Stream Crossing Alternatives

December 13, 2013

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California Department of Forestry and Fire Protection

Outline

I. Introduction
II. Types of Crossings Available
III. What Can Go Wrong at Crossings?
IV. Proper Design and Construction for New or Replacement Crossings
V. Post-Fire Considerations
VI. Summary—Take Home Messages
VII. References for Stream Crossings

I. Introduction

- ***Why are stream crossings a BIG deal?***

- **Monitoring results tell us that crossings often have problems (~20%) and that a high percentage of sediment delivery to streams occurs at or near crossings.**
- **Crossings are built in risky locations subject to large environmental stressors.**
- **Crossings are built with planned failure in mind.**
- **Crossing structures have an expected life.**
- **Crossing design, installation, or maintenance is often inadequate.**

No such thing as a "permanent" culvert crossing

II. Types of Crossings Available

Types of Crossings

A. Culverts
B. Open Bottom Arches
C. Bridges
D. Fords
E. Temporary Crossings
   – Temporary Fords [e.g., Spittler log fill, rock fill, etc.]
   – Temporary Culverts
   – Temporary Bridges

No Permanent Humboldt Log Crossings

Which One Should I Use?

Depends on…

- Watercourse class (e.g., fish present?).
- Watershed drainage area and expected size of 100 year flood flow.
- Channel slope; landslide susceptibility.
- Maintenance expected.
- Amount and type of traffic expected.
- Road type (permanent, seasonal, temporary).
- Amount of wood and sediment expected to reach the crossing location.
- Topography at the crossing site (incised or flat?).

A. Culverts

- Culverts in forest settings very common (~70% of crossings)--mainly steel or plastic.
- Aluminum <u>not</u> used as much since the mid-1980's—too expensive. At that time, plastic pipes became available.
- Plastic now used heavily (particularly up to 48 inches—especially in the Coastal Mountains).

A. Culverts

- **Pro's**
  - **Good for small, non-fish headwater streams where winter maintenance is possible and will occur.**

- **Con's**
  - **Require lots of maintenance!**
  - **Steel--expected life often only ~25 years (typical range 20-50 years).**
  - **Relatively high probability of failure, especially from sediment and woody debris.**
  - **Bad for fish passage.**


Steel 48 inch Culvert—
Mendocino County;
projecting inlet
JUN 20 2002

Plastic 18 inch Culvert—
(single wall); Humboldt County

Double Wall Smooth-Invert Plastic Pipe- High Density Polyethylene (HDPE); Western Oregon

Plastic Pipe Pro's and Con's

- **Caltrans expects a *minimum* life of 50 years for HDPE pipes exposed to sunlight. UV damage is generally not a concern (may be 75+ yrs).**

- **Benefits that HDPE pipe have over CMP include: (1) light weight, (2) ability to be cut with hand tools (saws, chainsaws, etc.) that don't pose a large fire hazard, (3) abrasion resistant, and (4) resistant to corrosion due to low pH soils.**

- **Double-walled pipes are very common now and provide:**
  - **more rigidity to accommodate higher static (overburden) and dynamic traffic loads.**
  - **a lower roughness (n) value to increase the conveyance capacity of the pipe (about the same as a concrete pipe).**

- **Problems: (1) increased flow velocities on inclined culverts; and (2) significant energy dissipation structures are often needed below HDPE pipes.**

- **Biggest problem: Fire Damage.**

Holes left where plastic culvert burned in small drainages

Roca/Rosa 2007 Fires

San Diego County

Photo: R. Eliot, CAL FIRE (retired)


Burned Plastic
Culvert
Glendale, OR

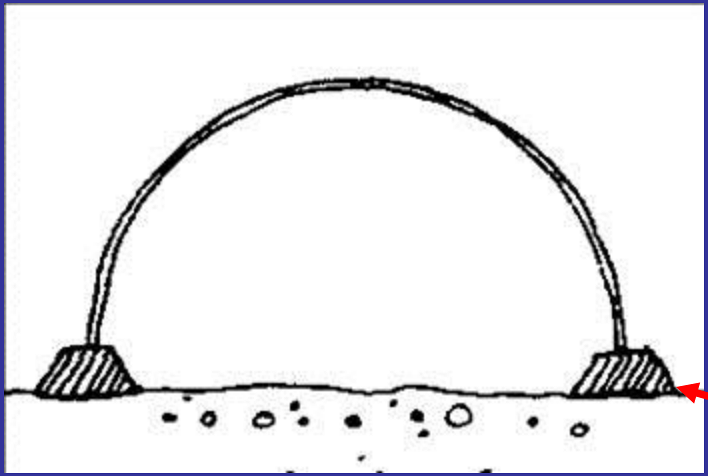

Lockheed Fire 2009
Santa Cruz County


Steel Culvert with
Concrete Headwall—
Santa Cruz County

Pipe Arch Culvert Crossing—Tehama County—Deer Creek Watershed. Note Rock Headwall/ Wing Walls

B. Open Bottom Arch

- **Pro's**
  - Excellent for fish passage.
  - May be cheaper than a bridge.
- **Con's**
  - Expensive.
  - Will require a professional engineer design.
  - Can fail by undermining if concrete footings not on solid rock base.



Concrete footing

Image: Weaver and Hagans 1994


Open Bottom Arch,
Latour Demonstration
State Forest, Shasta
County


Open Bottom Arch—
Freshwater Creek Watershed,
Humboldt County
Replaced a 10 ft Round CMP
10.18.2006

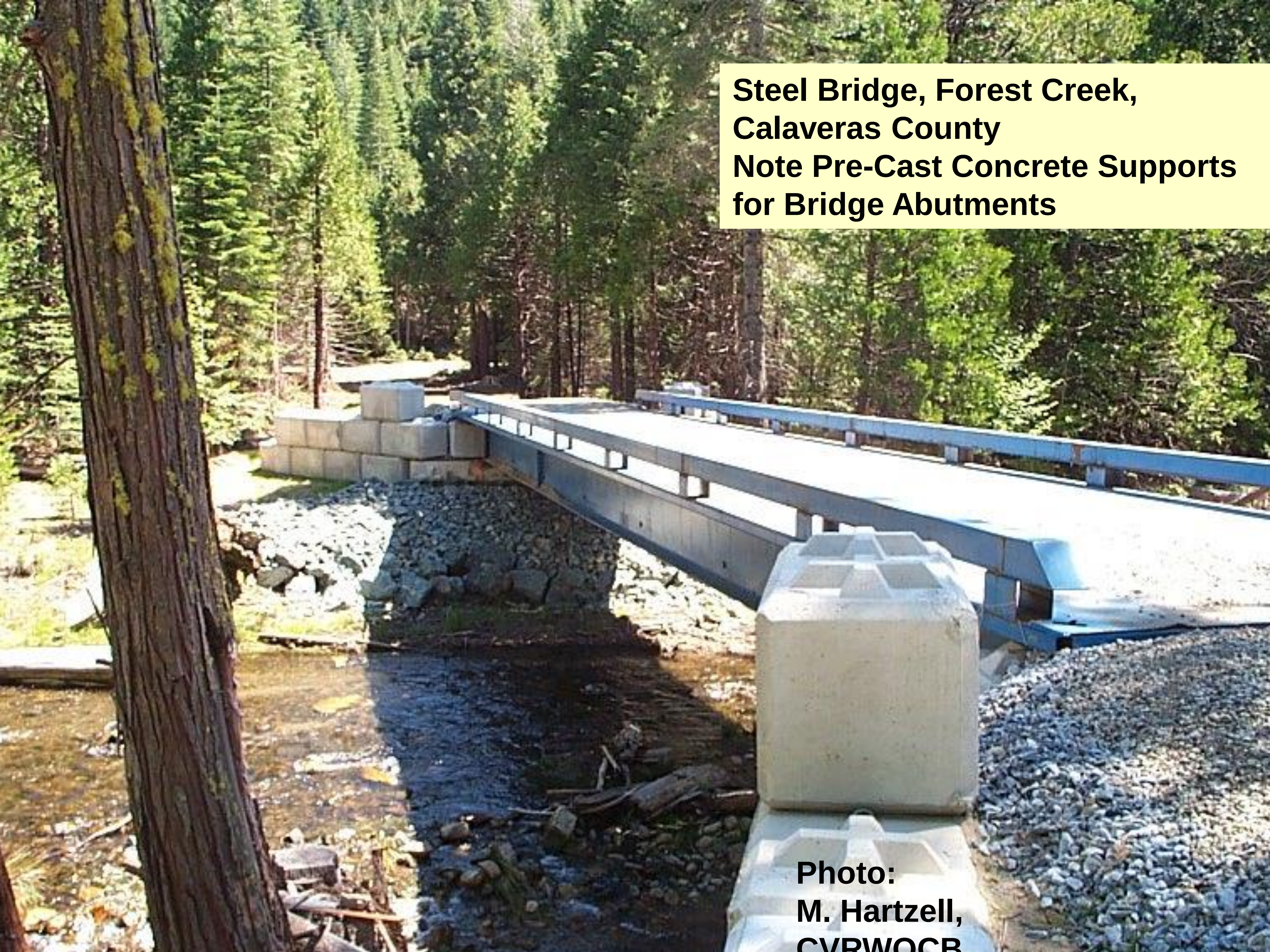
C. Bridges

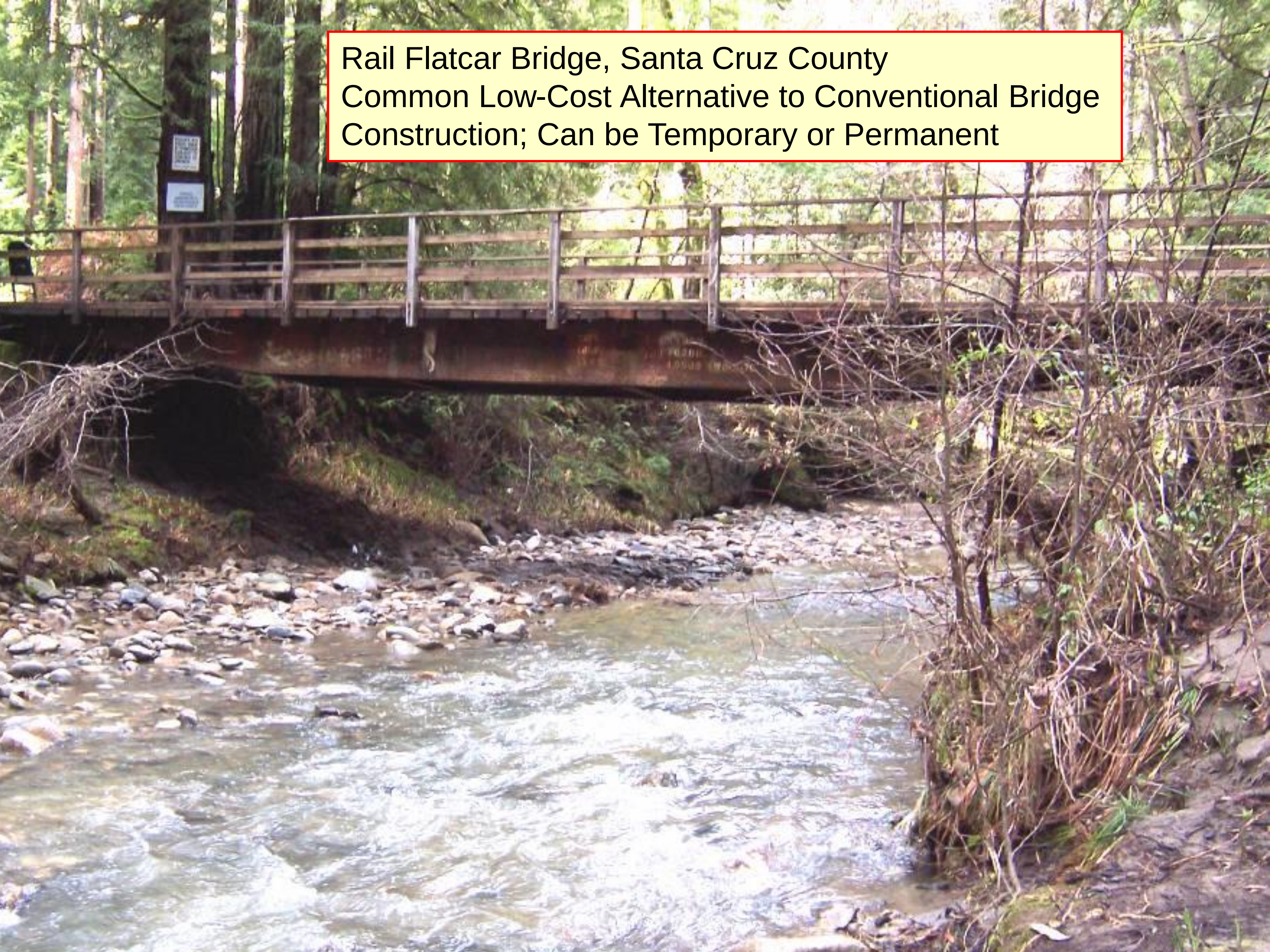
- **Pro's**
  - Excellent for fish passage.
  - If built correctly, long expected life (low chance of failure).
  - Little impact to the stream channel.
  - Little sediment entry.
  - Low overall environmental impact.
  - Good for incised stream channels/larger watercourses.

- **Con's**
  - Expensive.
  - Railroad flatcar bridges are $20,000 to $50,000, depending on length (55 ft or 90 ft) + $10,000 or more to install).
  - May require Professional Engineer design.


"Legacy Crossings":
Log Stringer Bridge
Mendocino County


Big River Steel Bridge
Mendocino County


Steel Bridge, Forest Creek,
Calaveras County
Note Pre-Cast Concrete Supports
for Bridge Abutments
Photo:
M. Hartzell,


Rail Flatcar Bridge, Santa Cruz County
Common Low-Cost Alternative to Conventional Bridge
Construction; Can be Temporary or Permanent

D. Ford Crossings

- **Pro's**
  - Often relatively inexpensive alternative for small to medium sized streams w/stable bottoms.
  - Low maintenance.
  - Low chance of failure if designed correctly.
  - Better than a pipe where winter maintenance will not occur (no plugging).
  - Not very sensitive to specific flow volumes ("forgiving").
  - Good for channels susceptible to landslides/debris flows.
- **Con's**
  - Can have high sediment entry, high impact to stream channel, especially with lots of traffic.
  - Rock ford crossings can fail easily if not designed correctly.
  - Not passable during flood flows!
  - Improved ford crossings (concrete slabs) bad for fish passage—prone to scour around edges.

Unimproved Wet Ford Crossing with Chronic Sediment Entry into Hinckley Creek

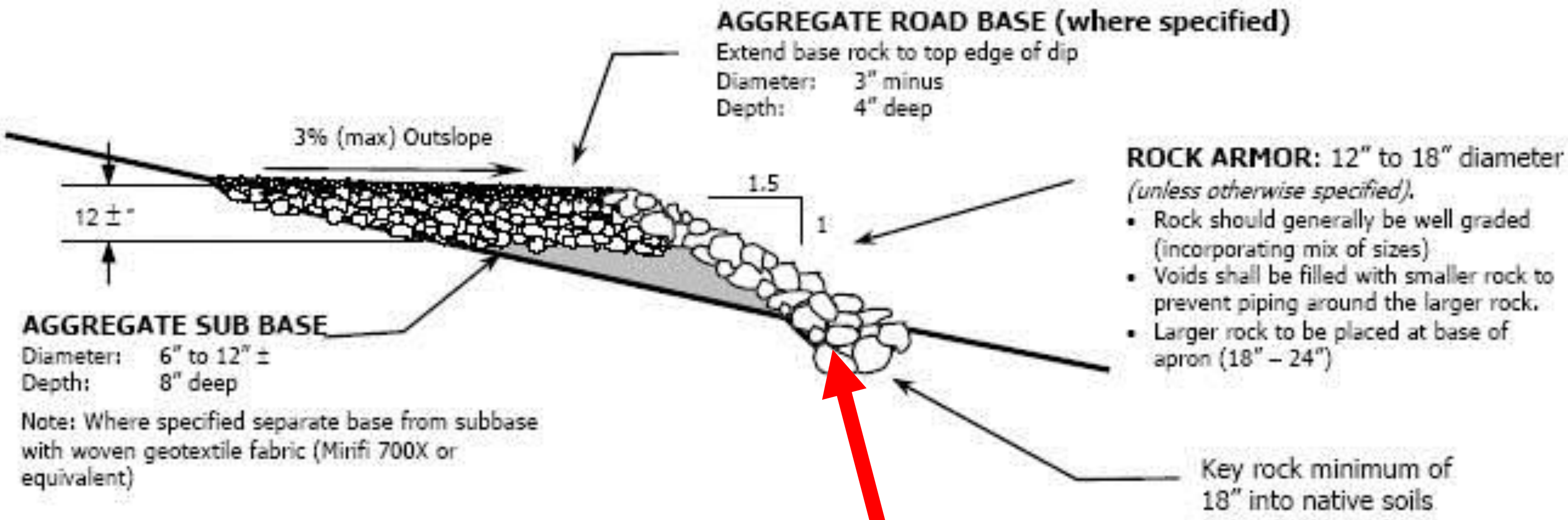
Santa Cruz County

NOT DESIRABLE


Rock Ford Crossing—
Mendocino County.
Rock must be large
enough to resist
movement in winter
storms

Rock Ford Design Specifications

Tim Best, CEG



Large rock (18-24 in) needed at base of crossing


Concrete Slab Ford—Tehama County—Ponderosa Way.
Pave across live streams to maintain water quality with regular traffic (get scour at edge).

Concrete Slab Ford—Tehama County—Crane Mills

Thomes Creek "The Slab."

Brett Rohrer DFG


Vented Ford—Butte County

Diagram of a Vented Ford Crossing (Keller and Sherar 2003)

b. Improved (Vented) Ford with Culvert Pipes in a Broad Channel

Note that armoring must extend to the 100 yr High Water Level on either side of the pipes.

Comparison of Crossing Types Impacts on Water Quality

- **Culverts: higher catastrophic failure risk; lower chronic sediment input.**

- **Fords: lower catastrophic failure risk; higher chronic sediment input.**

- **Chronic Water Quality Effects from sediment entry:**
  - **Highest: fords and culverts**
  - **Lowest: bridges**

E. Temporary Crossings

- **Pro's**
  - Little impact to stream channel if designed and implemented correctly.
  - Almost no chance for failure.
  - Complete fish passage.
  - Relatively inexpensive.
  - Required for temporary roads (pulled by October 15th).
- **Con's**
  - Higher sediment input, especially if built incorrectly.
  - High sediment input if removed incorrectly.

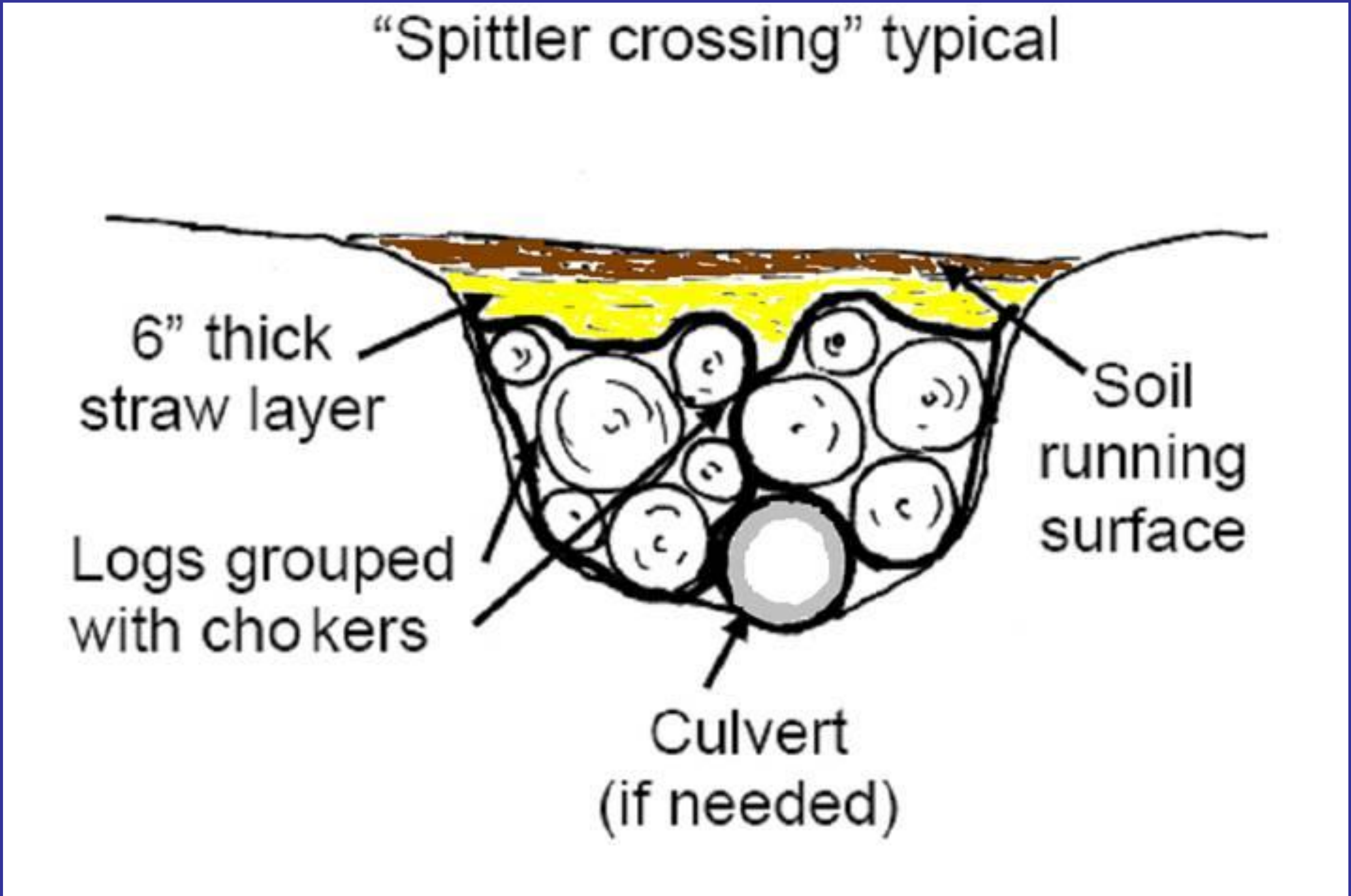


Image: T. Spittler, CGS (retired)


Temporary Spittler
Crossing—Tehama
County

Temporary 12 inch plastic pipe

Santa Cruz County

Photo: Stacy Stanish, DFW


Temporary Culverts with
Rock Fill (Clean Gravels)
Shasta County

Temporary Bridge Crossing—SF Stanislaus River, Tuolumne County—SPI and PG&E. Cost effective; quick installation and removal; little disturbance

Image: Hartzell, CVRWQCB


Temporary Bridge, Soquel Demonstration
State Forest, East Branch Soquel Creek

Crossing Crosswalk

Watercourse Type	Crossing Alternatives
Class I fish-bearing	1. Temporary crossing; 2. Bridge; 3. Open-bottom arch; 4. Pipe arch culvert
Class II non-fish bearing perennial	Culvert or Temporary Crossing
Class II non-fish bearing intermittent (headwater)	Culvert or Rock ford (or Temporary crossing)
Class III ephemeral	Rock ford or Culvert (or Temporary crossing)

PREFERRED ALTERNATIVES FOR FISH-BEARING CROSSINGS

The following alternatives and structure types should be considered in order of preference (NMFS 2001):

1. ***Nothing*** - Road realignment to avoid crossing the stream.

2. ***Bridge*** - spanning the stream to allow for long term dynamic channel stability.

3. **Bottomless arch, embedded culvert design, or ford**.

4. ***Non-embedded culvert*** - this is often referred to as a hydraulic design, associated with more traditional culvert design approaches limited to low slopes for fish passage.

III. What Can Go Wrong at a Crossing?

(short answer—LOTS!)


Plugging of the pipe
inlet with sediment

Terrace Development

Crossings with terraces or sediment wedges above the inlet often have insufficient capacity to pass flood flows.

Terraces upstream of the culvert inlet indicate past ponded conditions.

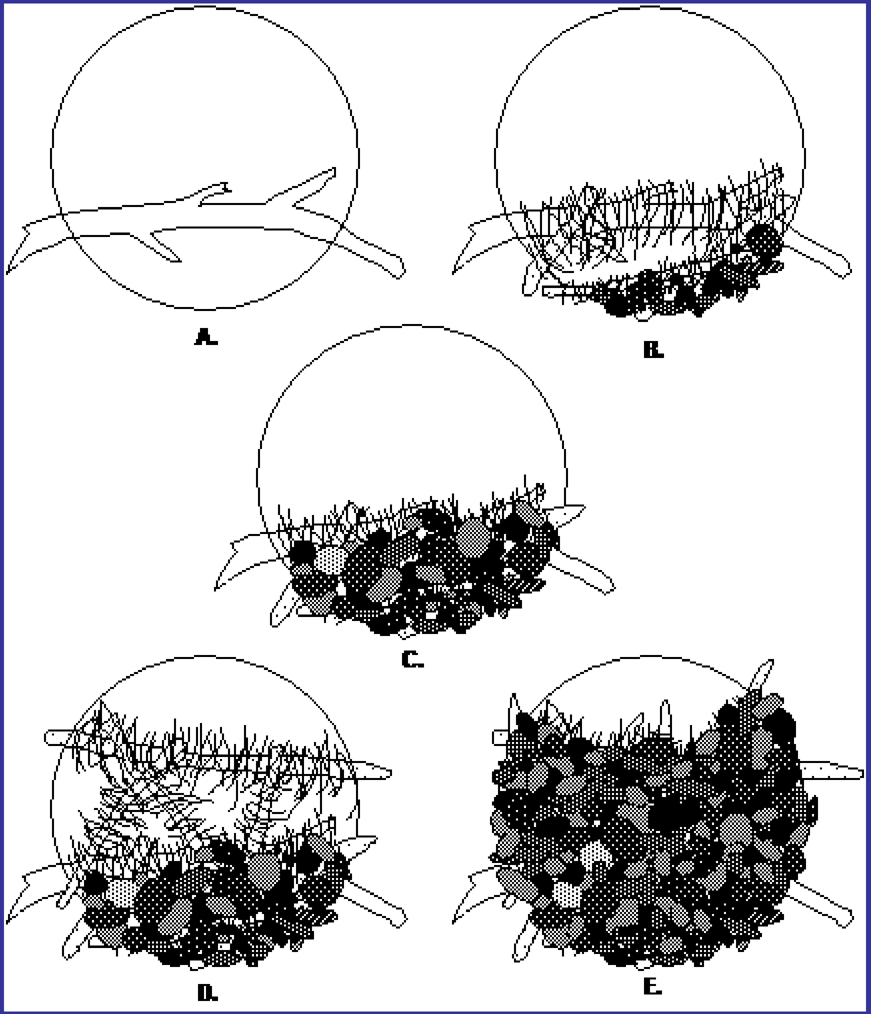
Culverts Blocked by Woody Debris

Photo: Wopat, CGS

Photo: Wilson, CVRWQCB

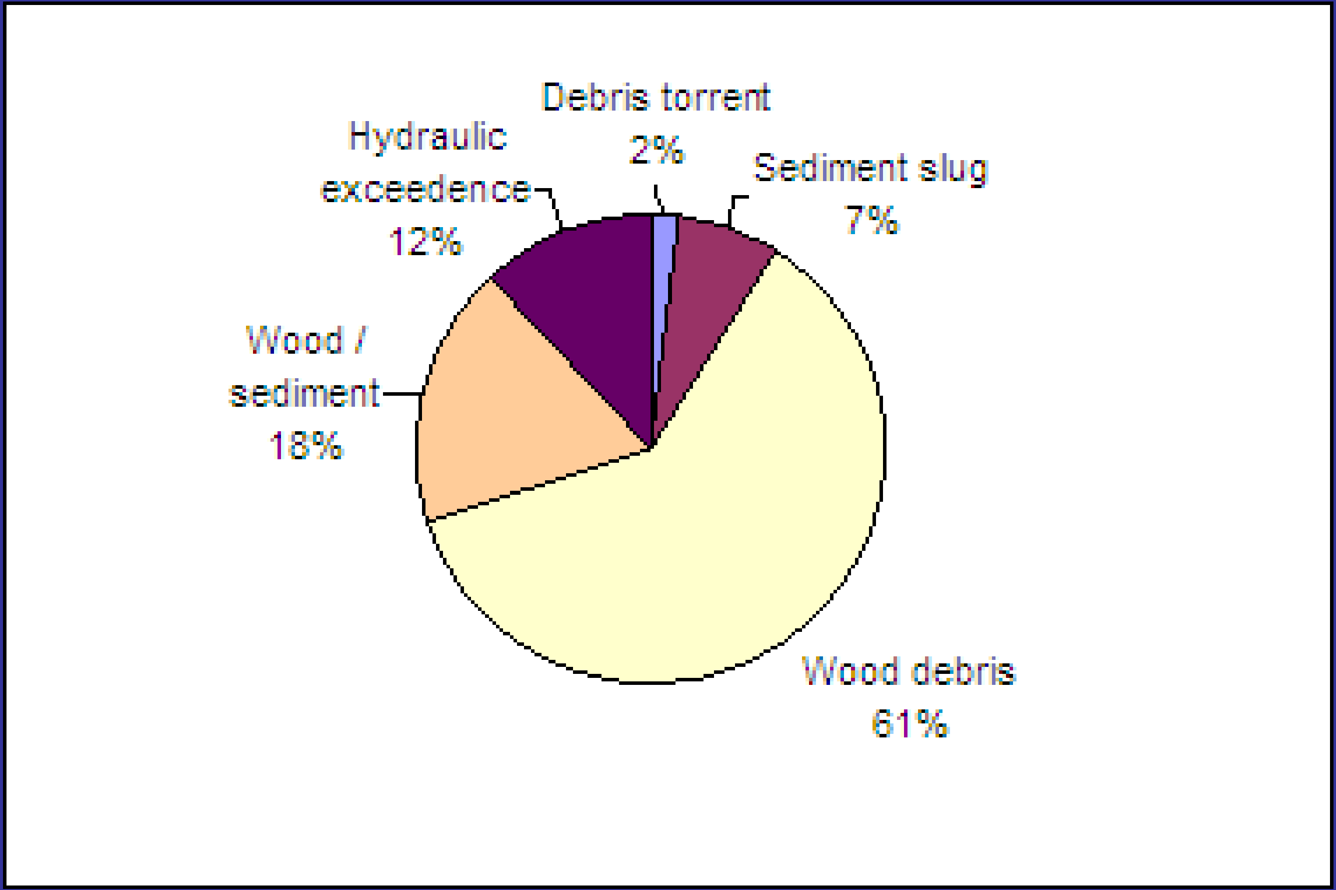

Upper
Sacramento River
Basin 2009
Photo: M. Boone,
CVRWQCB

Typical Woody Debris Lodging at the Culvert Inlet (Flanagan 2004)




JUN 5 2002

Failure Mechanisms for Culverts Along Forest Roads in Northwest CA Associated with Storms < 12 RI (Flanagan 2004)



n = 57


Redwood Creek Watershed,
Humboldt County
Photo: Pacific Watershed Associates

Humboldt County Crossing—Inlet Blocked

Photo: Scanlon, CAL FIRE


Lassen National Forest
Photo: Derrig, USFS

Stream Diversion from Blocked Culvert Inlet

Photo: Pacific Watershed Associates

Example of Stream Diversion Gullies — Redwood Creek Watershed

Photos: Bundros, RNSP (retired)

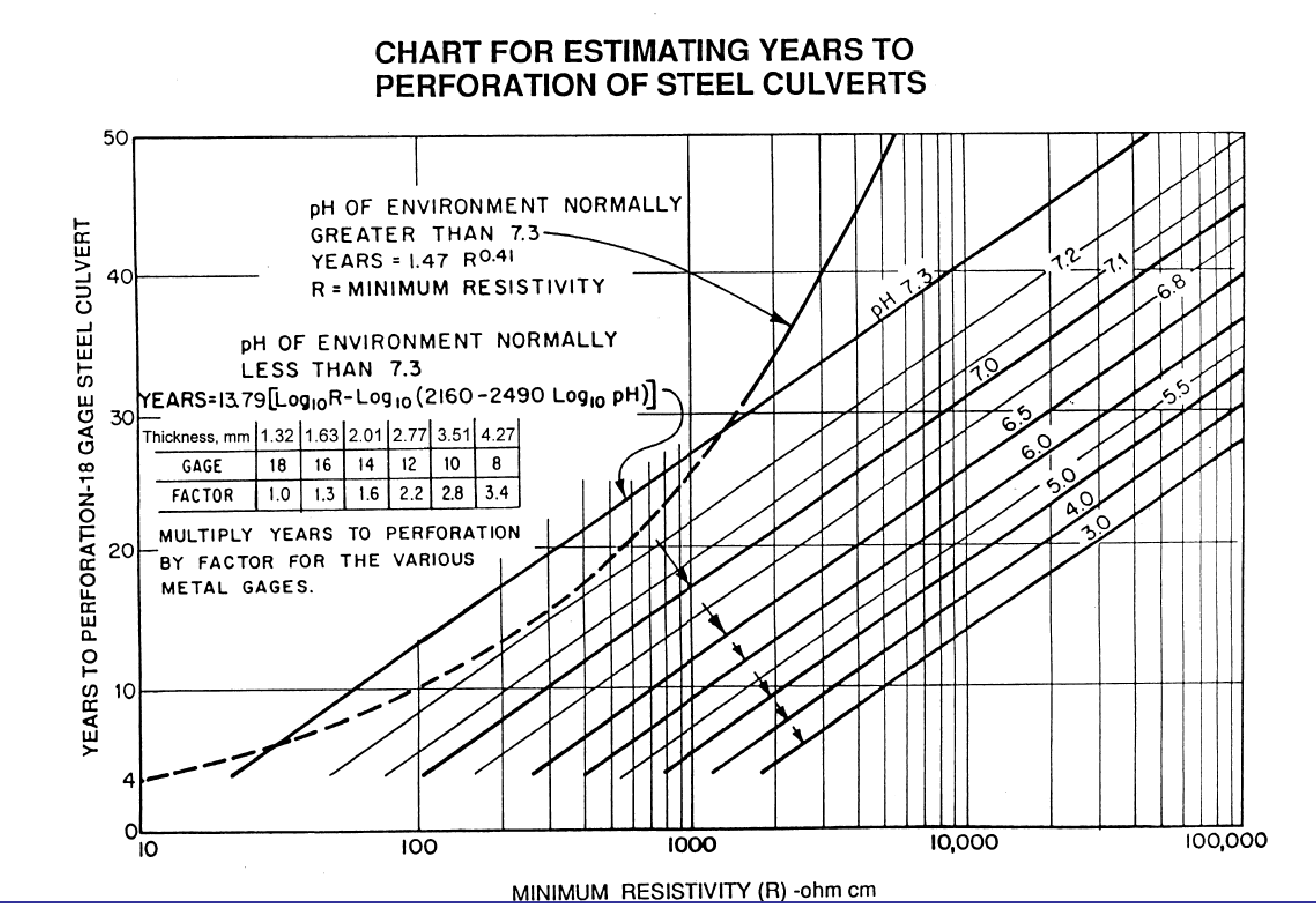
Installation Problems!

Lassen County Steel Culvert--culvert bands were probably not attached correctly

Corrosion Problems in Steel Pipes

ACCELERATED CORROSION and low SERVICE LIFE have been linked to: (1) water with a low pH, and (2) low soil resistivity of the site and backfill materials (relative quantity of soluble salts in the soil or water).

Clay and clay loam soils are more corrosive than sands and sandy loams



Caltrans 1999, California Test 643


Pipe Installed in western Mendocino
County 20-30 yrs ago

Culvert Crushing and Plugging

Elevated Outlet in Fish Stream

Cottaneva Creek, western Mendocino County
Pipe replaced with a bridge by MRC


Failed Open Bottom Arch Crossing—Tehama County
After first winter, 5 feet of scour at inlet, undermining footings by 2 feet

Failed Rock Ford Crossing—Undersized Rock


Soquel Creek Bridge
January 1982
Photo: Swanson, NRCS

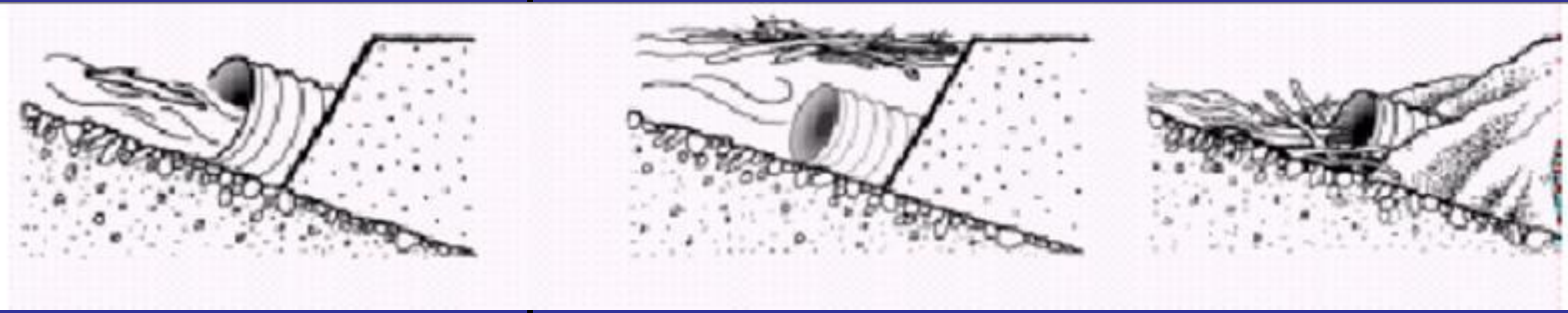
IV. Proper Design and Construction for New or Reconstructed Culverted Stream Crossings*

[In addition to Proper Design for 100 yr Flood Flow]

***If you Modify a Stream's Bed or Banks, you must <u>First</u> Notify the California Department of Fish and Wildlife and Obtain a <u>Streambed Alteration Agreement (or 1600 Agreement)</u>**

1. Culverts Should Not Pond Water

(Furniss and Others 1998)



HW/D < 1.0
(suggest 0.67)

GOOD

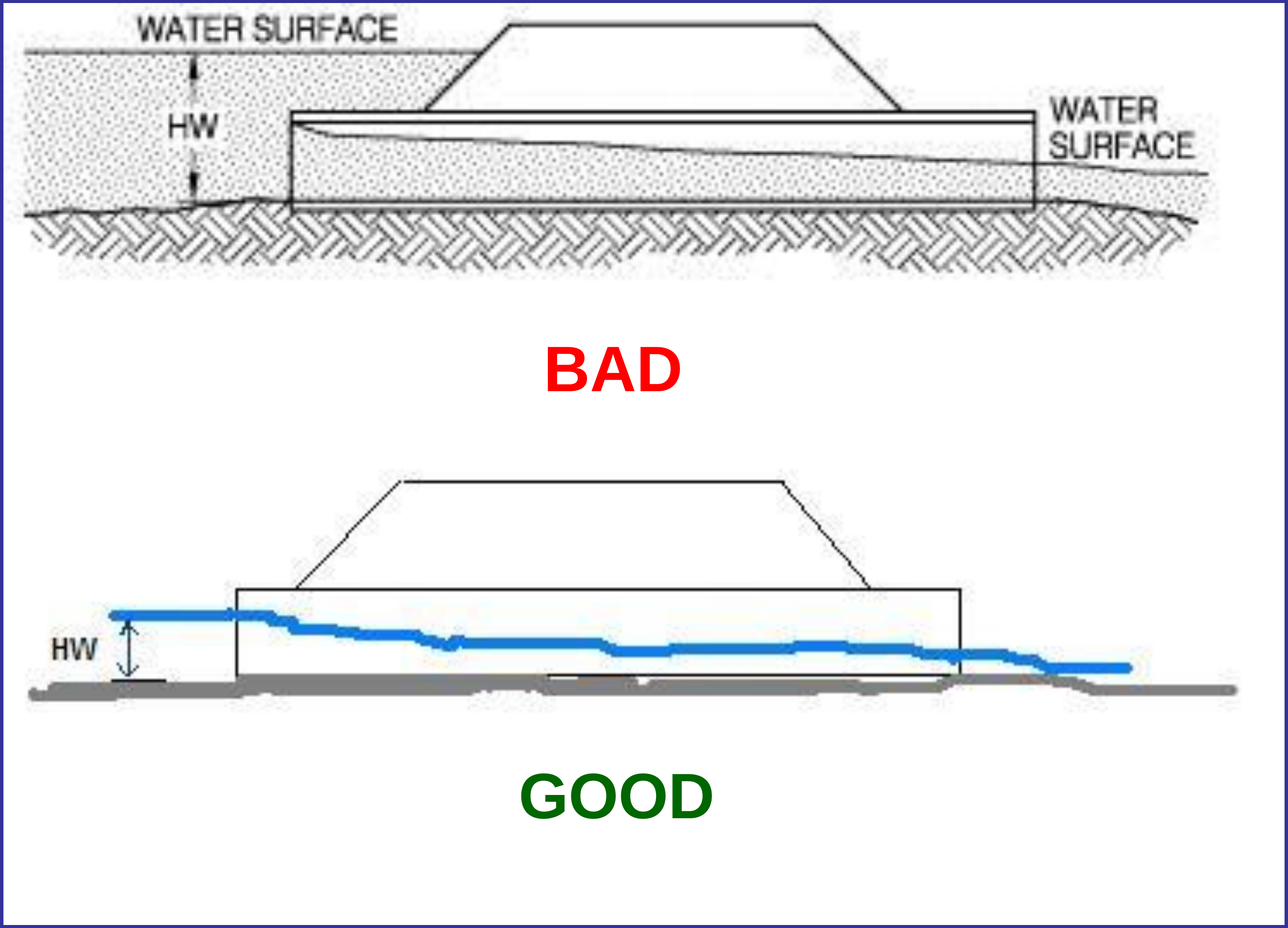
Reduced Plugging Hazard

HW/D > 1.0

HW/D > 1.0

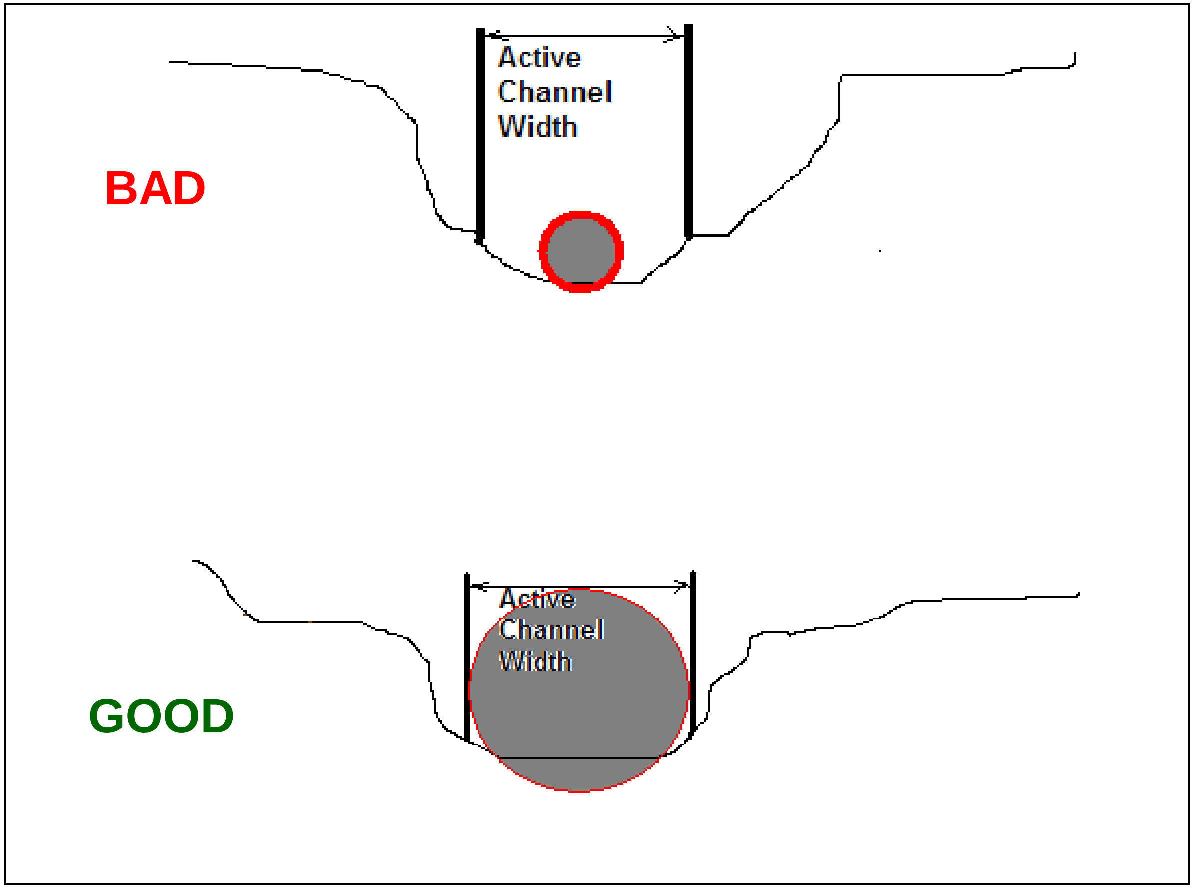
BAD

Culverts Should Not Pond Water



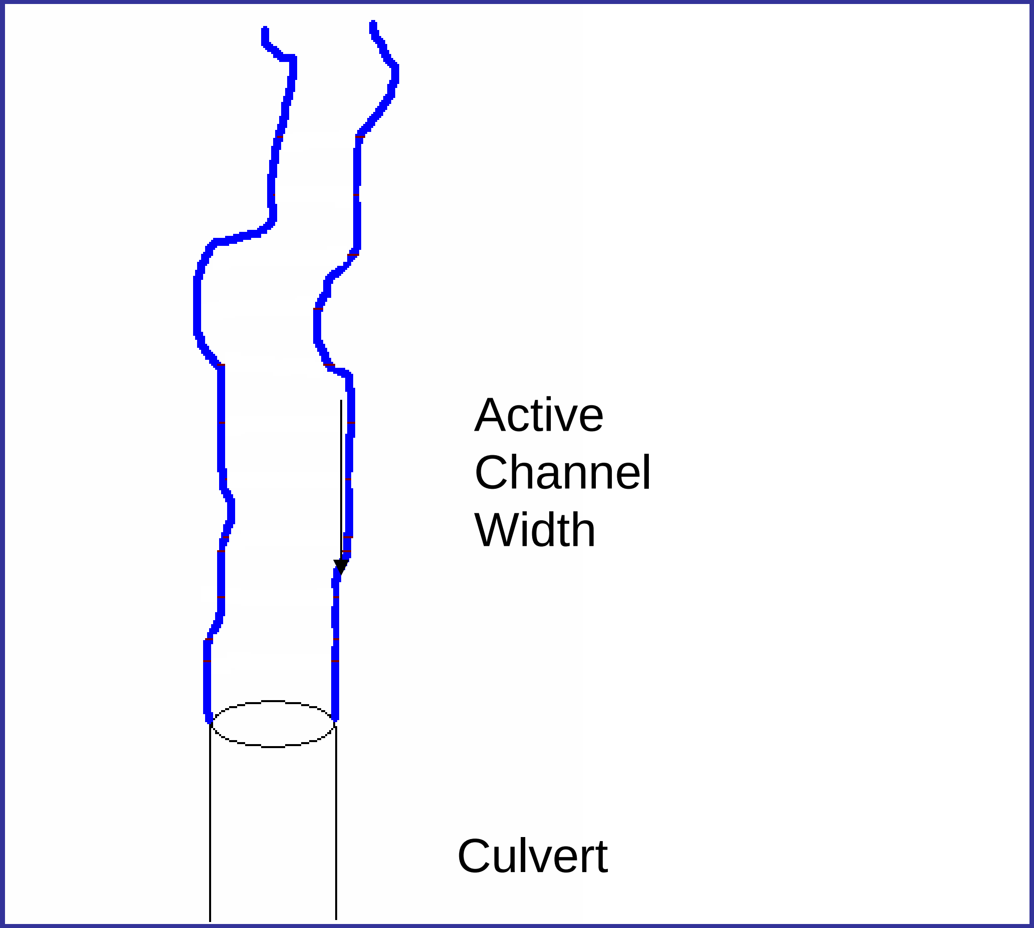
2. Utilize Culverts as Wide or Nearly as Wide as the Active Channel Width

Channel Width vs. Culvert Inlet Diameter

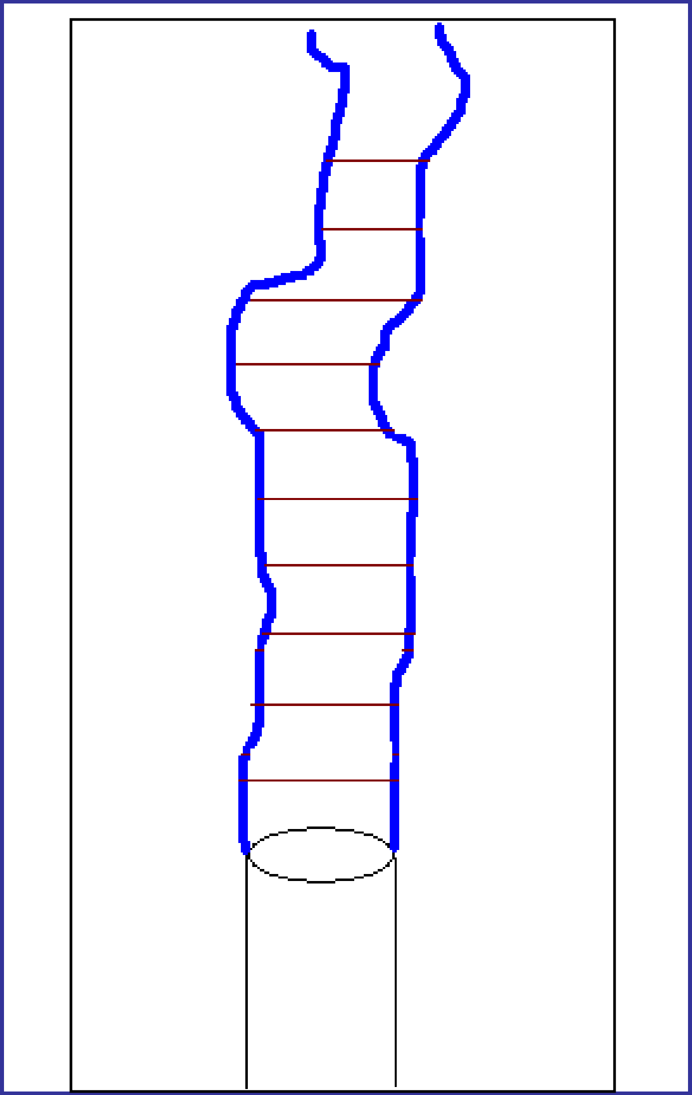


Small pipe in a wide channel = high risk of plugging by woody debris

Channel Width vs. Culvert Inlet Diameter



Determining Active Channel Width



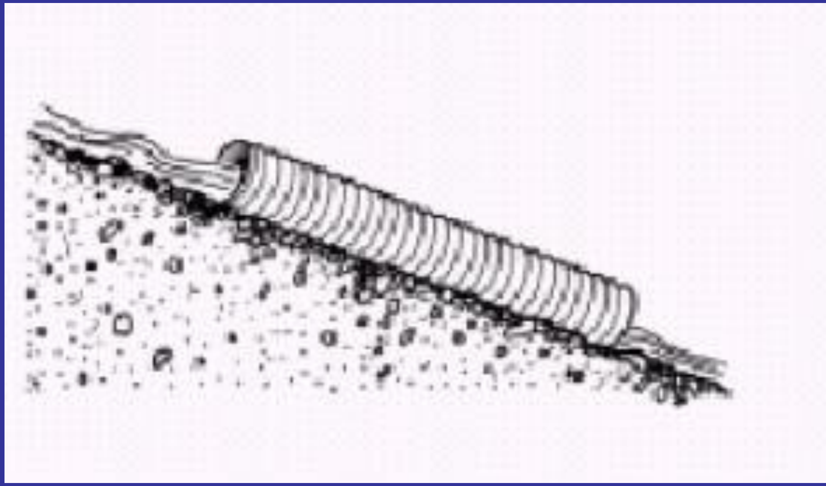
Make 10 systematic measurements of active channel width.

20 ft intervals, beginning 20 ft above the pipe inlet.

Calculate average width.

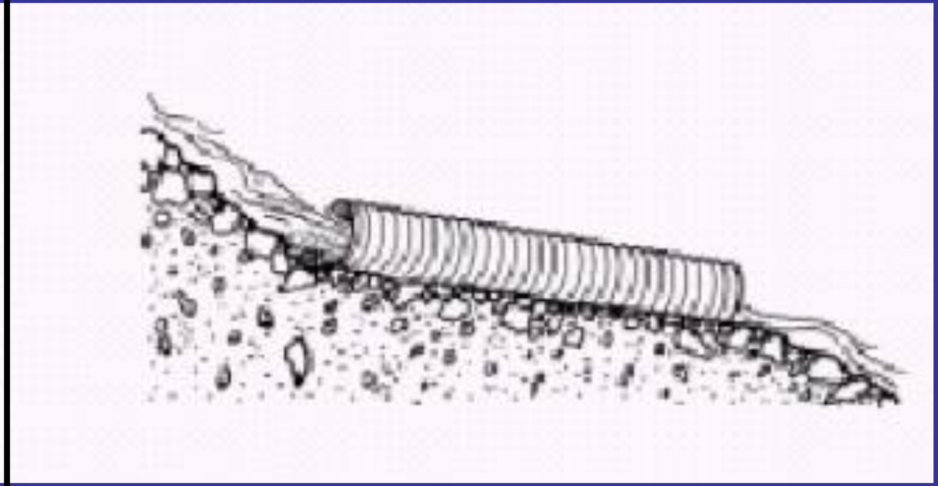
3. Culvert Should Maintain Channel Grade to Avoid Bedload Accumulation

(Furniss and Others 1998)



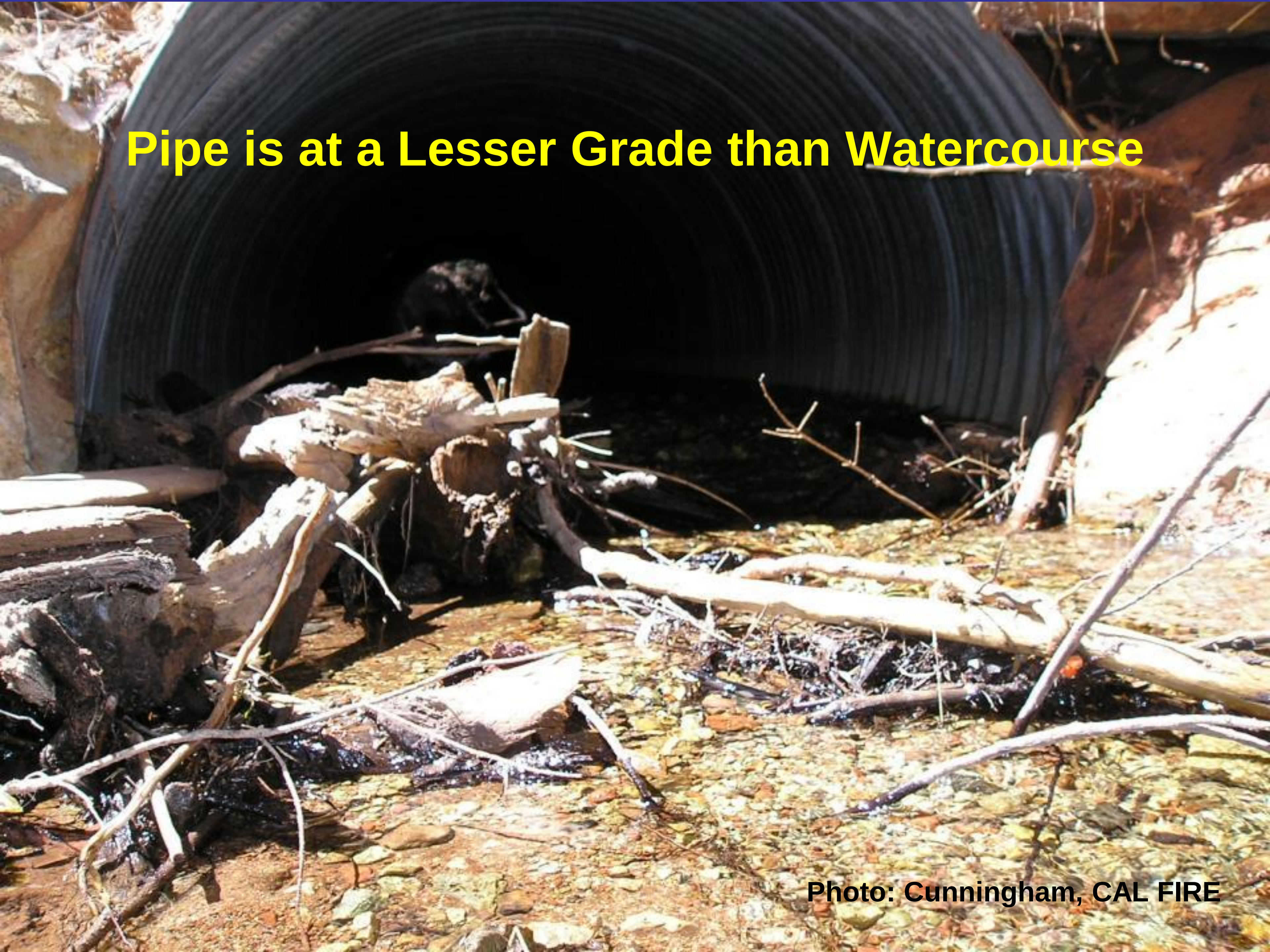
GOOD

Reduced Plugging Hazard

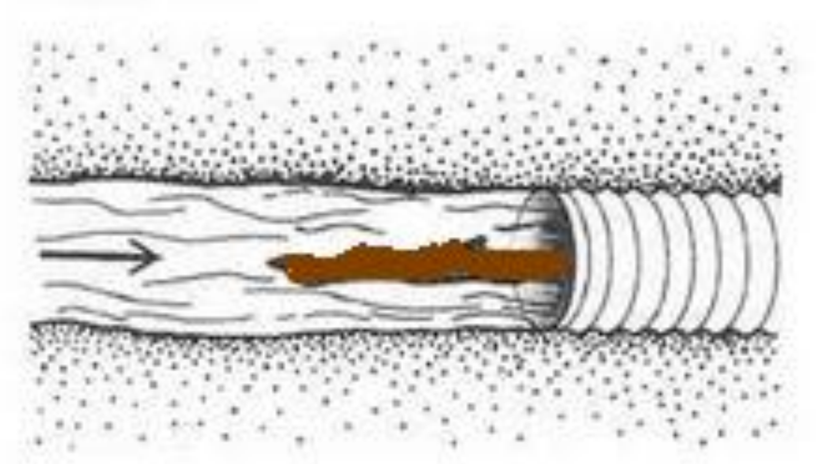


BAD

Pipe slopes of <3% may be prone to bedload sediment accumulation.


Pipe is at a Lesser Grade than Watercourse
Photo: Cunningham, CAL FIRE

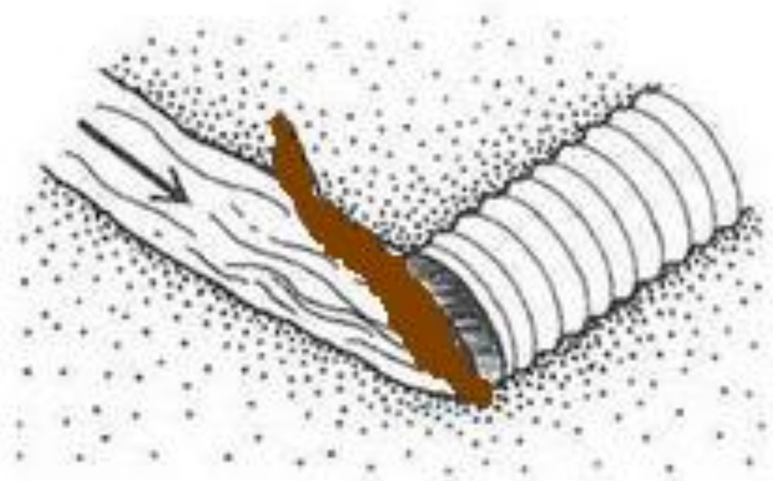
4. Culverts Should be Placed on the Same Alignment as Natural Stream Channel (Furniss and Others 1998)



GOOD

Reduced Plugging Hazard

BAD



Misaligned Crossing

After Construction

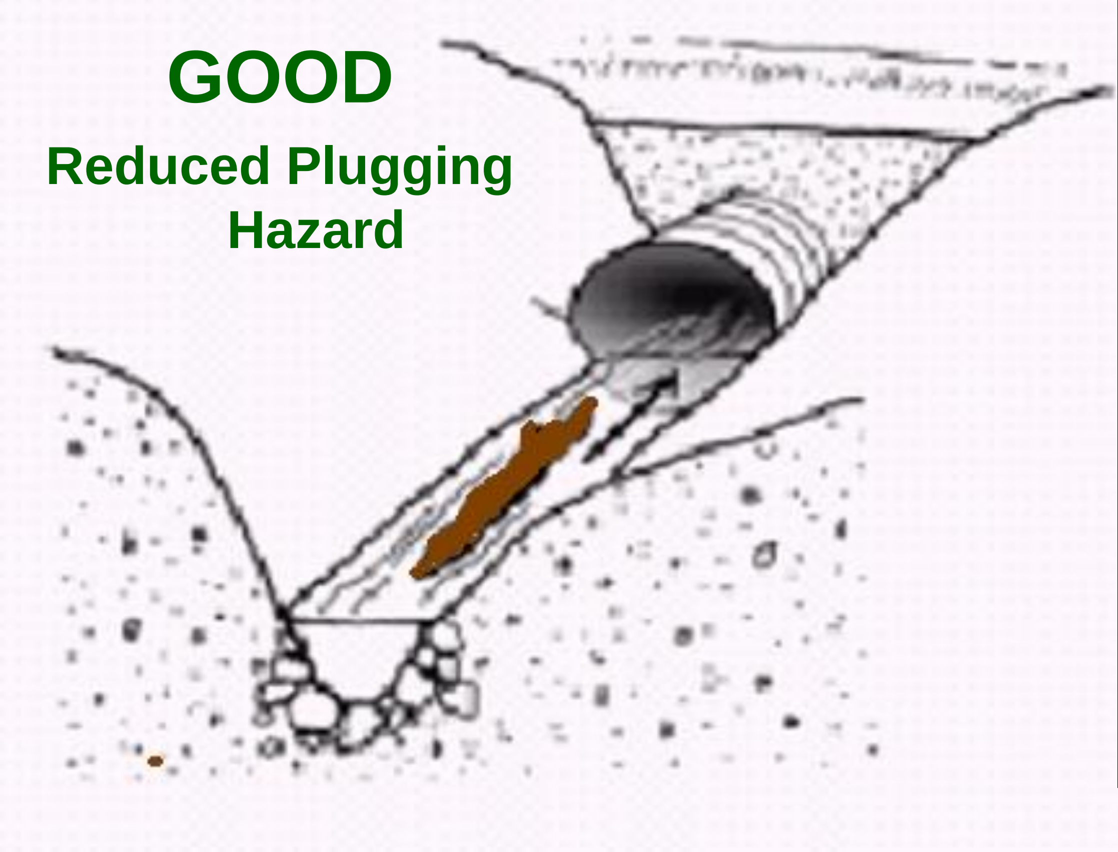
After One Winter

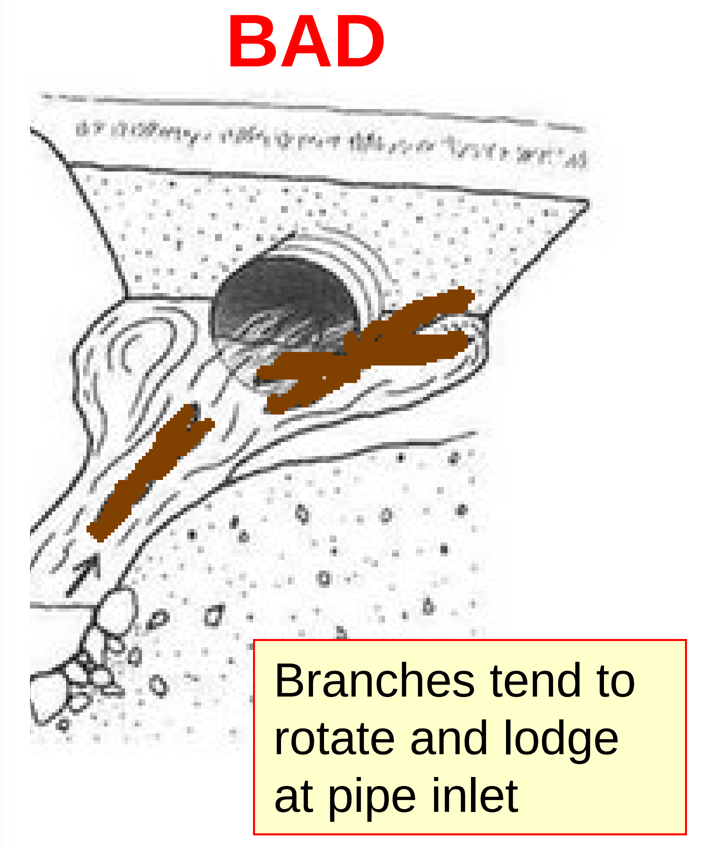
Misalignment can result in Road Fill/ Bank Erosion!

Photos: Harris, UCB (retired)

5. Culverts Should Not Create Wide Areas Near the Pipe Inlet

(Furniss and Others 1998)






Lassen National Forest

6. Single Large Pipe—<u>Not</u> Multiple Pipe Barrels

- **Installing multiple pipes is a bad strategy for passing woody debris.**

Use Single Large Pipe to Minimize Plugging Potential!

7. Critical Dip Installed to Prevent Diversion Potential—Required BOF Rule since 1990

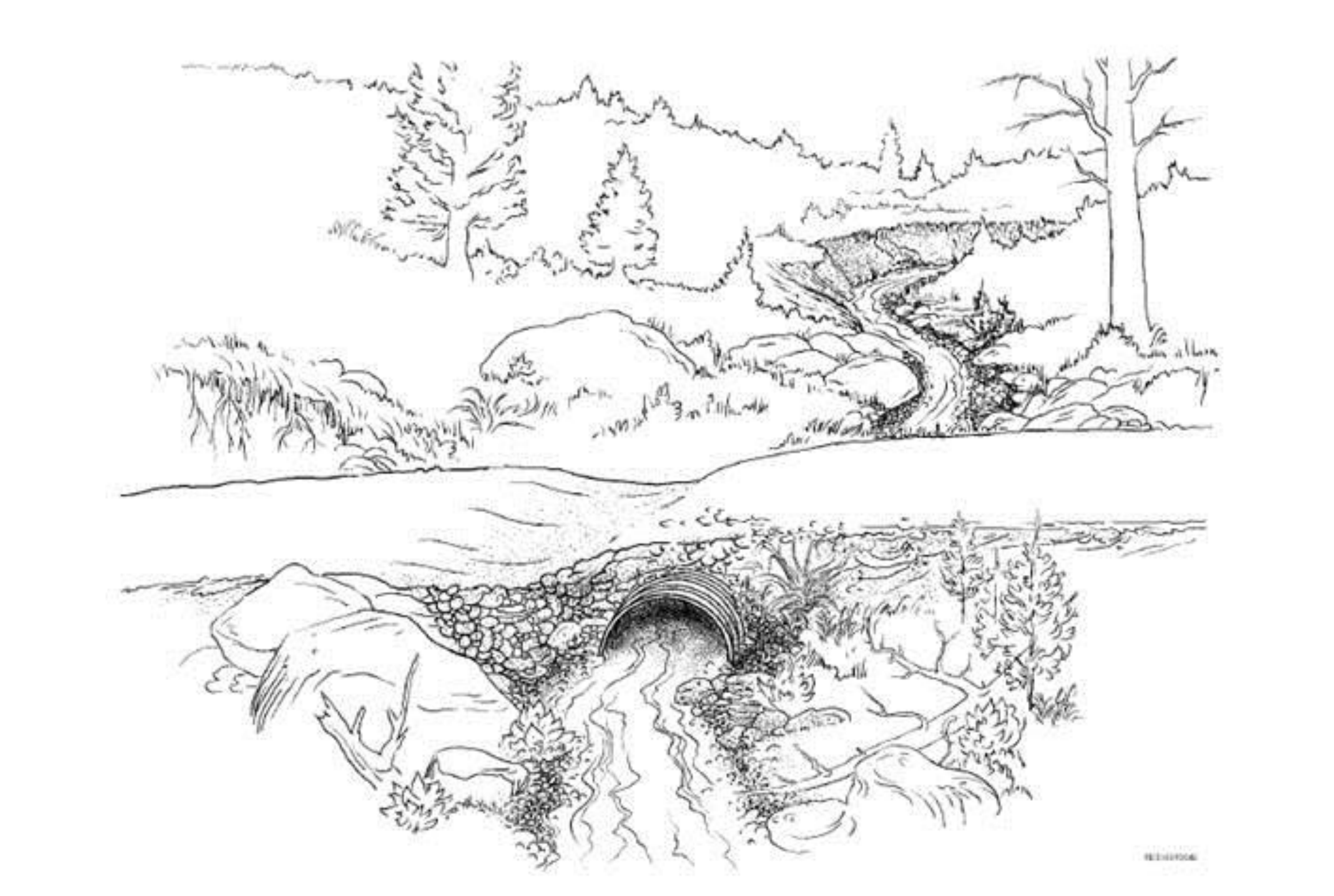


Image: Furniss et al. 1997

Goal: Keep water in its natural drainage!

Functioning Critical Dip

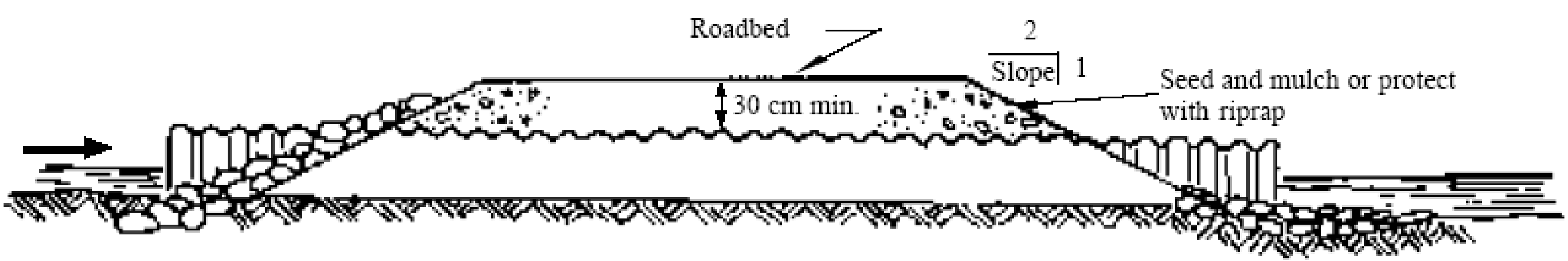
Image: B. Weaver, PWA

8. Culvert Installation--
Depth of Fill Over Culvert

- **Cover the top of metal pipes with fill to a depth of at least <u>12 inches</u> to prevent pipe crushing by log trucks (or at least 1/3 of pipe diameter for larger pipes).**
- **Minimum cover of 24 inches for concrete pipes.**

Typical Culvert Installation with a Projecting Inlet

(Keller and Sherar 2003)



- At least 12 inches of fill over pipe
- Rock armored inlet and outlet to prevent erosion of the fill

8. Culvert Installation (cont'd)

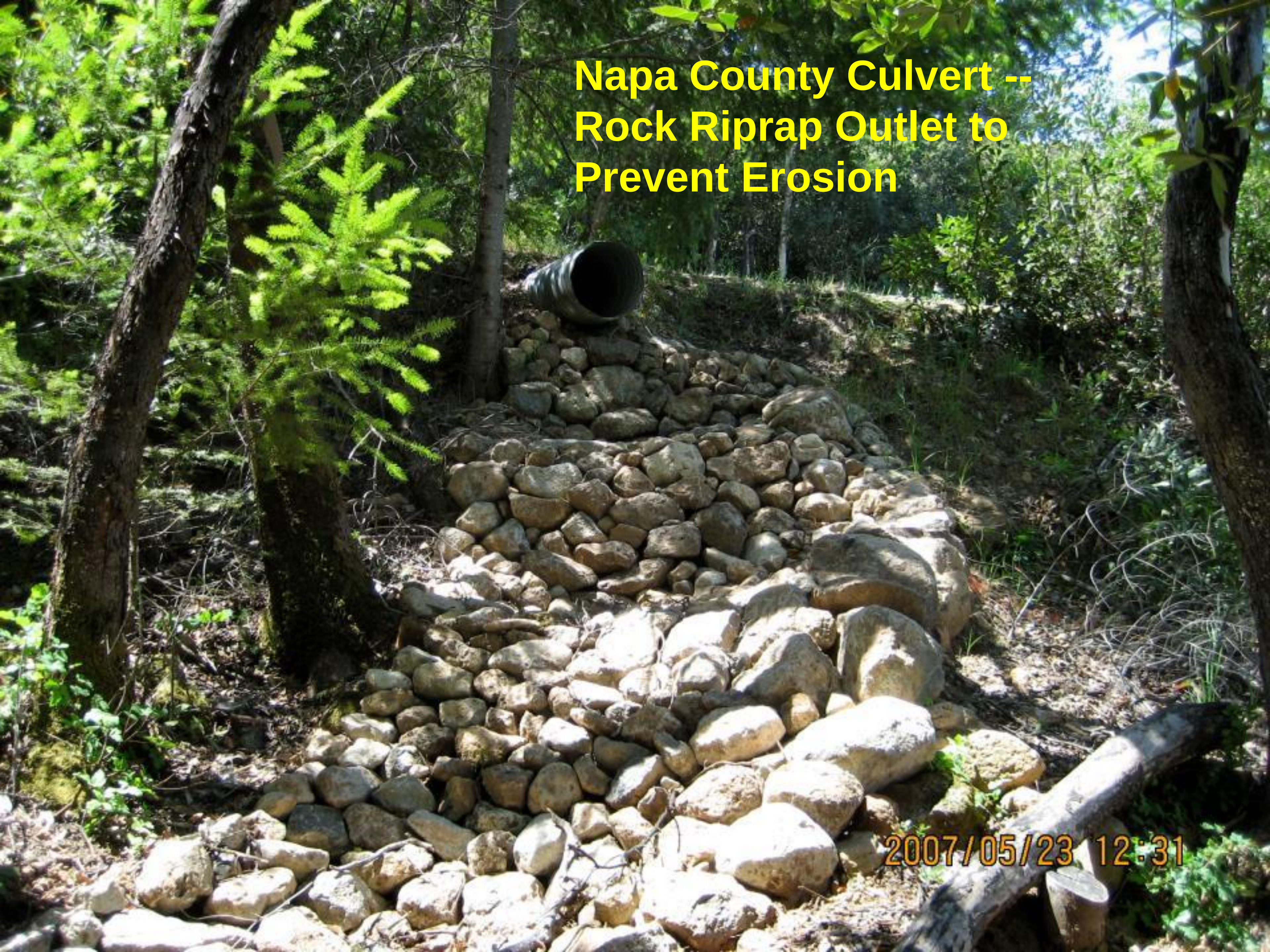
- Both ends should extend at least one foot beyond the edge of the fill material.
- Backfill material around the pipe should be moist, well-graded soil with up to 10% fines and free of rocks (avoid non-cohesive uniform fine sand).
- Backfill material should be well compacted (compacted in 6 inch lifts or layers).
- Both the culvert inlet and outlet should be armored with rock to protect against erosion.


6. 2. 2004


6. 2. 2004

48 inch Steel Culvert with Mitered Inlet, Rock Armoring

Lassen County


Napa County Culvert --
Rock Riprap Outlet to
Prevent Erosion
2007/05/23 12:31

8. Additional Techniques to Reduce Crossing Problems


Flared Metal End Section
Lassen National Forest
Photo: Derrig, USFS

Steel Culvert with Flared Metal End Section, Tahoe National Forest


Steel 84 inch Culvert with
Mitered Inlet—Mendocino Co.
11 16 '95


Mitered Pipe Inlet
Tehama County
NOV 8 2004


Miter too far away from fillslope; should be maximum of 6 inches—not 1-2 feet
Photo: Gordon Keller, USFS (retired); supplied by Don Lindsay (CGS)

Mitered Inlets

- **A mitered culvert is formed when the culvert is cut to conform with the plane of the embankment slope.**
- **Beveled inlets reduce wood blockage and plugging.**
- **Bevel the inlet edge to increase flow efficiency and reduce pipe size by <10%.**
- **"Mitered ends are much less likely to be plugged by ice, debris, or beaver" (*Wisconsin Transportation Bulletin*).**


Simple Fence Post
Trash Rack
Santa Cruz County
APR 27 200


Caltrans Welded Metal
Trash Rack for 12 ft CMP,
Highway 299 Trinity
County
Photo: Wopat, CGS

Costs of Additional Techniques

- Simple Trash Rack (Fence Posts)
  - <$50 (but requires abundant maintenance!)
- Bevel (Mitered) End Section
  - ~$50 - $100
- Flared Metal End Section
  - 36 inch pipe -- ~$500
  - 48 inch pipe -- ~$1,100
  - 60 inch pipe -- ~$2,000

State of California
The Resources Agency
Department of Forestry & Fire Protection

Designing Watercourse Crossings for Passage of 100-year Flood Flows, Wood, and Sediment

California Forestry Report No. 1

Peter Cafferata, Thomas Spittler, Michael Wopat, Greg Bundros, and Sam Flanagan

February 2004

Guidebook produced in 2004 to assist foresters in designing watercourse crossings and predicting flood flows

Available online at:

http://www.fire.ca.gov/resource_mgt/downloads/100yr32links.pdf

V. Post-Fire Impacts to Crossings

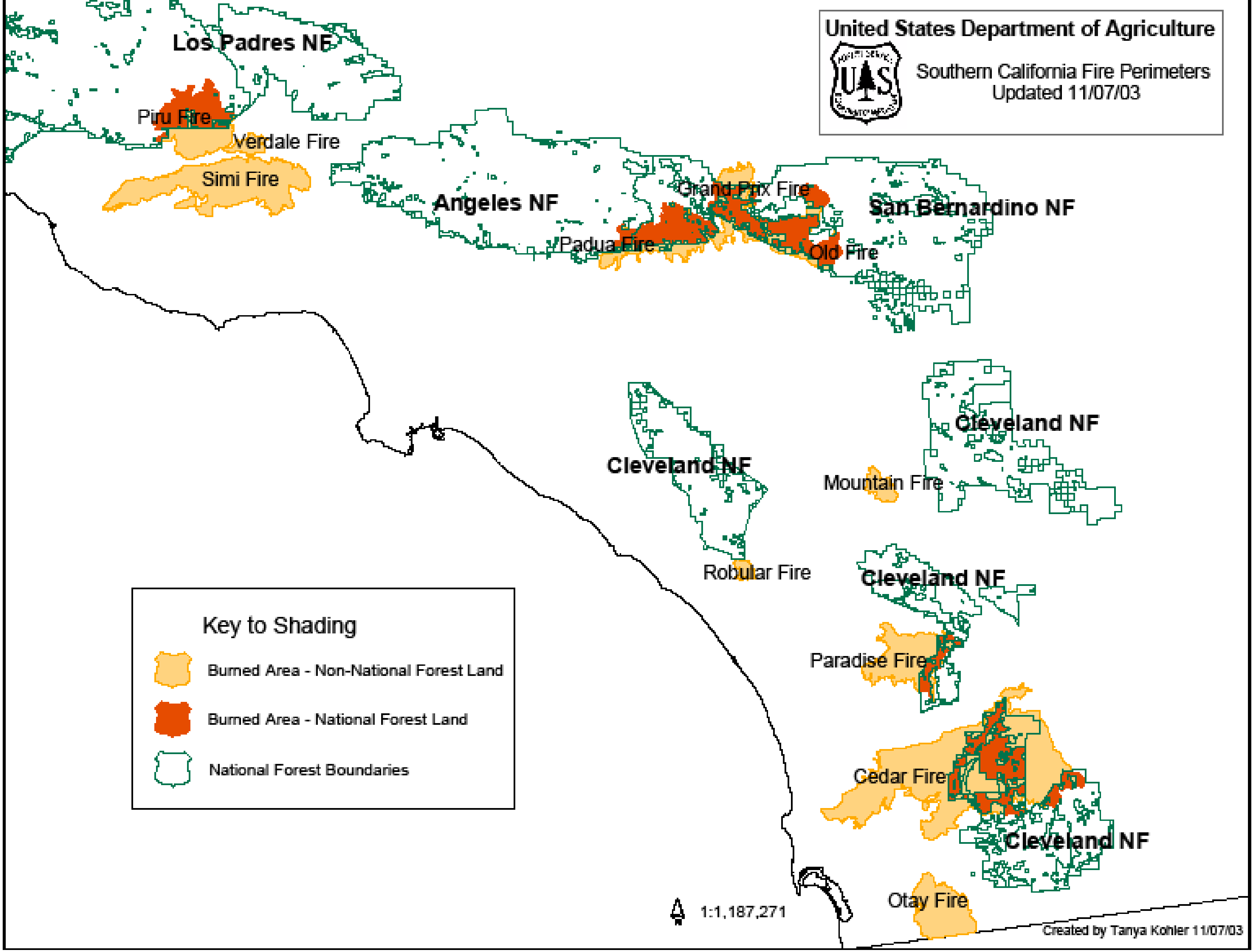
- Fire suppression impacts.

- Impacts associated with large winter storm events.

Paradise Fire 2003--Damaged Culvert

Inside Ditch and Culvert Inlet Filled in by Dozers during Suppression Efforts Willow Fire 2002, Tuolumne County


Butte Ligtening
Complex 2008


United States Department of Agriculture
Southern California Fire Perimeters
Updated 11/07/03
Los Padres NF
Piru Fire
Verdale Fire
Simi Fire
Angeles NF
Grand Prix Fire
San Bernardino NF
Padua Fire
Old Fire
Cleveland NF
Cleveland NF
Mountain Fire
Robular Fire
Cleveland NF
Paradise Fire
Cedar Fire
Cleveland NF
Otay Fire
Key to Shading
Burned Area - Non-National Forest Land
Burned Area - National Forest Land
National Forest Boundaries
1:1,187,271
Created by Tanya Kohler 11/07/03

Piru Fire 2003
Crossing Failed Crossing After 2.66 inch Storm

Peak stream flows commonly double first winter.

Sediment yields commonly increase 2 to 40 X depending on size of storms.

Photo: Hubbert 2007 -- TREATMENT EFFECTIVENESS MONITORING FOR SOUTHERN CALIFORNIA WILDFIRES

Piru Fire 2003
Channel Scour Following Winter Storms--Failure of a Check Dam below a 60 inch Pipe

Photo: Hubbert 2007

Old and Grand Prix Fires-- Failure of Rolling Dip and Over-side Drain Following October 2004 Storm Events

Photo: Hubbert 2007

Cedar Fire 2003

Failure of Over-side Drain--Storm Damage that that Occurred During 2nd Year Storms

Photo: Hubbert 2007

Practices to Reduce Post-Fire Impacts at Crossings

1. Improve channel capacity and remove plugging hazards.

2. Inventory crossings and upgrade crossings where needed.

3. Install trash racks (must be maintained).

4. Maintain/monitor crossings during the winter, especially during and immediately after large storms.

Channel Clearance on Arrowhead Fire, 2002, San Bernardino Co.

Old-Grand Prix Fires
San Bernardino County 2003

Old-Grand Prix Fires 2003

Old-Grand Prix Fires 2003

Culverts with High Plugging Potential Inventoried; Manter Fire 2000, Sequoia NF

Marek Fire 2008, Los Angeles County

Old and Grand Prix Fires 2003--
Culvert Before Being Cleaned Out

Photo: Hubbert 2007

Piru Fire 2003
12 inch Culvert Replaced with a 48 inch Pipe—note Rock Armoring at Inlet

Paradise Fire 2003—Repaired Culvert

Padua Fire 2003
Debris Deflector Trash Rack in front of Culvert Inlet

Photo: Hubbert 2007

Marek Fire 2008, Los Angeles County

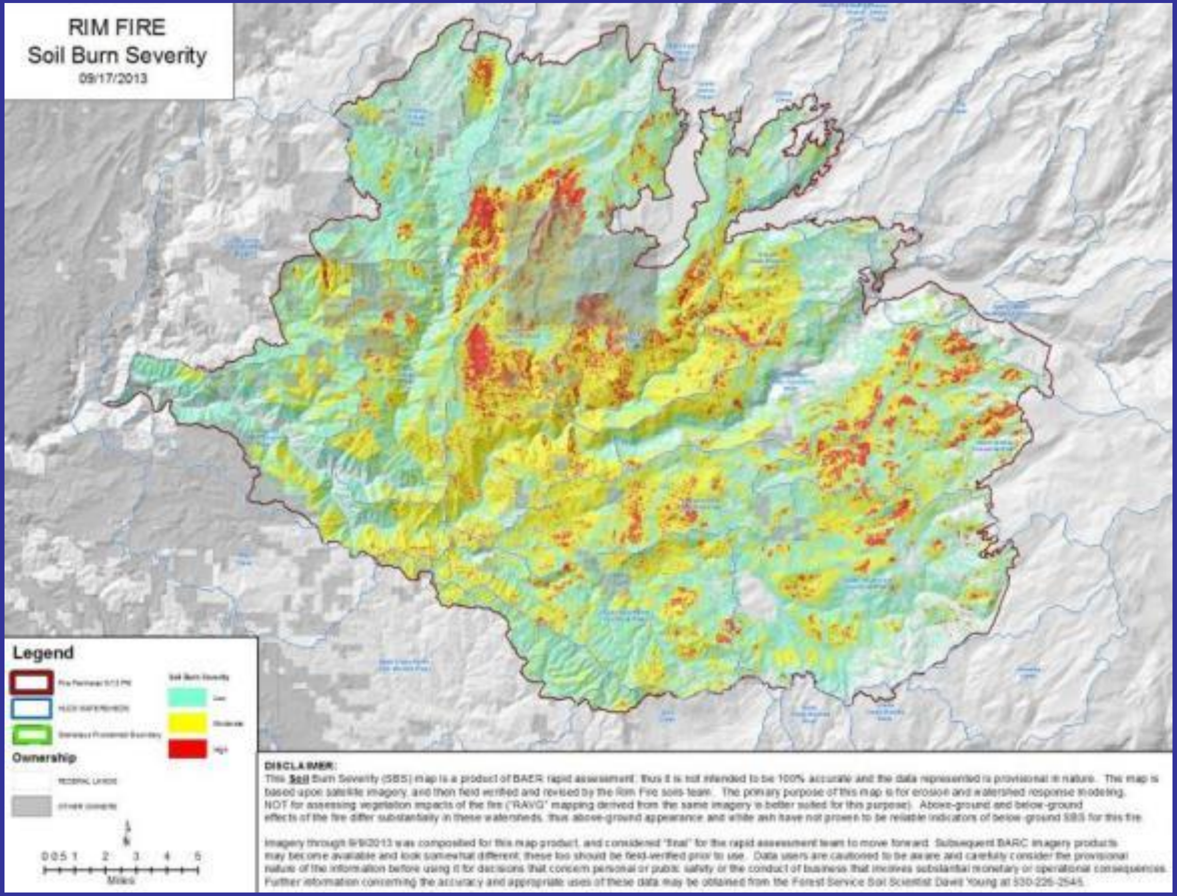
Steel Rail Debris Rack

Maintaining Crossings During the Winter Period

Photos: Furniss, USFS

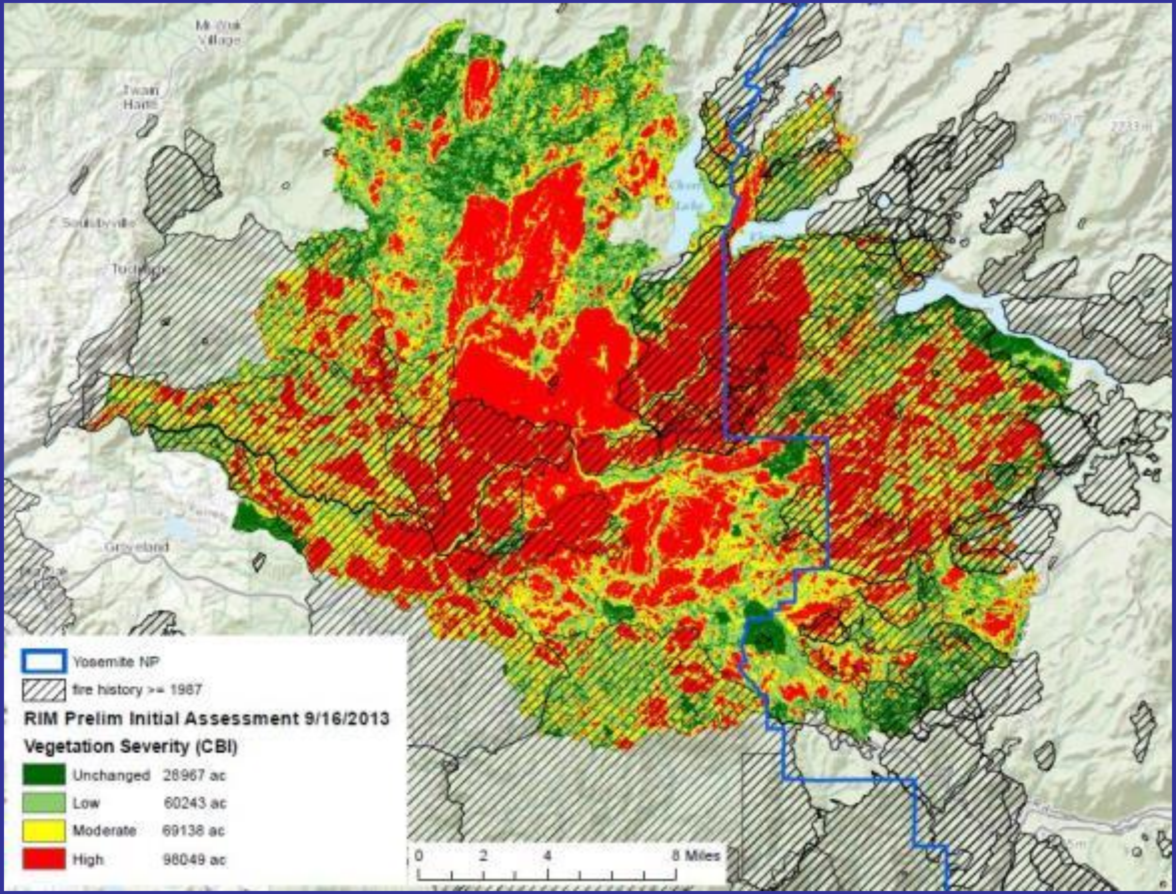

EXAMPLE FOR POST-FIRE
IMPACTS TO CROSSINGS
2013 Rim Fire

Soil Burn Severity Map



56% of the fire is either unburned or received a low-severity burn,
37% sustained a burn of a moderate severity, and
7% burned at high severity

Vegetation Burn Severity Map



35% unchanged or low-severity,
27% moderate severity, and
38% high severity

The Confluence of the Tuolumne and Clavey Rivers before and after the Rim Fire

Photos by Joshua Viers (left) and Andy Bell, UC Davis Center for Watershed Sciences

Tuolumne River near Lumsden Campground

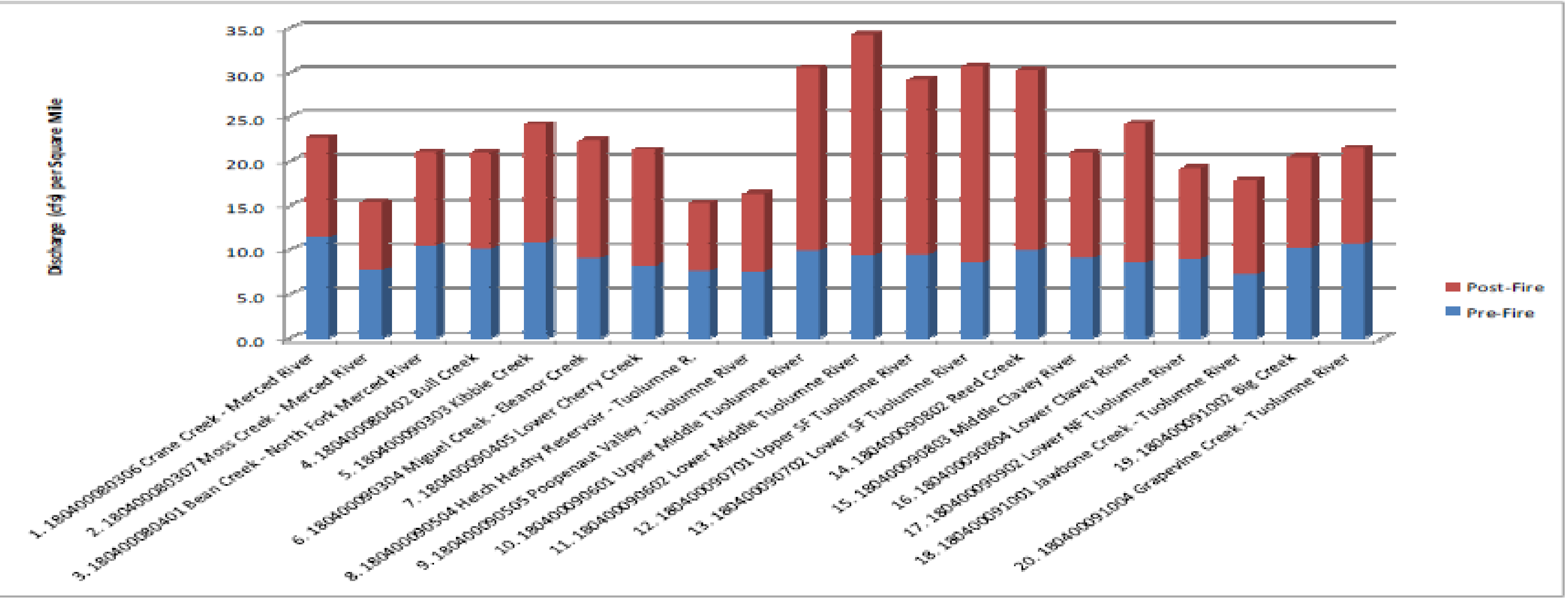
Photo: USFS BAER Report

Old Warning Sign Placed on Public Road

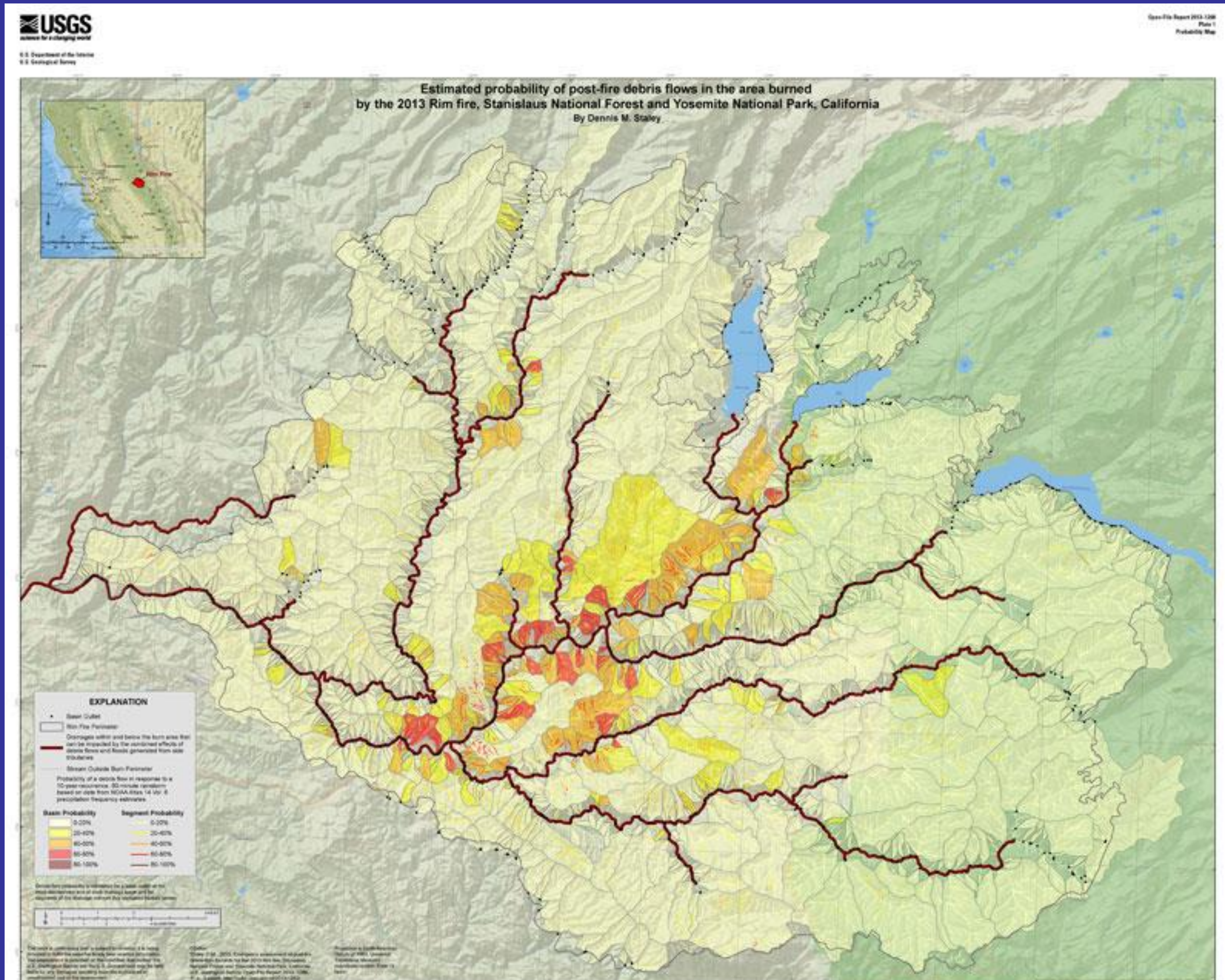
2013 Rim Fire

- **257,314 acres burned in the Tuolumne River Canyon.**
- **High soil burn severity areas: Landscape responses to a $Q_{1.5}$ (or a flow with a recurrence interval of 1.5 years) flow as if it were a *10-year event*.**
- **Moderate soil burn severity areas: Landscape responses to a $Q_{1.5}$ flow as if it were a *5-year event*.**
- **Low soil burn severity areas: Landscape responses to a $Q_{1.5}$ flow as if it were a *1.75-year event*.**
- **Predicted post-fire peak flows for sub-watersheds using combined (pro-rated) values show an increase of about 1 to 5 times pre-fire values.**

Pre-Fire and Post-Fire Streamflow Estimates (per square mile) for Selected Subwatersheds



Estimated Probability of Post-Fire Debris Flows



The National Weather Service has worked with the CA-NV River Forecast Center and the USGS to develop **precipitation thresholds that will likely trigger debris flows, rock slides, ash movement, and flash floods** within the Rim Fire.

These are the initial values we will be utilizing going into this winter:

0.2" in 15 minutes
0.3" in 30 minutes
0.5" in 1 hour
0.9" in 3 hours
1.4" in 6 hours

Within the Rim Fire, the post-fire watershed threat should be reduced measurably after 3-5 years.

Inventorying Crossings as Part of BAER Team Work

Debris flow prone channel, with a concrete armored fill

Undersized but relatively <u>low</u> risk of failure

Pipe is half the width of active channel

No diversion potential, but <u>high risk crossing</u>

The watershed above has debris slide slopes in the headwaters, and likely has an inner gorge at the toe of an earth flow

Culvert at <u>high risk</u> of failure along a chip-sealed road

<u>Recommendation</u>: Install an additional CMP above the existing pipe

Poorly Aligned Class III Watercourse Crossing; Upgrade Work Required

Burned Out Plastic Culvert, Rim Fire

Burned Out Plastic Culvert, Rim Fire

Rim Fire Culvert—Buried with a Damaged Inlet

Upgrading a Culvert Impacted by the Rim Fire

Installing a Rock Ford Crossing

Building a Rolling Dip on a Forest Road

A total of ~ 290 miles of fireline and roads were found to require repair work

VI. Summary (Take Home Messages)

- Stream crossings are high risk locations for sediment entry and road travel limitations (20% have problems).

- Crossings need to be built correctly for large flood flows (100-yr return interval), as well as sediment and wood passage.

- Numerous types of crossings are available (no one “right answer”)—pick the type that fits the features of the landscape, the maintenance that will be possible, and the legal requirements (e.g., fish passage).

VI. Summary (Take Home Messages)

- Numerous problems can occur at all types of crossings, indicating that frequent monitoring observations are needed, with upgrading performed as required.
- Simple guidelines are available for culverted crossings to ensure that new or reconstructed crossings have reduced risk of failure and WQ impact.
- After large, intense wildfire, crossing need to be inventoried to determine what upgrade work is required.
- Crossings must be maintained over time—you cannot install them and expect them to function properly without proper upkeep—clean/maintain on a regular basis and during/after large storm events.

VII. Stream Crossing References

- Cafferata and others 2004 -- Designing Watercourse Crossings for Passage of 100-year Flood Flows, Wood, and Sediment
- Clarkin and others 2006 -- Low-Water Crossings: Geomorphic, Biological, and Engineering Design Considerations
- Flanagan 2004 – Woody Debris transport Through Low-Order Stream Channels of northwest California—Implications for Road-Stream Crossing Failure
- Flanagan and others 1998 -- Methods for Inventory and Environmental Risk Assessment of Road Drainage Crossings
- Flanagan and Furniss 1997 -- Field Indicators of Inlet Controlled Road Stream Crossing Capacity
- Furniss and others 1998 -- Response of Road Stream Crossings to Large Flood Events in Washington, Oregon, and Northern California
- Furniss et al. 1997– Diversion Potential at Road-Stream Crossings
- Keller and Sherar 2003, Chapter 8 -- Culvert Use, Installation, and Sizing
- Merrill and Casaday 2001—BMPs for Culvert Replacement
- Weaver and Hagans 1994—Forest and Ranch Roads (Chapter V-Drainage, VI-Construction)
- ODF 2002 -- Determining the 50-year Peak Flow and Stream Crossing Structure Size for New and Replacement Crossings