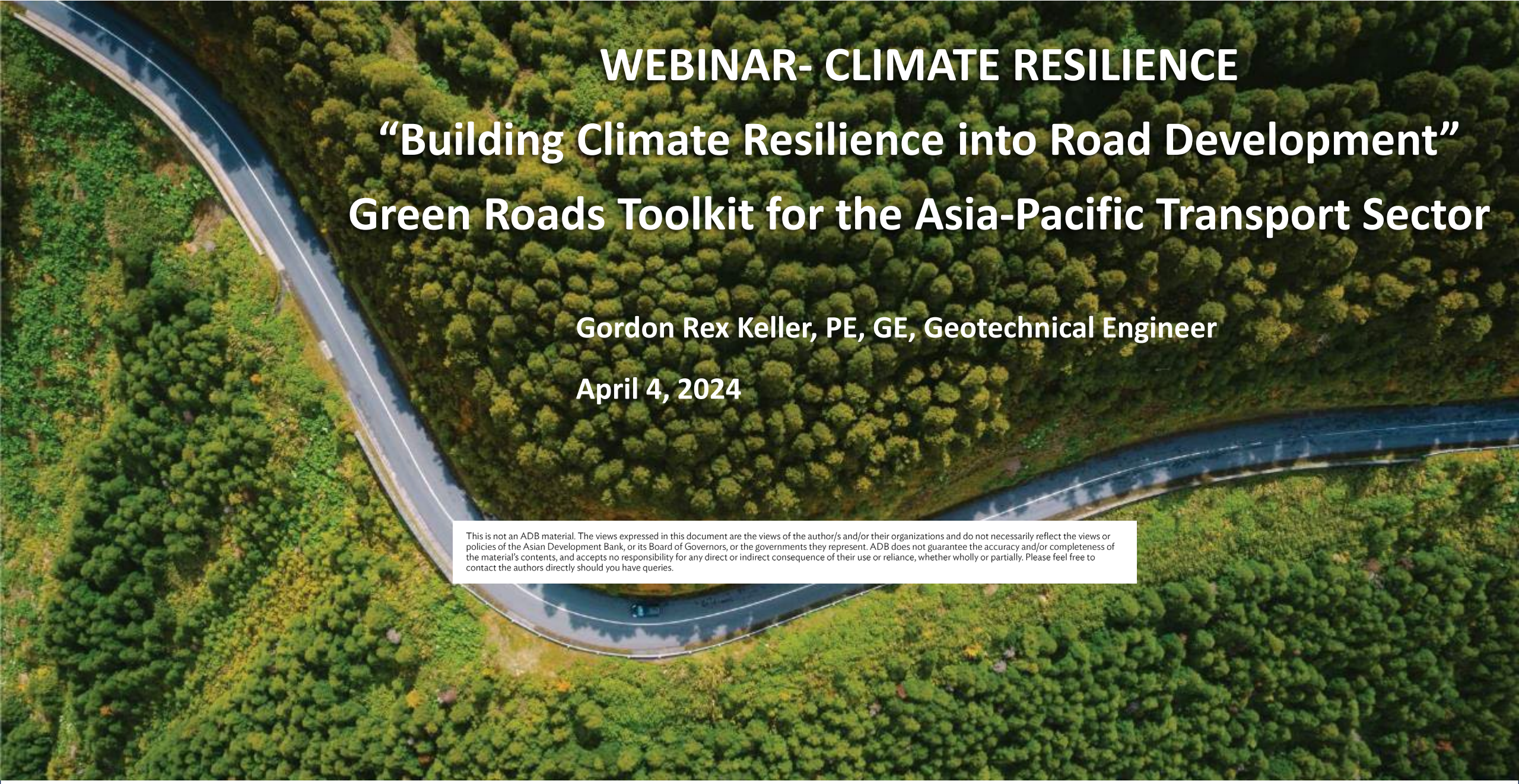

WEBINAR- CLIMATE RESILIENCE

"Building Climate Resilience into Road Development"

Green Roads Toolkit for the Asia-Pacific Transport Sector

Gordon Rex Keller, PE, GE, Geotechnical Engineer

April 4, 2024

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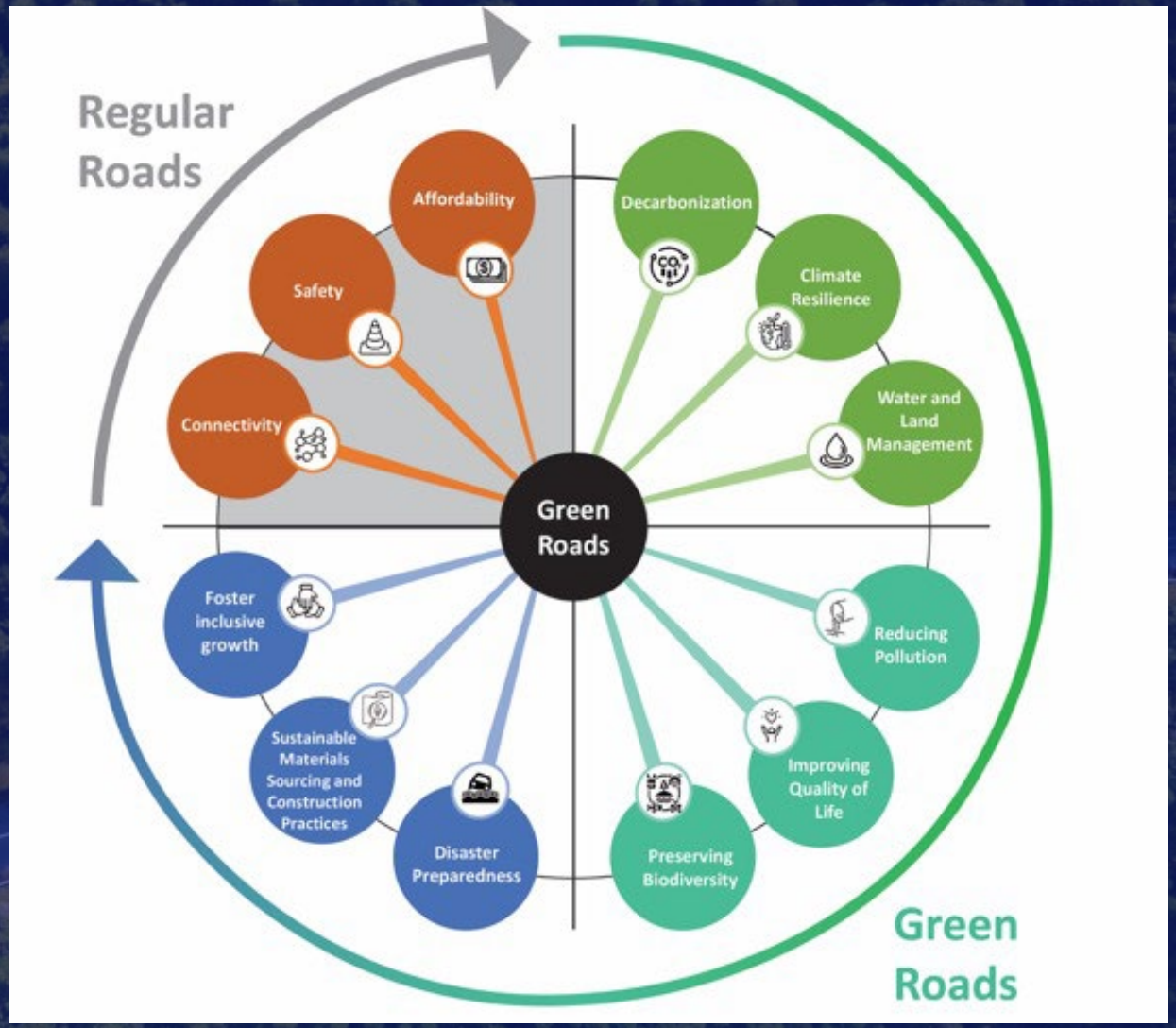
What are Green Roads?

Comparing Regular Roads and Green Roads

- ✓ Creating connectivity and access
- ✓ Safeguarding safety
- ✓ Making affordable transport possible
- ✓ Working towards decarbonization
- ✓ Ensuring climate resilience
- ✓ Creating beneficial water and land management
- ✓ Reducing pollution
- ✓ Improving quality of life
- ✓ Preserving biodiversity
- ✓ Supporting disaster preparedness
- ✓ Sourcing materials sustainably
- ✓ Fostering inclusive growth



Synergies between the themes!

Climate Resilience

Building Climate Resilience into Road Development

- ✓ **Climate-related damage to road infrastructure costs countries between 1-3% of their GDP annually (World Bank)**
- ✓ **Making infrastructure more climate-resilient can add about 3 percent to the upfront costs but has benefit-cost ratios of about 4:1 (Global Commission on Adaptation)**

Key intervention areas:

2.1. Climate-resilient road design

2.2. Stabilization of slides

2.3. Resilient routing/ avoiding vulnerable areas

2.4. Resilient road maintenance

2.5. Enhancing Road and Bridge Climate Resilience

2.6. Enhance climate resilience of roads in permafrost regions

2.7. Nature-based Solutions for climate resilience

Using appropriate size culverts

Deep rooted vegetation for slope stabilization

Stabilization of slopes

Streambank protection

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Resilient Road Maintenance

✓ 2.4.1 Stay Current on Road Maintenance

<u>Key maintenance areas:</u>

- Grading the road surface
- Keeping drainage ditches open
- Unplugging pipes
- Removing roadside vegetation
- Filling potholes/pavement cracks/resealing
- Painting/replacing signs/barriers/guardrails

Keep Drainages/Pipes Clean- Prevent Water Concentration

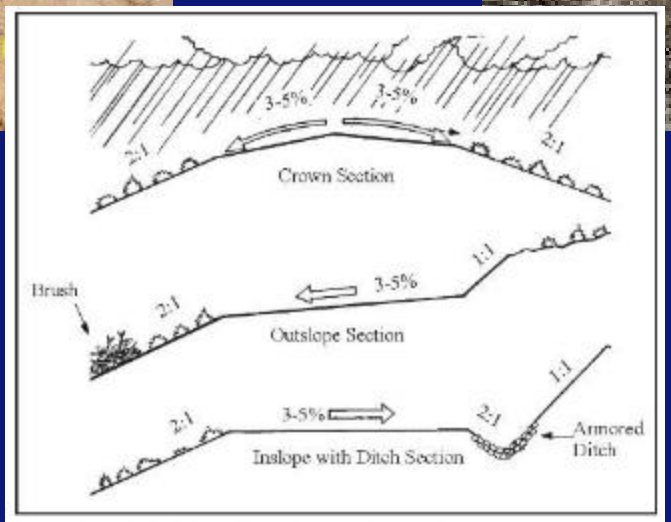


Figure 7.1 Typical road surface drainage options.

2.1 Climate Resilient Road Design

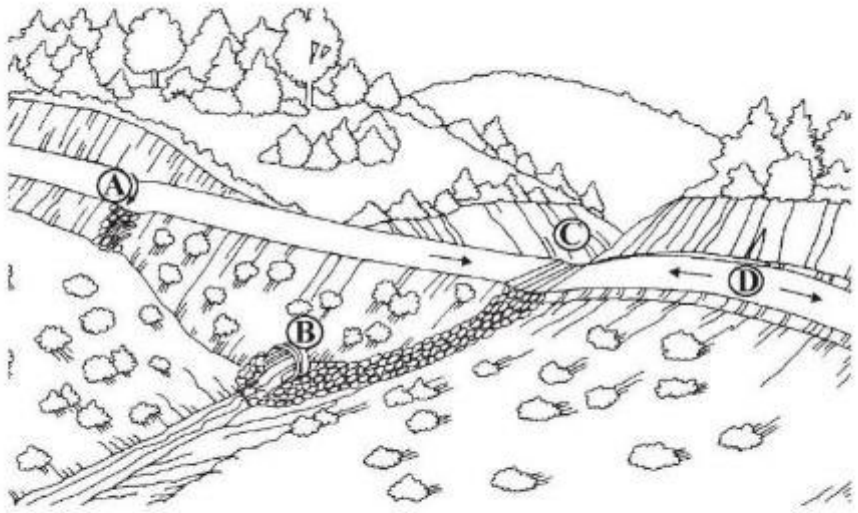
✓ 2.1.1 Preventing Stream Diversion at Road-Stream Crossings

Key interventions:

- Disperse the Flow
- Prevent Flow Concentration
- Prevent culvert Plugging
- Use an Overflow Dip
- Armor the Embankment

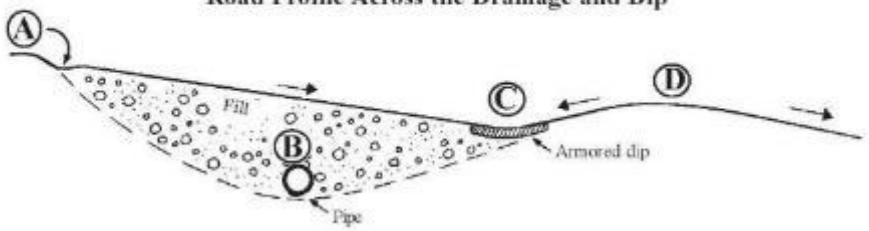
Stream Diversion Prevention Dips

Culvert Installed with Protection using an Armored Overflow Dip to Prevent Washout and Fill Failure

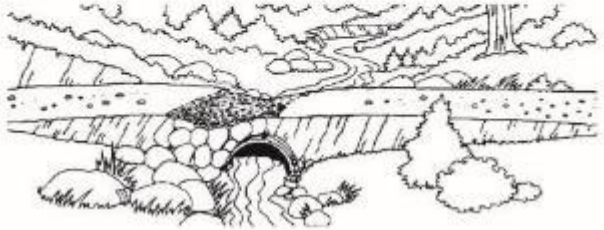


(A) Roadway Cross Drain (Dip)
(B) Culvert
(C) Overflow Protection Dip
(D) High point in the road profile

Road Profile Across the Drainage and Dip

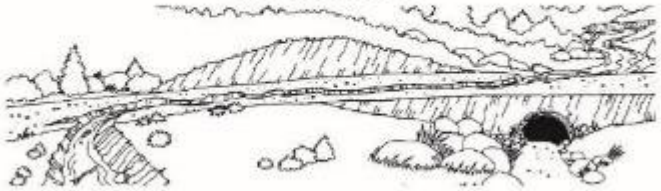


Good Installation

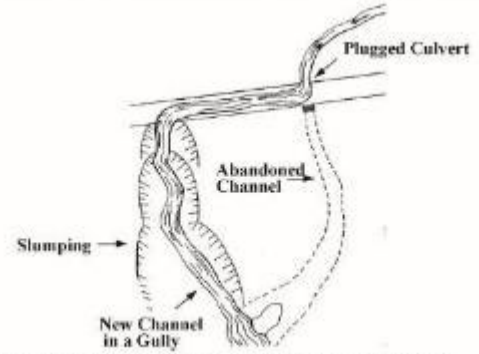


a. Armored dip over a low fill to prevent stream diversion.

Poor Installation



b. Sketch of a stream diverted down the road, forming a new channel.



Diversion Prevention Fill Armor

2.1 Climate Resilient Road Design

✓ 2.1.2 Avoiding Using Small and Multiple Culverts

Key interventions:

- Maintain and clean culverts periodically
- Use larger cross-drain culverts
- Use 1-meter minimum size
- Avoid multiple small culverts
- Consider the debris moving in the ditch or channel
- Consider maintenance needs/methods

Increase standard cross-drain size (800-1000 mm vs 400-600 mm)

Small Pipes Plug Easily!

Multiple Small Pipes Also Plug Easily

2.2 Stabilization of Road Sides

✓ 2.2.1 Complete Ground Cover In Disturbed Areas

Key interventions:

- Cover Barren Areas!!
- Apply Mulches and Netting
- Apply Leaves and Compost
- Apply Wood Chips or Rock
- Achieve Vegetative Cover for long-term protection
- Apply Cover Before the Rainy Season

To Prevent Erosion--
Drainage Control and Ground Cover

Control of Water

Ground Cover

Nets, RECP, Hydromulch

Vegetative Ground Cover

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2.2 Stabilization of Road Sides/Slides

✓ 2.2.2 Deep Rooted Vegetation For Slope Stabilization

✓ <u>Key interventions:</u>

Choose Locally Adaptable Vegetation

Choose Species that will Resprout

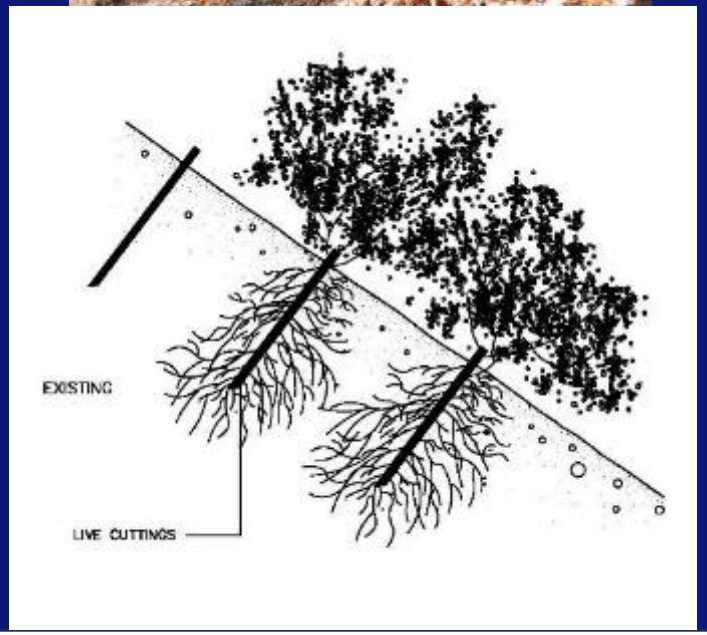
Choose Varieties with Deep, Dense Root Systems

Use Live Stakes on Shallow Slope Failures

Consider Vetiver Grass where Appropriate

Problems with Shallow-Rooted Vegetation

Deep Rooted Vegetation



2.2 Stabilization of Road Sides

✓ 2.2.3 Hardening Road Embankments

✓ <u>Key interventions:</u>

Armor the road surface

Armor the fill embankments

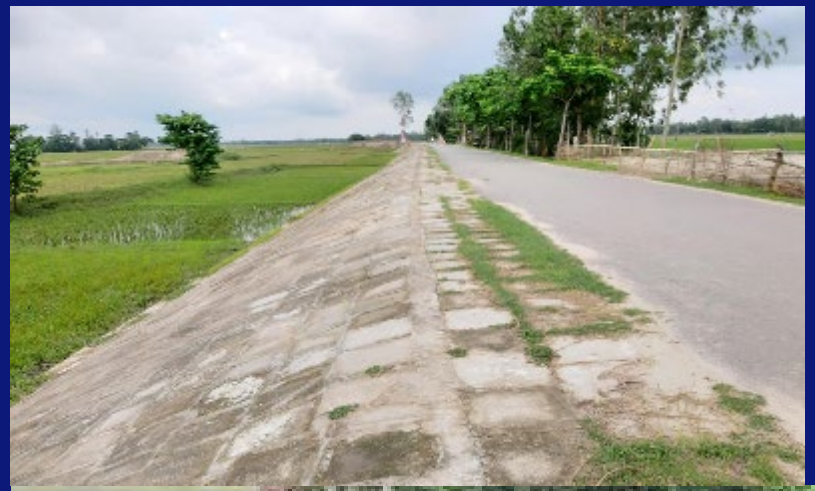
Cover the entire slope

Key into the toe of the embankment

Mix vegetation with hard armor

Choose materials that are durable

Armored Road Embankments



2.2 Stabilization of Road Sides

✓ 2.2.5 Armoring the Roadway Driving Surface

- ✓ <u>Key interventions:</u>
- ✓ Apply durable material to the road surface
- ✓ Gravel is the most common road surfacing
- ✓ Many option exist-asphalt, gravel, concrete, pavers
- ✓ Use foamed bituminous stabilization on roads
- ✓ Consider durability and cost
- ✓ Consider soil type and traffic
- ✓ Improves traffic condition and driving surface
- ✓ Minimizes ruts, dust and erosion

Armor the Road Surface —Many Options

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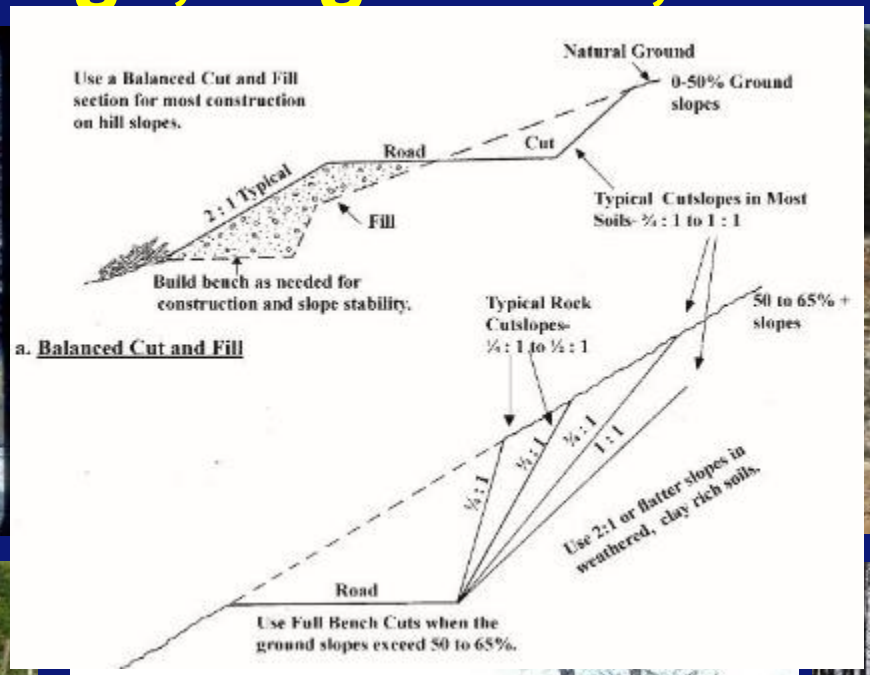
2.2 Stabilization of Road Sides/Slides

✓ 2.2.6 Stabilization of Unstable Cuts and Fill Slopes

- ✓ <u>Key interventions:</u>
- ✓ Choose Typically Stable Slope Angles
- ✓ Control Drainage
- ✓ Use Vegetation for Shallow Failures
- ✓ Use Soil Bioengineering
- ✓ Use Vegetated Reinforced Soil Slopes (VRSS)
- ✓ Select Cost-effective Retaining Structures
- ✓ MSE (Mechanically Stabilized Earth) Walls are Cost-effective
- ✓ Use “Deep-Patch” Fill Slope Reinforcement

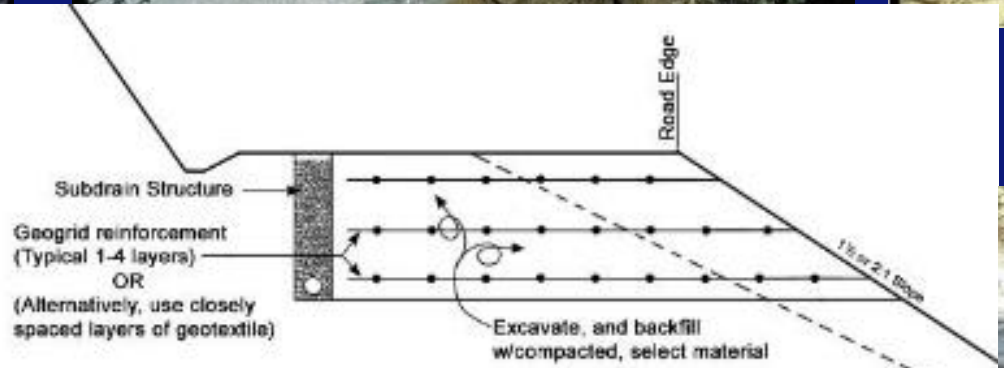
The Problem-SLOPE INSTABILITY

SOLUTIONS-Drainage, Vegetation, Anchors, Buttresses



SOLUTIONS-MSE & Gravity Walls

Deep



CROSS-SECTION OF TYPICAL DEEP PATCH
ROAD EMBANKMENT REPAIR

Patch

2.3 Resilient Routing/Avoiding Vulnerable Areas

✓ 2.3.1 Moving Roads Out Of Channel Migration Zones

<u>Key interventions:</u>

Stay Off Flood Plains and Terraces

Avoid Channel Migration Zones

Move the Road as Needed

Armor Streambanks when Needed

Rock Riprap Stream Armor

Avoid Gabions if Possible

Direct Flow Away from the Streambank

Avoid the Channel Migration Zone

1. Move the Road!!
2. Armor Streambanks or Redirect Flow



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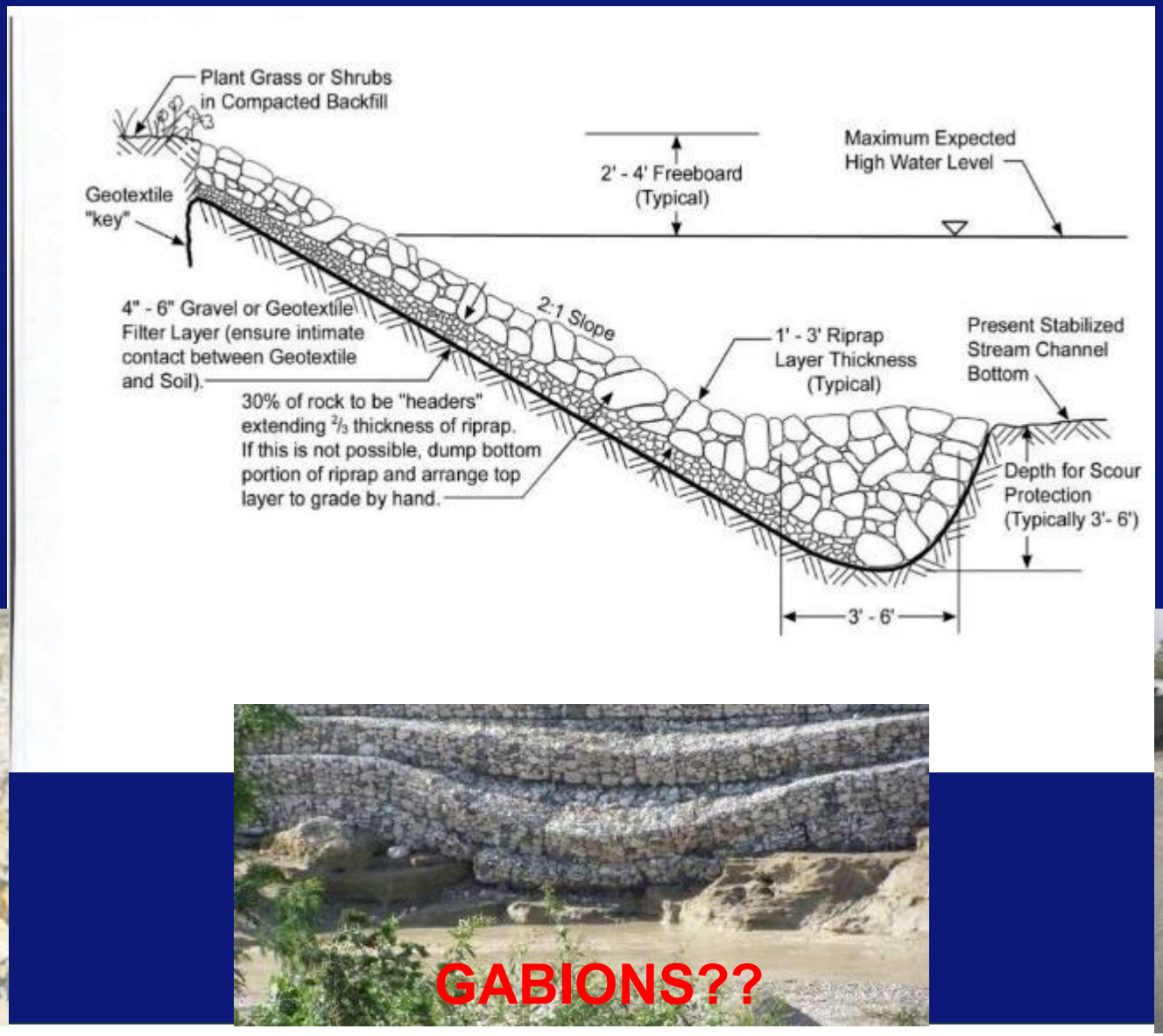
Use Riprap Armoring

Riprap Armor Design



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2.3 Resilient Routing/Avoiding Vulnerable Areas

✓ 2.3.2 Avoid Wet and Unstable Areas

Key interventions:

- Avoid unstable terrain and slides
- Avoid steep slopes over 65%
- Avoid hummocky terrain
- Minimize stream crossings
- Avoid wet, bog areas or springs

Terrain to Avoid

Other Problematic Locations

2.5 Enhancing Road and Bridge Climate Resilience

✓ 2.5.2 Climate Adaptation Measures for Bridges

<u>Key interventions:</u>

Provide Adequate Span

Avoid Constriction of Channel

Avoid Mid-Channel Piers

Remove Debris and Obstructions

Protect against Scour

Remove Aggradation

Consider Bridge Replacement Cost

KEY BRIDGE ISSUES

- **Obstructions**

- **Lack of Capacity**

- **Scour Issues**

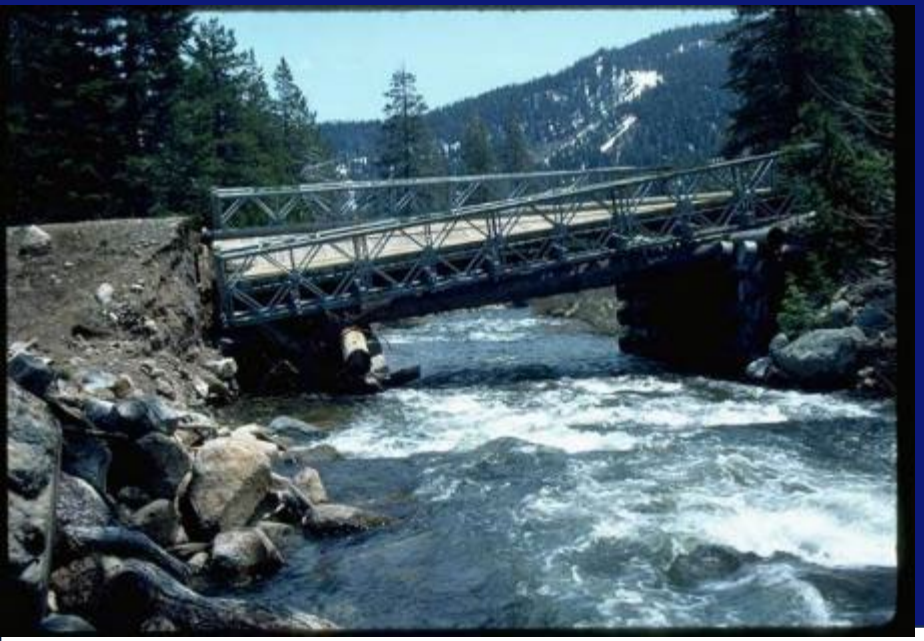
Replace “Scary” Bridges

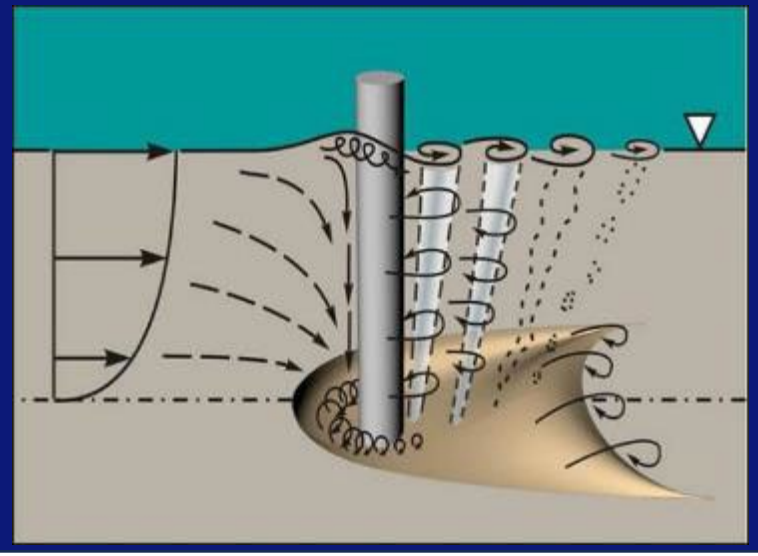
Remove Debris/Trees in Channel

Maintain Capacity and Freeboard

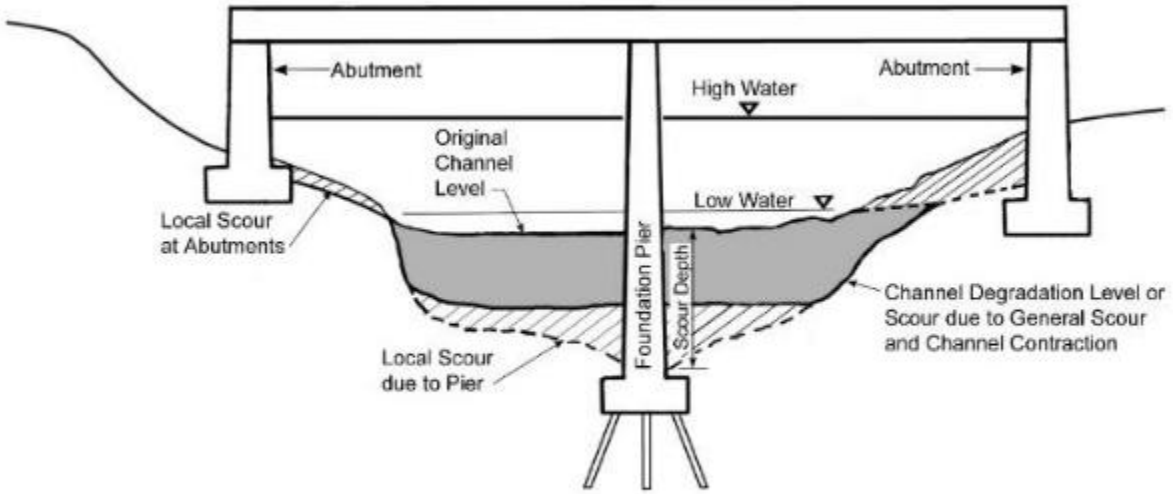
Beware of Aggradation--
Remove the Deposited Sediment!

Bridge Scour





Bridge Scour Protection



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BRIDGE REPLACEMENT OPTIONS
ABC-Accelerated Bridge Construction

(GRS) Abutments

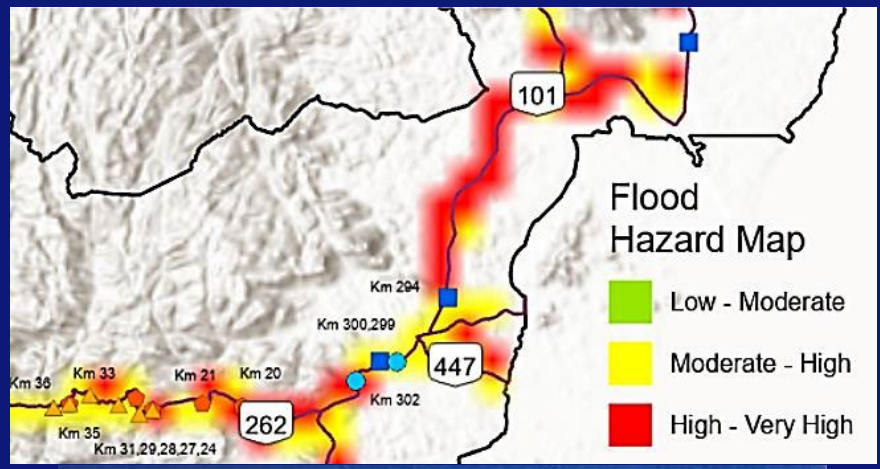
Buried Bridges

2.5 Enhancing Road and Bridge Climate Resilience

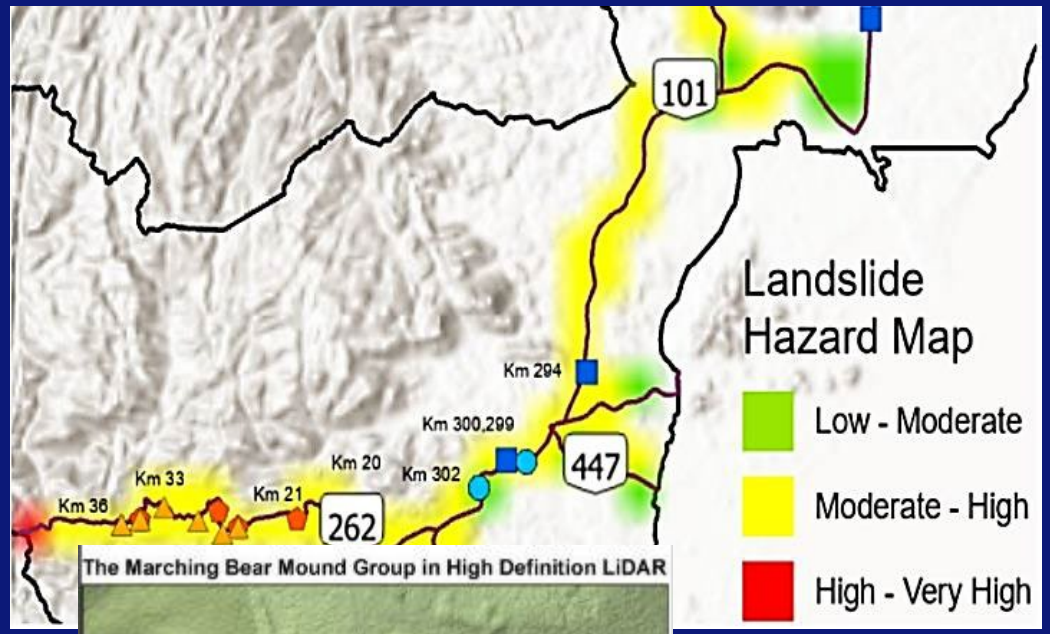
✓ 2.5.3 Artificial Intelligence Use in Climate Resilience

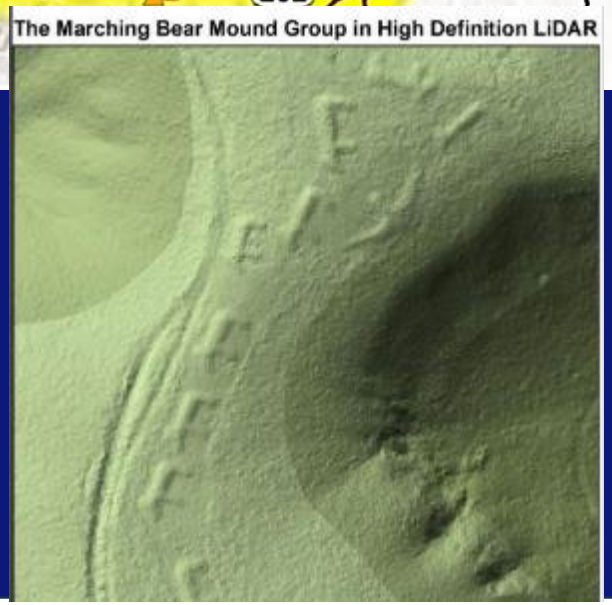
Key interventions:

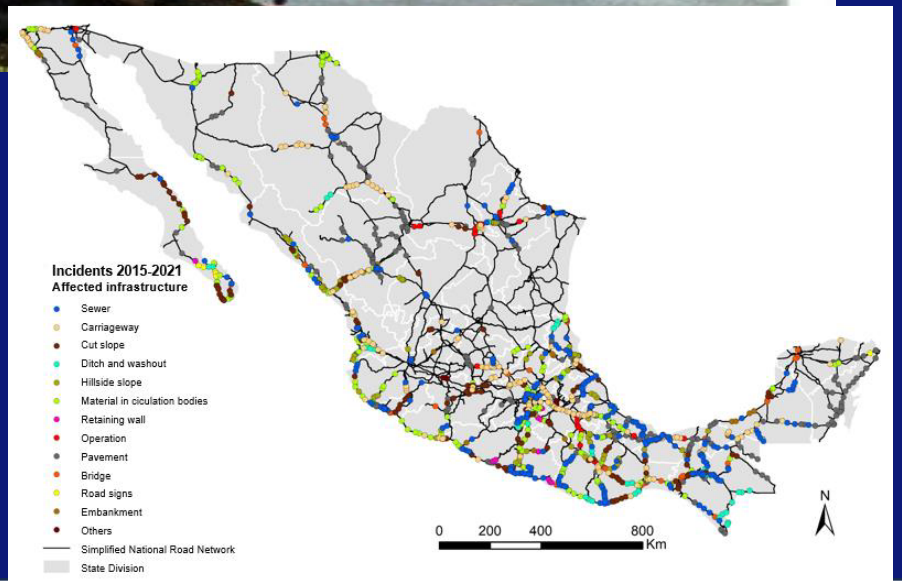
- Use of Information Technology
- Use of Remote Sensing and Satellites
- Big Data Mining/Analysis
- Forecasting Climate Impacts
- Prioritizing High Risk Sites
- Identifying Flood and Landslide Areas



Use of Artificial Intelligence







2.6 Enhancing Climate Resilience in Permafrost

✓ 2.6.1 Using Geocells for Soil And Slope Stabilization

Key interventions:

Confining looses sands and gravels

As an insulating layer over frozen ground

As forms for concrete roads

Rapid stabilization over soft soils

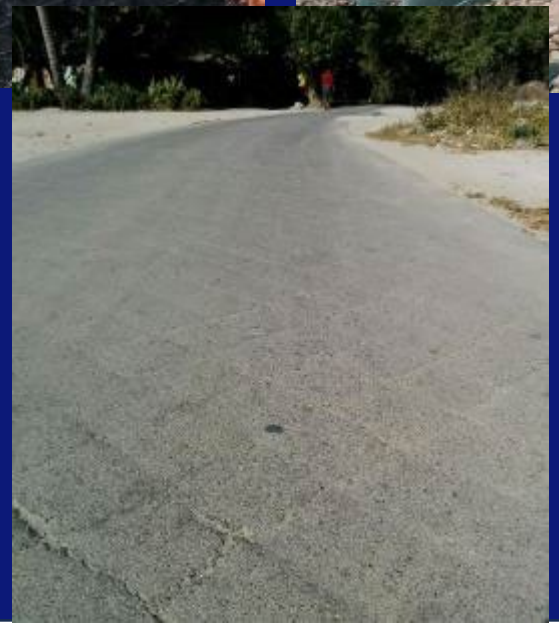
Surface slope stabilization

As retaining structures

In low-water crossing driving surface

Confining gravels for drainage blanket

Uses of Geocells



2.6 Enhancing Climate Resilience in Permafrost

✓ 2.6.2 Thermosyphon Cooling Under Paved Roads

Key interventions:

Construction in Permafrost

Paving Over Frozen Ground

Keeping Subgrades Frozen

Preventing Zones of Thawing

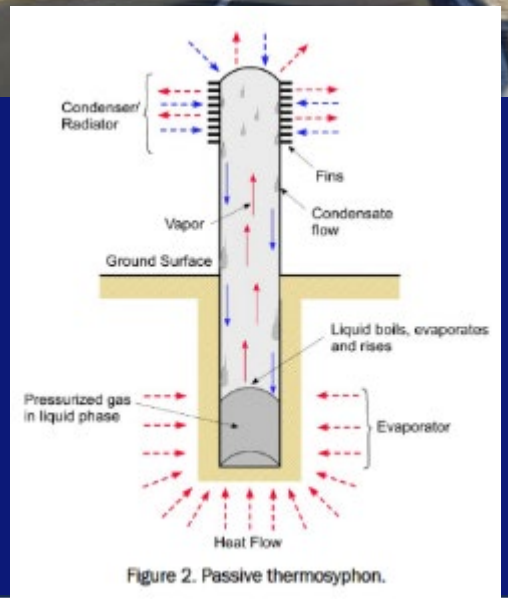


Figure 2. Passive thermosyphon.

2.7 Nature-Based Solutions for Climate Resilience

✓ 2.7.1 Promoting Nature-Based Solutions For Roads

Key interventions:

- Vegetative Erosion Control
- Vegetative Contour Barriers
- Soil Bioengineering
- Detention Ponds
- Rain Gardens
- Green Swales/Bioswales
- Grass-Stabilized Sand Dunes

Vegetative Protection/Bioengineering/Ground Cover

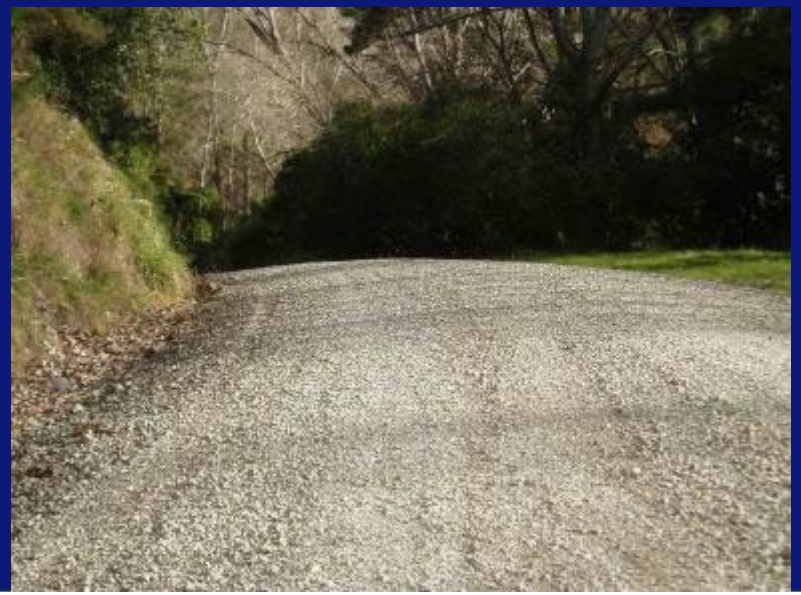
2.5 Enhancing Road and Bridge Climate Resilience

✓ 2.5.1 Need for Best Engineering Practices for Climate Resilience

Key interventions:

- Environmental Analysis/Interdisciplinary Approach
- Construction Quality Control
- Compaction Around Culverts
- Surface Drainage Control
- Properly Sized/Installed Culverts
- Properly Graded Surfacing Materials
- Streambank Protection
- Stabilized Slopes
- Ground Cover for Erosion Control

Engineering Best Practices



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2.1 Climate Resilient Road Design

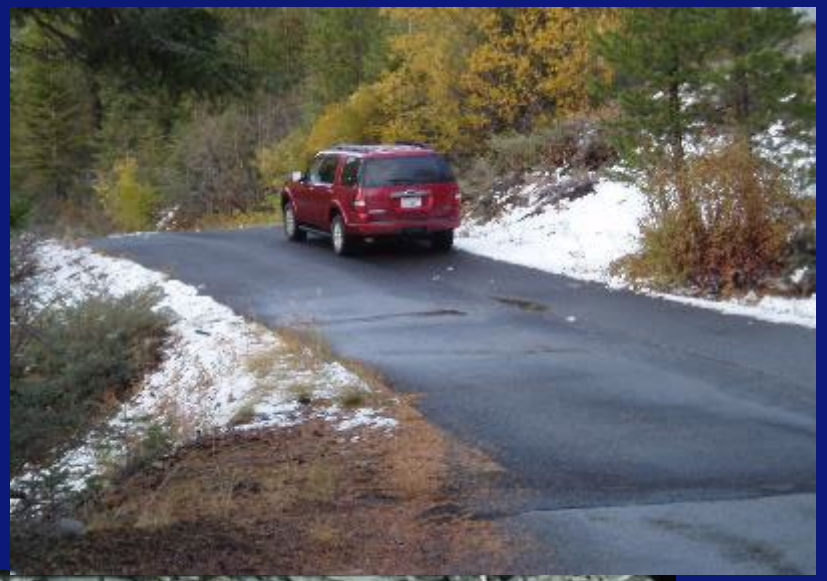
✓ 2.1.4 Road Surface Drainage to Prevent Water Damage

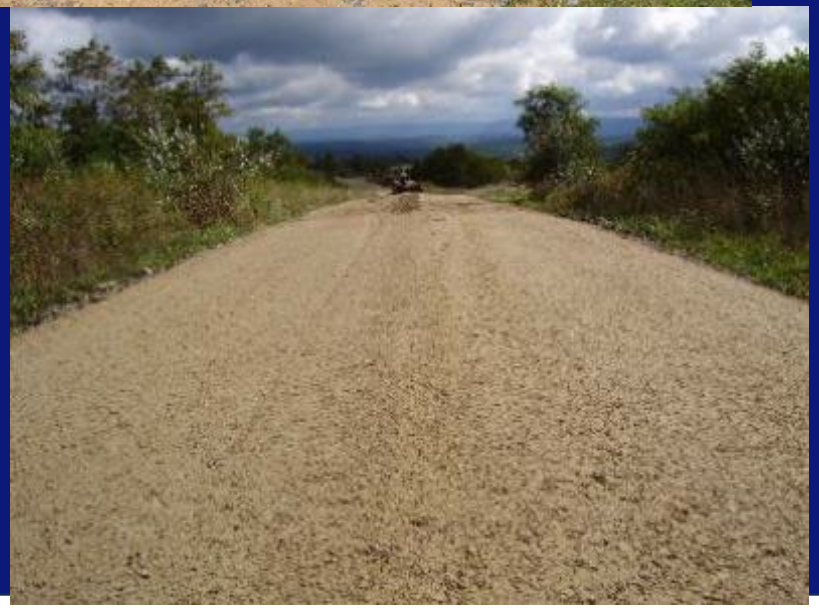
Key interventions:

- Prevent Water Concentration
- Control the Water
- Use Frequent Rolling Dips
- Use Catchwater Ditches
- Armor Ditches
- Armor the Outlet to Dips/Pipes
- Run Leadoff Ditches into Vegetation

Prevent Water Concentration and Damage

Control Water/Dissipate Energy



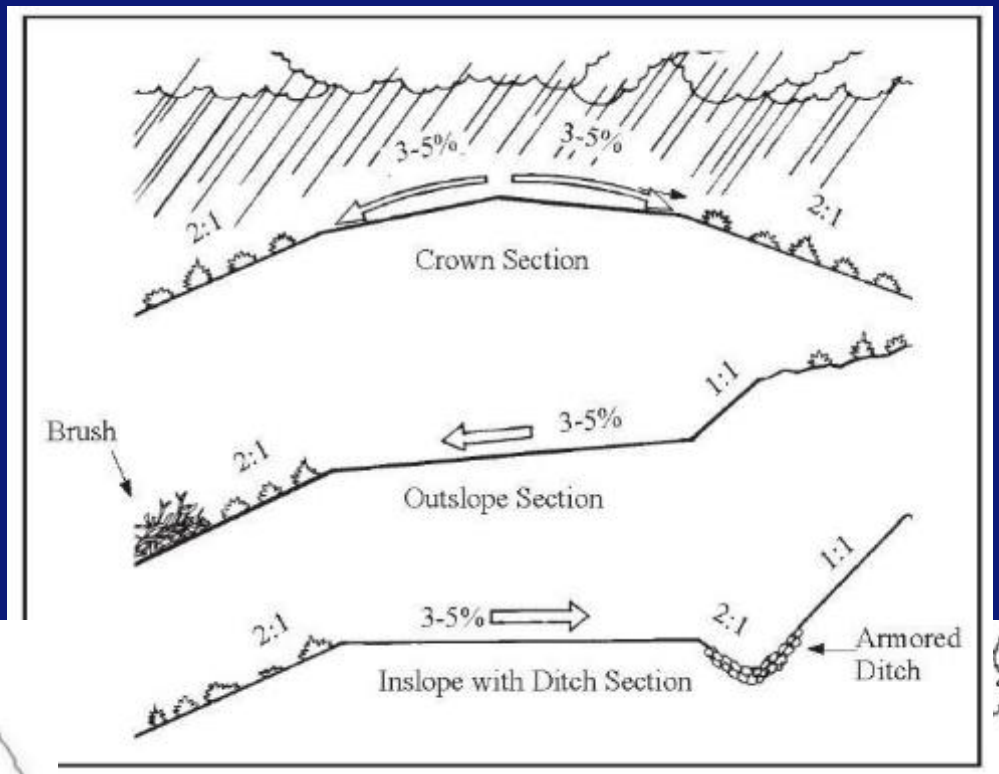


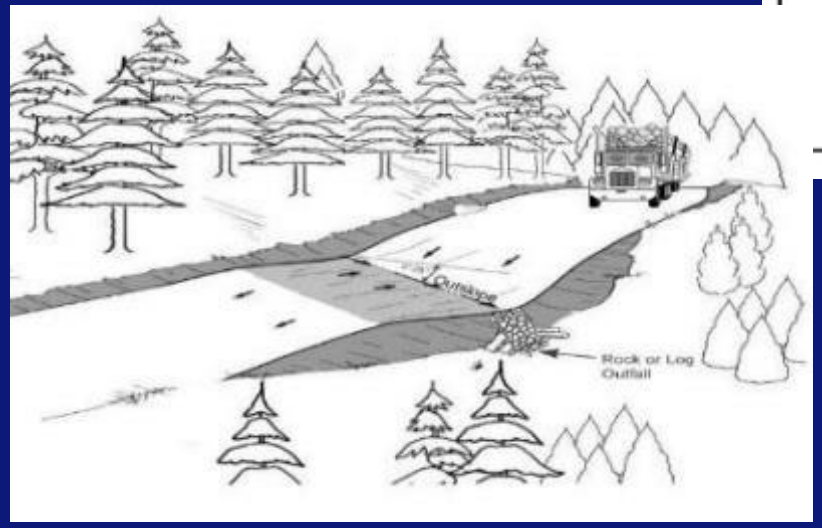
2.2 Stabilization of Road Sides

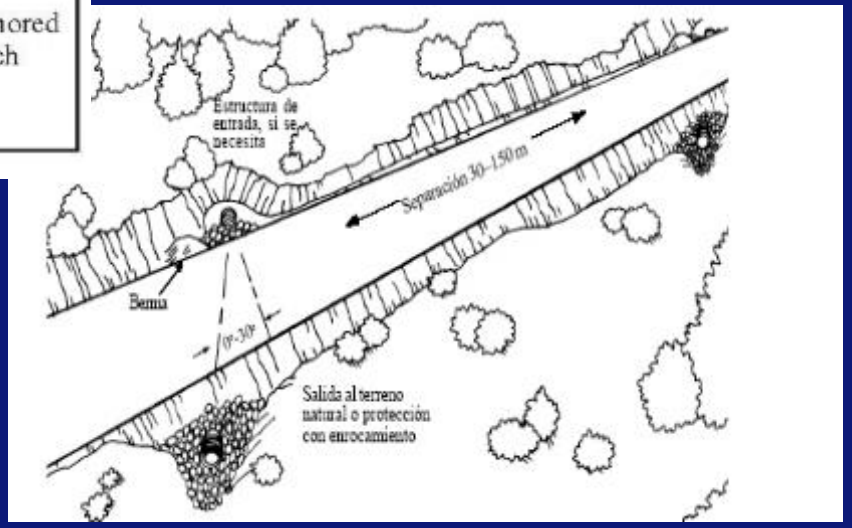
✓ 2.2.4 Preventing Road Surface Water Concentration

- ✓ Key interventions:
- ✓ Disperse Water Frequently
- ✓ Inslope , Outslope or Crown Surface
- ✓ Use Frequent Cross- Drains
- ✓ Use Frequent/Well -spaced Rolling Dips
- ✓ Roll the Road Grades
- ✓ Use Frequent Lead-off Ditches

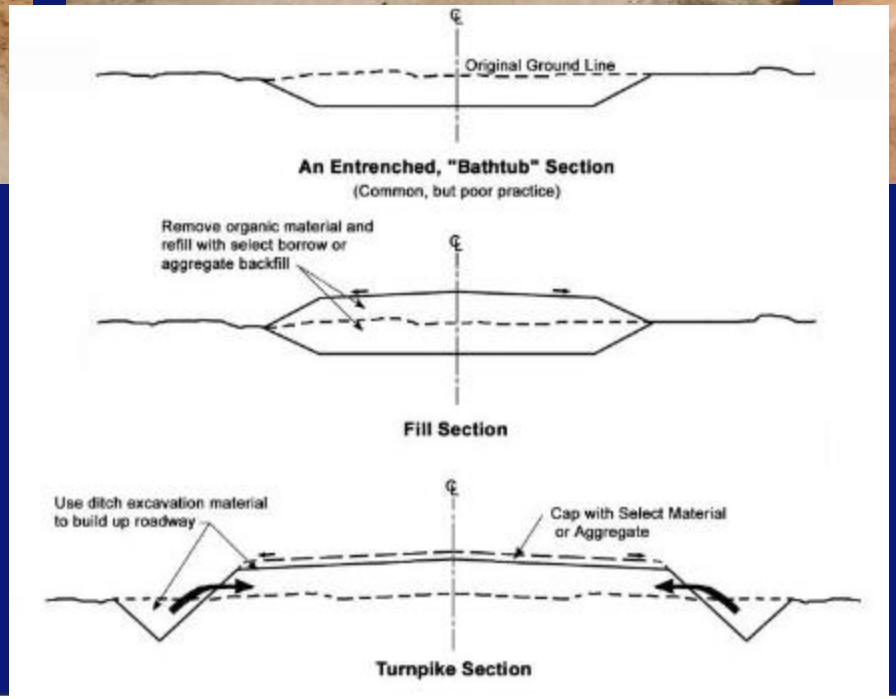
Prevent Water Concentration/Disperse Flow







Prevent Entrenchment--Water Concentration



POOR

GOOD!

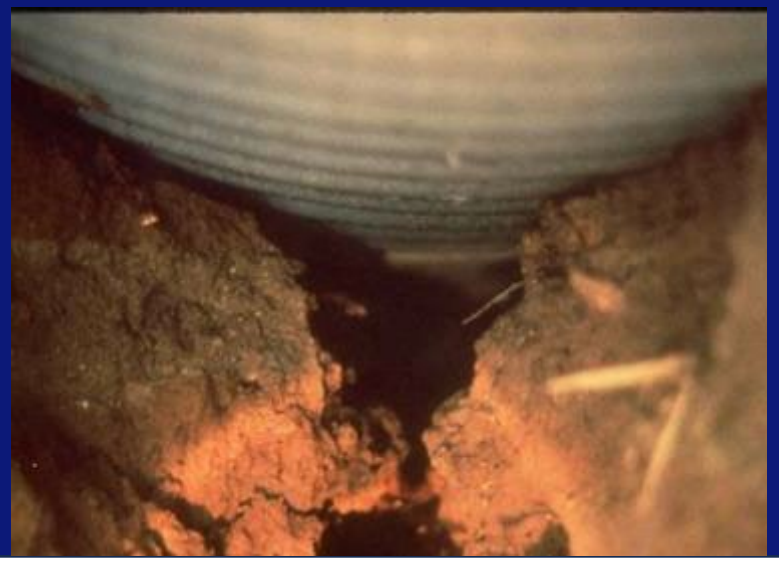
2.1 Climate Resilient Road Design

✓ 2.1.3 Climate Resilient Culvert Design

Key interventions:

- Use Stream Simulation Concepts
- Use Adequate Sized Pipes
- Maintain and Repair Damaged Pipes
- Prevent Pipe Plugging
- Prevent Stream Diversion
- Protect Pipe Inlets & Outlets
- Avoid Small Pipes that Plug Easily
- Water Harvesting/Beneficial Uses of Culvert Water

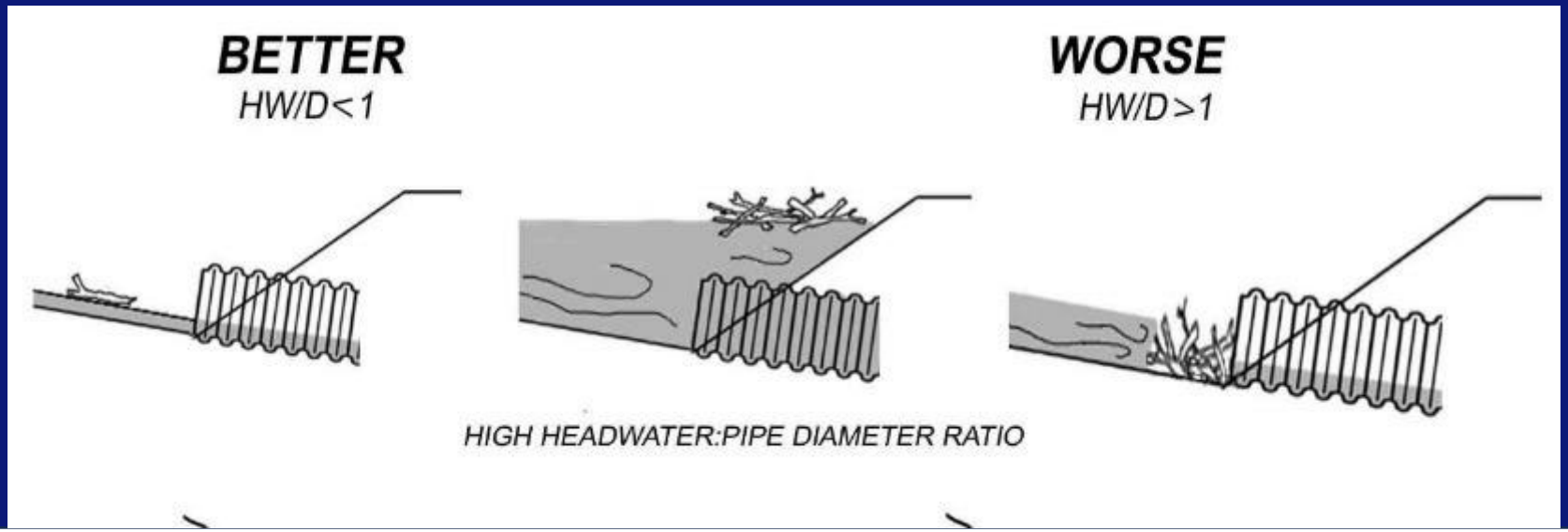
Problematic Culverts



Increase Capacity, Improve Design

- Q50-100 vs Q25 Design Flow
- Increase Rainfall Intensity ”i”

- Use ≥ Bankfull Width
- HW/D ≤ 1.0



CLIMATE RESILIENT CULVERTS
Increase Capacity—How Much??

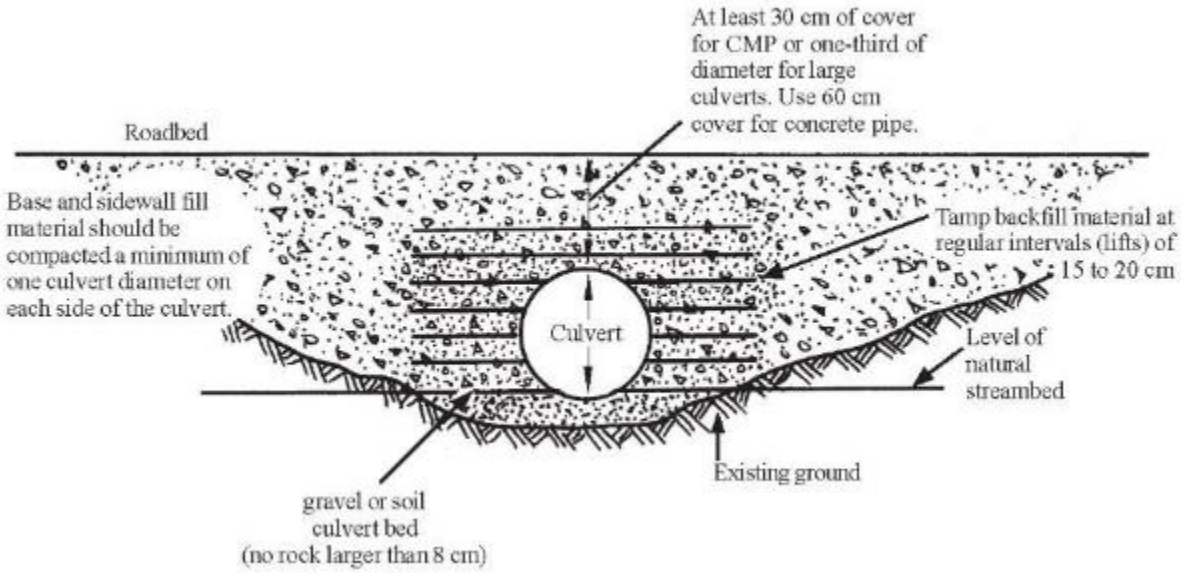
Increase Design Flow by 20-30 percent

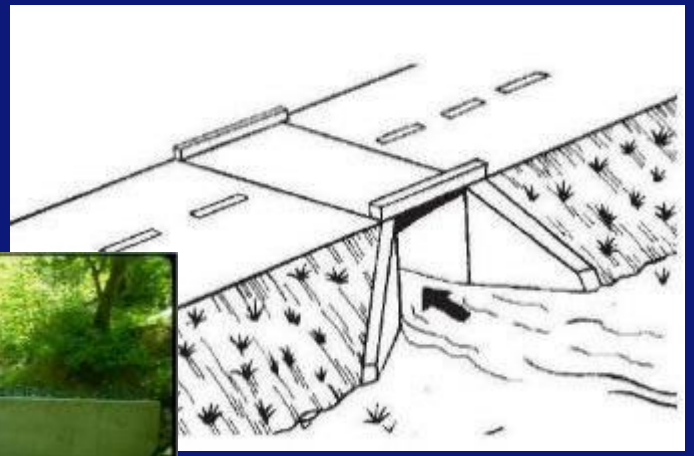
Increase Recurrence Interval Q100 vs Q25 (from USGS regression equations)

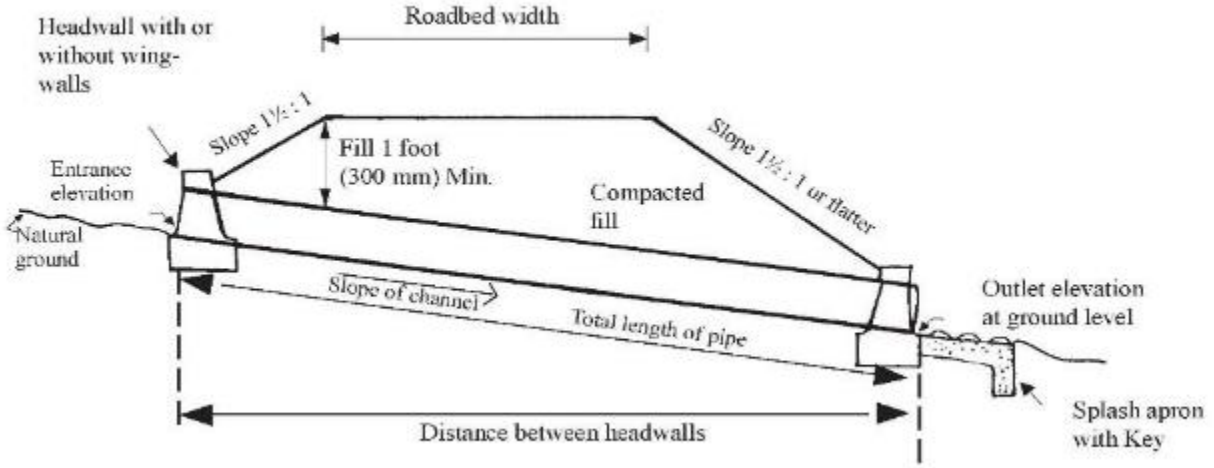
Modify Frequency on IDF Curve – 100 vs 50 yr curve with Corresponding Increased Rainfall Intensity (i)

Temperature Scaling to adjust rainfall intensity (i)

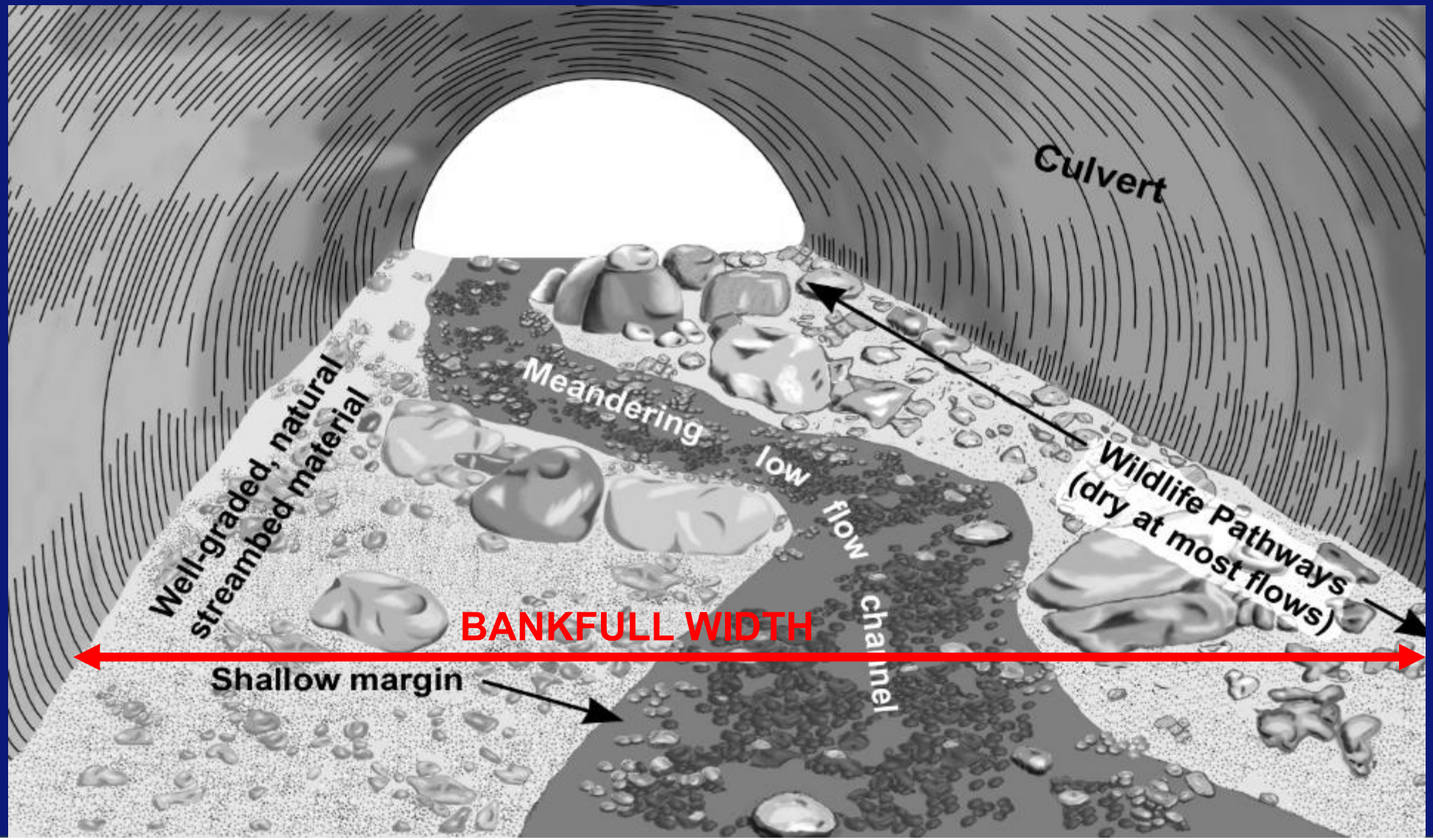
Culvert Compaction, Inlet and Outlet Control







Use Stream Simulation Concepts



CULVERTS
Use Stream Simulation Concepts

Stream Simulation Culvert Costs

Stream Simulation culverts generally cost more initially

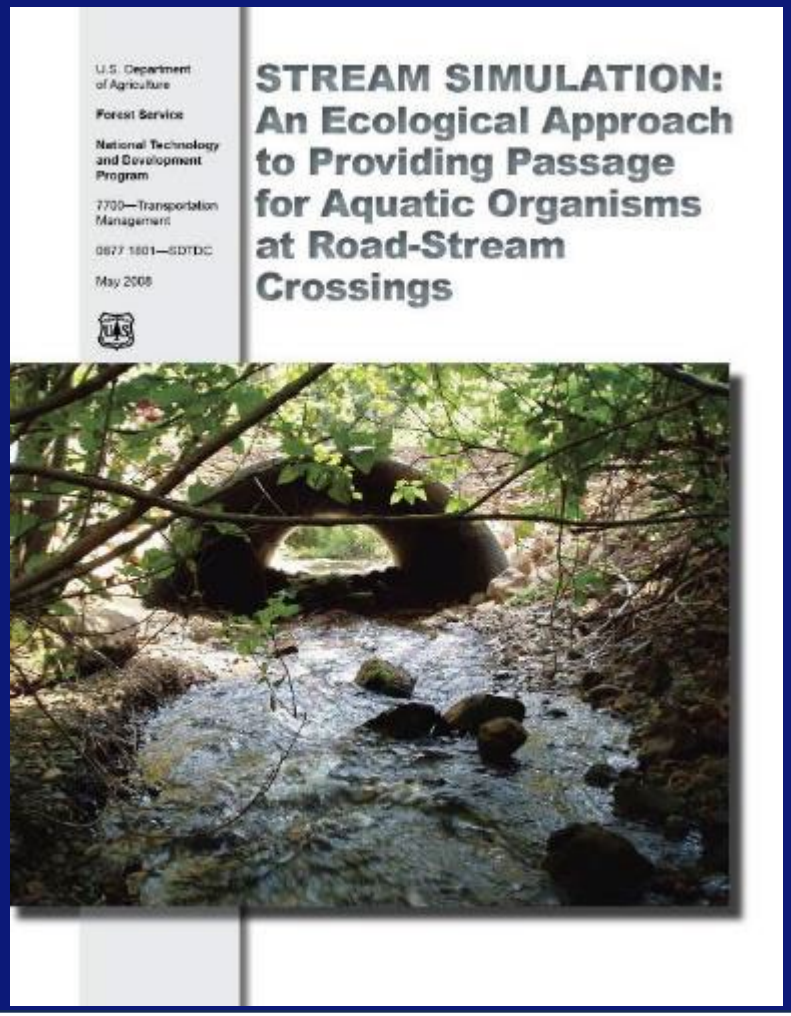
Life cycle costs are often equal or less

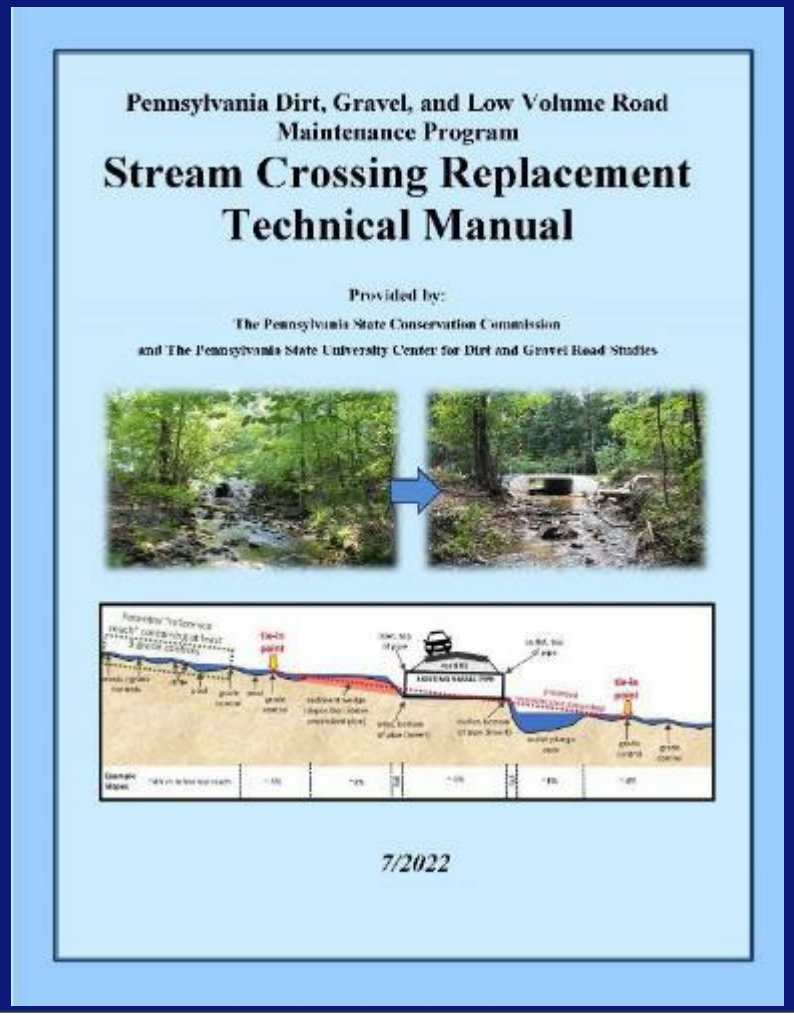
Culvert passes larger flows = less damage or replacement/repair

Less problems with debris = less maintenance

Less need for armoring

Stream Simulation Culverts

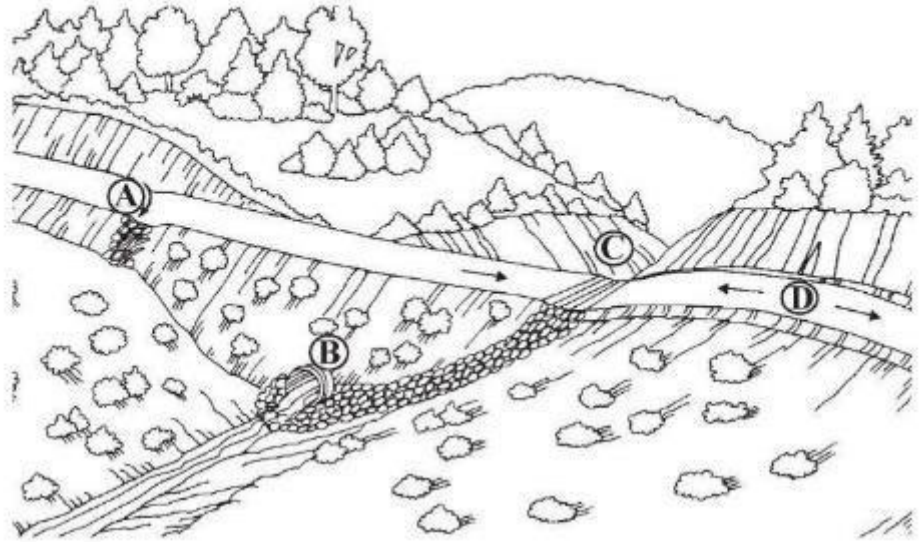




Penn State CDGRS

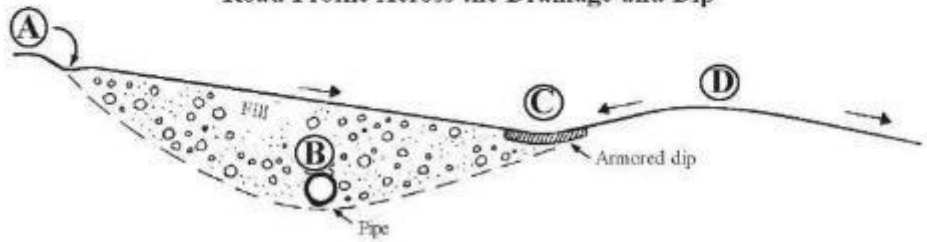
Prevent Stream Diversion

Culvert Installed with Protection using an Armored Overflow Dip to Prevent Washout and Fill Failure



(A) Roadway Cross Drain (Dip)
(B) Culvert
(C) Overflow Protection Dip
(D) High point in the road profile

Road Profile Across the Drainage and Dip



Culvert Plugging Problems

In Mountains, 85 % of culvert failures are from plugging

ADB

META

IRF

Prevent Culvert Plugging with Added Trash Racks

BEFORE

AFTER

ADB

META

IRF

DAMAGED CULVERTS--Less Capacity-More Risk

Climate Resilience

- ✓ **Climate-related damage to road infrastructure costs countries between 1-3% of their GDP annually (World Bank)**
- ✓ **Making infrastructure more climate-resilient can add about 3 percent to the upfront costs but has benefit-cost ratios of about 4:1 (Global Commission on Adaptation)**

Key intervention areas:

2.1. Climate-resilient road drainage design

2.2. Increased Stabilization of roadsides

2.3. Resilient routing/ avoiding vulnerable areas

2.4. Resilient road maintenance

2.5. Enhance Climate Resilience of roads and bridges

2.6. Enhance climate resilience of roads in permafrost regions

2.7. Nature-based Solutions for enhanced climate resilience of roads

2.8. Landscape Management

Using appropriate size culverts

Deep rooted vegetation for slope stabilization

Stabilization of slopes

Streambank protection

3. Water and Land Management

- ✓ **Water is responsible for 80% of road damage to unpaved roads and 30% of damage to paved roads**
- ✓ **It is estimated that 20% of the global land surface is within one kilometre of road**
- ✓ **Roads have a major impact on local hydrology – often with negative consequences – this can be turned around into beneficial water management using the road infrastructure**

Key intervention areas:

3.1. Water harvesting and run-off storage

3.2. Agricultural Water management

3.3. Groundwater management

3.4. Reduced waterlogging and protecting natural channels

3.5. Preventing landslides

3.6. Erosion and Gully control

3.7. Avoiding sand dune movement

3.8. Green routing

Field trench from road

Road made from excavation of drainage canal

Gully rehabilitation

Overflow road

7. Disaster Preparedness

- ✓ **Disasters triggered by natural hazards and escalating climate change impacts pose a huge threat to economic and social development worldwide in Asia and the Pacific.**
- ✓ **Roads play an important role in disaster risk reduction as well as in disaster response (such as flood and fire management).**

PREPAREDNESS- RESPONSE-RECOVERY

Key intervention areas:

7.1. Flood mitigation by road network (compartmentalization)

7.2. Flood resilience of the road network

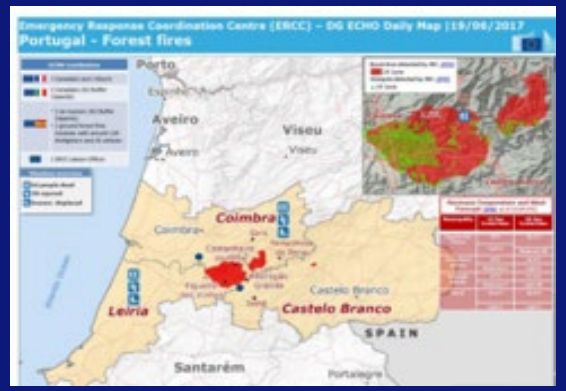
7.3. Road network capacity to deal with emergencies

7.4. Evacuation and access plans

7.5. Fire prevention

Roads used as shelter

Upland water retention



Map of fire breaks

Road crossing stabilizing river course

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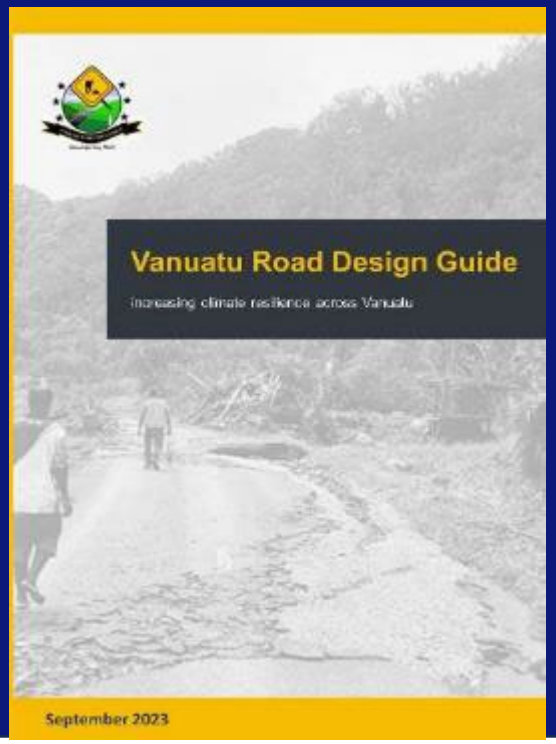
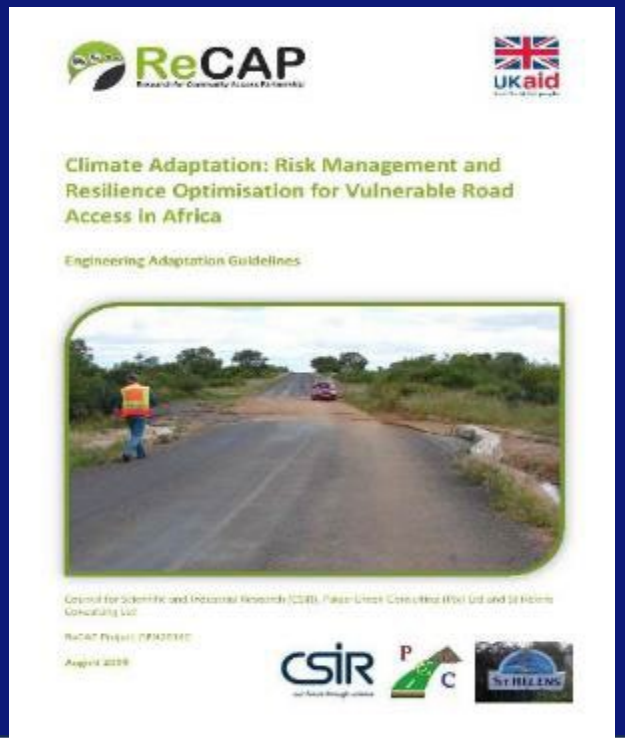
-RECAP Climate Adaptation- Engineering Adaptation Guidelines

-Vanuatu Road Design Guide-Increasing Climate Resilience





Thank you

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- Subscribe to the Green Roads Community of Practice
- Share good experiences
- Share suggestions for the Green Roads Toolkit and Guidance Note