Culverts and Low-Water Crossings: Tools, Techniques, and Considerations for Aquatic Organism Passage

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Background Material

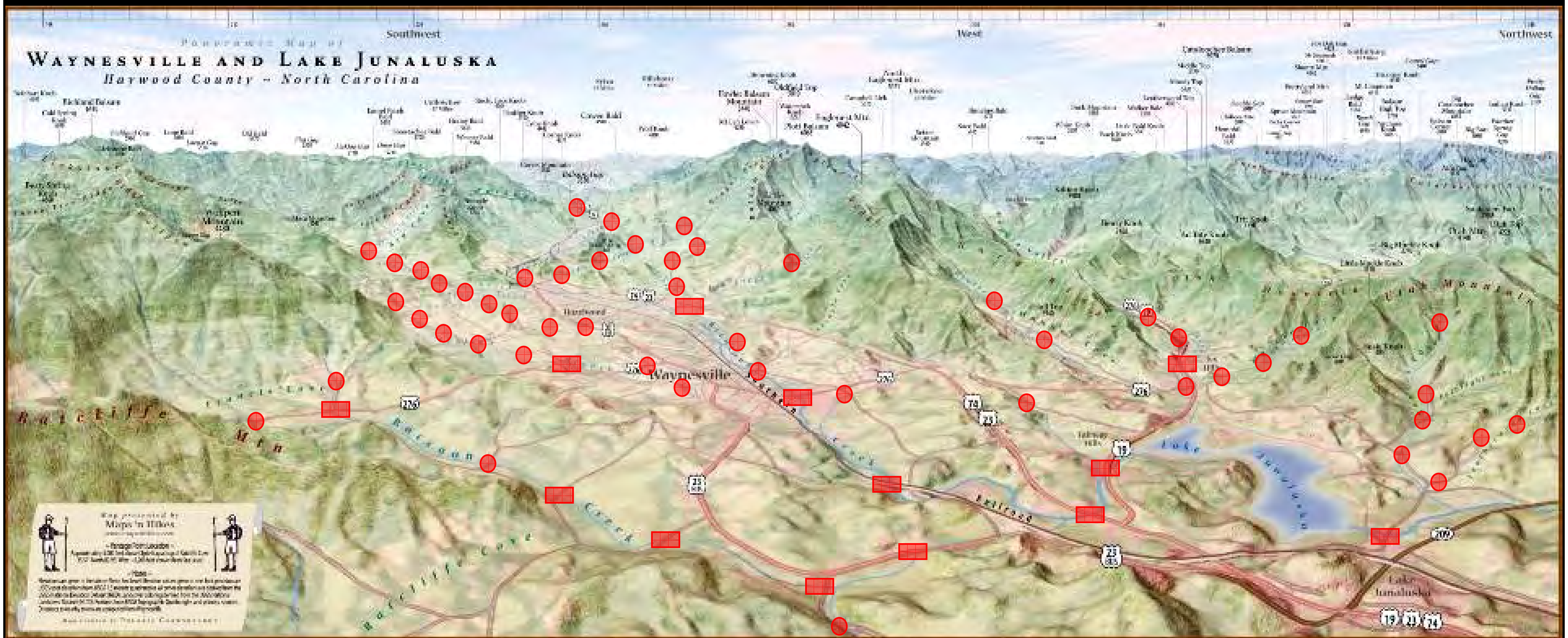
- NRCS Biologist National Fish and Wildlife Net Training - 10/04/2007
  - Scott Jackson, UMASS (Passage Ecology)
  - Kozmo Bates, AquaKoz and WDFW (Culverts and Tidegates)
  - Dick Quinn, FWS (Fish Ladders)
  - Archived at NRCS Biologist SharePoint

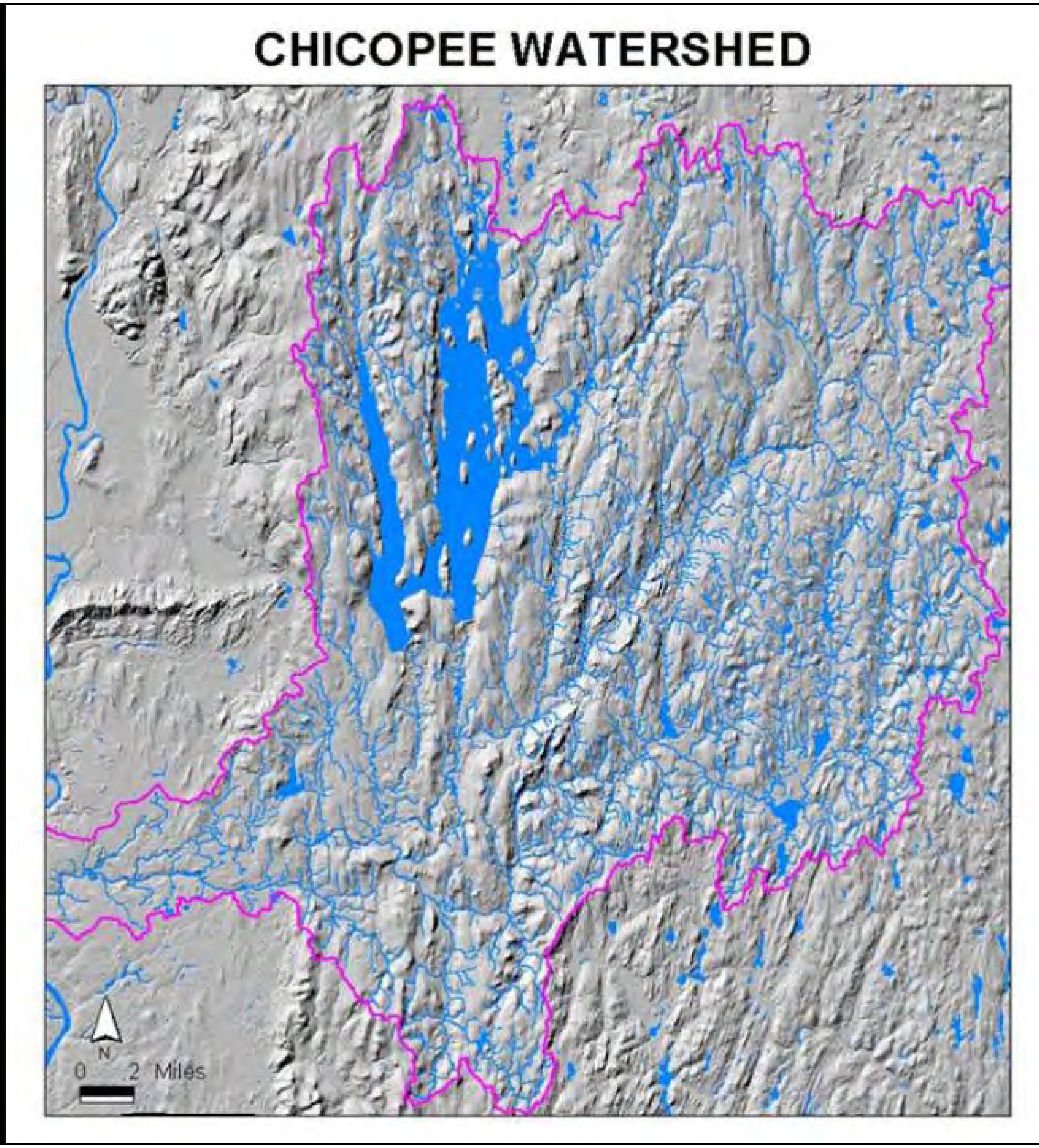
- ENTSC NetMeeting - 03/26/2008
  - Aquatic Organism Passage: An Overview of Ecology, Analyses, and Tools
  - Archived at ENTSC website under "East NTSC Workshops and Net Meetings"

Road-Stream Crossings

Culverts

Low-water Crossings

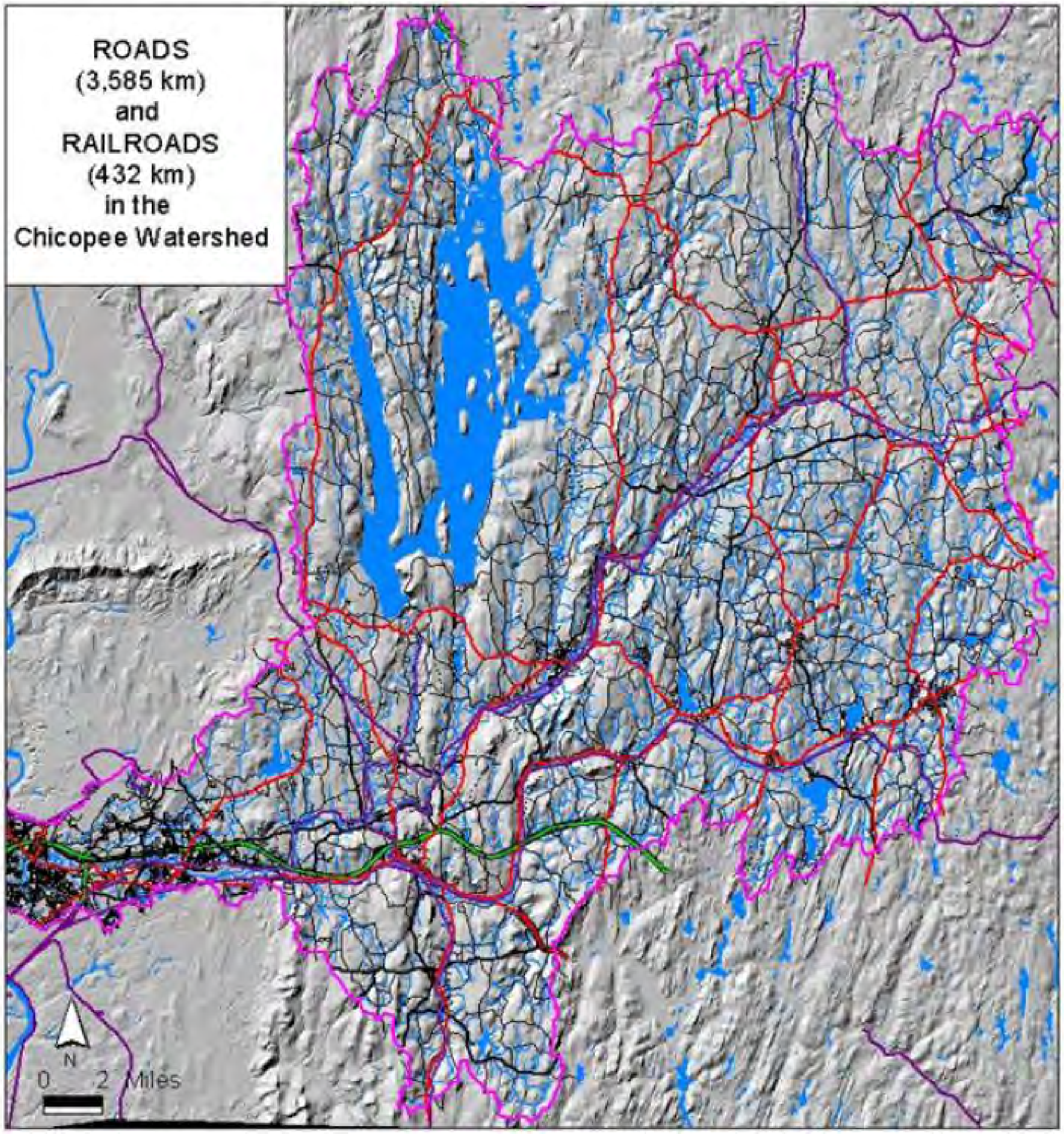

Southwest
West
Northwest
Waynesville and Lake Junaluska
Haywood County ~ North Carolina
Waynesville
Lake Junaluska
Map presented by
Maps 'n Hikes



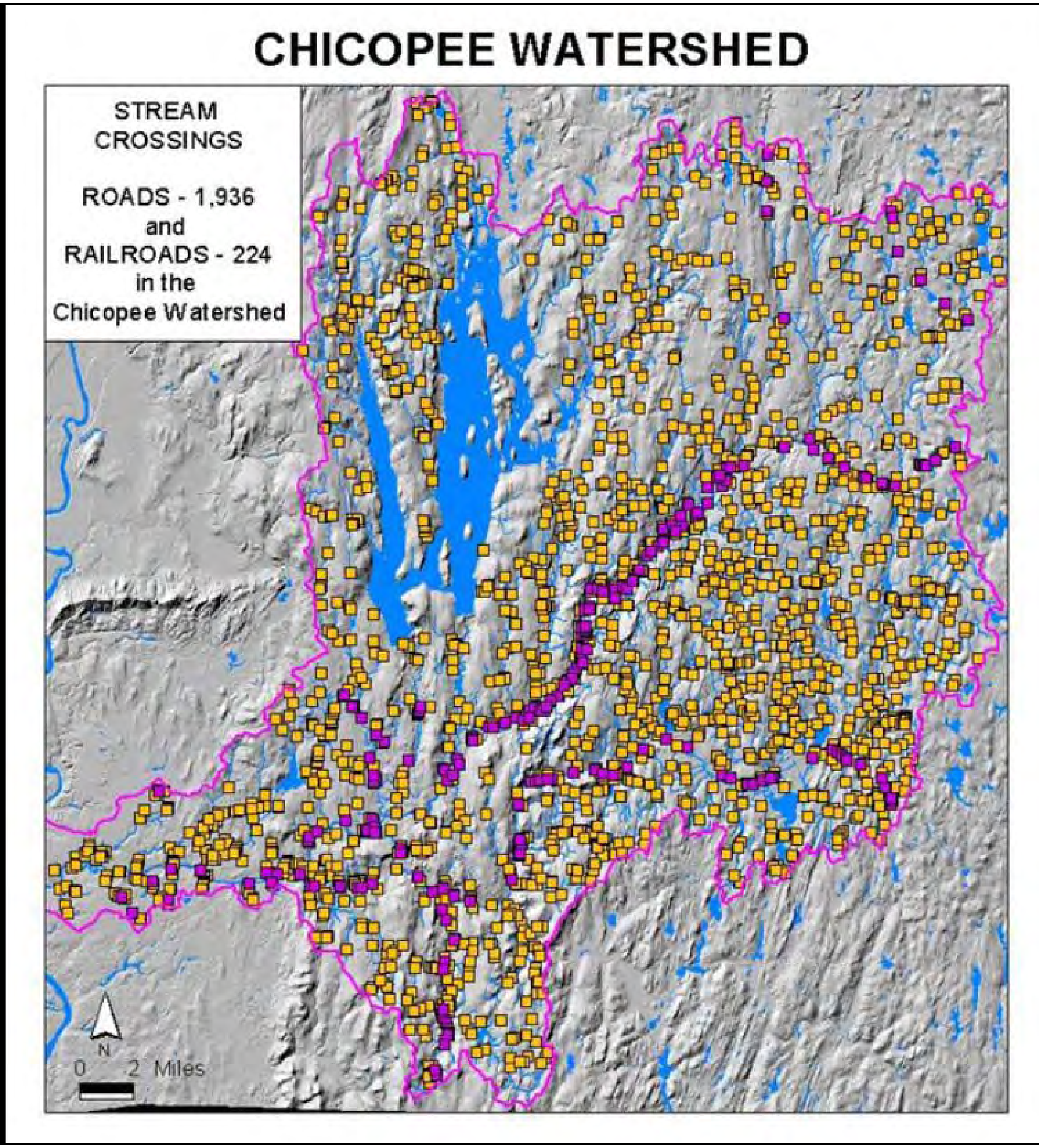
721 mi^2

Graphic: MA Riverways Prgm

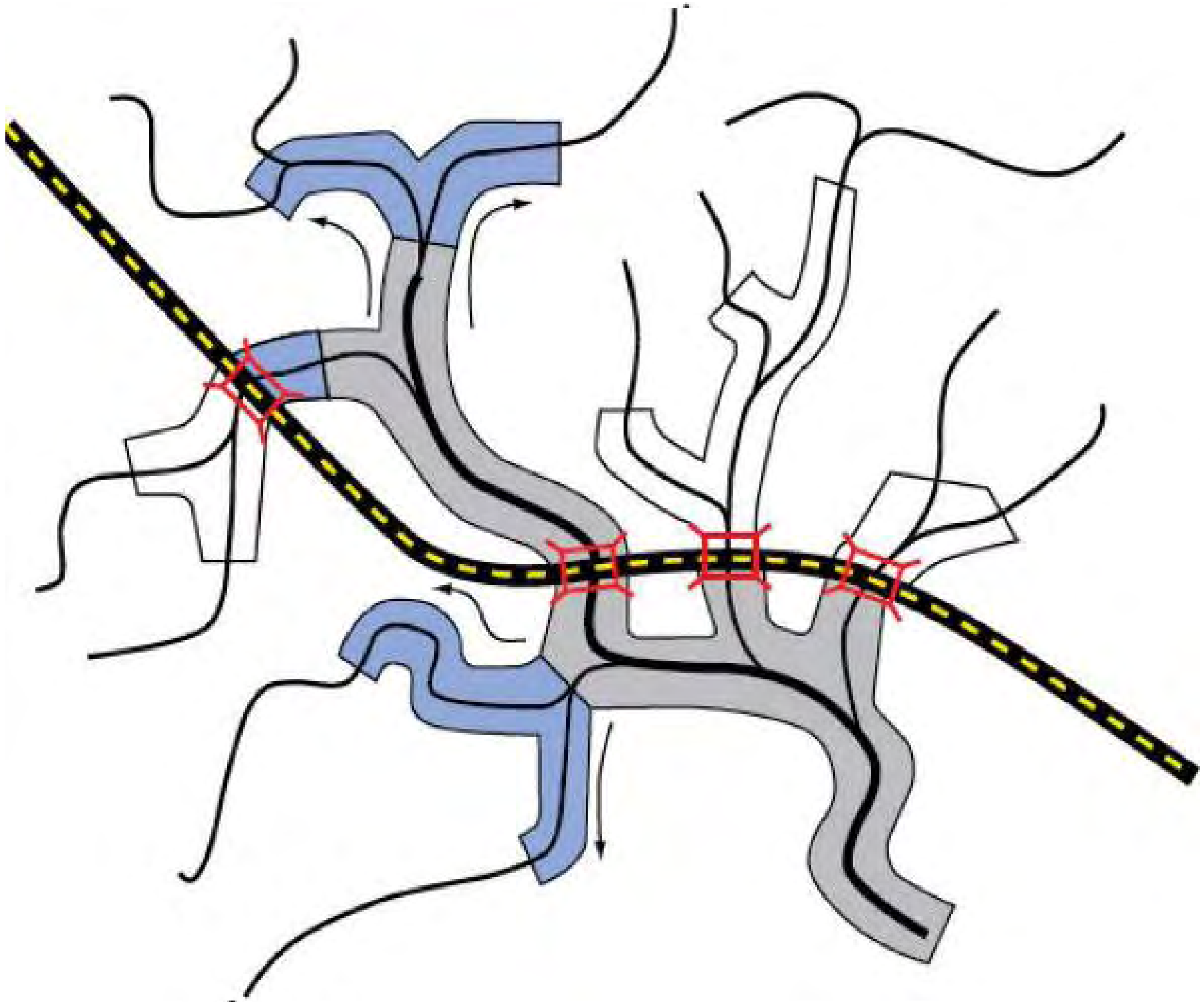
CHICOPEE WATERSHED



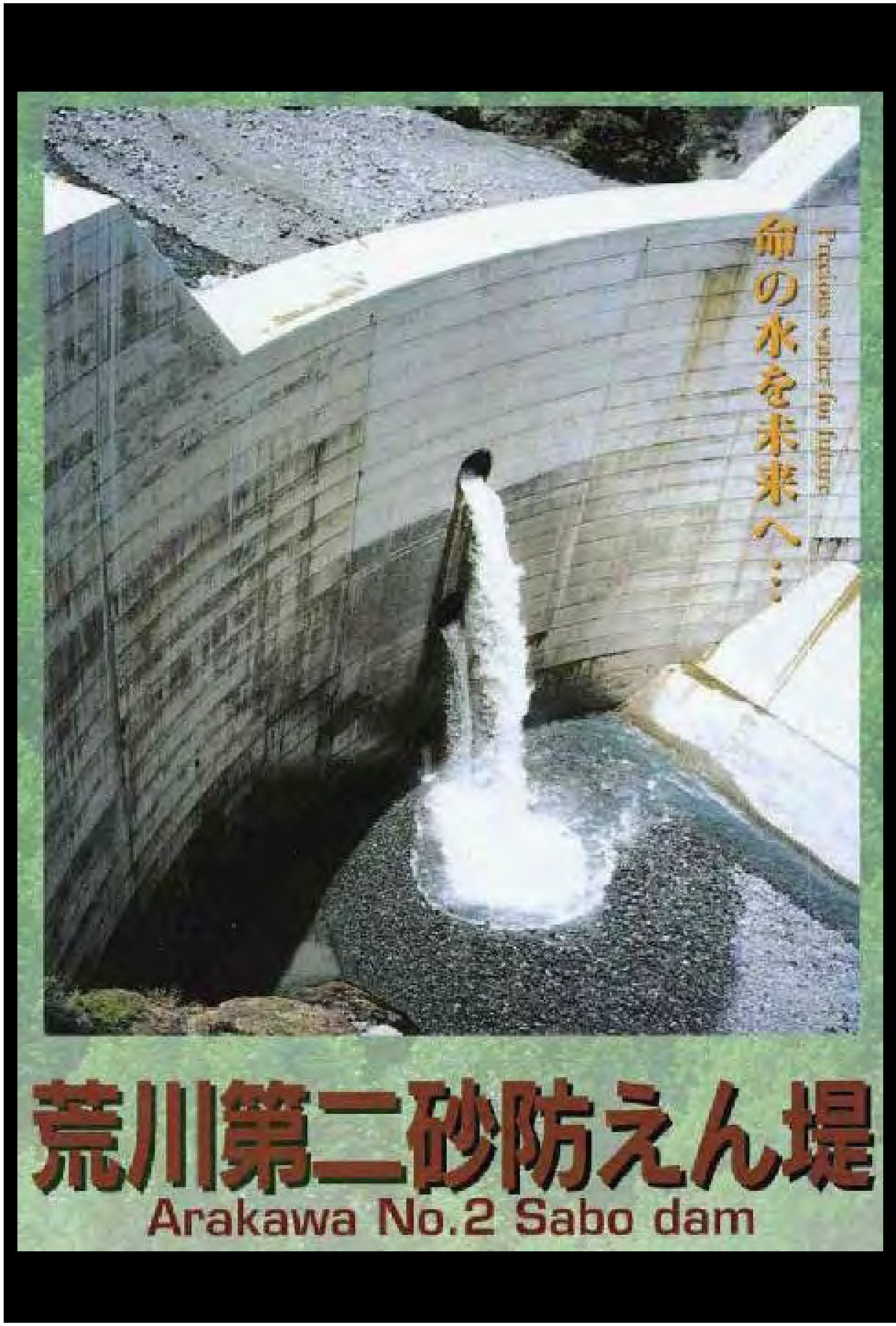
Graphic: MA Riverways Prgm

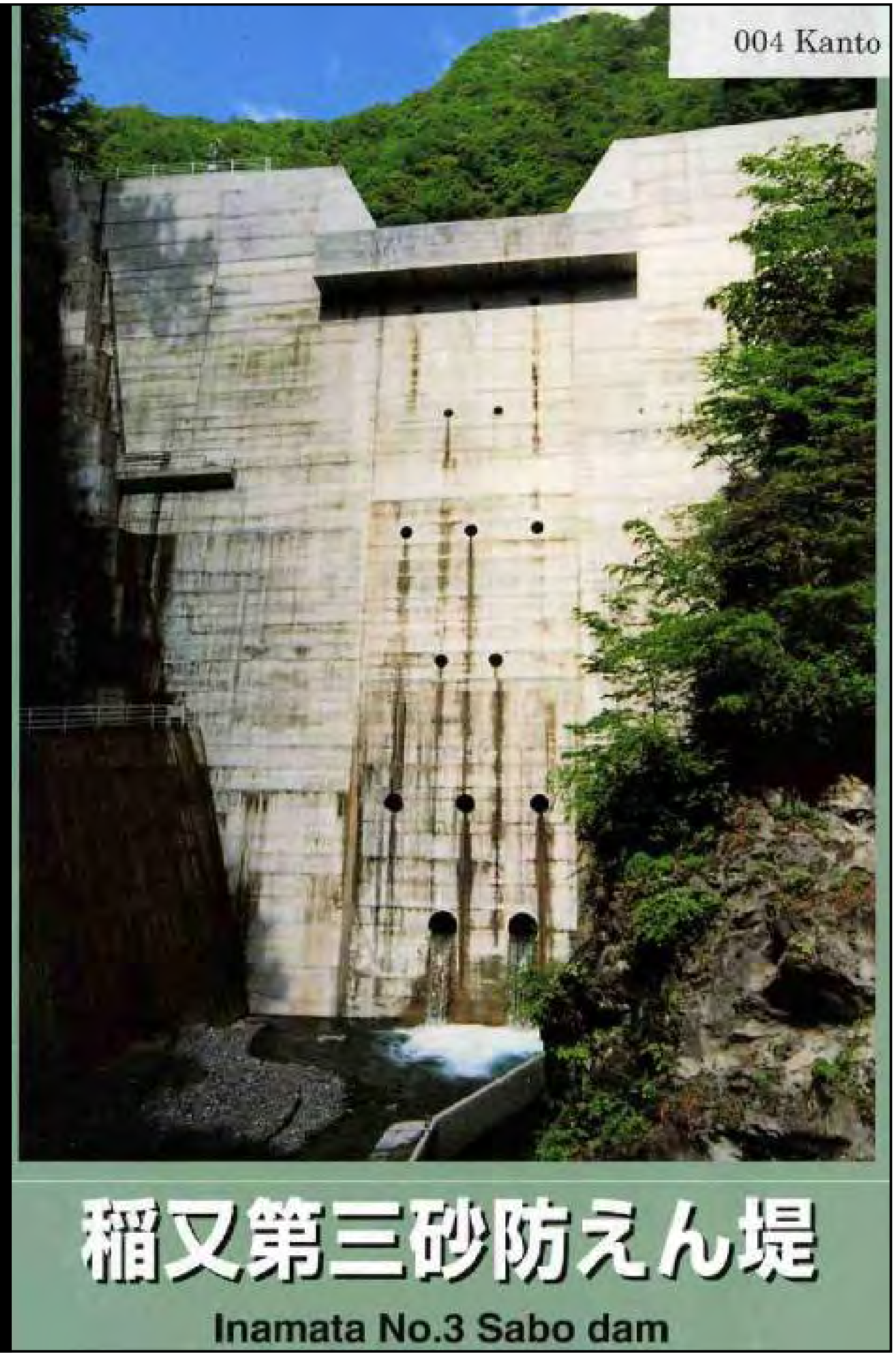


Graphic: MA Riverways Prgm



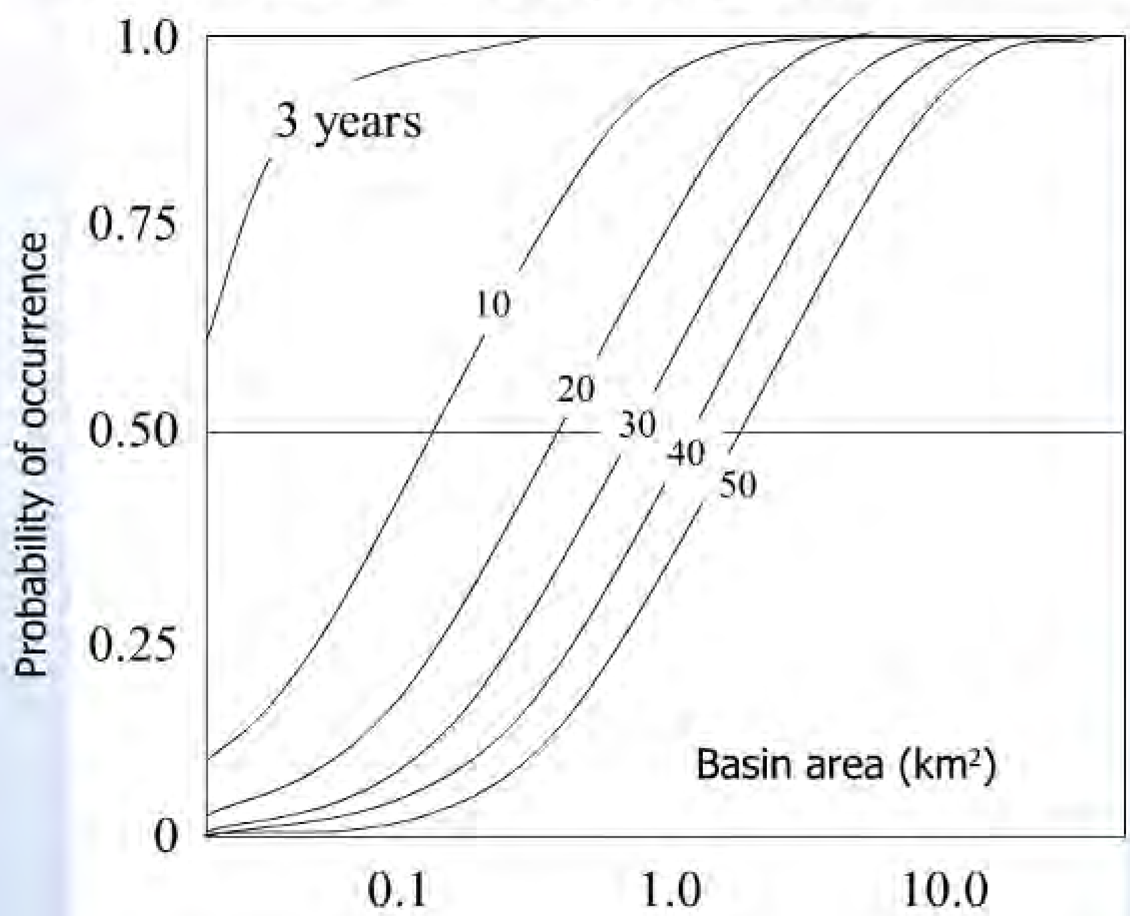
Graphic: Scott Jackson, UMASS


命の水を未来へ…
荒川第二砂防えん堤
Arakawa No.2 Sabo dam


004 Kanto
稲又第三砂防えん堤
Inamata No.3 Sabo dam


Sakamoto in Fujiwara-town
2002/ 07/ 18 no.3
Asia Air Survey co., ltd.

Persistence: a matter of space and time



(Morita and Yamamoto 2002)

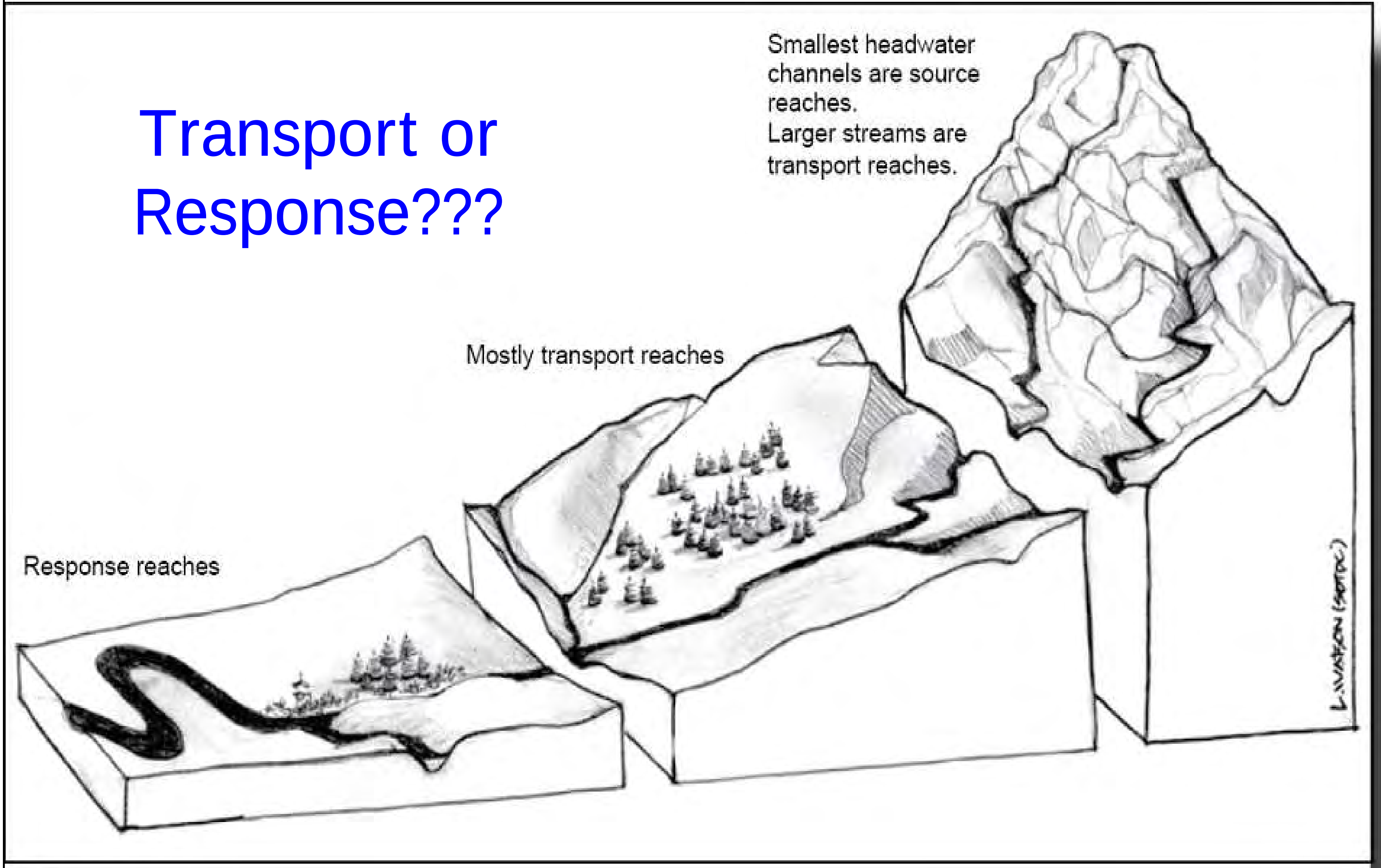
Biological Consequences of Impaired Passage

- Fragmented populations more susceptible to serious decline or extinction
- Reduced gene flow leads to genetic problems
- Poorly distributed populations have little or no buffer to catastrophe

Assessing Crossing Function

- Climate
- Physiography
- Geology
- ***Watershed Context***
- ***Reach-specific***
- ***Site-specific***

Road-Stream Crossings: Watershed Context



Transport Reach

North Carolina

New Hampshire

Response Reach

Tennessee

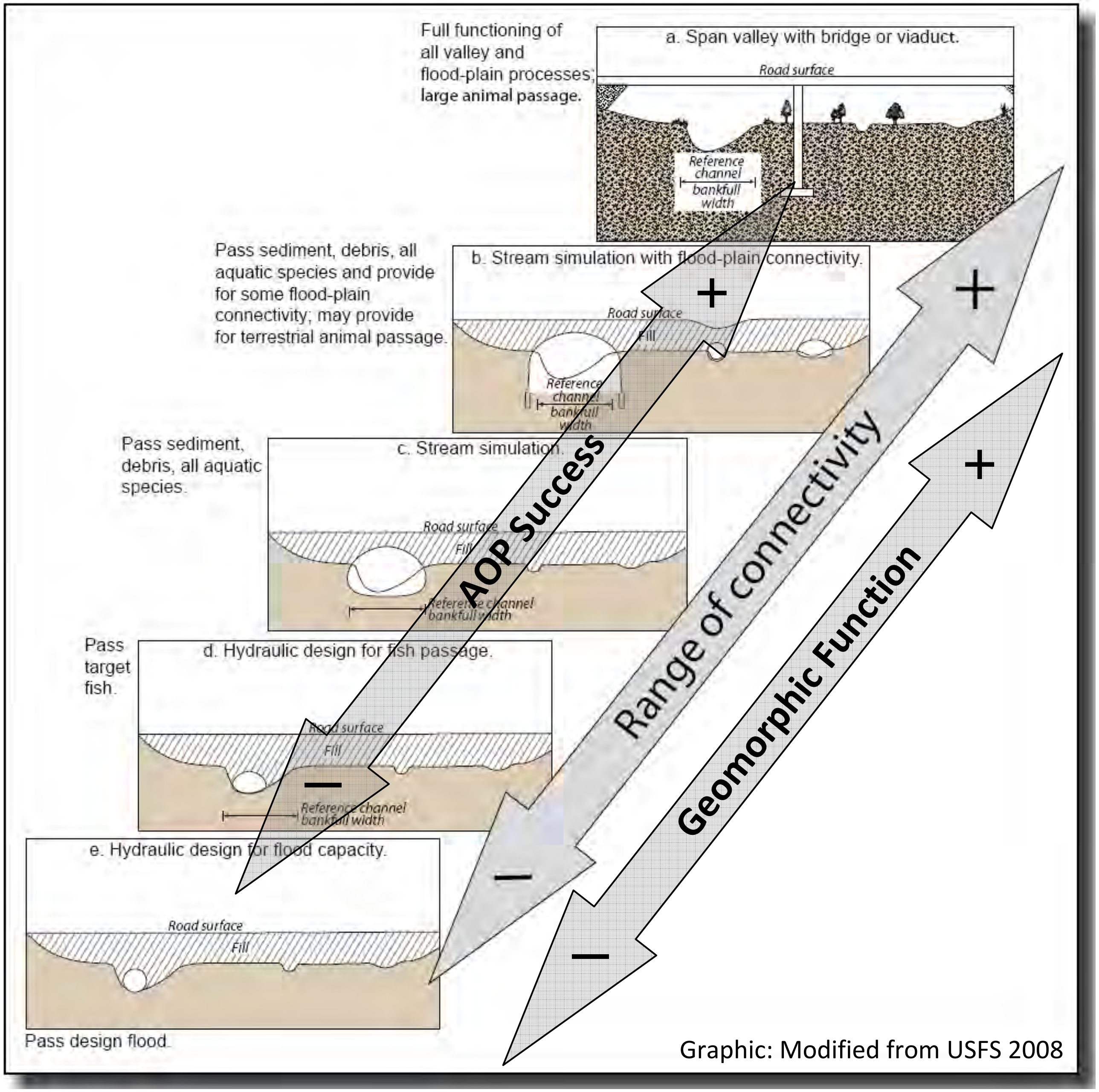
Maryland

Response Reach

South Carolina

Alabama

Road-Stream Crossings: Watershed Context



Geomorphic Effects of Road-Stream Crossings

- Sediment and wood transport cycles are disrupted
- Barriers and associated features alter surface and shallow groundwater flow
- River habitat can be shifted to lake/wetland habitats
- **Culverts and low-water crossings are static structures in dynamic environments**

Photos: Carolyn Cook and Adam Dresser, Six Rivers NF

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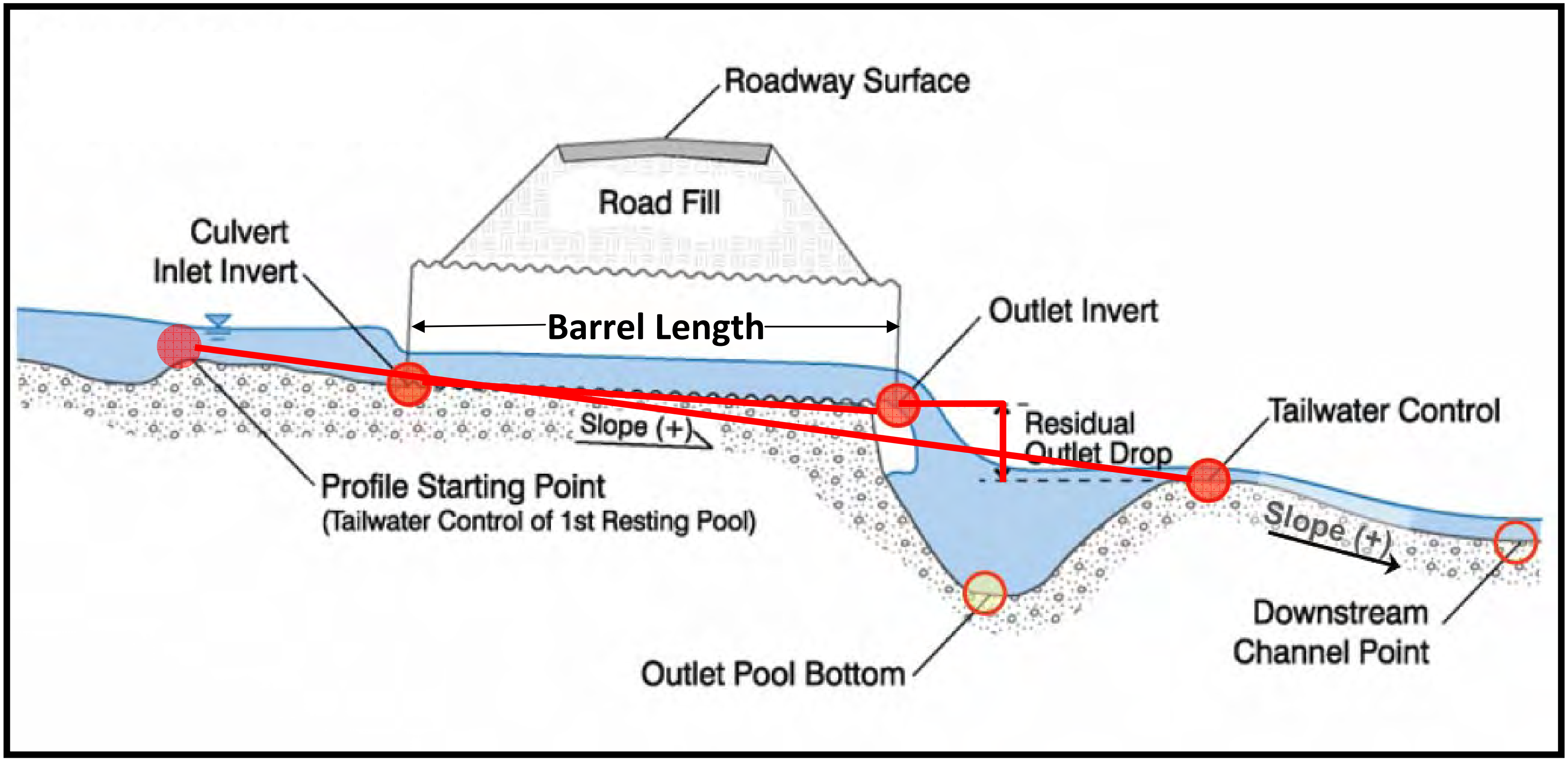
Road-Stream Crossings: Watershed Context

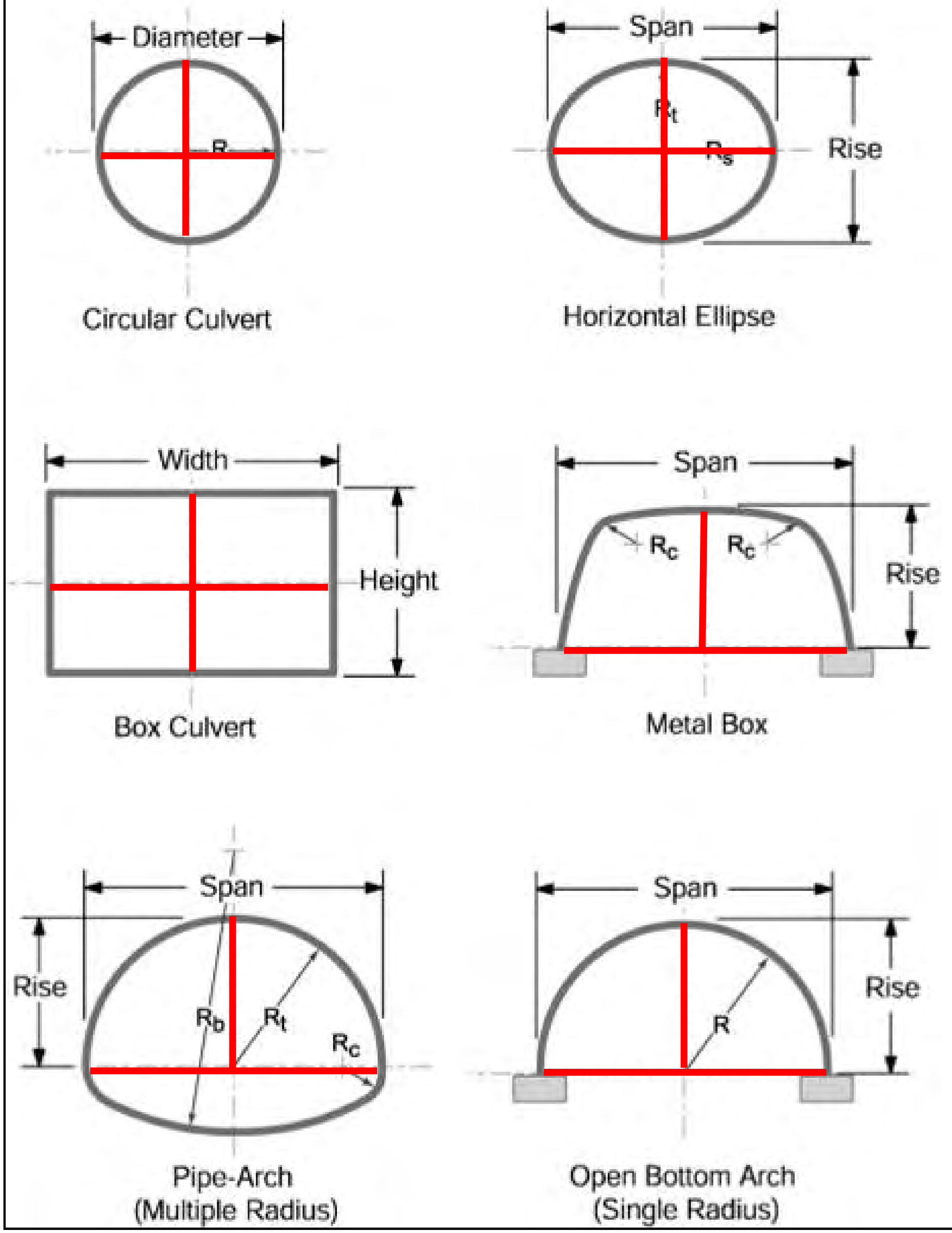
- Insight into understanding the present state of a given road-stream crossing
  - Event Chronology
- Highlight potential for geologic hazards to affect crossing function and longevity
  - Slope stability
  - Migrating headcuts
- *These factors are key to diagnosing present condition and forecasting the probable range of channel changes*

At-a-Culvert Passability

- Passage condition and site stability are two sides of the same coin
- Understanding "why a crossing looks that way" is key to predicting AOP success or failure
- Describe the hydraulic effects of a culvert

Road Crossing Anatomy--Culvert

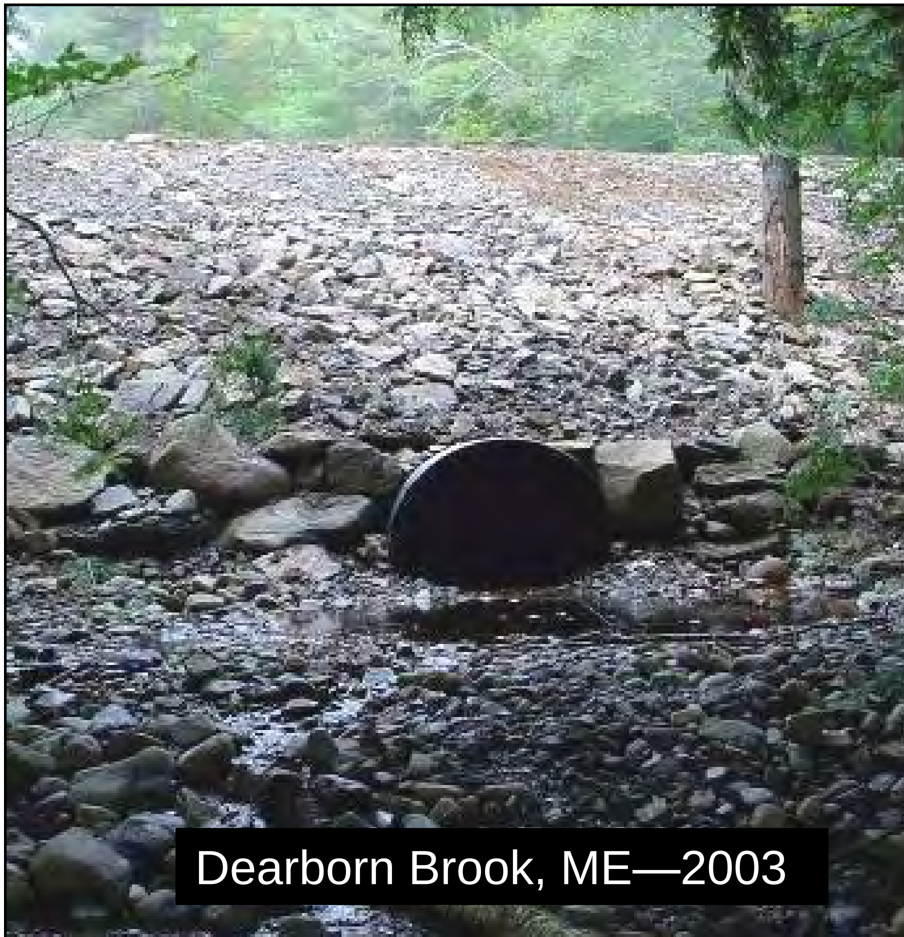


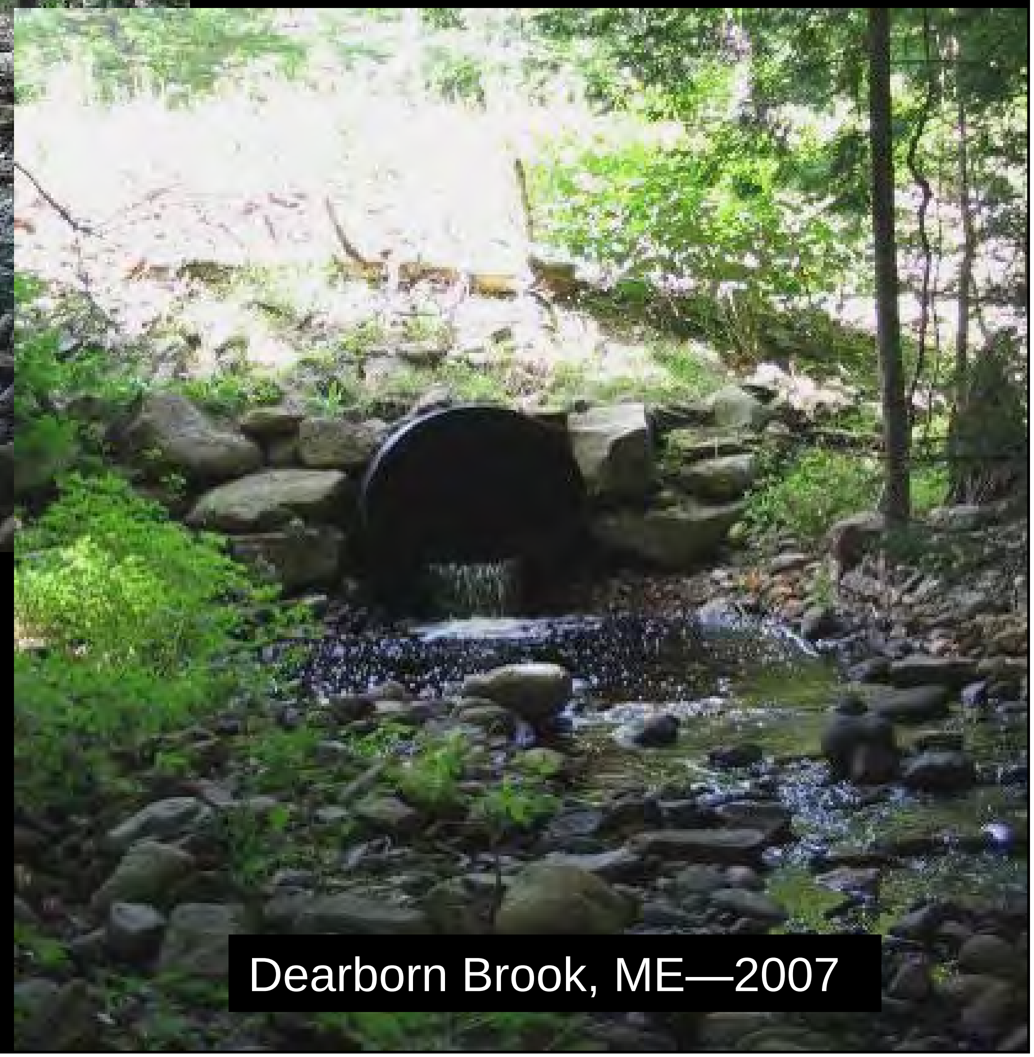


Common Culvert Types and Shapes

Culvert and Channel Geometry and Gradient

- Most culverts designed and built according to conventional methods constrict the channel
- Most culverts affect stream gradient
- Each of these factors affects the stream's ability to move water, sediment, and organic material.


Dearborn Brook, ME—2003


Dearborn Brook, ME—2007

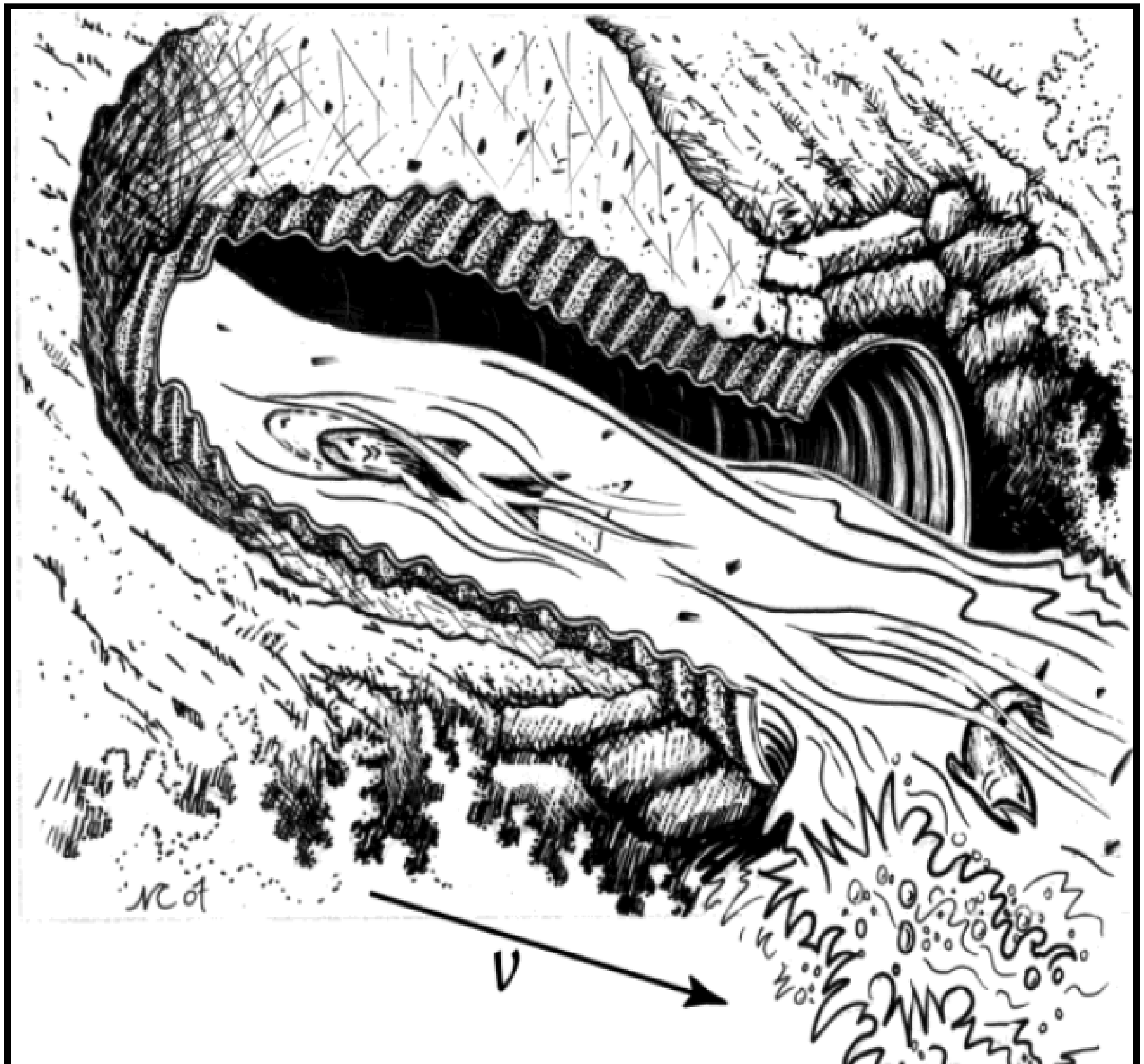
Four years after installation at grade

K. Gullett Photo

Road-Stream Crossings: Geomorphology and AOP

- Passage success is controlled by the effect road-stream crossings have on streamflow, sediment, and organic material.

- Aquatic organisms have limits on their abilities to swim, crawl, slither, wiggle, etc.

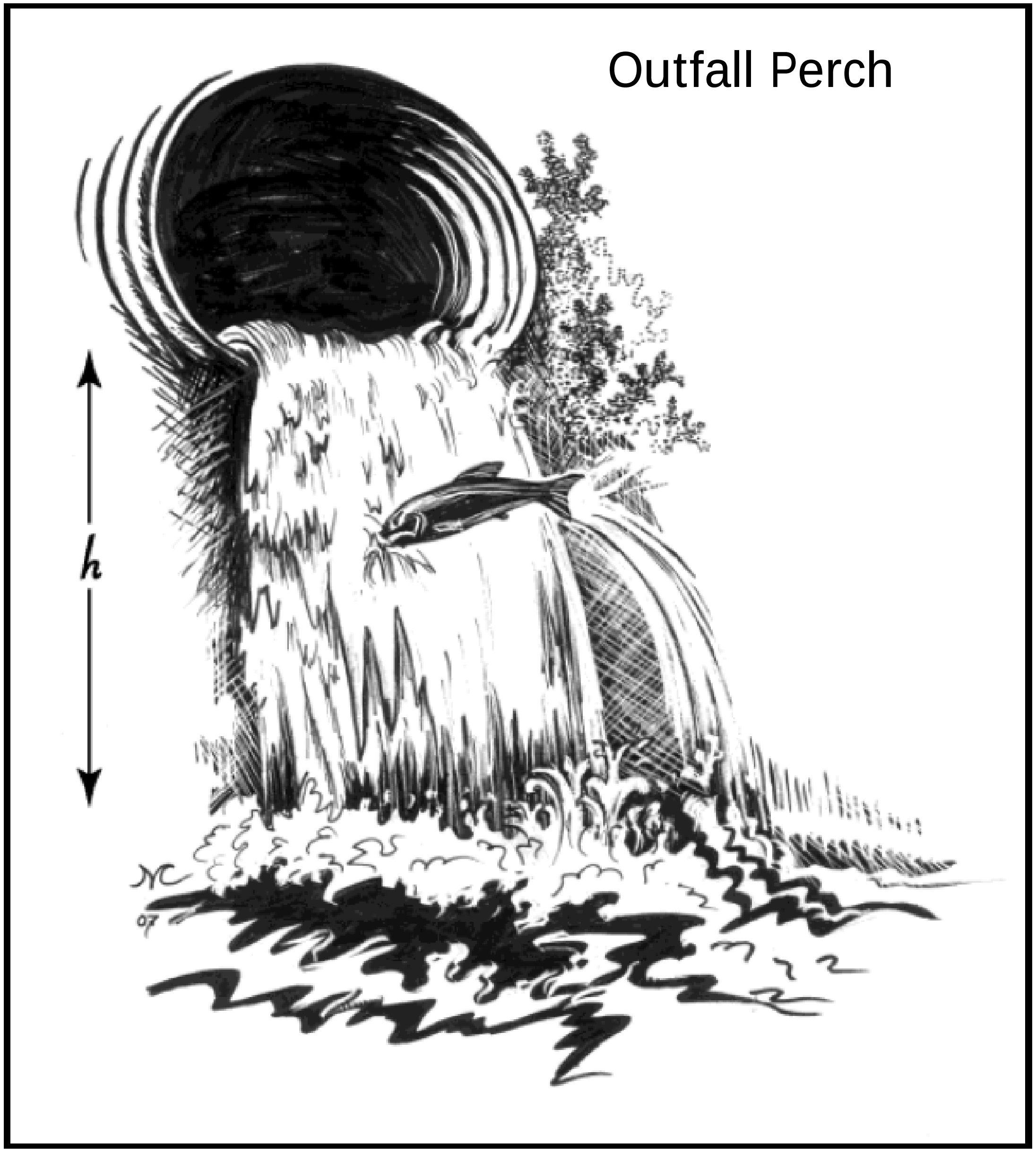


Excessive Velocity

Velocity

- Exceeds movement ability of organisms
- Occurs when a culvert is:
  - Too small
  - Too steep
  - Too smooth

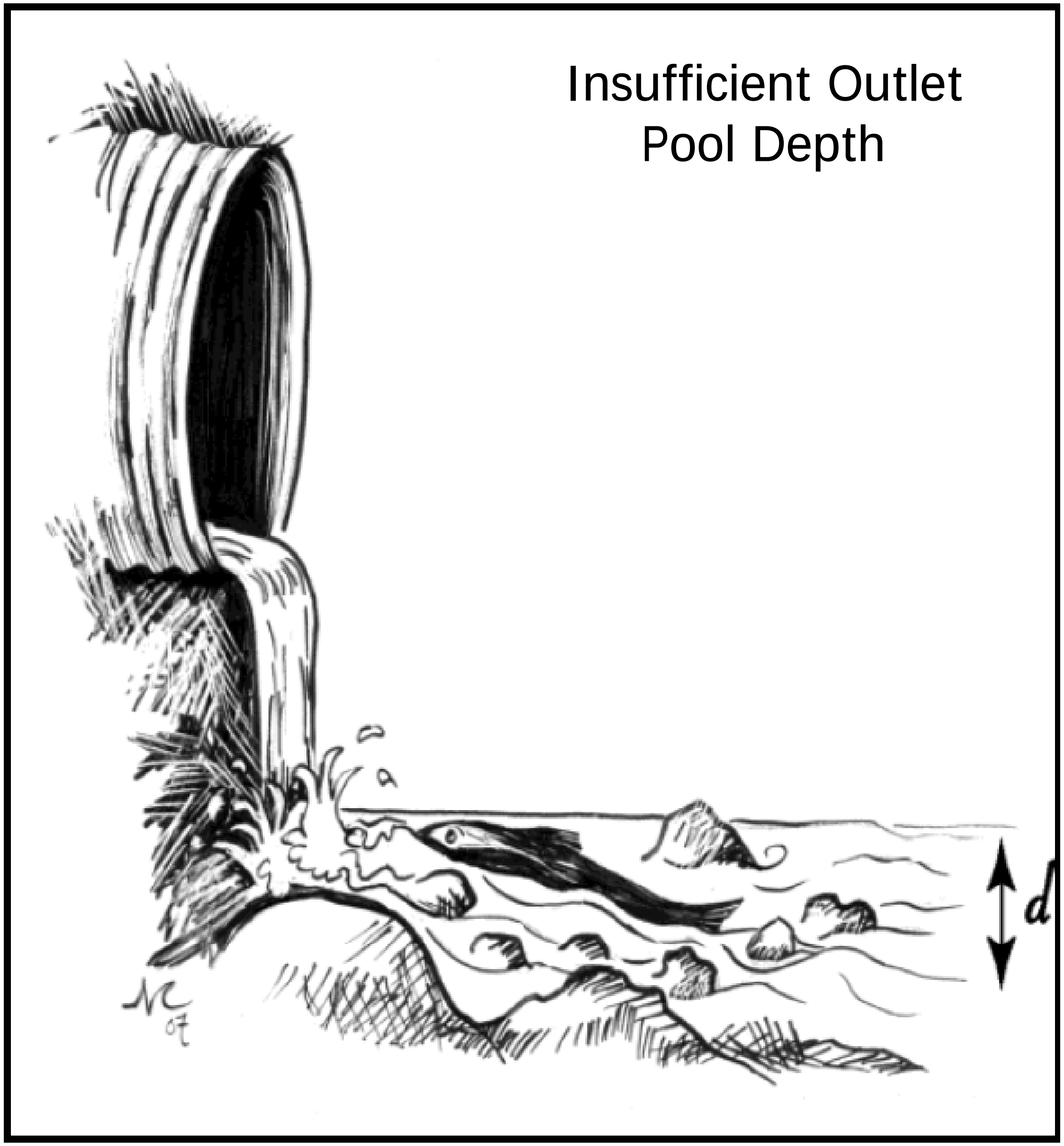
Graphic: Natalie Cabrera, USFS



Jump

- Exceeds the leaping abilities of organisms
- Occurs when:
  - Scour degrades outlet pool (culvert is too small or steep)
  - Headcut migrates upstream

Graphic: Natalie Cabrera, USFS

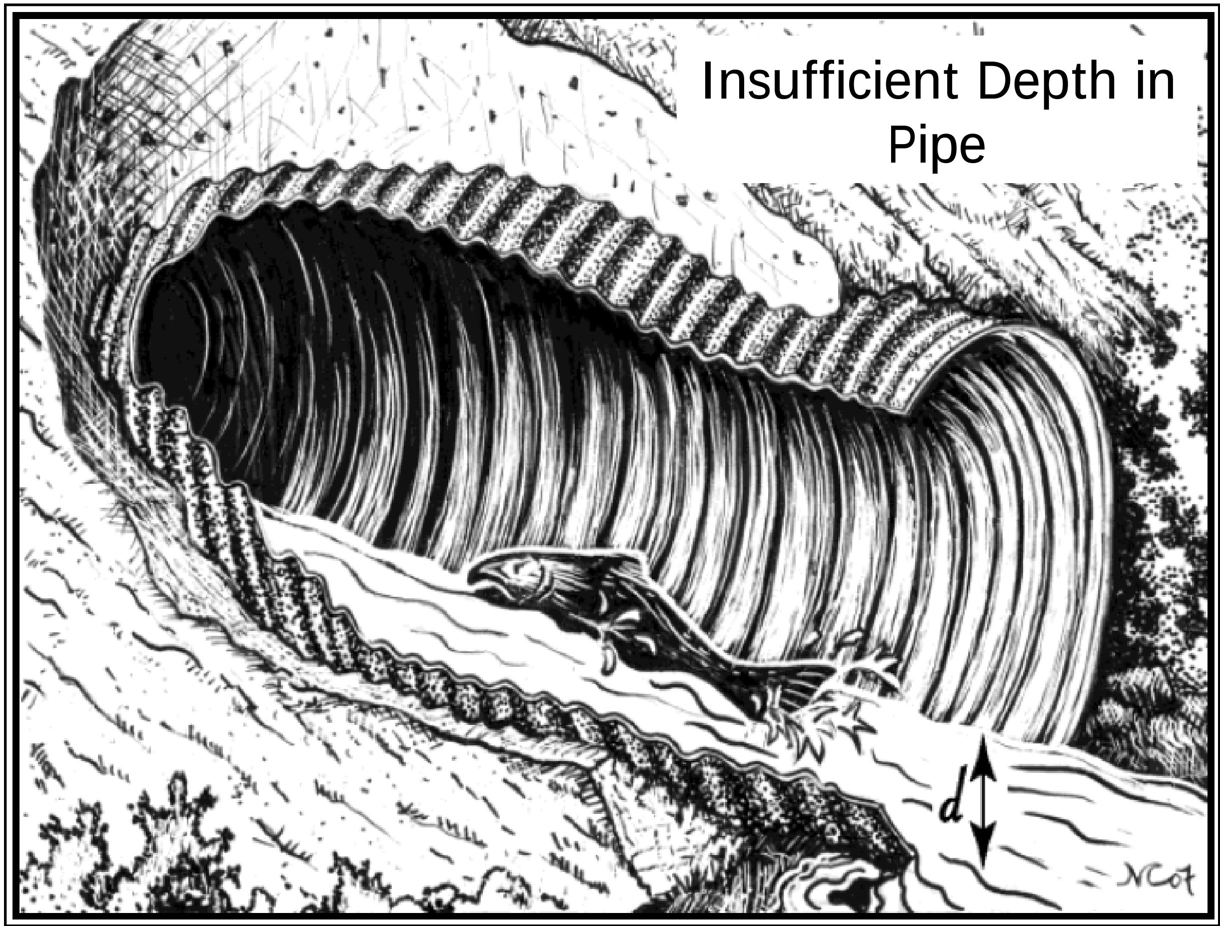


Graphic: Natalie Cabrera, USFS

Pool Depth

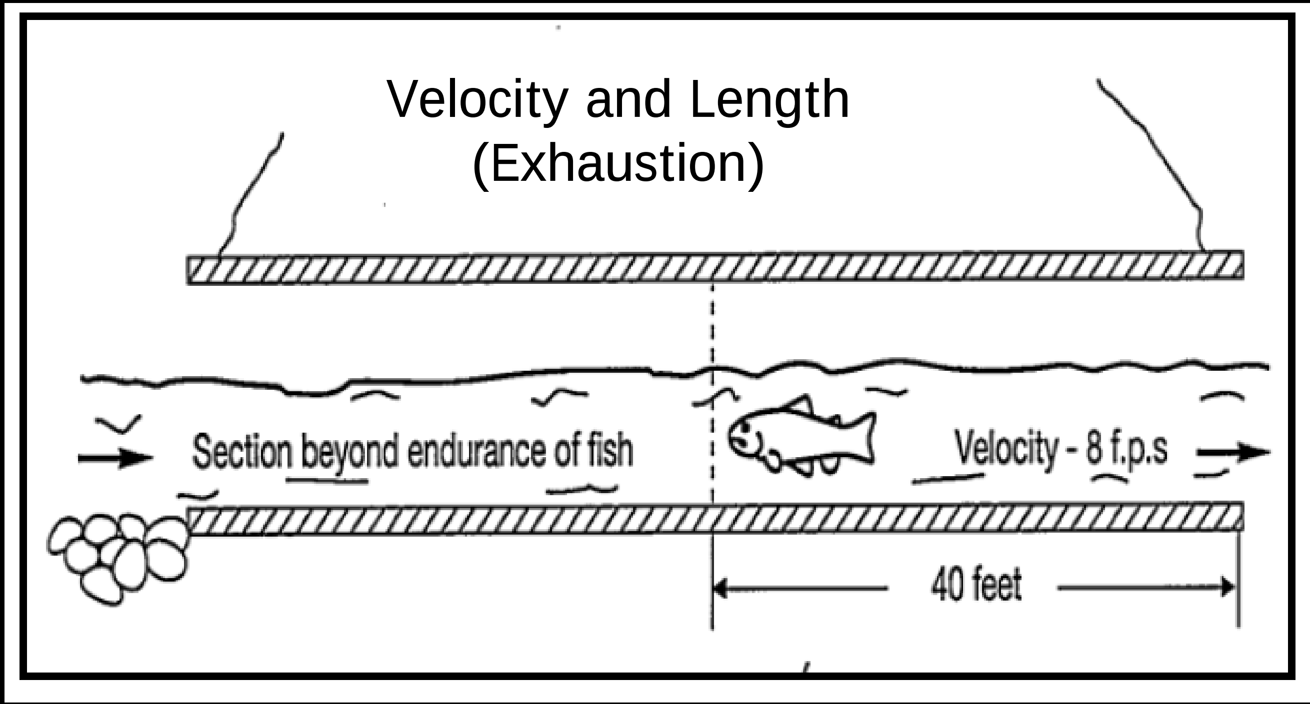
- Outlet pool is too shallow and/or turbulent for organisms to get into pipe
- Occurs when:
    - Riprap fills outlet pool
    - Outlet scour erodes channel
    - Culvert outlet fitted with apron

Pipe Depth



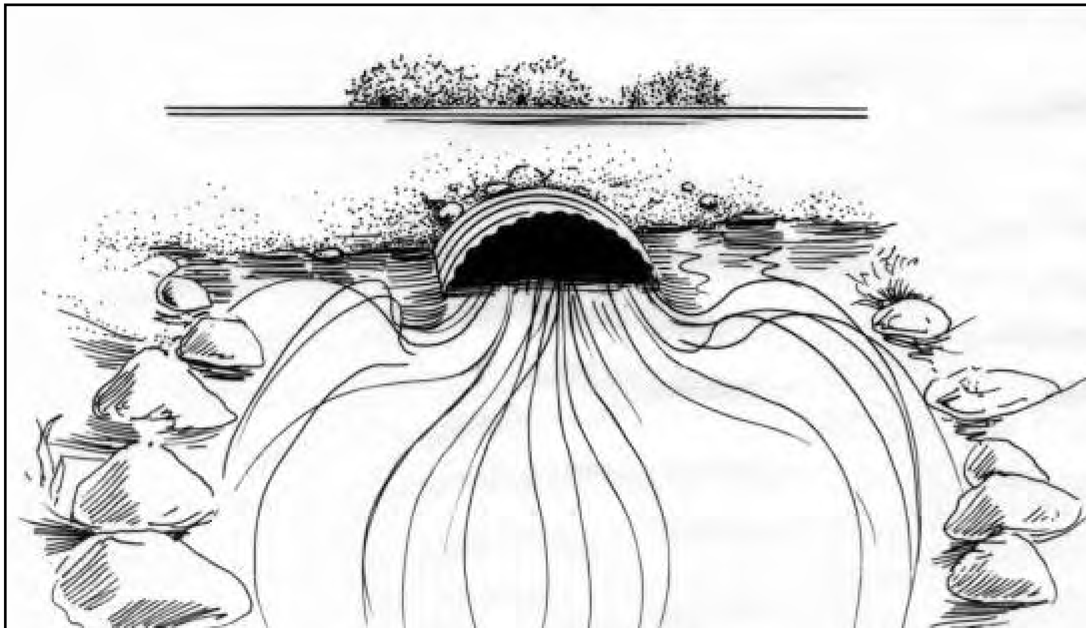
- Water inside culvert is too shallow for swimmers
- Occurs when culvert is:
  - Too steep
  - Too big (rare)
  - Subject to widely fluctuating streamflow

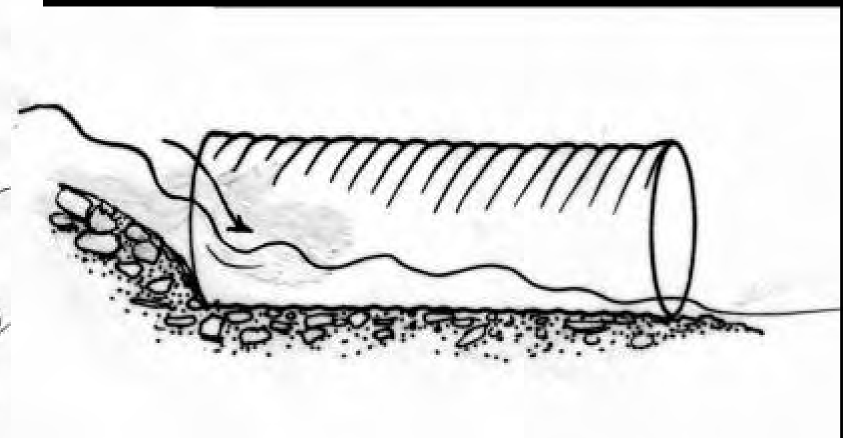
Graphic: Natalie Cabrera, USFS



Exhaustion

- Combined effect of velocity and pipe length exceed stamina of organism
- Occurs when an undersized culvert is also quite long.





Inlet contraction/drop

- Excessive velocity and/or turbulence at inlet exceeds movement abilities of organisms
- Occurs when an undersized culvert:
    - is outfitted with head and/or wingwalls
    - creates a depositional bar

Other Barrier Types

- Debris accumulations
- Behavioral
- Absence of bank edge areas
- Discontinuous channel substrate
- Culvert alignment

Geomorphic Effects of Road-Stream Crossings

- When assessing passage condition, remember not to be oriented only to the culvert itself

- Assessing the physical effect on a stream includes more than just the roadway and crossing feature—it includes the reach of river upstream and downstream of the crossing.

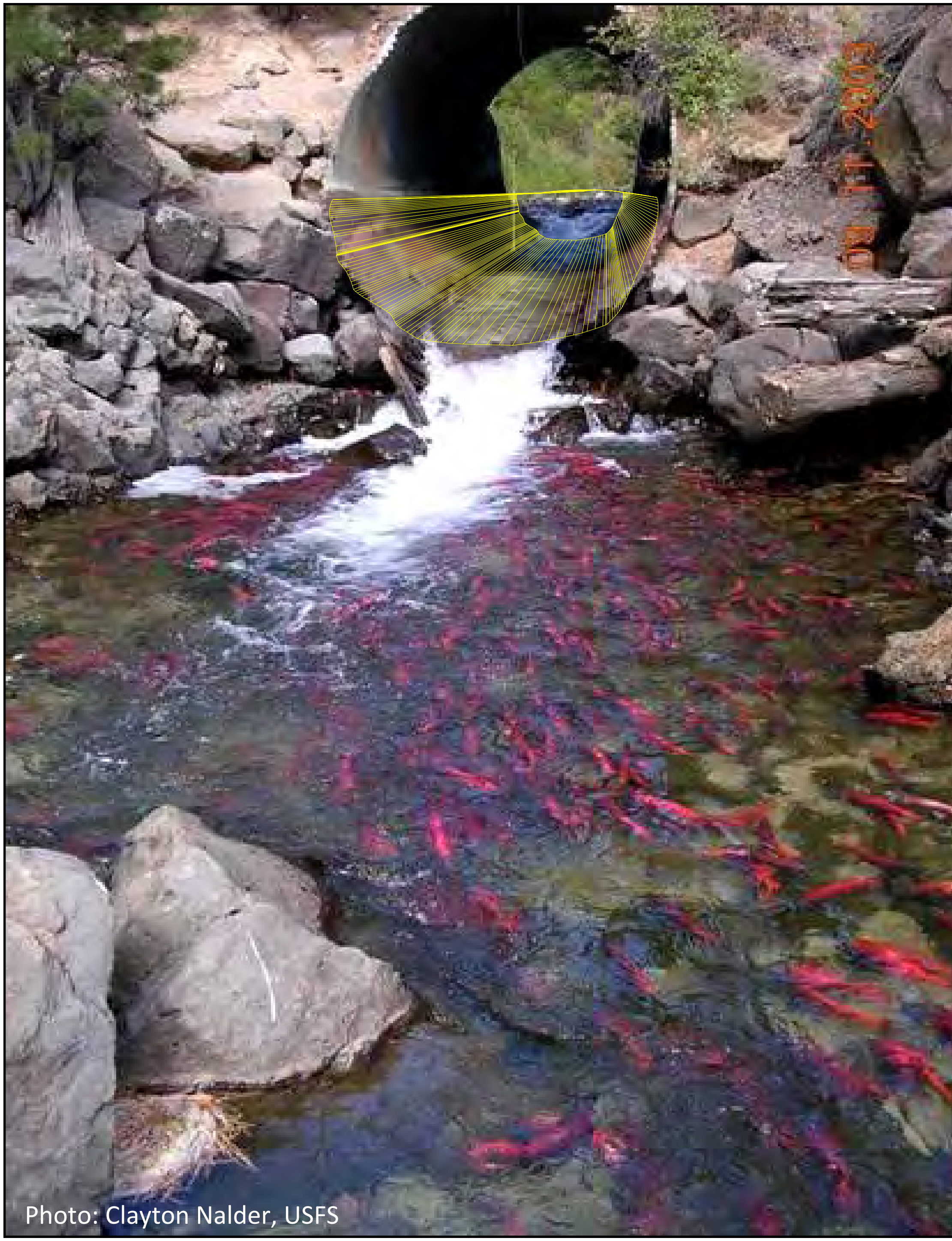


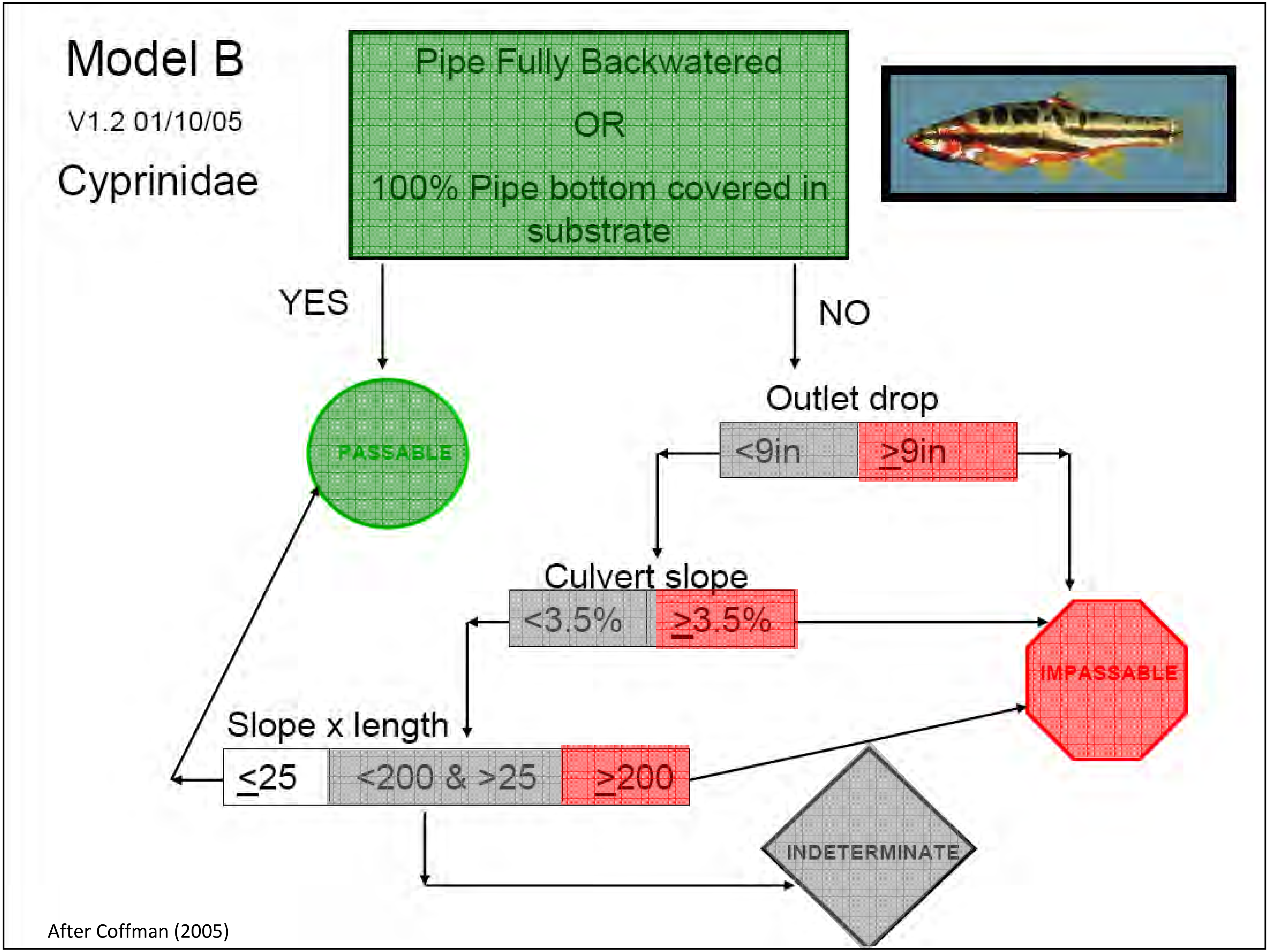
Photo: Clayton Nalder, USFS

How is this culvert a barrier???

- Outlet pool depth
- Jump
- Barrel velocities
- Barrel depth
- Barrel roughness
- Inlet drop
- Inlet contraction

Coarse Filters to Assess Passage

- Culverts can be quickly assessed because the following largely control passability:
  - barrel length and width
  - outlet elevation
  - presence or absence of substrate
  - barrel slope

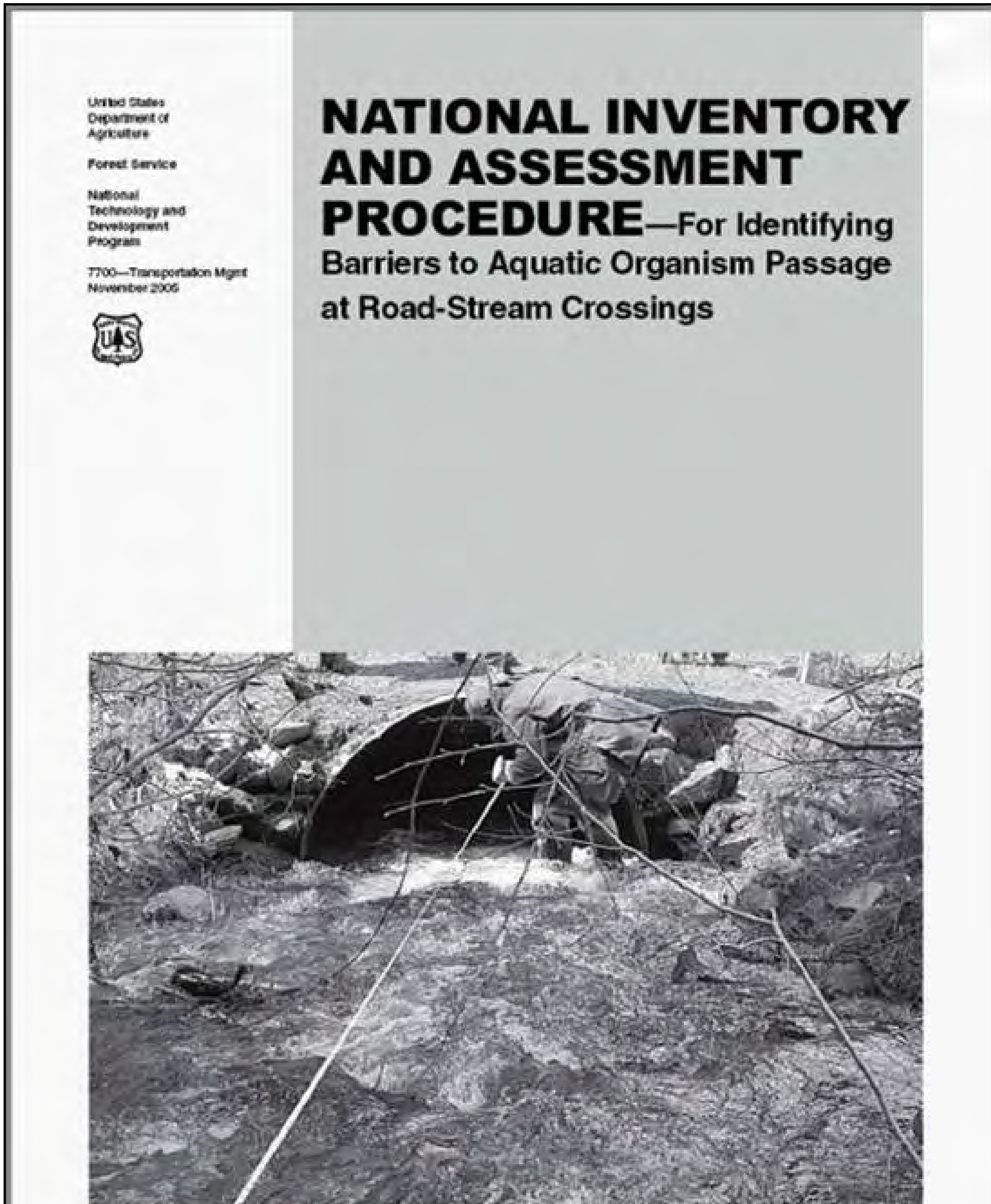


After Coffman (2005)

Coarse Filter Categories

Formal Barrier Inventory and Analyses Methods

- Provide data to quantify passage condition
- Prioritize crossing replacement within a watershed
- Initiate design
- Approximate replacement or new construction cost



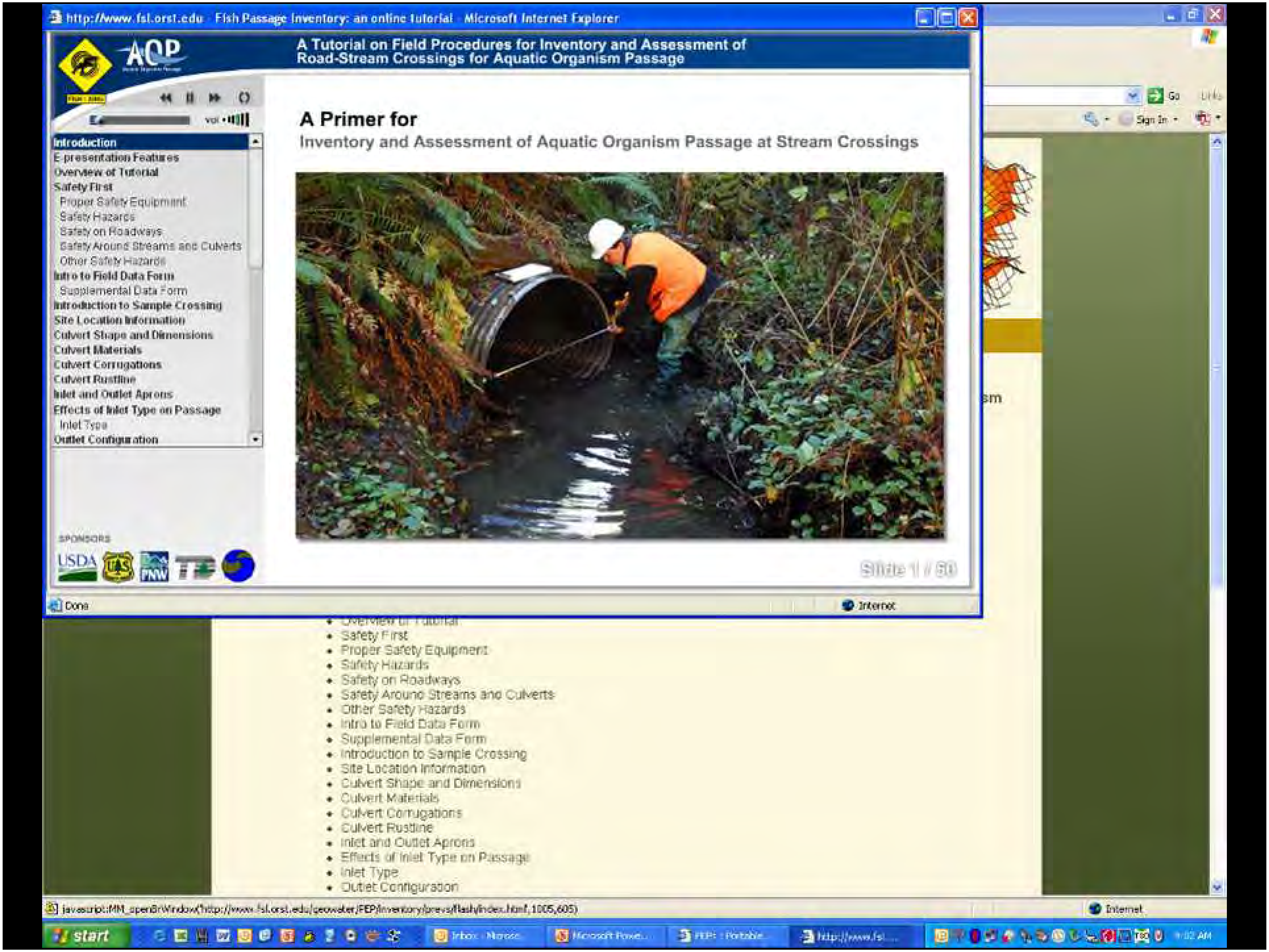
www.stream.fs.fed.us/publications/PDFs/NIAP.pdf

- Most western states have protocols
- More and more eastern states
  - MA
    - http://www.streamcontinuity.org
  - ME
    - http://www.fws.gov/northeast/gulfofmaine/index.htm
  - VT
    - http://www.vtfishandwildlife.com/library/Reports_and_Documents/Fish_and_Wildlife/Interim_Guidelines_for_Aquatic_Organism_Passage_Through_Stream_Crossing_Structures_in_Vermont.pdf

Online Tutorial

- **A Tutorial on Field Procedures for Inventory and Assessment of Road-Stream Crossings for Aquatic Organism Passage**

- http://www.fs.fed.us/pnw/pep/PEP_inventory.html?x=1



http://www.fsl.orst.edu - Fish Passage Inventory: an online tutorial - Microsoft Internet Explorer
AOP
A Tutorial on Field Procedures for Inventory and Assessment of
Road-Stream Crossings for Aquatic Organism Passage
A Primer for
Inventory and Assessment of Aquatic Organism Passage at Stream Crossings
Introduction
E-presentation Features
Overview of Tutorial
Safety First
Proper Safety Equipment
Safety Hazards
Safety on Roadways
Safety Around Streams and Culverts
Other Safety Hazards
Intro to Field Data Form
Supplemental Data Form
Introduction to Sample Crossing
Site Location Information
Culvert Shape and Dimensions
Culvert Materials
Culvert Corrugations
Culvert Rustline
Inlet and Outlet Aprons
Effects of Inlet Type on Passage
Inlet Type
Outlet Configuration
SPONSORS
USDA
PNW
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Safety First
Proper Safety Equipment
Safety Hazards
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Inlet Type
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start

USDA United States Department of Agriculture

Forest Service

Rocky Mountain Research Station

General Technical Report RM-245

Stream Channel Reference Sites:

An Illustrated Guide to Field Technique

Cheryl C. Harrelson

C. L. Rawlins

John P. Potyondy

http://www.stream.fs.fed.us/publications/PDFs/RM245E.PDF

- Overview:
  - Site Selection
  - Drawing a Site Map
  - Surveying Basics
  - Measuring Channel Cross Sections
  - Floodplain and Bankfull Indicators
  - Longitudinal Profile Measurement

Culvert Barrier Cliff Notes

- Complete Barriers
  - Barrel is perched (elevated) above the outlet pool.

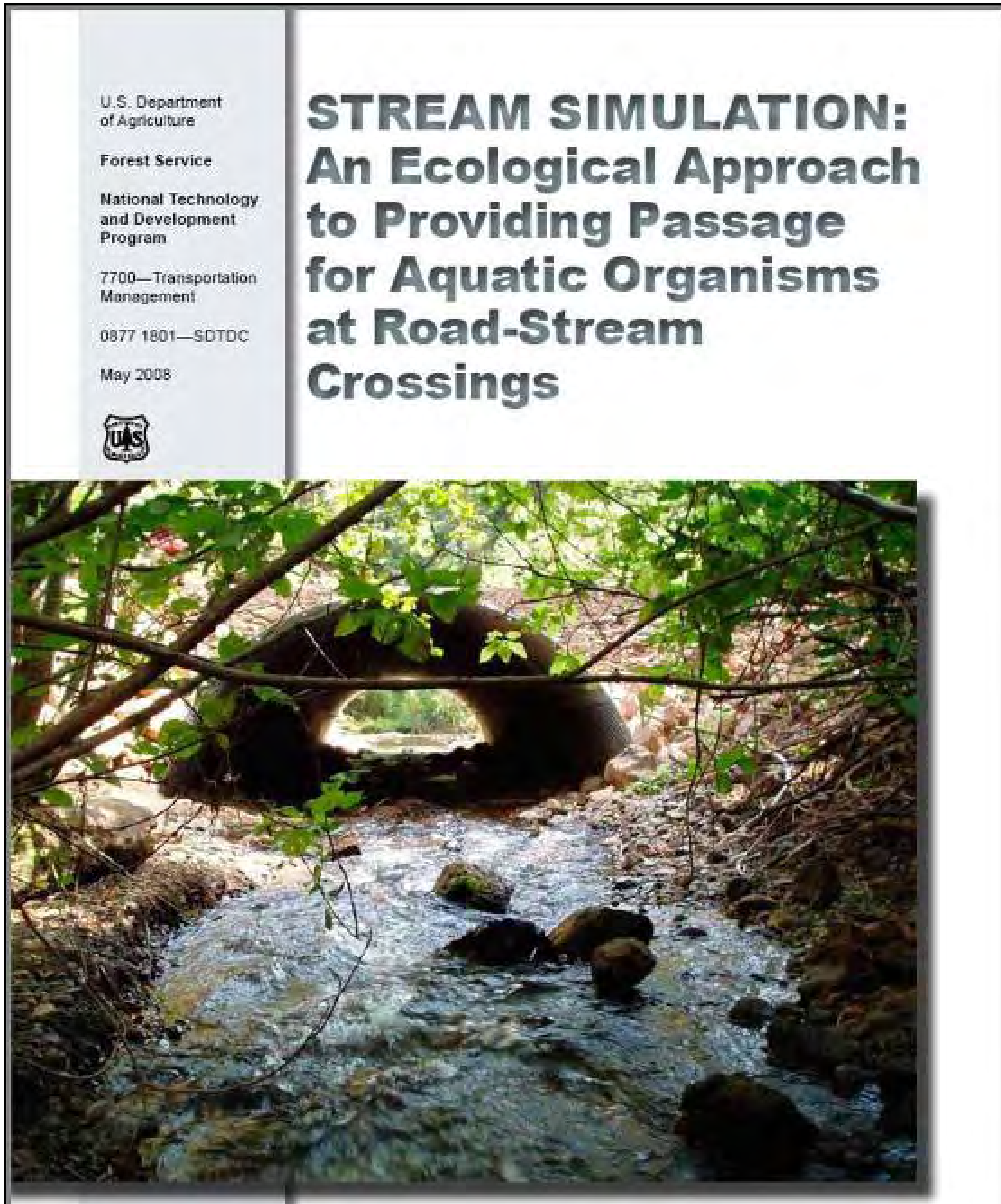
- Temporary Barriers
  - Barrel width is less than the bankfull channel width.
  - Barrel slope is greater than the channel slope.
  - Barrel is free of substrate
  - Crossing (barrel and aprons) is excessively long with no resting areas.

- Partial Barriers
  - Culverts where the
    - Barrel alignment doesn’t match the stream alignment;
    - Inlet or outlet is plugged with debris;
    - Inlet or outlet shows sign of erosion or instability.


You’ve got a willing landowner and culvert barrier to AOP… NOW WHAT???

Working With Road Crossings

- Consider the road and crossing—Any chance for removal and/or closure???
- If removal and replacement isn't an option, consider retrofit
  - Channel manipulations
  - Baffles
- If replacement is an option—put in a "stream simulation culvert"



http://www.stream.fs.fed.us/fishxing/aop_pdfs.html

- Completed in May 2008, available online August 2008
- ***Simply outstanding reference!***
- Overview:
    - Ecological Considerations
    - Managing Roads for Connectivity
    - Intro to Stream Simulation
    - Watershed and Reach Review
    - Site Assessment
    - Stream Simulation Design
    - Final Design and Contract Prep
    - Stream Simulation Construction

Stream Simulation

- Premise—A channel that simulates characteristics of the adjacent natural channel will present no more of a challenge to aquatic organism passage than the natural channel

It is a geomorphic—rather than a hydraulic or biological—design

Pay Close Attention Where:

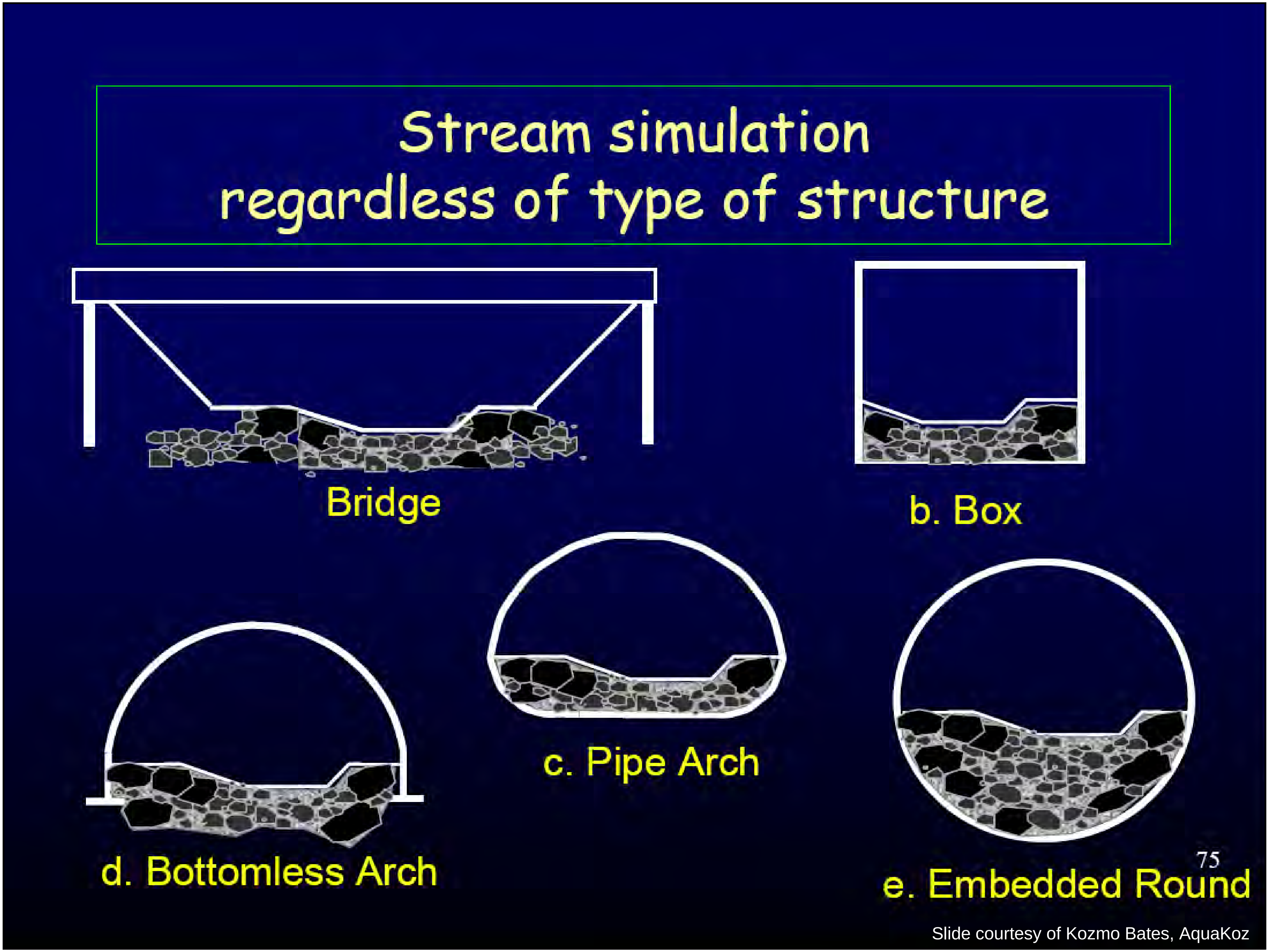
- Large elevation drops exist through the crossing
- High floodplain conveyance is evident
- Active lateral channel migration is occurring
- Depositional features are evident
- Reaches are prone to debris flows or high large woody debris loads
- Channels are prone to icing
- Channels have intermittently exposed bedrock

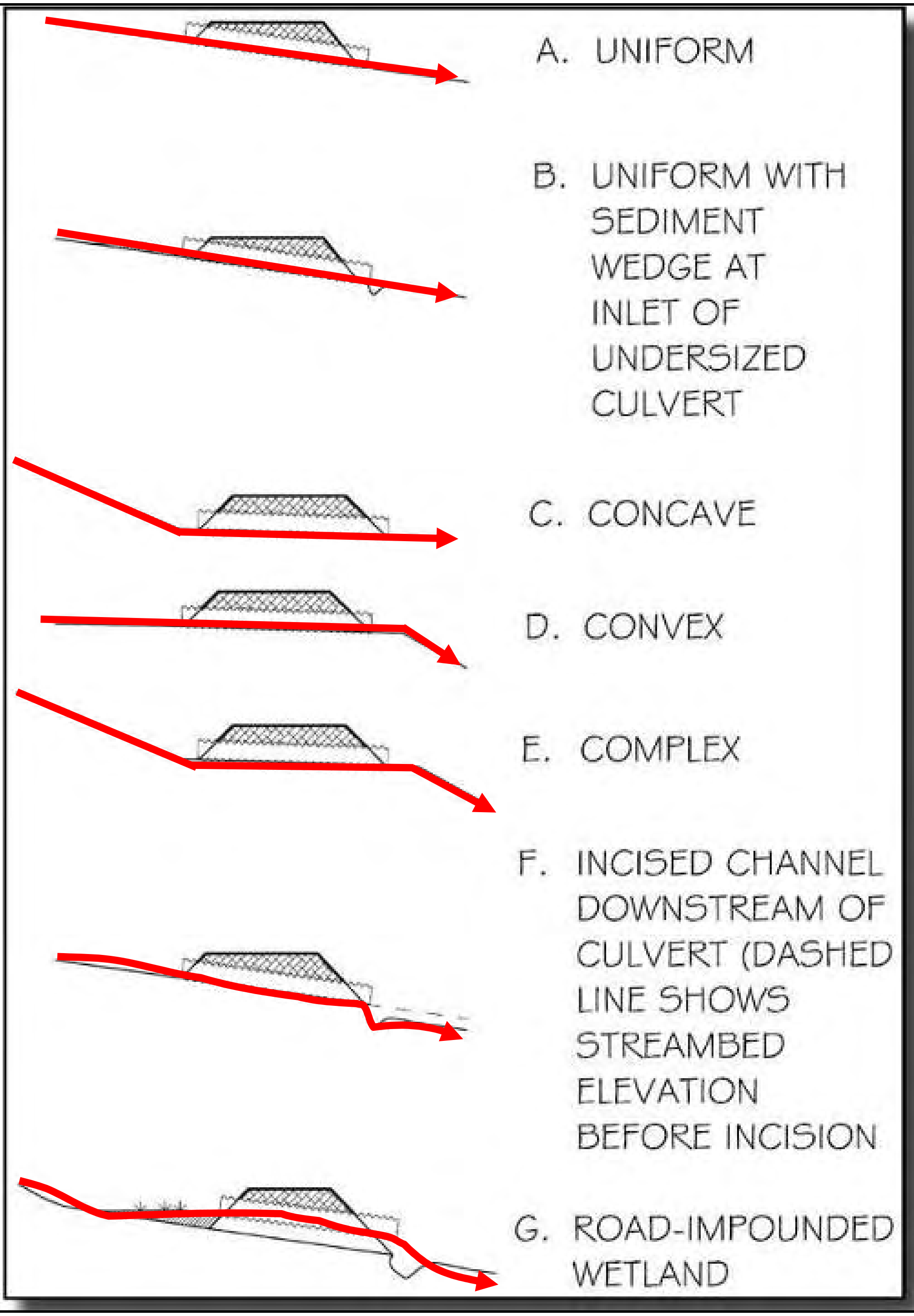
Stream Simulation

- Geomorphic Design
- Simulate natural channel reference reach
  - Bankfull geometry
  - Channel slope
  - Channel structure
    - Chanel type
    - Bed mobility
  - Mobile bed in a stable channel

August 2007

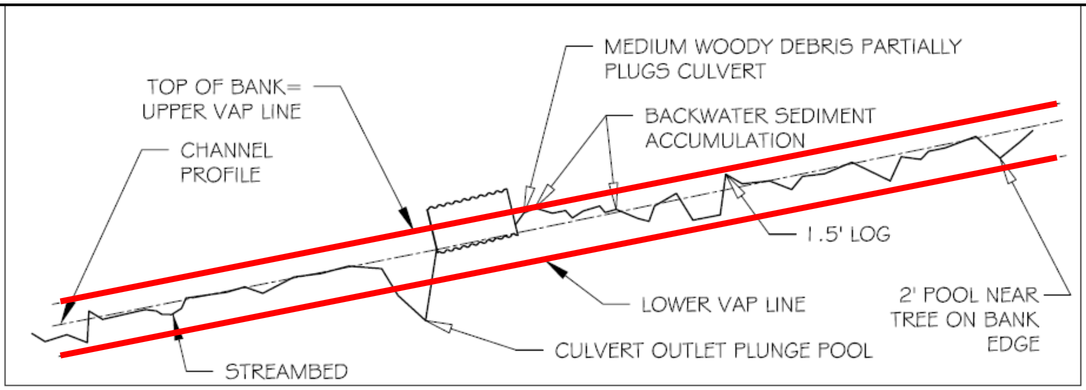
May 2008


Stream simulation
regardless of type of structure
Bridge
b. Box
c. Pipe Arch
d. Bottomless Arch
e. Embedded Round
75
Slide courtesy of Kozmo Bates, AquaKoz

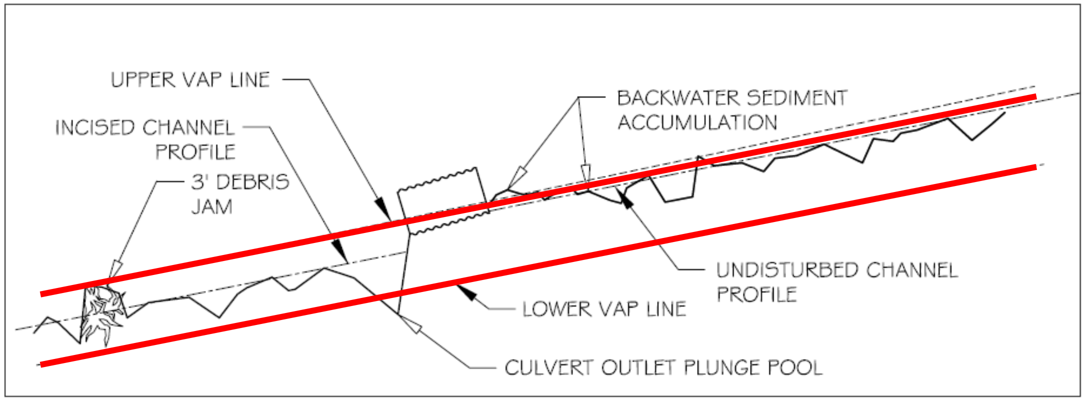

A. UNIFORM
B. UNIFORM WITH SEDIMENT WEDGE AT INLET OF UNDERSIZED CULVERT
C. CONCAVE
D. CONVEX
E. COMPLEX
F. INCISED CHANNEL DOWNSTREAM OF CULVERT (DASHED LINE SHOWS STREAMBED ELEVATION BEFORE INCISION
G. ROAD-IMPOUNDED WETLAND

USFS 2008

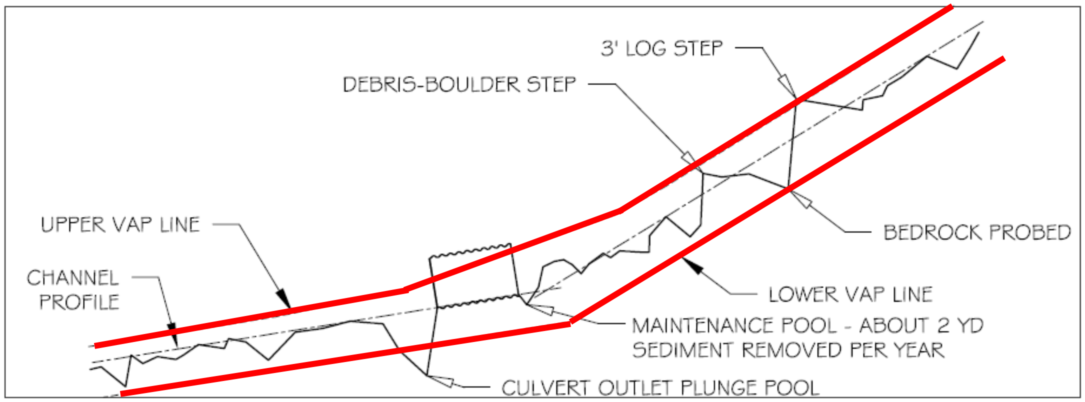
USFS 2008



A. UNIFORM PROFILE



B. INCISED CHANNEL PROFILE

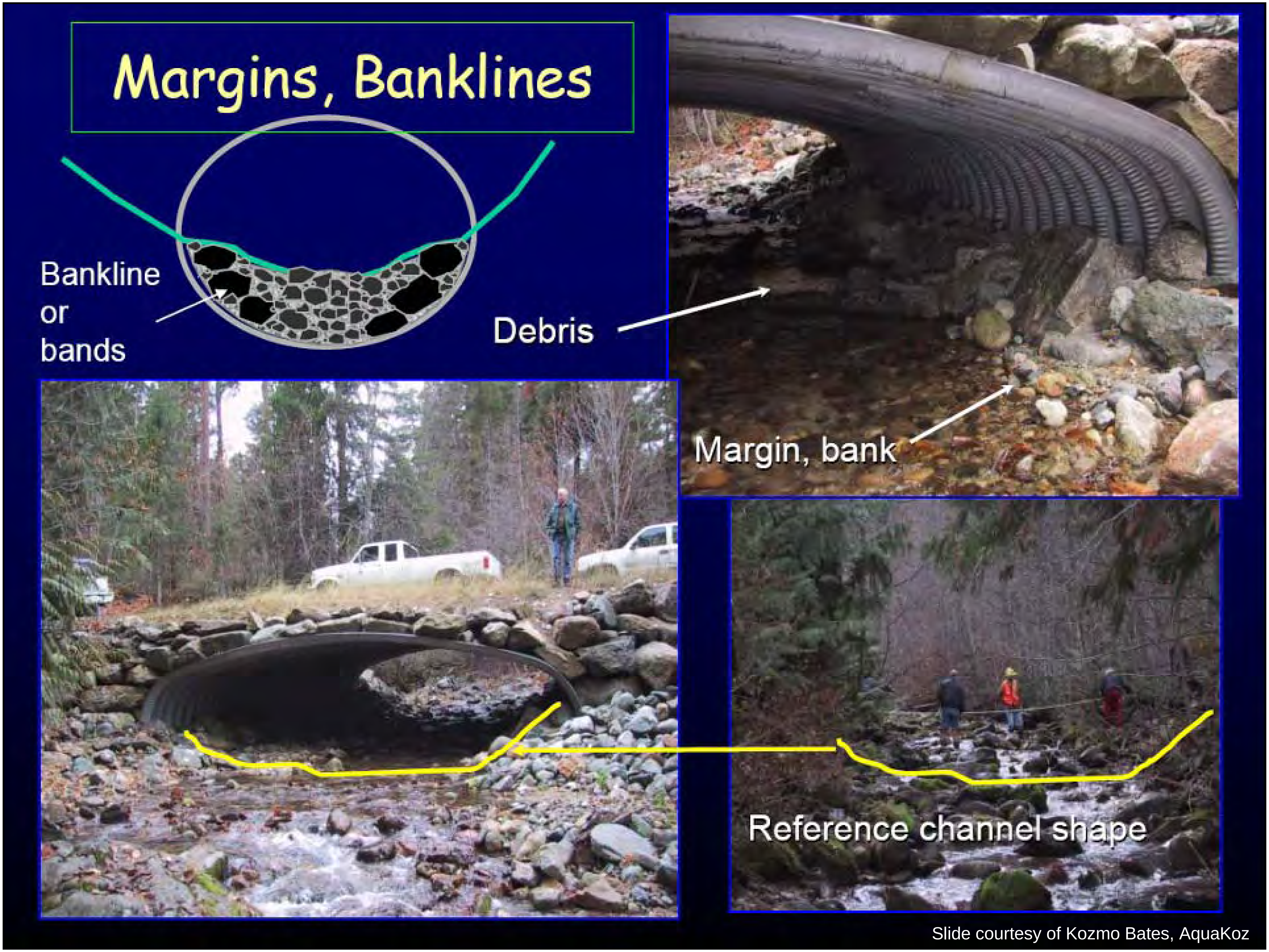


C. CONCAVE SLOPE TRANSITION

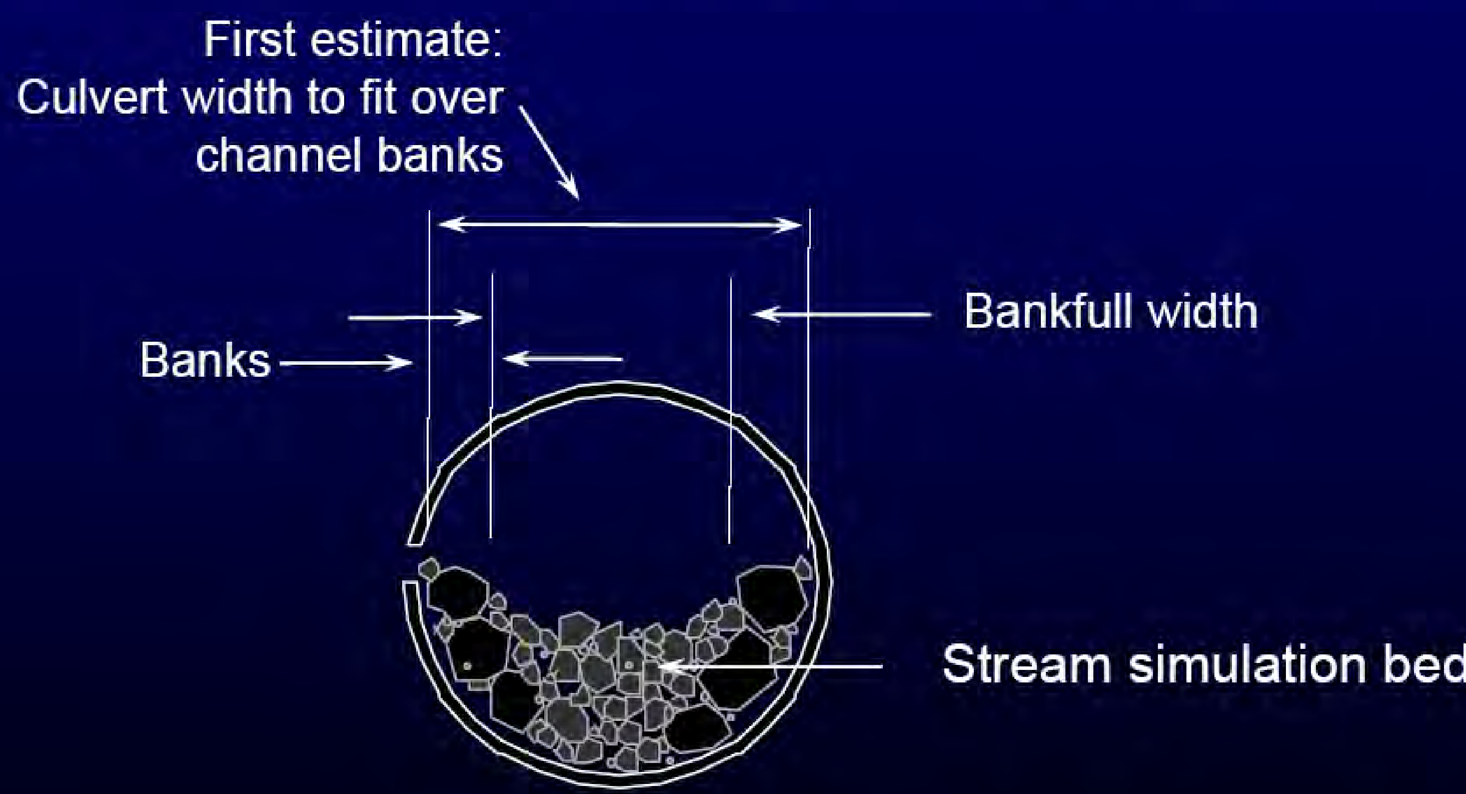
Bed Design Objectives

- Simulate the natural streambed
  - Bed shape
  - Particle diversity
  - Roughness
  - Mobility
  - Forcing features
  - Control permeability


SULLAIR

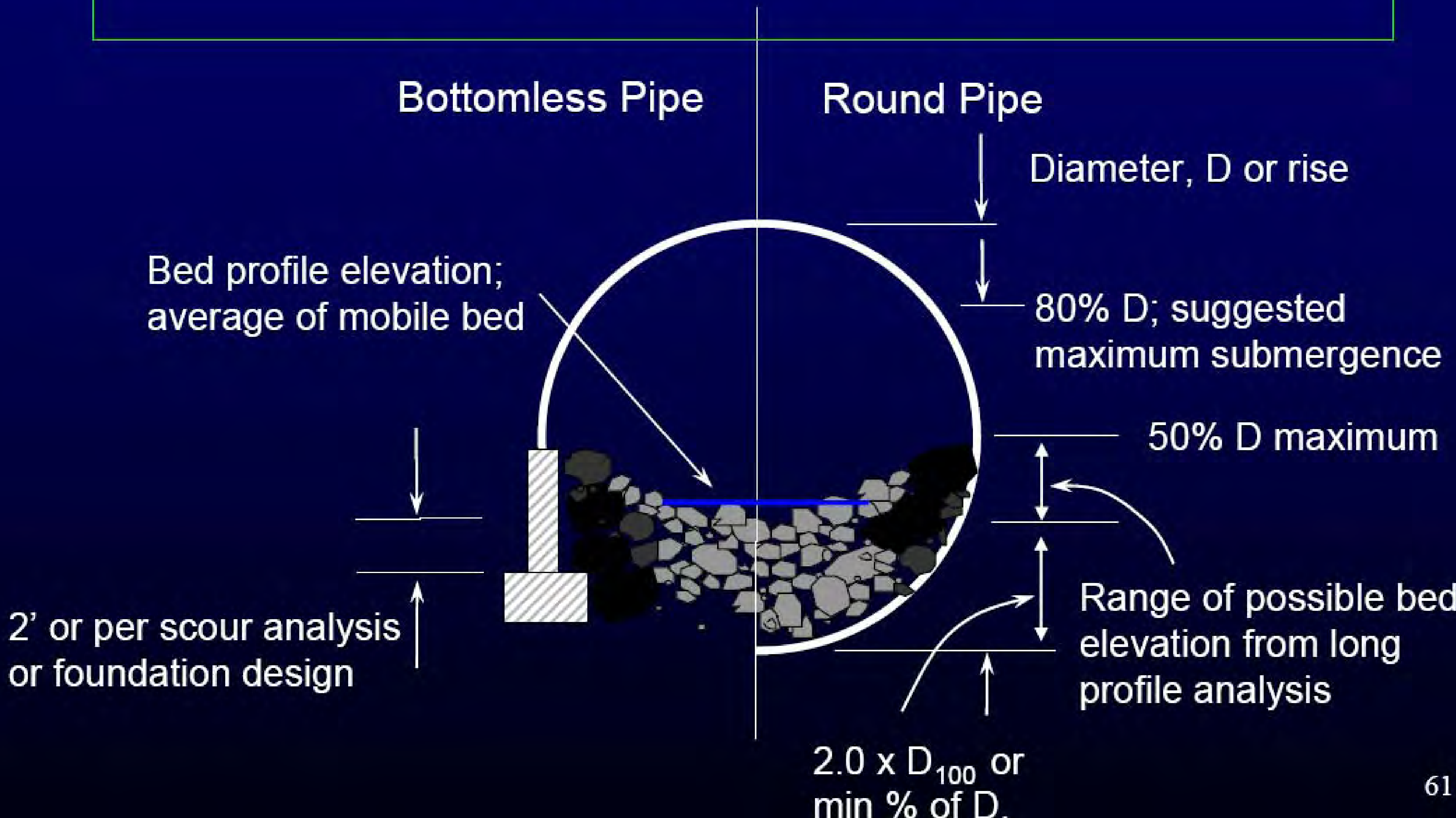

Margins, Banklines
Bankline or bands
Debris
Margin, bank
Reference channel shape
Slide courtesy of Kozmo Bates, AquaKoz

Stream Simulation
First estimate of culvert width



Slide courtesy of Kozmo Bates, AquaKoz

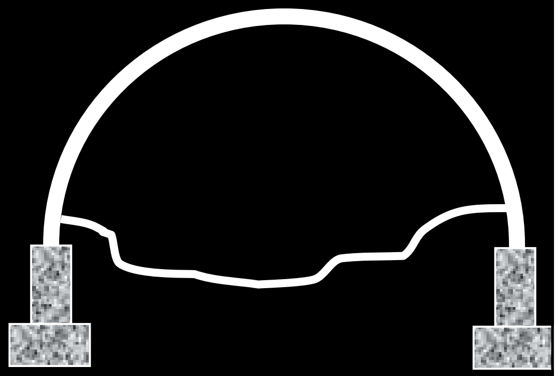
Culvert Elevation



Slide courtesy of Kozmo Bates, AquaKoz

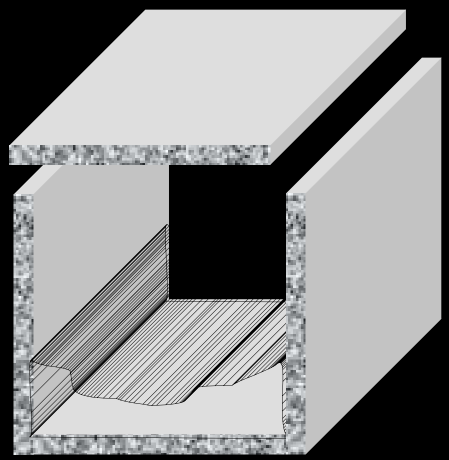
Bottomless vs. Pipe

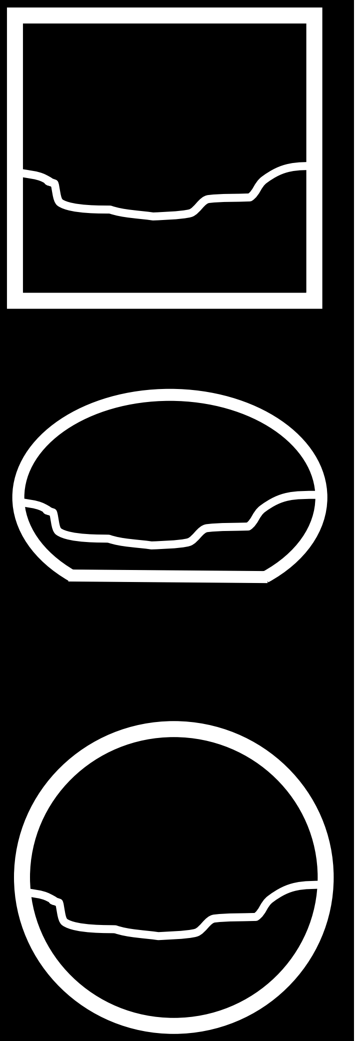
- Placed over existing streambed or top loaded
- Can be placed over/attached to bedrock
- Footings can be shaped to bedrock
- Concrete stemwall resists abrasion and corrosion
- High bed shear strength reduces bed failure risk
- Bed compaction easier



Pipe vs. Bottomless

- Pre-assembly reduces construction time
- Not vulnerable to scour or headcut
- No need to isolate flowing water from concrete
- Cheaper, less complex construction
- Smaller footprint
- Higher load capacity in poor foundation soils





Culvert Design—Stream Simulation

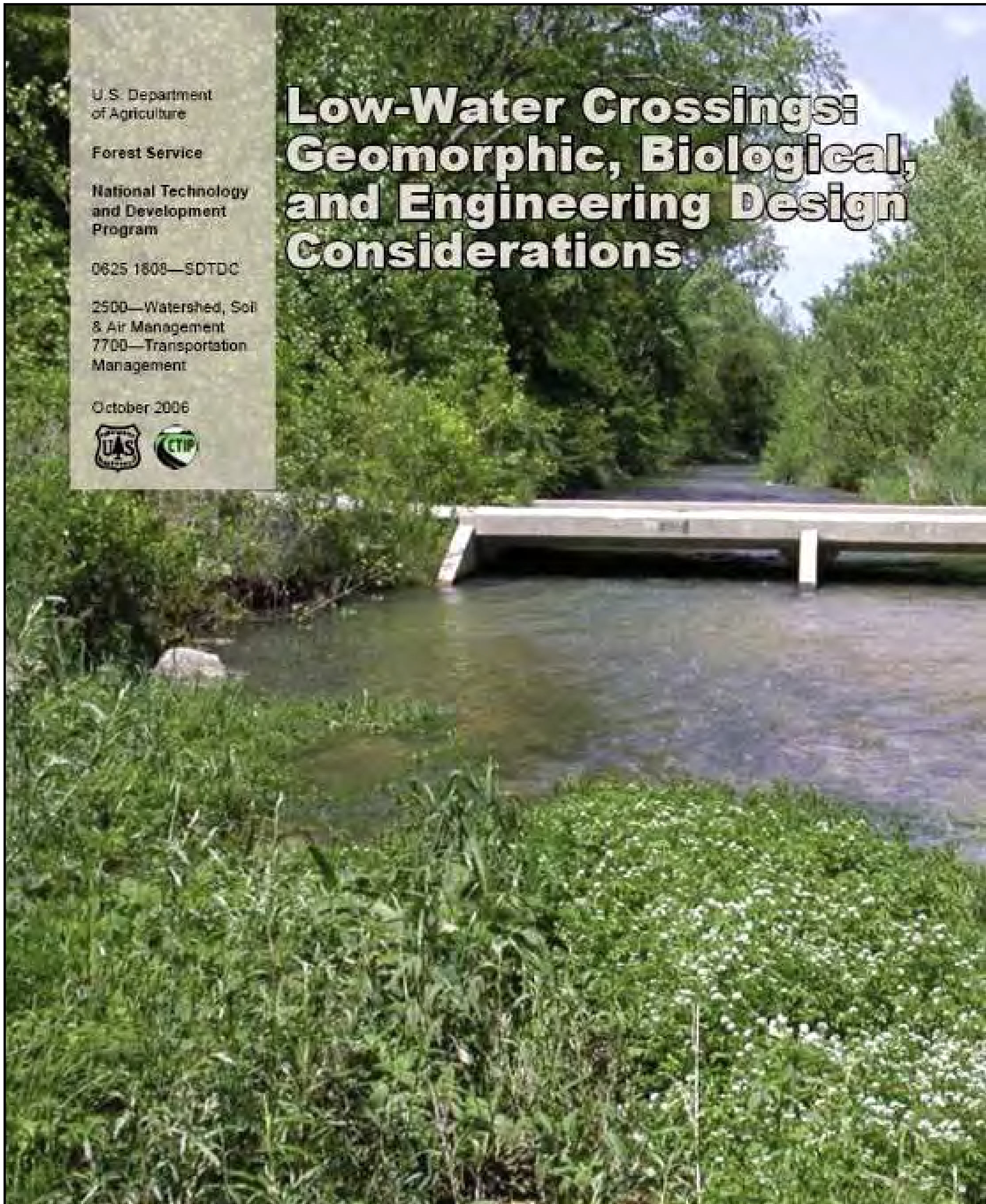
Reference reach

Stream simulation
21 years after construction

18’ x 9’ open bottom arch
BFW 17’, 6% slope
Step pool morphology

Slide courtesy of Kozmo Bates, AquaKoz


Few’s Ford—Eno River, NC



http://www.fs.fed.us/eng/pubs/pdf/LowWaterCrossings/index.shtml

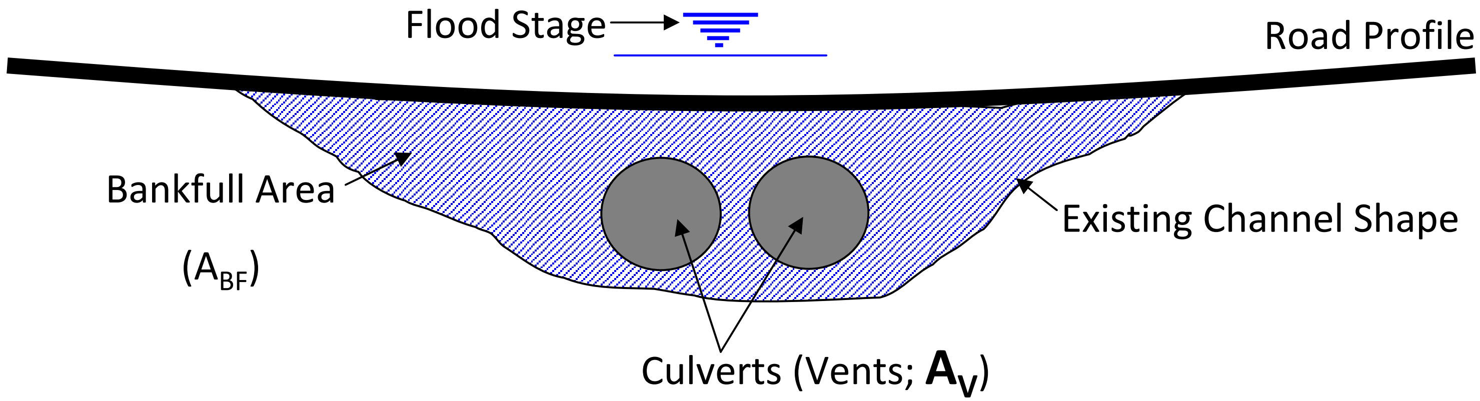
Overview:

- Planning: The Big Picture
- Site Selection
- Design Elements, Considerations and Tools
- Low-Water Crossing Types: Pros, Cons, Idiosyncrasies, and Anectodes

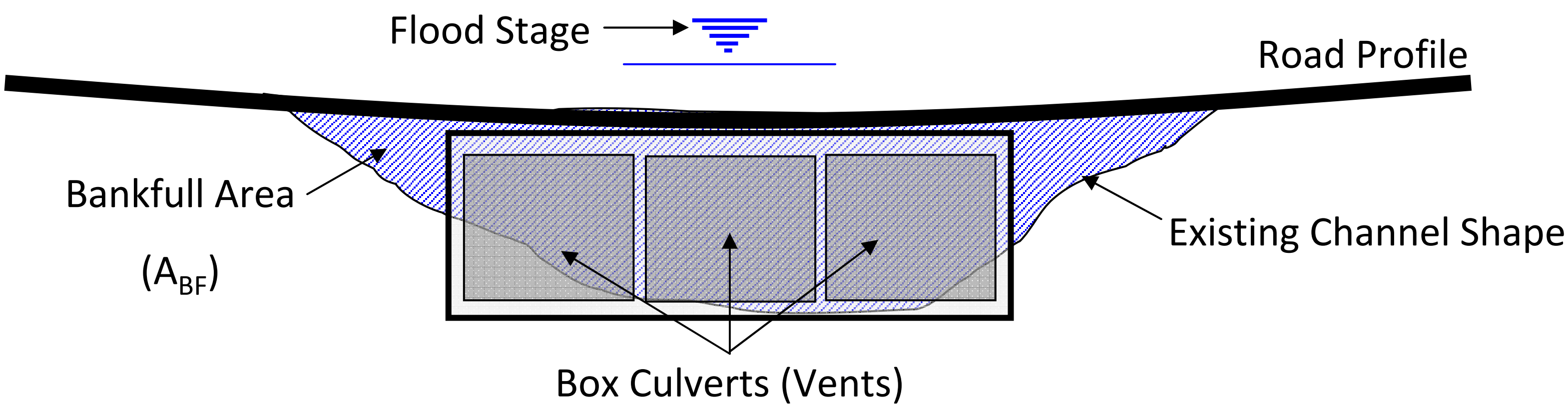
Low-Water Crossings

- Usually built on low-volume roads or unimproved roads on private land
- Cost efficient and easily (relatively) maintained
- Can be built to pass debris and sediment somewhat efficiently
- Static section in a dynamic system

Vent-Area Ratio (VAR)

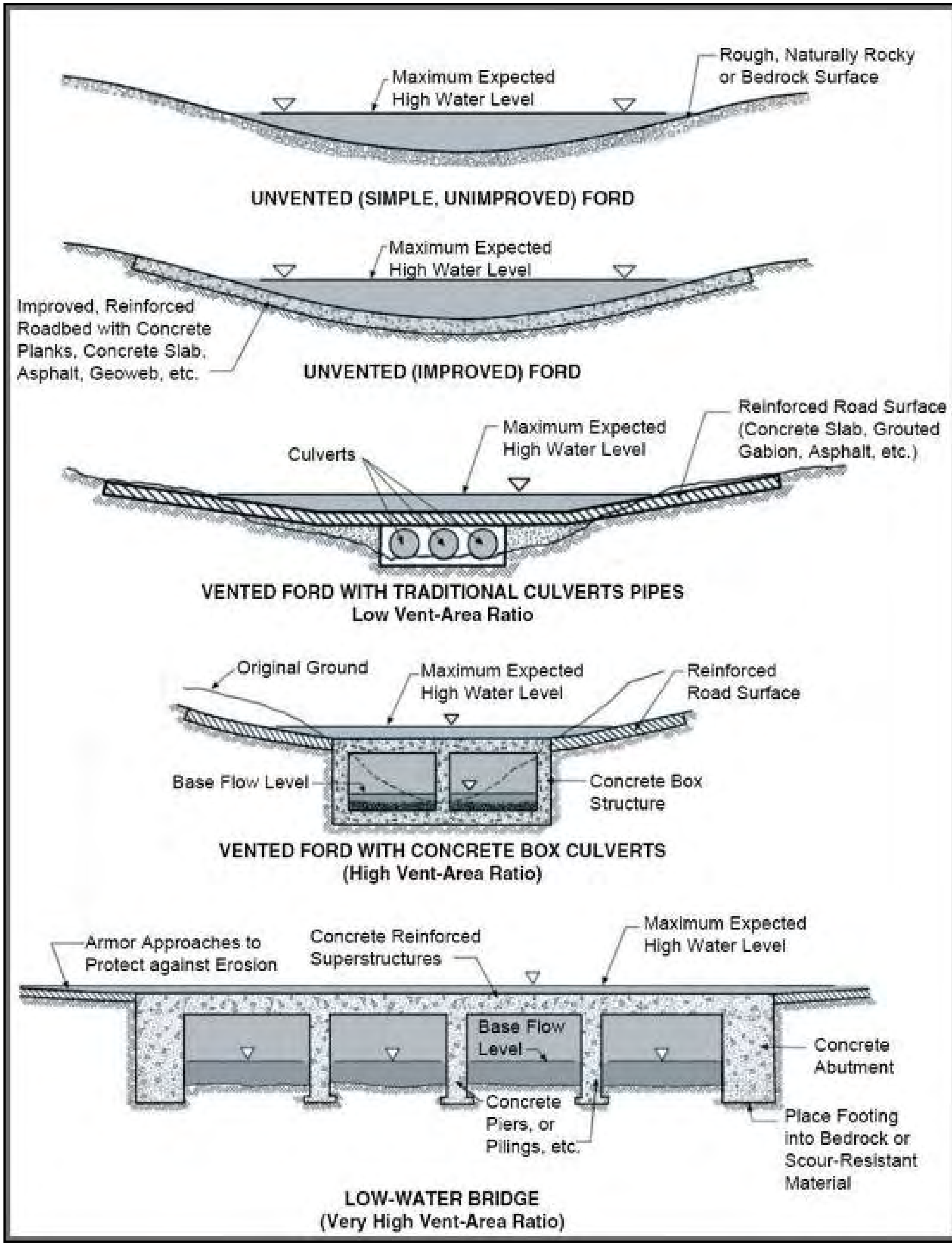


Low Vent-Area Ratio: $A_V << A_{BF}$



High Vent-Area Ratio: $A_V \geq A_{BF}$

Graphic: Modified from Keller and Clarkin (2007)



Low-Water Crossings: Common Types

Graphic: Keller and Clarkin (2007)

Low-Water Crossings

- Affect passage much the same way as culverts
  - Shallow depth, high velocity
  - Drop along downstream face
  - Vents (culverts or concrete boxes) clean and free of substrate
- All different barrier categories—complete, temporary, and partial
- More improved usually means bigger barrier


Illinois
Texas

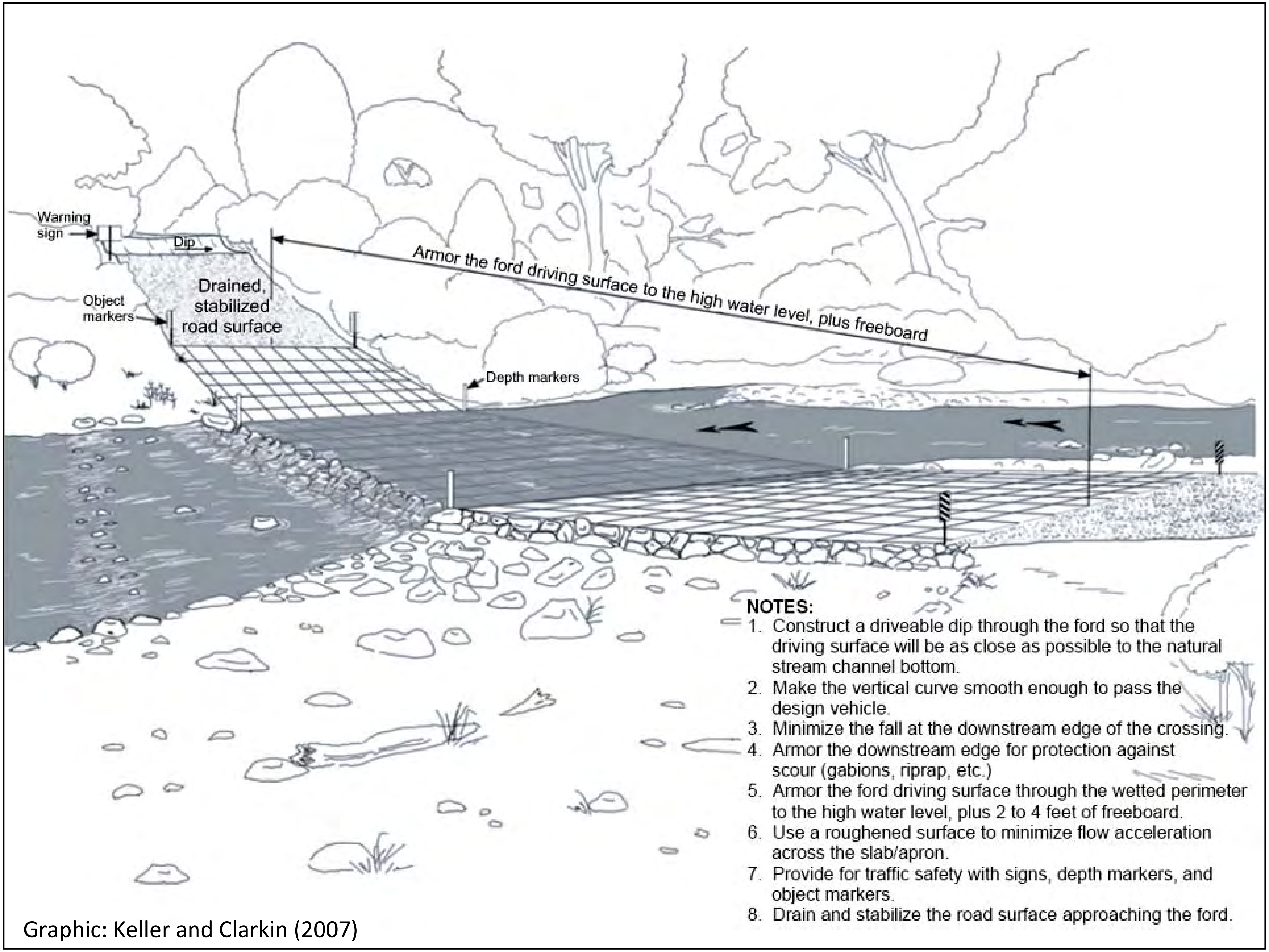

Arkansas

Low-Water Crossings: Analysis and Design

- Place the crossing within the context of the watershed
  - Transport or Response Reach???
- Conform to existing channel geometry and slope
- Match the crossing to the shape of the existing channel
- Align the crossing perpendicular to the downstream axis of the channel


Oregon
North Carolina

D. Porior Photos



Graphic: Keller and Clarkin (2007)

Low-Water Crossing Barrier Cliff Notes

- Complete Barriers
  - Downstream edge creates an elevation drop
  - Crossing vents are undersized corrugated metal or concrete box culverts
- Temporary Barriers
  - Livestock and/or equipment crossings where streamflow is fast and shallow (less than six inches deep) across smooth or uniform surface
  - Stream flows through rather than over course road surface material
- Partial Barriers
  - Road surface is covered with debris;
  - Upstream or downstream margins show signs of erosion or instability.

END