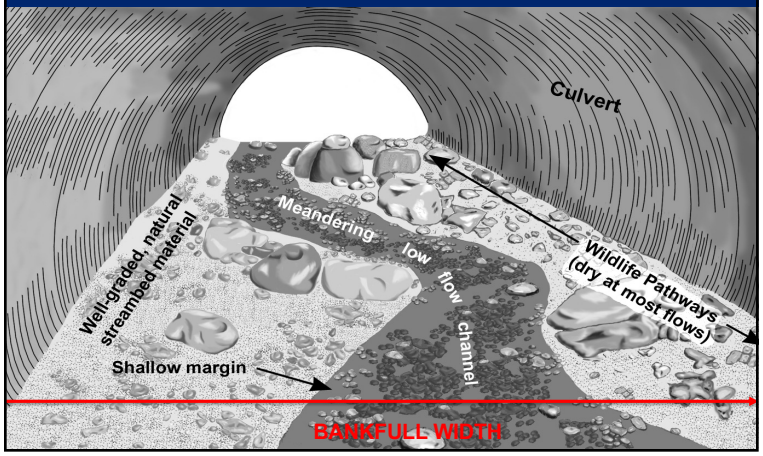
DAMAGED CULVERTS
Less Capacity-More Risk

49

CULVERTS
Use Stream Simulation Concepts

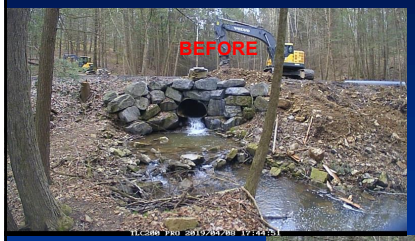
50

CULVERTS
Use Stream Simulation Concepts



51

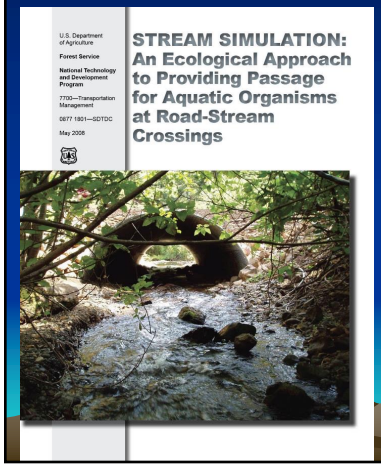
Stream Simulation

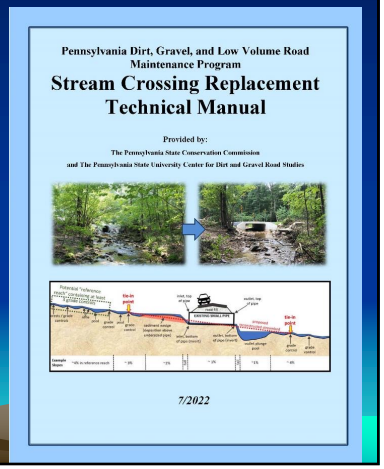


Penn State CDGRS

52

Stream Simulation Design





53

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

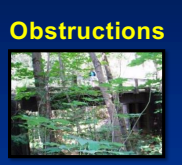
Less problems with debris = less maintenance

Less need for armoring

54

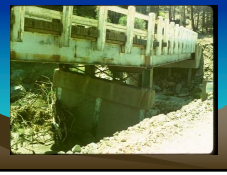
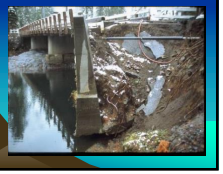
BRIDGE ISSUES

- Obstructions
- Lack of Capacity
- Scour Issues



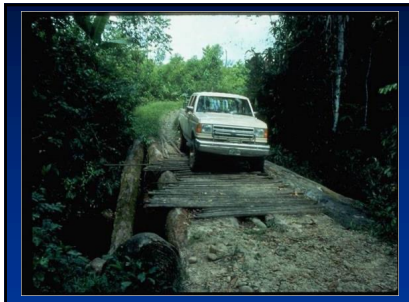


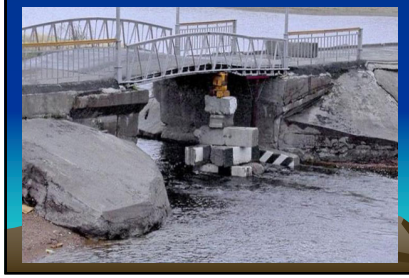
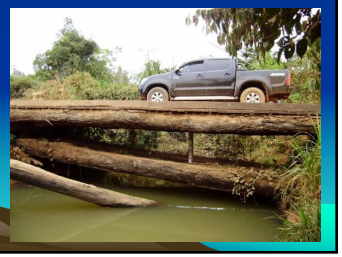


55

"Scary" Bridges

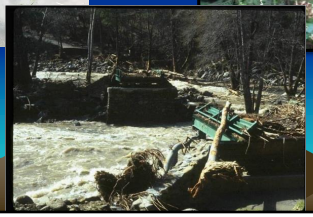


56

BRIDGES
Remove Debris/Trees in Channel
Avoid Mid-Channel Supports

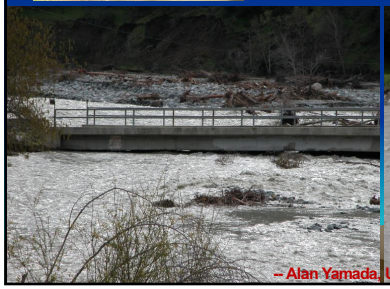


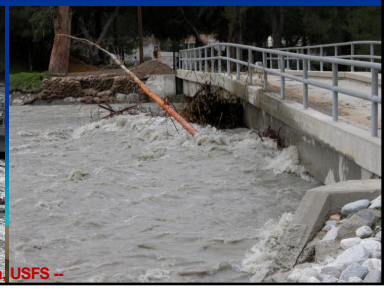


57

BRIDGES
Maintain Capacity and Freeboard





58

BRIDGES
Aggradation--
Remove the Deposited Sediment!

59

BRIDGES
Scour

60

BRIDGES
Use Scour Protection

61

BRIDGE REPLACEMENT
ABC-Accelerated Bridge Construction

62

63

64

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

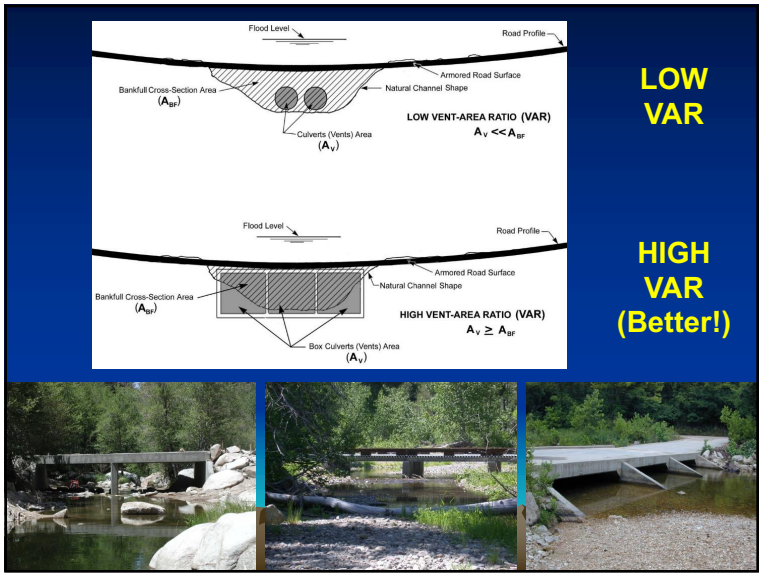
65

66

FORDS or LOW-WATER CROSSINGS

Small Pipes Plug Easily

67



68

FORDS or LOW-WATER CROSSINGS

69

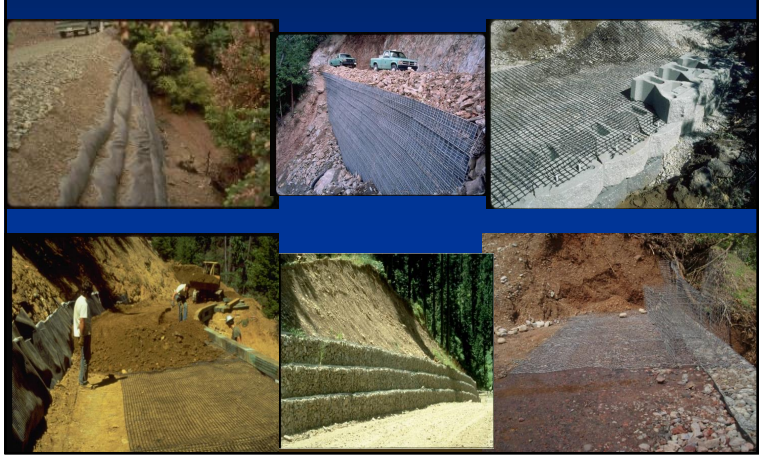
SLOPE INSTABILITY

70

SLOPE STABILIZATION
Drains/Walls/Buttresses/Nails

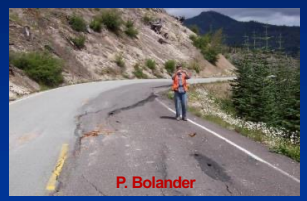
71

SLOPE TREATMENTS
MSE & GRS Walls



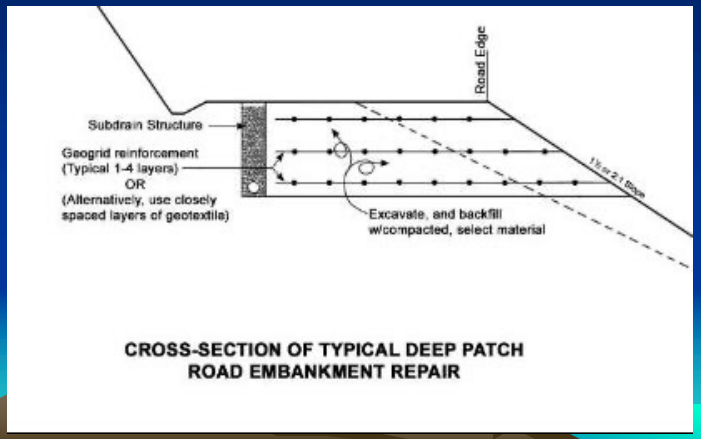
72

SLOPE TREATMENTS
Deep Patch Shoulder Reinforcement



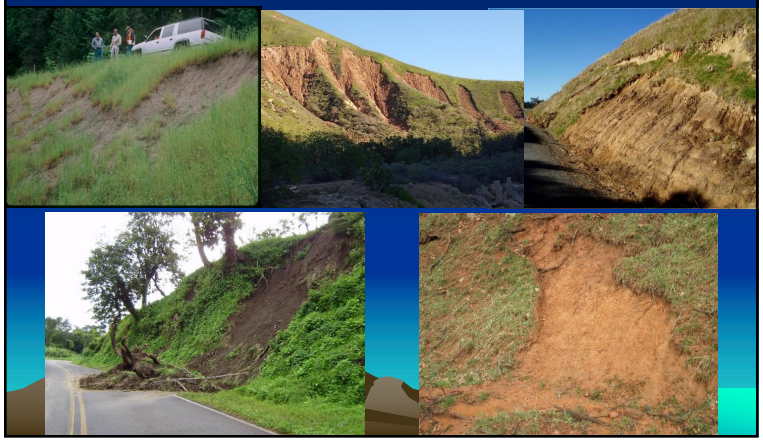
73

Deep Patch Shoulder Reinforcement



74

SLOPE TREATMENTS
Problems with Shallow-Rooted Vegetation

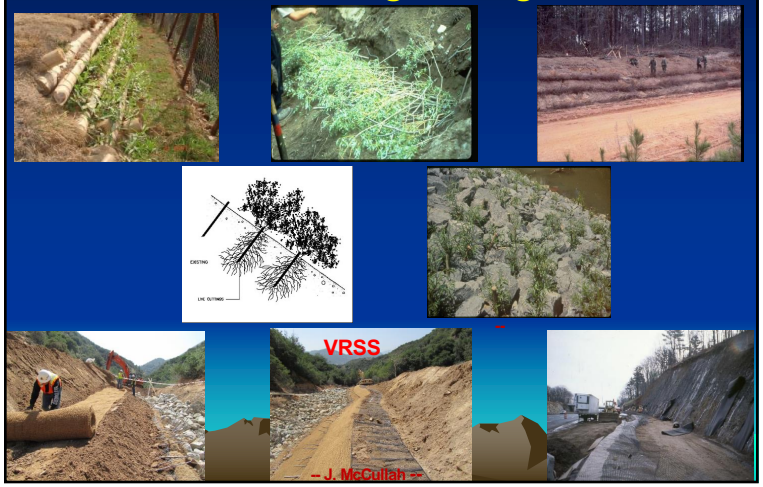


75

SLOPE TREATMENTS
Deep-Rooted Vegetation

76

SLOPE TREATMENTS
Soil Bioengineering

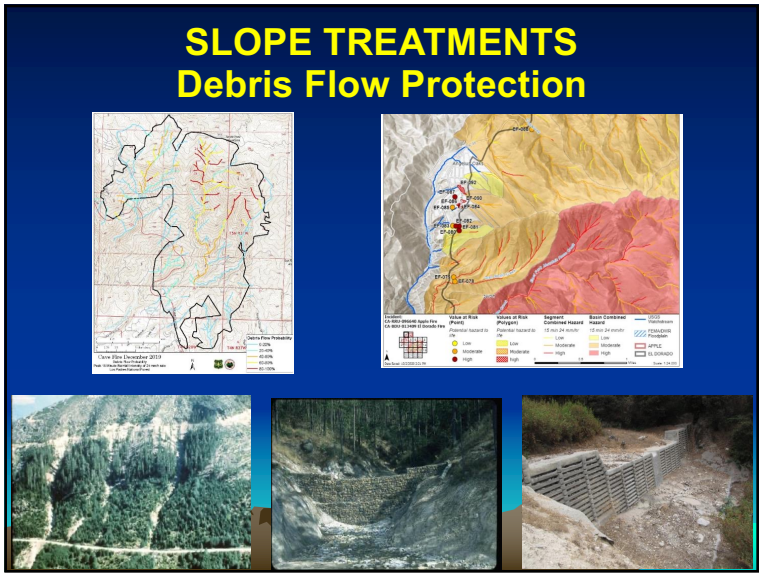


77

SLOPE TREATMENTS
Debris Flow Damage

78

79


SLOPE TREATMENTS
Debris Flow Protection

80


SLOPE TREATMENTS
Debris Flow Protection
D. Lindsay

81


EROSION CONTROL
Drainage Control and Ground Cover
Control of Water
Ground Cover

82

EROSION CONTROL
Deep Rooted Vegetation, Nets, RECP

83

INFRASTRUCTURE ASSESSMENT AND RISK

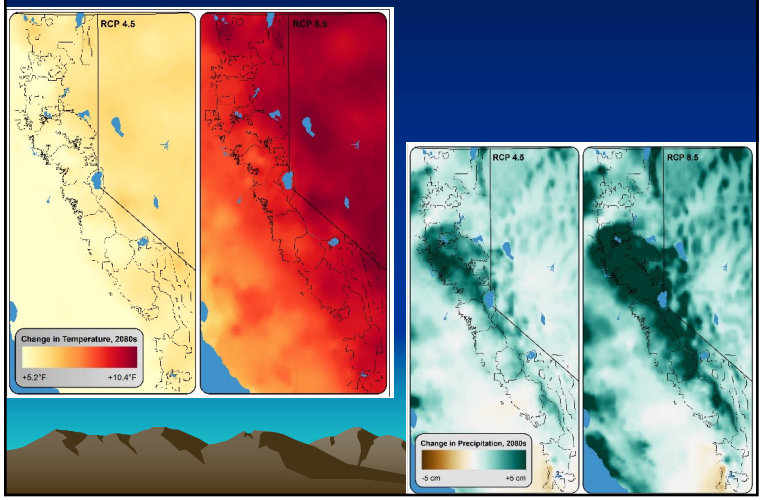
- Have good asset inventories
- Form an interdisciplinary team
- Identify the assets at risk
- Examine site data and history
- Study relevant climate data/stressors
- Study relevant hydrology projections
- Conduct risk assessment
- Rank asset vulnerability
- Prioritize needed work

INFORMATION SOURCES

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

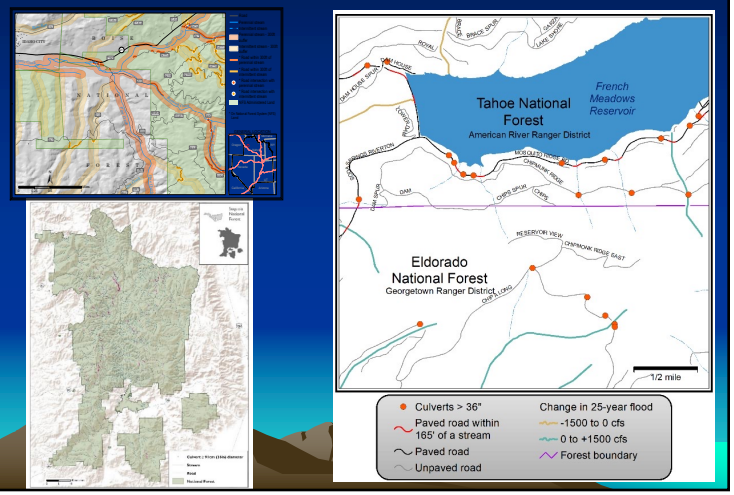
84

TOOLS/PRODUCTS

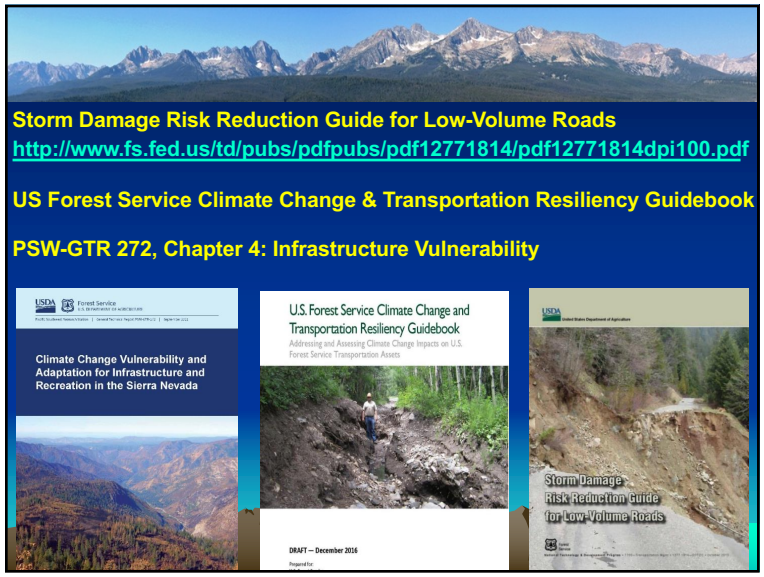


86

TOOLS/PRODUCTS



87


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
Climate Change Vulnerability and Adaptation for Infrastructure and Recreation in the Sierra Nevada
U.S. Forest Service Climate Change and Transportation Resiliency Guidebook
DRAFT – December 2016
Storm Damage Risk Reduction Guide for Low-Volume Roads

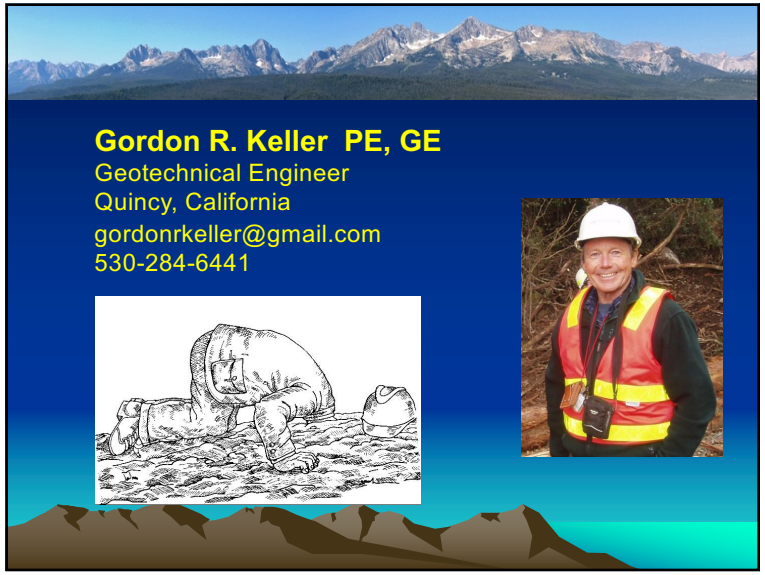
89


Selected References
Arranged by Topic:
Best Management Practices - General 147
Environmental Analysis 148
Planning Issues and Special Applications 148
Basic Engineering Considerations for Low-Volume Roads 151
Hydrology for Drainage Crossing Design 152
Tools for Hydraulic Design: Manning's Formula, Riprap, Filters, & Geosynthetics 152
Drainage of Low-Volume Roads 153
Culvert Use, Installation, and Sizing 153
Fords and Low-Water Crossings 154
Bridges 155
Slope Stability and Stabilization of Cuts and Fills 155
Roadway Materials and Materials Sources 156
Erosion Control: Physical, Vegetative, and Biotechnical Methods 157
Stabilization of Gullies 158
Best Management Practices- General
Environmental Protection Agency. Draft 2001. National Management Measures to Control Non-point Source Pollution from Forestry. EPA Contract No. 68-C7-0014, Work Assignment #2-20. Prepared for Office of Water, U.S. Environmental Protection Agency by Tetra Tech, Fairfax, Virginia. A comprehensive guide to measures for reducing water pollution from roads and logging activities.
Michigan Department of Natural Resources. 1994. Water Quality Management Practices on Forest Lands.
Minnesota Department of Natural Resources, Division of Forestry. 1994. Visual Quality Best Management Practices for Forest Management in Minnesota.
Montana State University. 1991. Montana Forestry Best Management Practices. Montana State University Extension Service. July BMPs also produced by Montana Department of State Lands in 1992.
Ontario Ministry of Natural Resources. 1988. Environmental Guidelines for Access Roads and Water Crossings. Queen's Printer for Ontario, Canada.
U.S. Department of Agriculture, Forest Service. 2000. Water Quality Management for NationalForest System Lands in California-Best Management Practices. Vallejo, CA: Pacific Southwest Region, U.S. Department of Agriculture, Forest Service. 186 pp.
Low-Volume Roads BMPs 147
Selected References

90


Thank You For Being Here

91


Gordon R. Keller PE, GE
Geotechnical Engineer
Quincy, California
gordonrkeller@gmail.com
530-284-6441

92