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

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Hello, and thanks for the introduction, David.

Over the next 45 minutes, I'll provide an overview of fish and aquatic organism passage at culverts and low-water crossings. I plan to cover a good bit of material, but won't have enough time to go into great detail. So, please feel free to contact me at any time to further discuss or get additional information on anything I talk about today.

I need to get through the entire slide set so that we cover elements outlined for continuing education credits. So, please hold questions until the end of the presentation.

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"

This netmeeting is the third associated with the Center presented in the last year and a half covering Aquatic Organism Passage. The first, part of a series sponsored by NRCS Biologists, was moderated by myself and included Scott Jackson, Kozmo Bates, and Dick Quinn. These national experts discussed Passage Ecology, Culverts and Tidegates, and Fish Ladders.

The second, delivered by me during another monthly netmeeting, covered largely the same material, with special emphasis on passage ecology and tools relevant to the East Region.

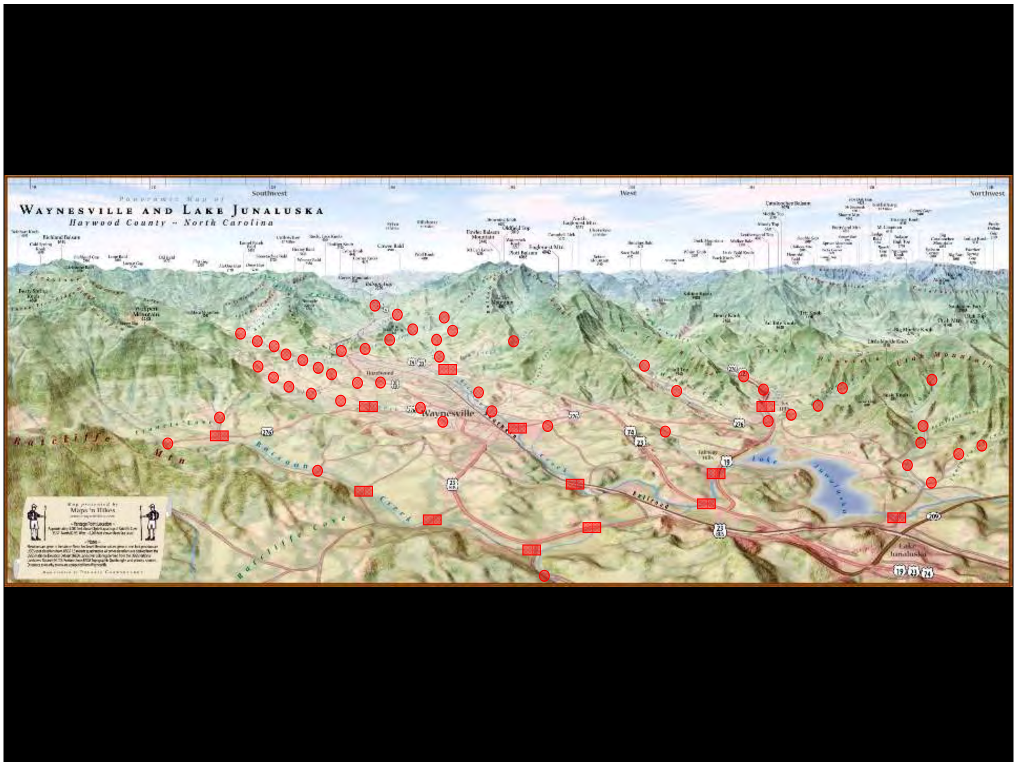
I encourage you to consult these two presentations for additional basic information on passage ecology and passage techniques—They're archived online or I can send either by request.

Today, I'll focus on road-stream crossings and their effects on river function, passage, and conservation biology. The first portion will focus on culverts, and the last 25% or so will concern low-water crossings.

So—here's a recurring theme I'll repeat a few times. Road-stream crossings are meant to be static sections in the most dynamic part of the landscape. So, they often pose problems for passage and stream stability. Although the theme of today's talk is aquatic organism passage, I'll be spending most of my time talking about how rivers interact with the landscape.

My reasons for this approach are:

1) Understanding how a river is "supposed" to look at a crossing is key to diagnosing the reasons passage and site stability might be impaired
2) You'll need to know a bit about river mechanics to know why a crossing is a barrier AND how to fix it.
3) And, using a geomorphic approach to assess passage condition is useful because we don't know the locomotive ability of a whole bunch of aquatic organisms.



So, when you take a look at any given watershed, the extent of road-stream crossings can be hard to get your head around. For example, a good rule of thumb is that there are 2 miles of road for every mile of stream in the eastern US, but how many times do those roads cross streams??? Usually quite a few.

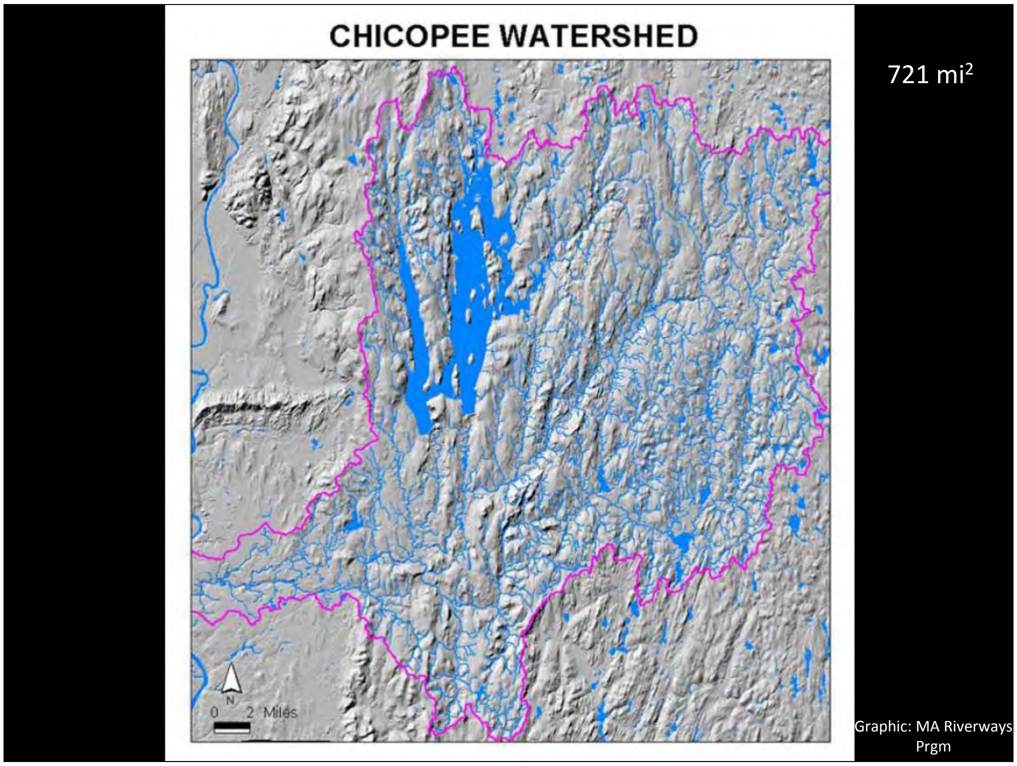
[CLICK] For the most part, bridges aren't usually a problem for either passage or stream function.

[CLICK] Culverts are much more numerous across the landscape—in fact culvert densities between 3 and 5 culverts per square mile are common.

That equates to over a million culverts in perennial streams across the US, and most of those are a problem for stream function and passage.

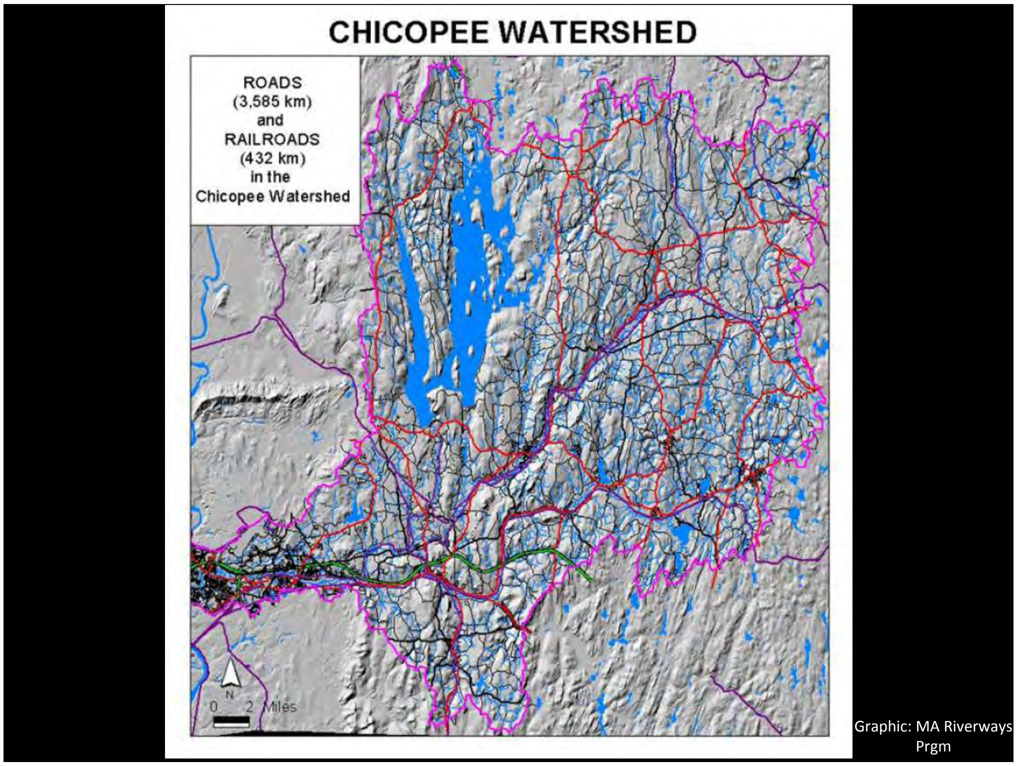
The biggest problems for populations arise when [MOUSE OVER] a series of culverts chops up a stream at many road crossings creating short segments of disconnected habitat.

[CLICK] Figures on low-water crossings are not easily obtained, but are likely on par with culvert numbers.



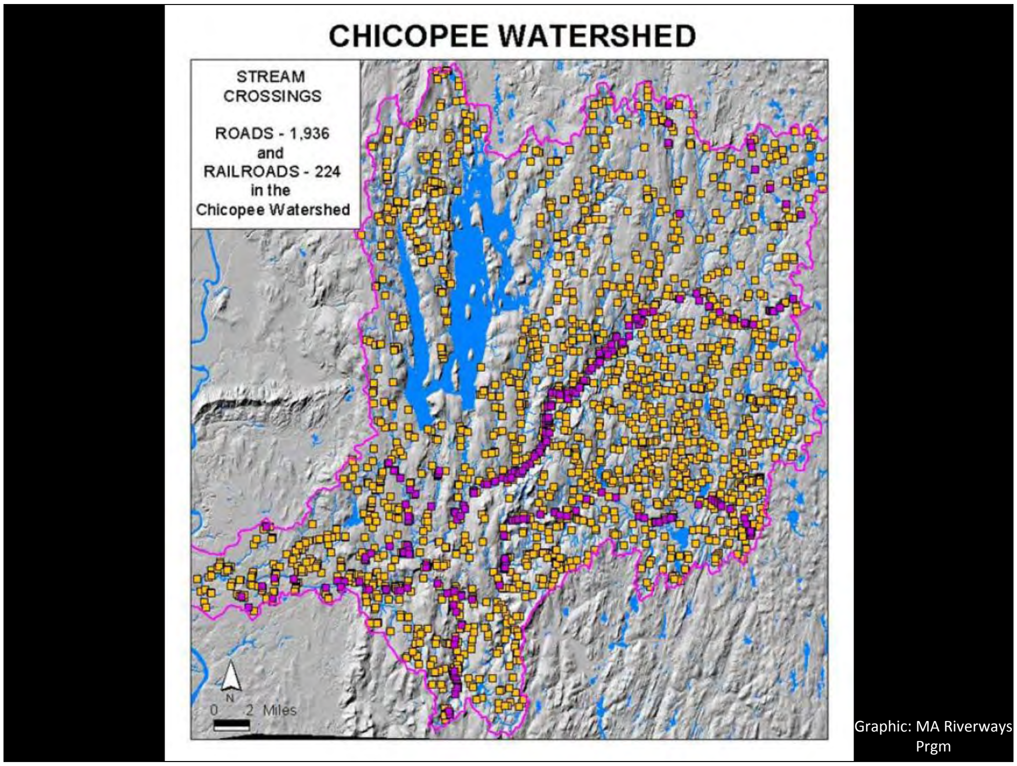
Here's an example of crossing density in a relatively small watershed in Massachusetts. This slide shows watershed hydrography, or the network of rivers, lakes, and wetlands.

This is the amount of habitat that'd be available to native aquatic animals in the absence of development.



Now, let's overlay the network of roads and railroads—about 2,500 miles in all.

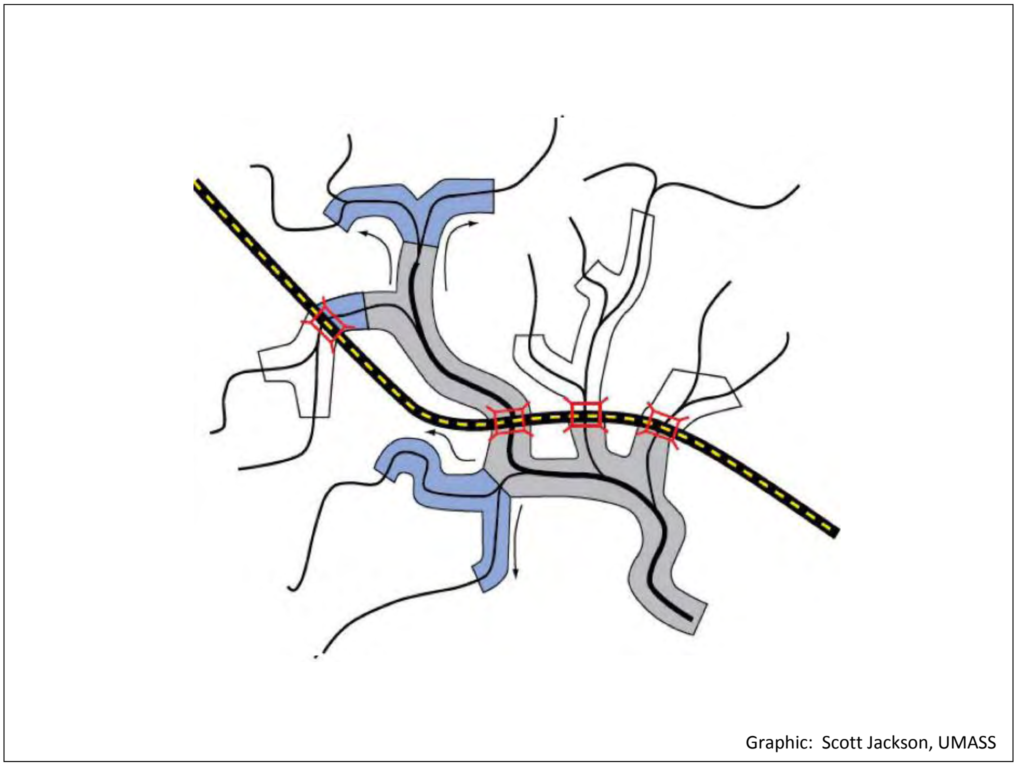
Road density in the Chicopee watershed is 3½ miles of road or railroad for every square mile of watershed.



Here is every location where those transportation routes cross streams—2,160 crossings in all.

If you assume that at least half of these are some sort of a barrier to passage, you've got more than 1 barrier crossing for each square mile of watershed.

As you might imagine, this creates a riverscape where there aren't a lot of stream reaches connected to themselves or other stream systems.



Zooming in on one of those reaches helps to illustrate the effect these crossings might have had on brook trout in the watershed.

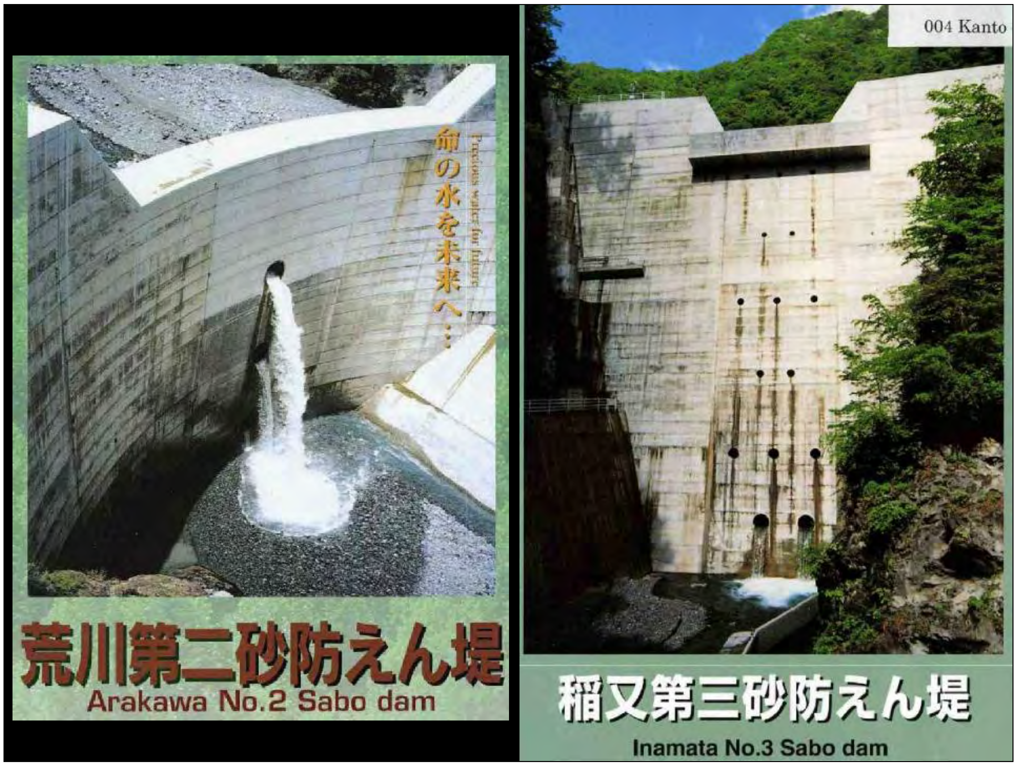
Prior to development, a population of brook trout occupied mainstem reaches of the network for most of the year, shown here in gray.

[CLICK] During spawning season, adult fish would move into headwater tributaries—shown in blue—to mate and deposit eggs.

[CLICK] However, construction of a road with substandard culverts blocks access to some of the spawning areas. This impairs reproduction, which decreases the overall population size and health.

This story can be told across most of the native range of eastern brook trout, and is a primary factor responsible for depressing many populations. In fact, most intact groups are found in small headwater areas across a fraction of their pre-development range.

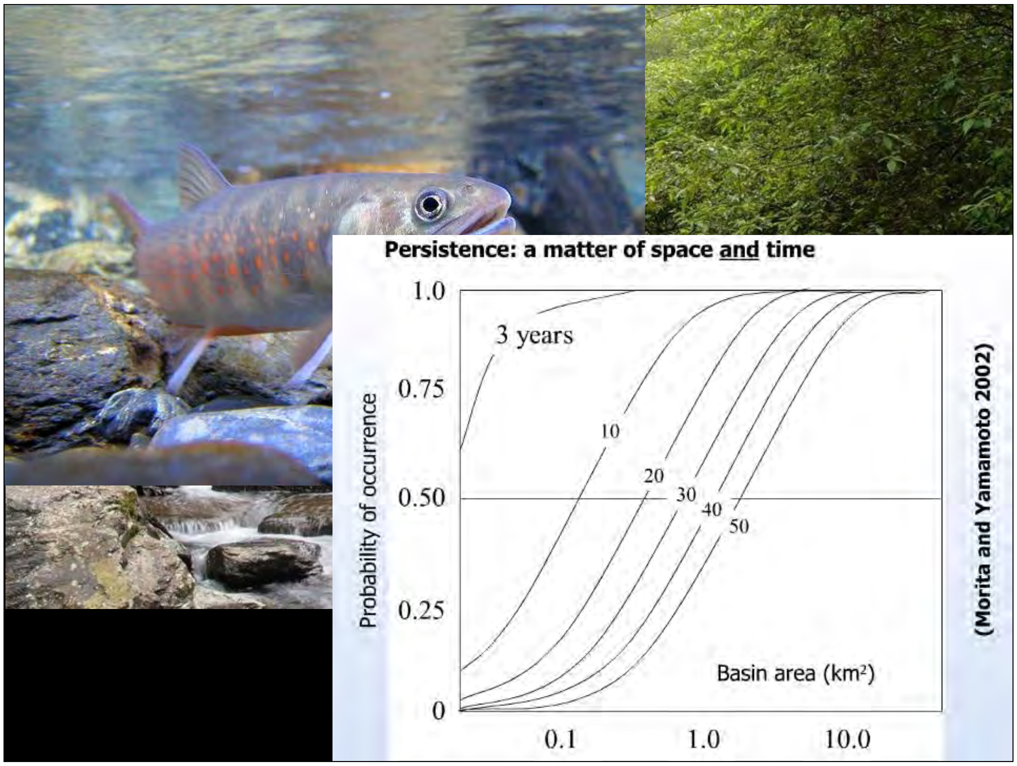
However, absolutely quantifying the effects this type of isolation has had on larger populations is difficult to do. We can often only make generalizations about present status and future chances for survival.



A recent study in mountain streams of northern Japan provides an interesting example of the effects of fragmentation in riverine systems. Sabo, or check, dams have been built by the thousands in an effort to control sediment discharge and mitigate major damage from debris flows and landslides generated by precipitation, earthquakes, or volcanoes.

These dams have been built for hundreds of years, but the biggest structures and greatest numbers have been completed in the last 50 years or so.

They provide some protection from major sediment events, but only have a finite amount of storage capacity.



They range in height from more than 100 to less than 5 feet, but their [CLICK] effects on white-spotted charr, resident salmonids related to brook trout, have been dramatic.

These fish exist as larger migratory individuals and small resident fish that normally interbreed. But, sabo dams are complete barriers that have isolated habitats and populations into many unconnected fragments.

[CLICK] Two researchers have shown that the probability of occurrence—or just survival—is related to watershed size, AND that genetic and population problems can occur in as little as 30 to 35 years following isolation. In addition, these researchers saw physical deformities on fish during field work that are usually associated with small population genetics. They've speculated that about 1/3 of the populations they studied will disappear in the next 50 years.

This study from char in Japan lends insight into the Eastern US's brook trout. Similar responses are likely occurring in isolated populations across the 16 states where they now persist.

Biological Consequences of Impaired Passage

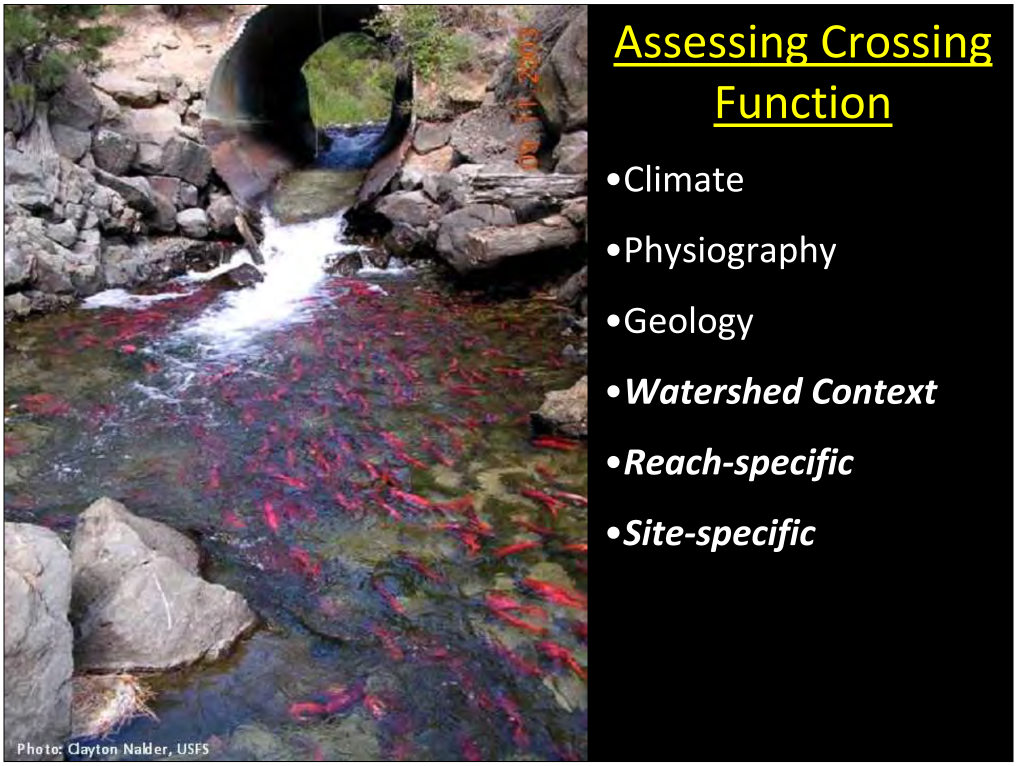
- Fragmented populations more susceptible to serious decline or extinction
- Reduced gene flow leads to genetic problems
- Poorly distributed populations have little or no buffer to catastrophe

So, restricting animals to small or isolated habitat patches by impairing migration has a number of consequences.

Complete barriers can, over years, extirpate migratory animals in upstream reaches.

Fragmented populations are more susceptible to serious decline or extinction, and reduced gene flow can lead to genetic problems that limit population fitness.

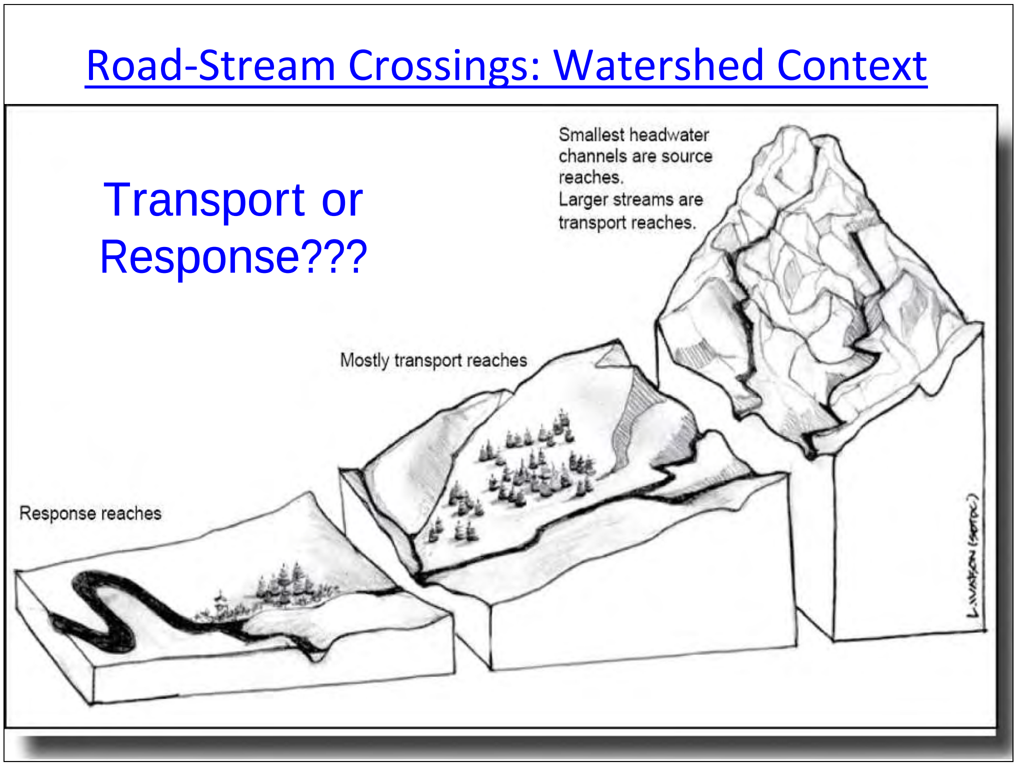
Populations that are poorly distributed across a river basin have little or no buffer to catastrophe.



Evaluating the effects a road-stream crossing has on passage can be difficult. In a few cases it's obvious—like these kokanee blocked by a culvert in Idaho. But for the rest of the cases—those where there aren't any bright red fish blocked below a culvert—gathering information about the stream system will help you understand how a crossing affects stream and passage condition.

Again--USING A GEOMORPHIC APPROACH WILL ALLOW YOU TO ASSESS PASSAGE CONDITION WITHOUT A DETAILED KNOWLEDGE OF INDIVIDUAL STREAM ORGANISMS, THEIR MOBILITY, OR MIGRATORY HABITS. Quantifying the departure of a stream from its "natural" state will allow you to describe the relative passability of a culvert.

Climate, Physiography, and Geology conspire to create watersheds, which is where we work. Identifying the factors that govern landscape condition is key to many of the types of work we do—and it's the same thing for aquatic organism passage.



Placing a crossing within the larger context of its watershed will help you to quantify the effect a site has had on stream morphology.

We know that watersheds can be segregated into 3 component parts—headwaters, transfer, and depositional. Knowing where a given road-stream crossing fits within these groupings will lend insight into a whole bunch of things—average substrate size, channel gradient and planform, the relative influence of vegetation on channel stability, and the important species and habitats.

Since the basic function of a river is to move water, sediment and organic material downstream, we can [CLICK[classify the stream segment affected by a crossing as either a Transport or Response reach. The central question to ask is this— “Is the main function of this reach to move material through it or to respond to the material delivered”???

Here are examples of transport reaches in North Carolina and New Hampshire. Transport reaches are characterized by steep gradients, boulder and cobble substrates with pockets of gravel and smaller material, and narrow or non-existent floodplains.

Channel morphology is often cascade or step-pool types, and the banks and beds are durable because they're made up of big rock and well embedded large woody debris.

Bankfull channel indicators can be hard to find because some reaches aren't fundamentally alluvial. Many of these channels are composed of lag deposits left by landslides, debris flows, or glaciers, as in the NH photo. Incidentally, a good surrogate for bankfull elevation in reaches like these is to measure the tops of the largest rocks across the channel at a section or along channel steps between pools.

Road crossings in these systems need to be steep and able to carry basically constant and periodically high bedload rates and large pieces of wood. Limited interaction between the river and its floodplain confines most high flow events to the channel margins. Channel changes associated with crossings are usually localized to the area near the road and culvert, extending up and downstream only a few channel widths.

Virtually all other stream segments in a watershed can be classified as response reaches.

Slopes can be locally steep, but the major differences are seen in overall smaller substrate sizes, more complex channel morphology, and the common presence of a well-defined floodplain bracketing the river.

Plane bed and pool-riffle architecture—as seen in these streams in Tennessee and Maryland is common. Substrates are mostly cobbles and gravels, and riparian vegetation helps govern channel stability, location, and geometry.

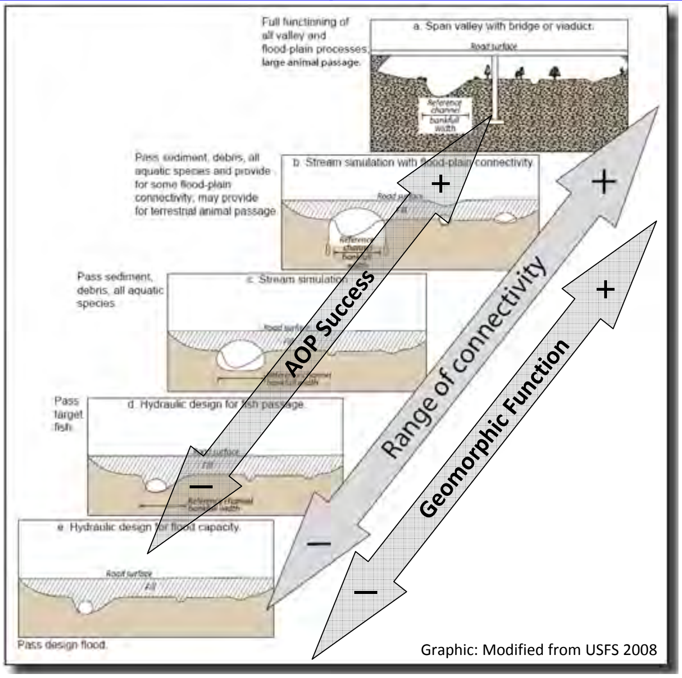
Lower elevation response reaches usually have pronounced meanders and complex morphology—like this river in South Carolina, and include dune-ripple channels such as this stream in Alabama just a feet from the ocean. Substrates are generally small and in large supply, and large woody material loads can be substantial.

Response reaches are where the majority of our customers live and work, and where we are most often asked to help. These reaches are sensitive to landscape and hydrologic changes within a watershed, and adjustments can be significant and fast.

Consequently, crossings in response reaches must be designed with consideration for a wide range of channel changes with the potential to extend for significant distances up and downstream.

These sites can be complex, but knowing the general tendency of a reach will help you identify the general trajectory of that reach with respect to geomorphic change.

Road-Stream Crossings: Watershed Context



At any road-stream crossing, the options for getting traffic over the river could range from a small culvert sized to handle a 25-year storm to a valley-spanning viaduct.

Addressing the watershed context of a crossing site allows you to identify the type of structure needed to produce the desired range of ecological connectivity between a river and its landscape and [CLICK] the level of geomorphic function necessary to ensure that the crossing has a reasonable chance of persisting through time.

[CLICK] In addition, as the relative range of connectivity and geomorphic function of a crossing structure increases, so does the relative level of passage success for animals that transit riparian corridors.

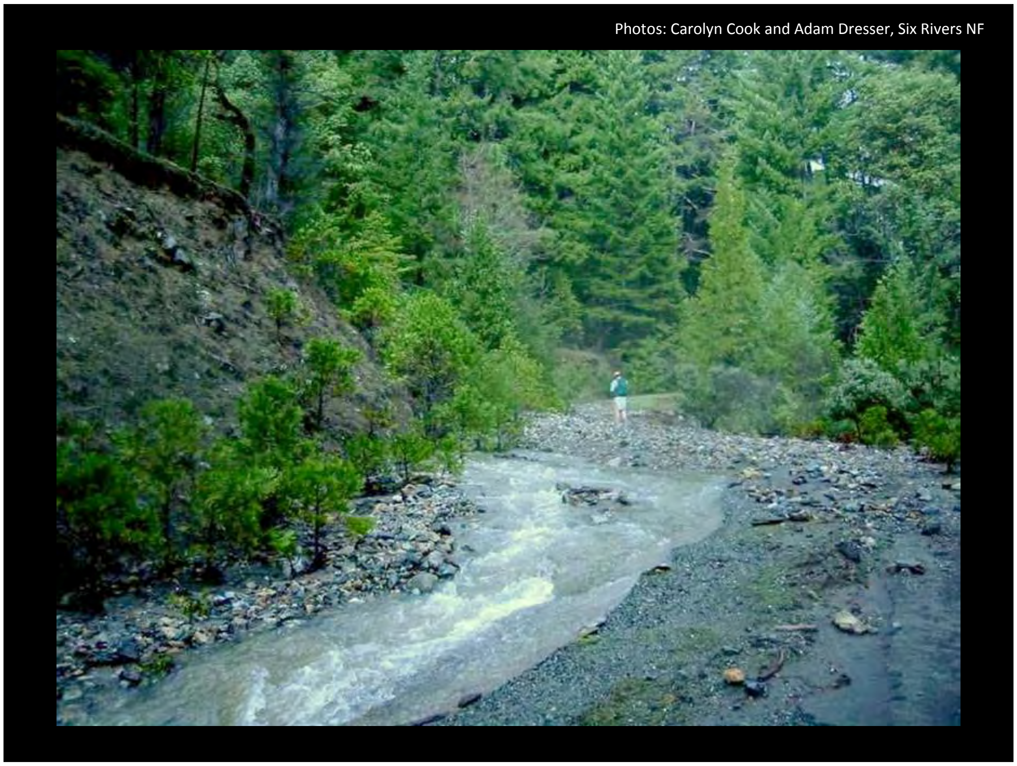
Geomorphic Effects of Road-Stream Crossings

- 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**

Taken as a whole, road-stream crossings often impair physical and chemical processes that create and maintain habitat.

Road crossings interrupt sediment and wood transport cycles, alter ground and surface water flow patterns, and can shift riverine habitat into areas more similar to lakes and wetlands.

[CLICK] Road crossings are meant to be static in a changing environment—a really tough standard to meet. Often, the environment around a road-stream crossing can change quickly, and in a big way.



Here’s an example of how one 48” culvert can significantly affect an entire landscape.

This pipe ran under a road in the Six Rivers National Forest in northern CA. Debris plugged the culvert, the stream backed up along the uphill side of the road prism, and a good portion of it was diverted and started flowing down the roadway.

The stream gradually crossed the road crown, found a low, erodible spot along the shoulder, and took off down the slope towards its former channel.

In a matter of hours, it carved a new stream channel through a previously forested hillside.

And began to erode the toe of the hillslope near its former channel location. As the toe of the slope became oversteepened, the hillside slipped and a large amount of sediment was delivered to the mainstem river at the bottom of the picture.

Here is a shot of the runout zone, and the impressive amount of erosion that occurred. This sequence of events can happen anywhere you have woody debris, topography, and runoff—which is a good chunk of the world.

Road-Stream Crossings: Watershed Context

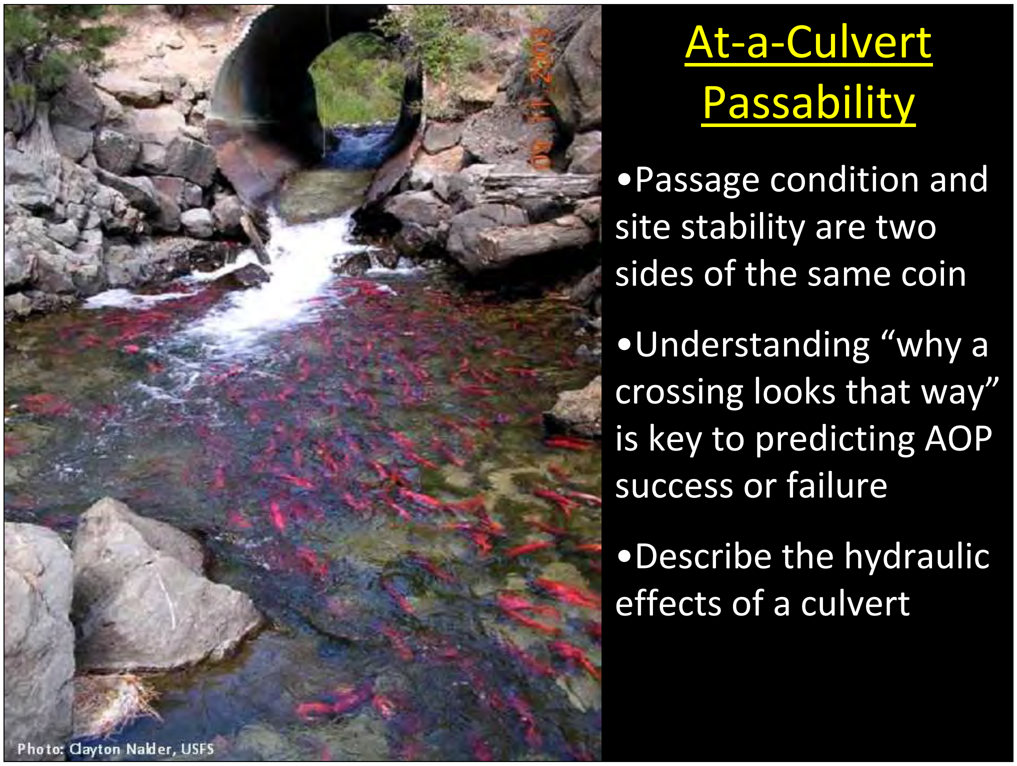
- Insight into understanding the present state of a given road-stream crossing
  - Event Chronology
- Highlight potential for geologic hazards to affect crossing function and longevity
  - Slope stability
  - Migrating headcuts
- *These factors are key to diagnosing present condition and forecasting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

Road-stream crossings can have a significant effect on the physiography of a watershed. That said, its useful to keep in mind that applying a larger view when working with a single crossing can help project success.

Understanding the types and recent histories of events that shape the present landscape can help you diagnose causality at a crossing.

Outlining the geologic hazards in an area can highlight locations where special attention may be needed.

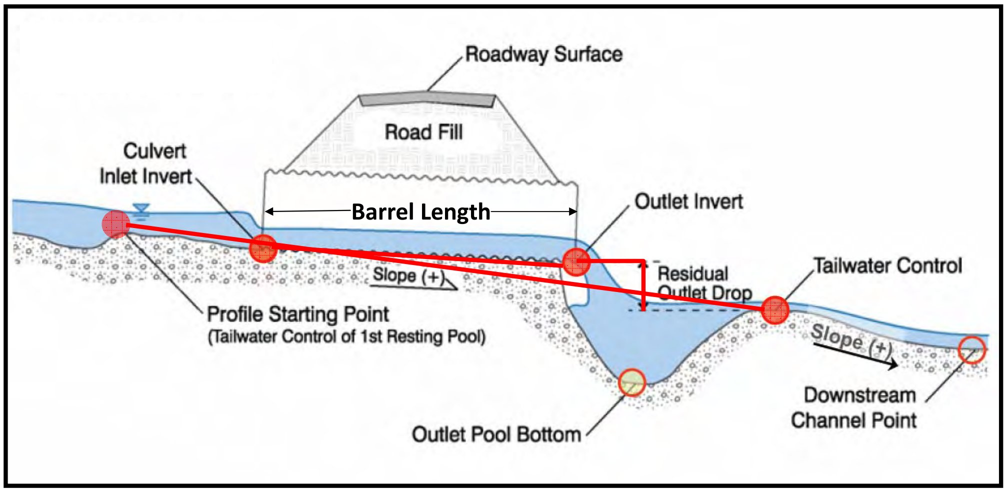
Taken as parts of the bigger picture, considering these factors can help you diagnose present condition and put some errors bars on the range of changes that may occur in the future under alternatives proposed for a crossing project.



So, when assessing passage quality at a given culvert, it helps to know as much as you can about the watershed and reach of stream.

Once the watershed context is framed out, it becomes necessary to describe the hydraulic effects of a culvert at the reach scale—and by extension—the animals that may try to migrate through it.

Road Crossing Anatomy--Culvert



Before we jump into culverts, I'd like to go over a few basic terms and metrics.

[CLICK] The elevations of a culvert inlet and outlet, coupled with its barrel length, give you culvert slope.

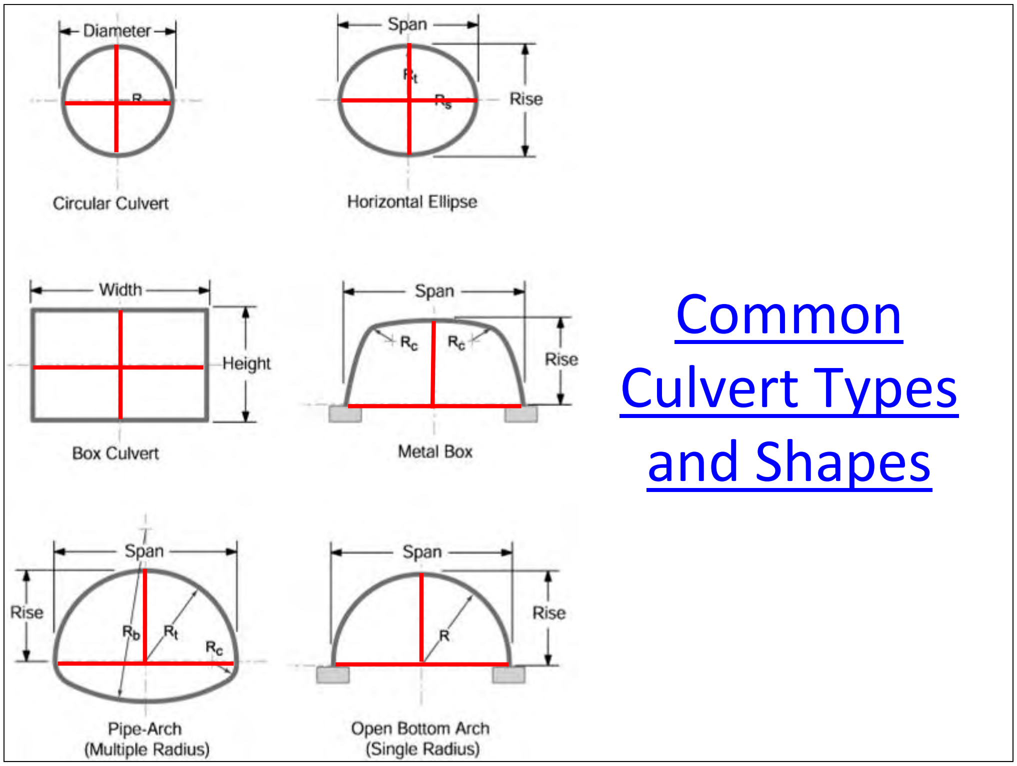
[CLICK] Including the elevations and length between headwater and tailwater controls will help you describe the energy available through the road crossing.

[CLICK] The elevation difference between the outlet of the culvert and the water surface of the pool beneath will help you quantify:

--the jump height a fish must possess to enter the culvert,

--the amount of scour the culvert has contributed to,

--or the amount of incision that has occurred from the downstream direction due to a migrating headcut.



Here is a good sample of most culverts out there today—variations occur, but these are the core set.

Culverts are usually described using two measurements—span and rise—coupled with the pipe's composition.

[CLICK] Span—or diameter in a circular culvert—describes the width parallel to the water surface.

[CLICK] Rise describes the height perpendicular to the water surface.

Generally, any culvert with a circular shape can be composed of high-density plastic or corrugated metal.

Box culverts are usually made of concrete sections, and arched culverts are often made up of metallic sections bolted together onsite.

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.

Most culverts in operation today were designed to pass a specified runoff or flow event generated from the drainage area above the crossing.

In addition, most of these culverts were likely installed at a slope that either matched the road surface or followed the gradient of the stream.

These two factors—sizing a culvert for discharge only and installing it at a fixed gradient—really affect a stream's ability to transport sediment and large woody material.

Here's an example of how conventional culvert design and installation often responds to a live stream setting.

This picture of a replacement pipe arch culvert on Dearborn Brook in Maine was taken just a few days after it was built in 2003. This was not an NRCS project.

[CLICK] This photo shows the same culvert in August of 2007. As you can see, the stream channel downstream of the culvert has eroded, and the culvert is now perched 18" above the outlet pool.

Sometimes two culverts are used to carry expected runoff, but more is not exactly better or more stable over time.

Each of these 6-ft pipe arches is perched, and together they do not provide enough capacity to transmit water and the material it carries through the road crossing without bed and bank erosion.

Whenever I would go to this site during high flow events, one pipe was plugged with debris while the other looked like a firehose. In four years—just 3 snowmelt seasons—these culverts developed a 2-foot drop.

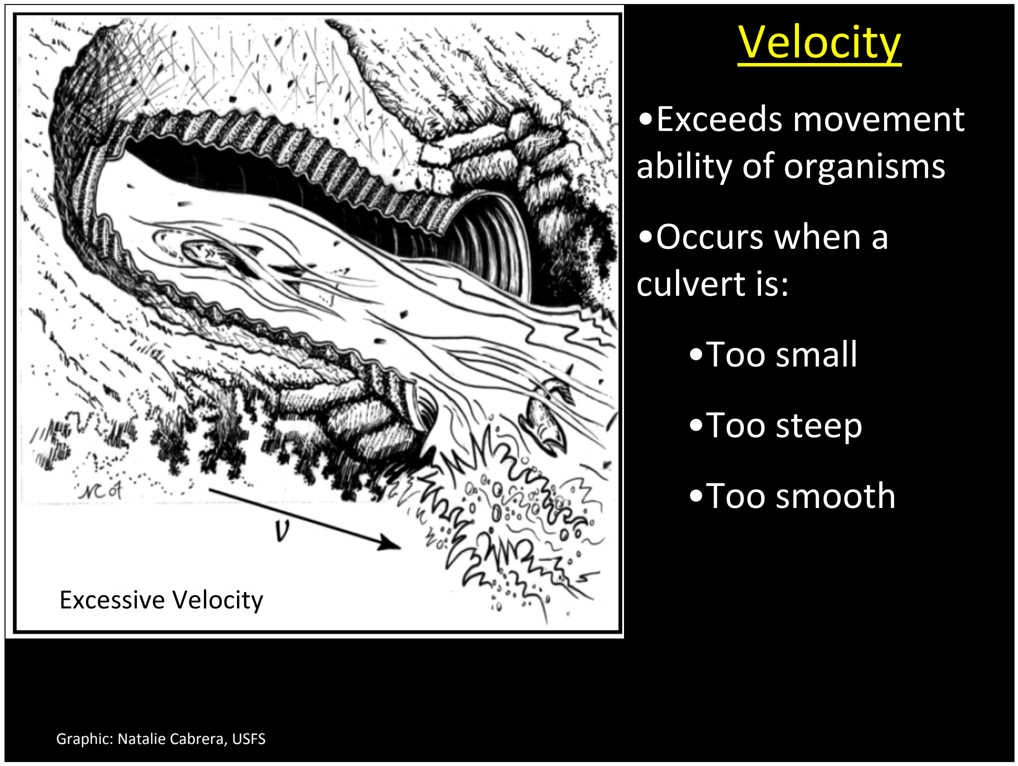
Road-Stream Crossings: Geomorphology and AOP

- 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.

So, we've seen road crossings can affect stream morphology and function in a relatively short amount of time. They also affect aquatic populations quickly—even instantly at the individual level.

Because,

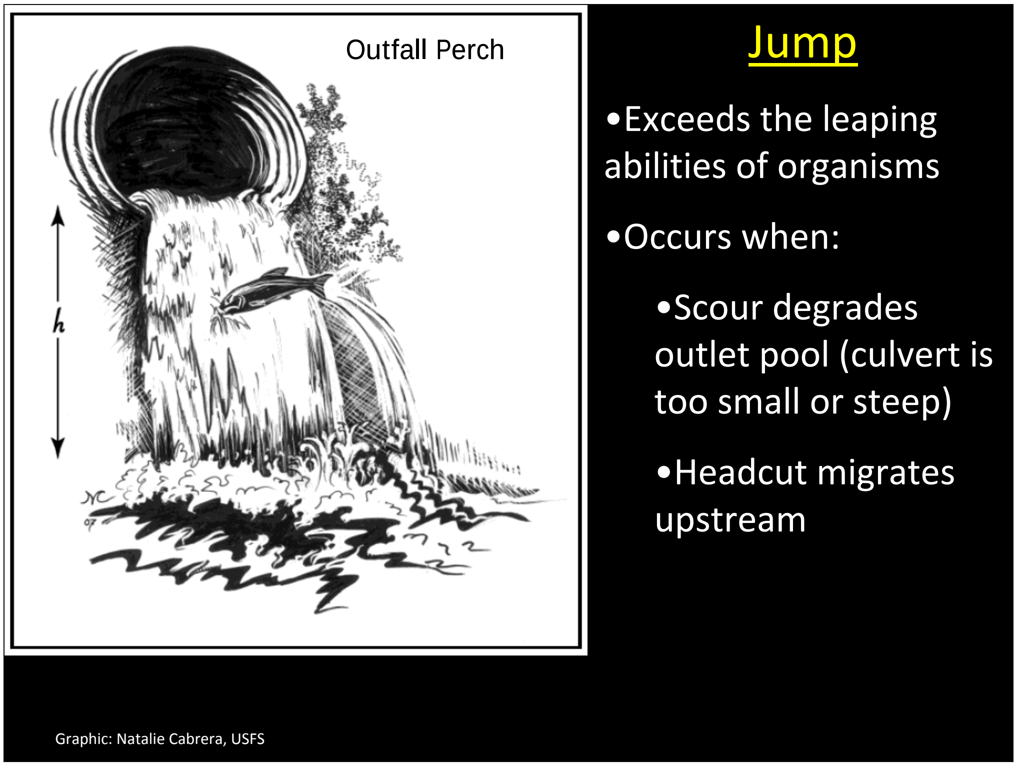
Every aquatic critter has an upper limit on their ability to move—whether its swimming, crawling, wiggling, etc.



When culverts affect stream morphology and hydraulics, they affect the ability of aquatic animals to move upward through the crossing.

This series of graphics describes the types of barriers often created by culverts. I've also tried to outline the crossing conditions present with each barrier type.

Velocity barriers occur when flowing water moves faster than an animal can move in the opposite direction. They're generally seen where culverts are undersized, set too steep, or composed of materials that are too smooth.

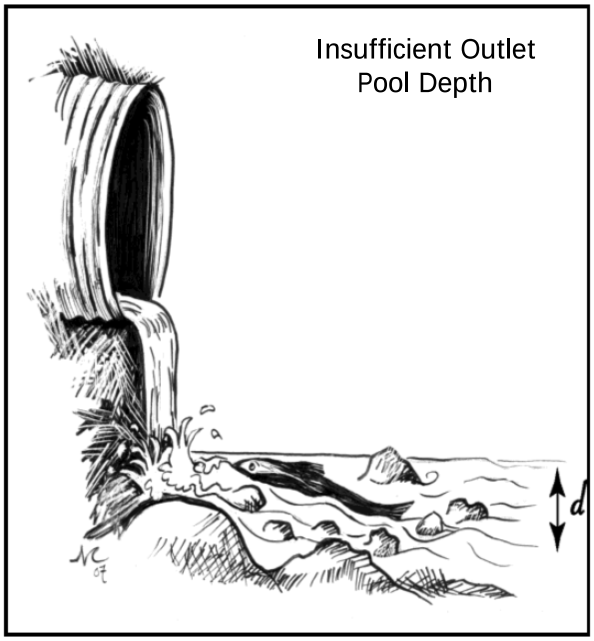


Jump barriers are the result of a large elevation difference between the outlet of the culvert and the tailwater pool. Although some fish can leap quite well, most aquatic organisms cannot. A wise wildlife biologist once told me “turtles can’t jump”.

Jump barriers occur where an undersized culvert causes local scour at the outlet, or when a headcut has migrated upstream and is temporarily stalled at the road fill.

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

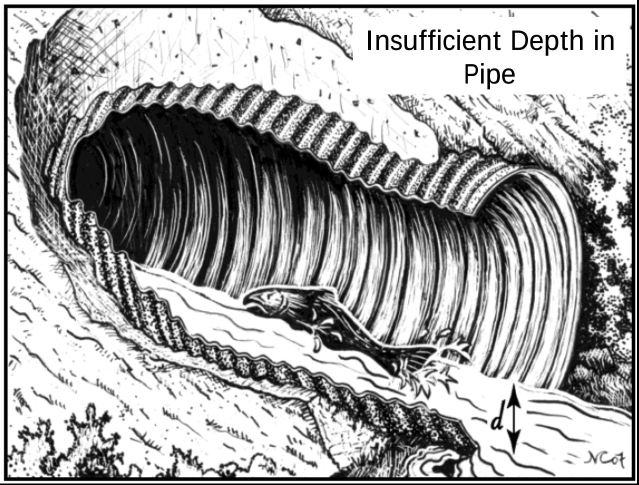


Graphic: Natalie Cabrera, USFS

Sometimes animals cannot enter a culvert because the outlet pool is too shallow for them to negotiate.

This can be caused by riprap added to the outlet overfall in an attempt to stop scour, or when outlet scour has eroded the channel down to immovable substrates or bedrock.

In some cases, insufficient outlet pool depth can be caused by an apron attached to the culvert outlet composed of metal or concrete.



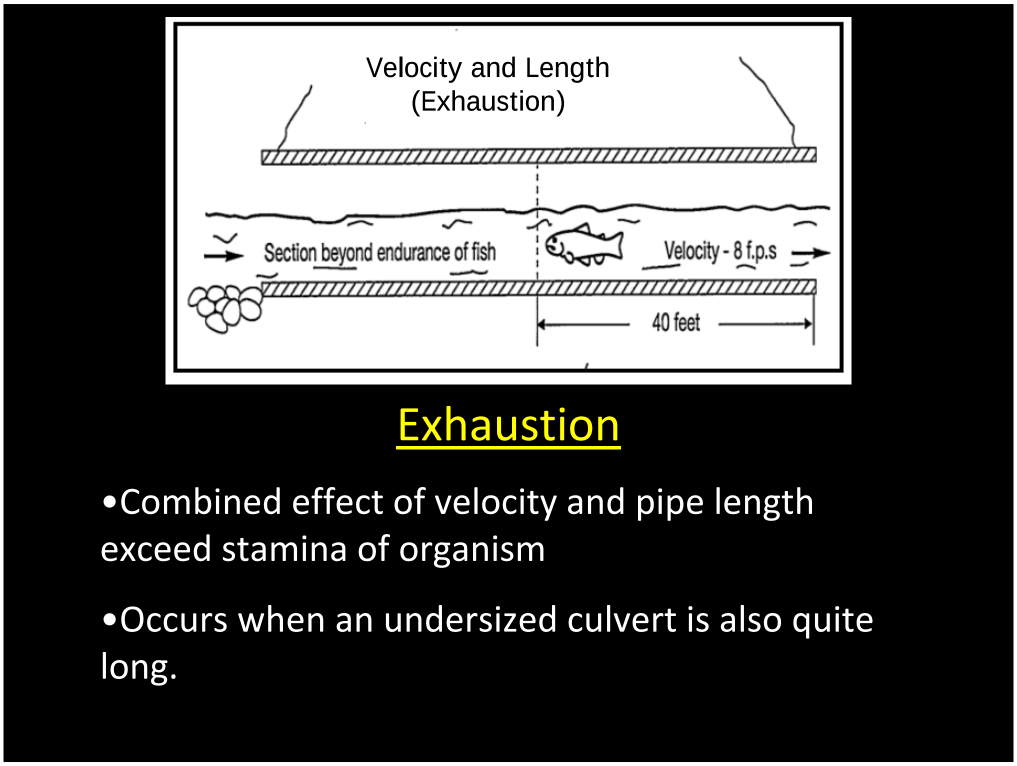
Pipe Depth

- 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

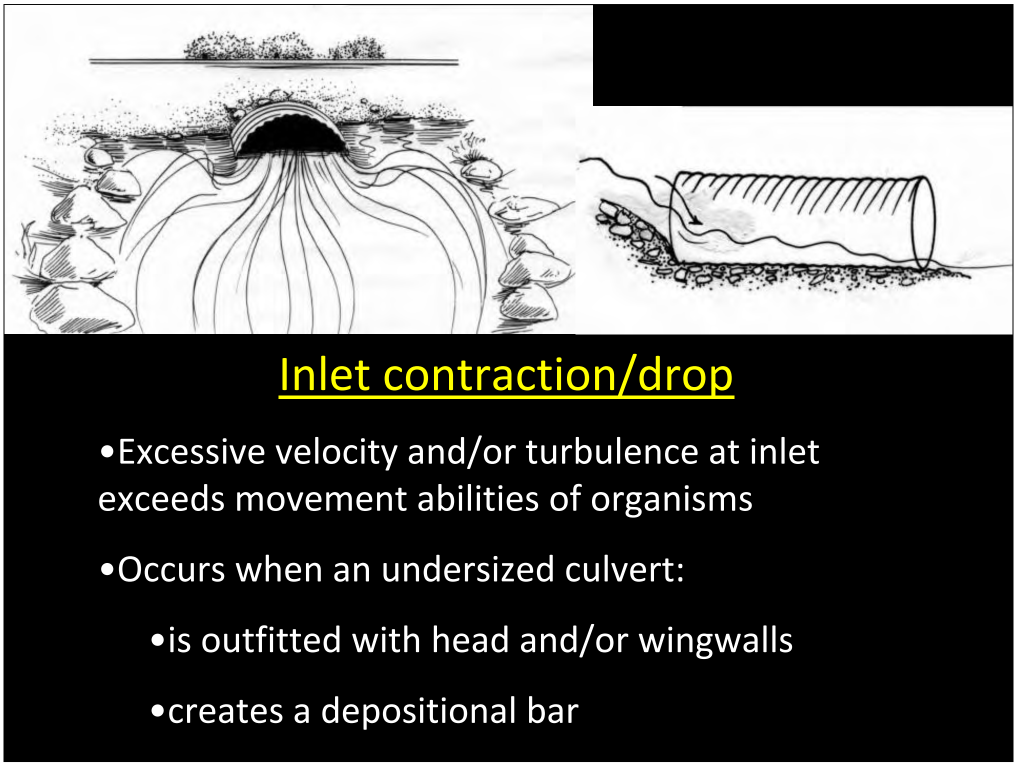
Barriers inside the pipe include water too shallow for swimmers to move through, and shallow flow depths are sometimes paired with turbulence.

This occurs when a culvert has been set too steep during construction, has been oversized for the stream setting, or is subject to widely fluctuating flows.



A long culvert with fast flowing water can be an exhaustion barrier. Animals can only maximize their effort to move for a finite amount of time before muscle fatigue sets in. Once exhaustion is reached, they're usually washed out of the culvert where they'll rest and try again.

This condition is generally produced by undersized culverts running under longer roads—four lanes and bigger.



Critters that make it into a culvert can face additional barriers at the inlet end. When a culvert barrel can carry more water than the inlet will supply, water backs up and drops into the inlet, forming a velocity and turbulence barrier.

Undersized culverts outfitted with headwalls and/or wingwalls often produce this condition. At low flow, you'll often see a depositional bar at the inlet that exacerbates the drop.

Other Barrier Types

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

Here are a few other ways culverts create barriers. Physical factors like debris accumulations, absence of bank or edge areas in the culvert barrel, and discontinuous or absent channel substrates commonly impede passage.

Some animals behaviorally avoid dark tunnels. Also, culvert alignment can create problematic hydraulics inside a pipe when the inlet doesn't line up with the incoming stream channel.

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.

The preceding barrier examples are specific to physical and hydraulic conditions associated with the culvert proper. They're a product of altered stream function adjacent to the road crossing, and often force changes that occur well up and downstream of the roadway.

Thus, it pays to consider a larger reach to assess the full effect of a crossing on passage and stream conditions, and the full range of measures that might be needed to mitigate problems.

This shot of both sides of a culvert crossing will hopefully help illustrate the last point. As you can see, [CLICK] water has backed up at the inlet side, and [CLICK] the culvert outlet resembles a firehose.

[CLICK] At low flow, this culvert looks decent enough. The outlet is not perched, but the barrel is clean and free of substrate. When seen at this flow, its easy to understand why—the inlet is nearly submerged and flow in the pipe is likely near supercritical.

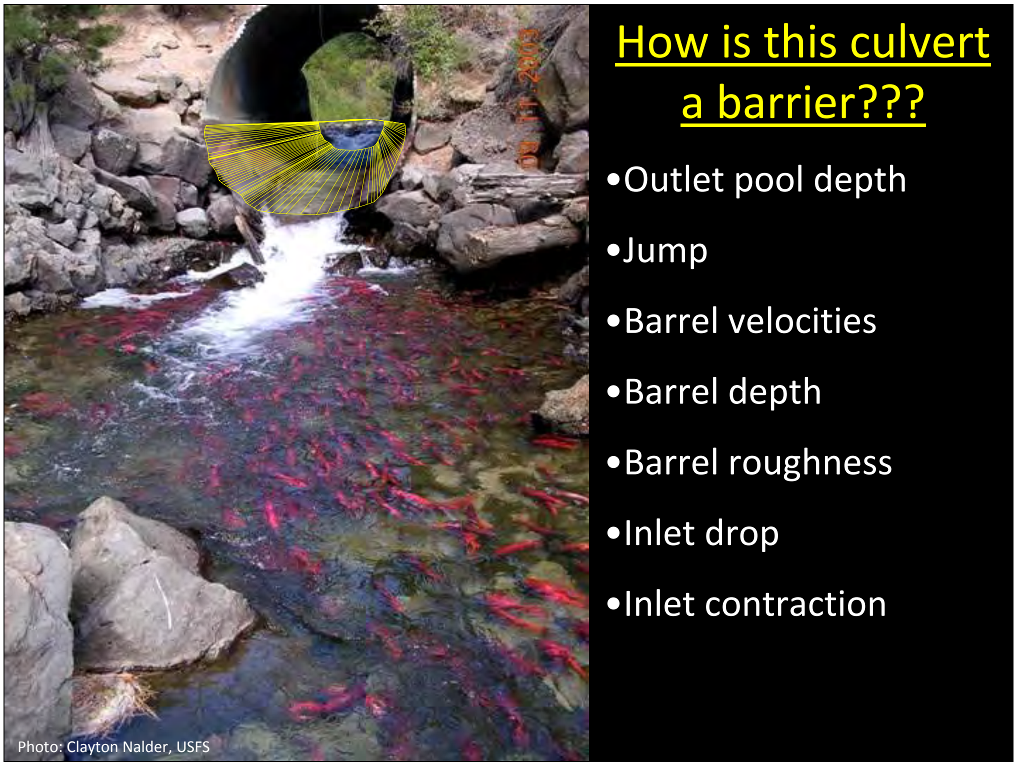
At low flow there are a few depositional features upstream of the inlet, they don't create inlet drop or contraction. Evaluating channel elevation and dimensions both outside and through the road crossing—say, 300' either side—reveals that:

--the span of pipe is less than ½ what it should be,

--the channel slope upstream of the crossing is half as steep as the downstream reach,

--and a bedrock outcrop provides a significant control on downstream erosion.

You need to take a look at a longer reach to identify the full range of passage effects a road crossing creates.



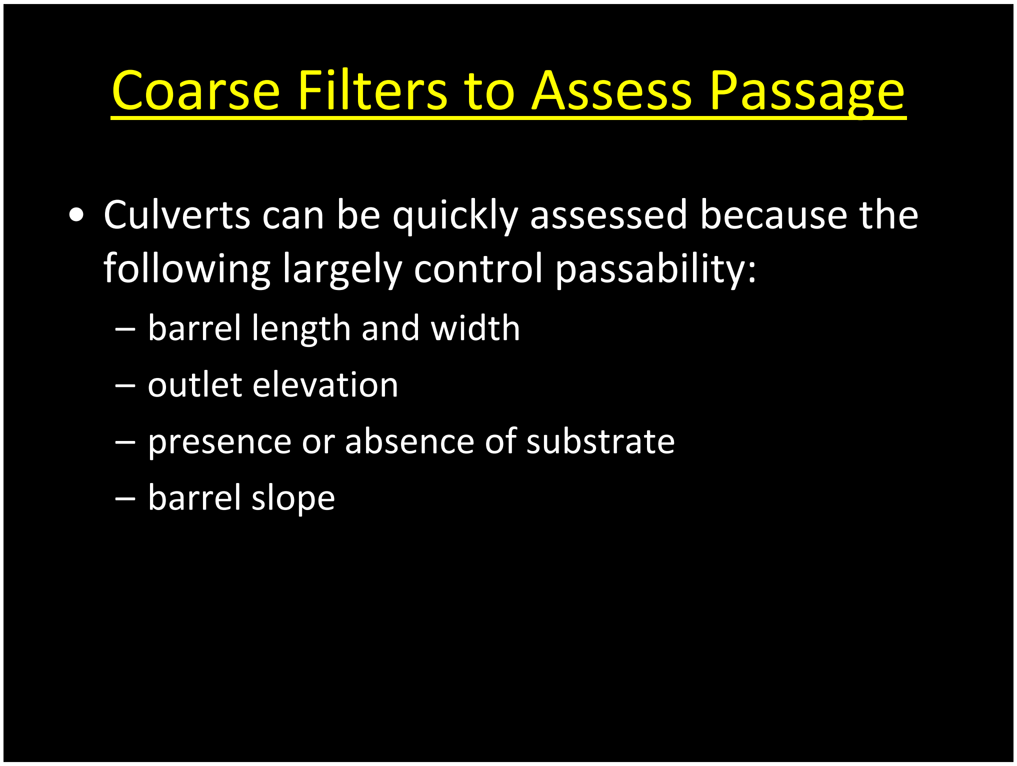
So, returning to this picture on the S. Fork Boise River again, I'd describe the barrier like this:

At this flow, insufficient outlet pool depth and a jump barrier exist at the outlet invert.

Fish able to negotiate that would likely find hydraulic conditions inside the barrel difficult because of high velocities and shallow depths associated with a pipe free of natural roughness elements.

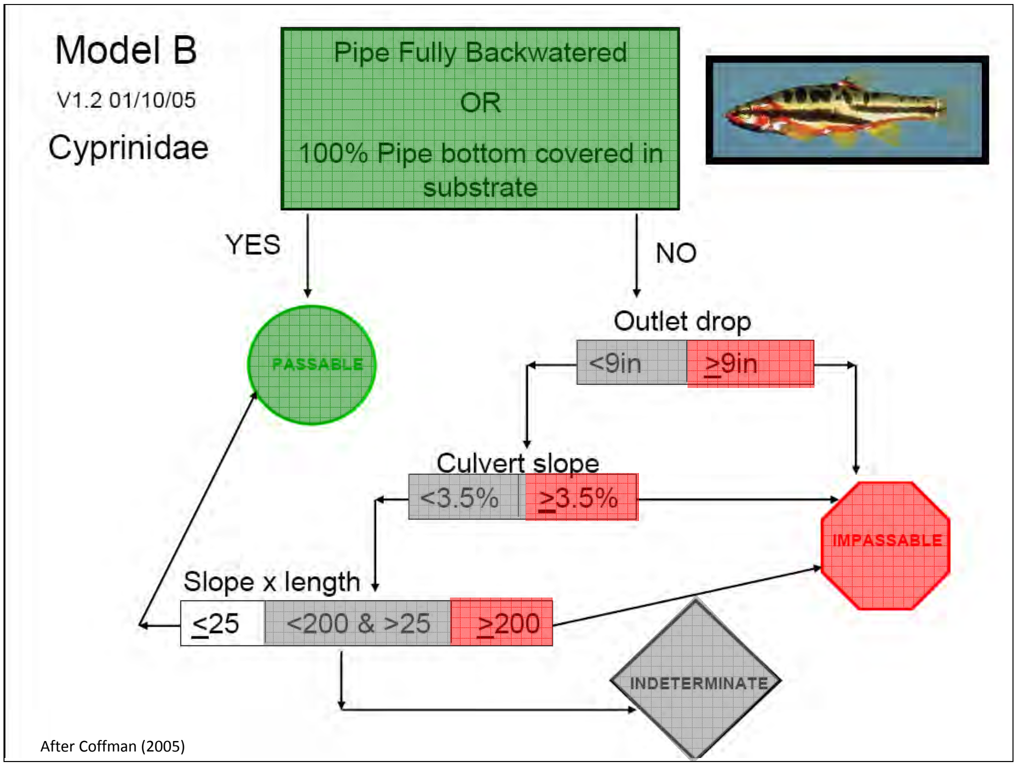
Finally, the drop at the inlet creates another velocity barrier, and if the length and slope of the culvert are known, we could asses its relevance as an exhaustion barrier as well.

A note—[CLICK[When you see a rust or stain line at the inlet end greater than 1/3 to 1/2 of the culvert rise—it's a good indication that the culvert is undersized and that passage and longterm stability problems are likely. That, incidentally, was the fanciest PowerPoint effect I have ever used…



Culvert length, span, slope, outlet drop, and whether or not there's substrate within the barrel are excellent predictors of a culvert's ability to provide or prevent passage.

Folks have used these facts to develop coarse filters for rapid passage assessment at culverts.



This model provides a coarse filter to address passage for shiners, chubs, and dace.

A culvert [CLICK] that is fully backwatered or completely floored with streambed substrates is assumed to be passable—or condition green.

Pipes [CLICK] with outlet drops greater than 9 inches, a slope greater than or equal to 3.5%, or where the slope-length product is greater than or equal to 200 are impassable—or condition red.

Combinations between [CLICK] these two extremes result in an indeterminate answer—condition gray—where additional data and analyses are necessary to fully assess passage conditions.

Ok—So here are some examples of the three categories from the previous slide.

An impassable culvert with a 14” drop and no substrate present in the barrel.

[CLICK] A fully passable culvert where the entire pipe bottom is covered with substrate.

[CLICK] And an indeterminate culvert with no outlet perch and some substrate present in the barrel. However, as you can see—if flow drops it appears as though a perch might develop which would create a barrier. So, additional measurements are needed.

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

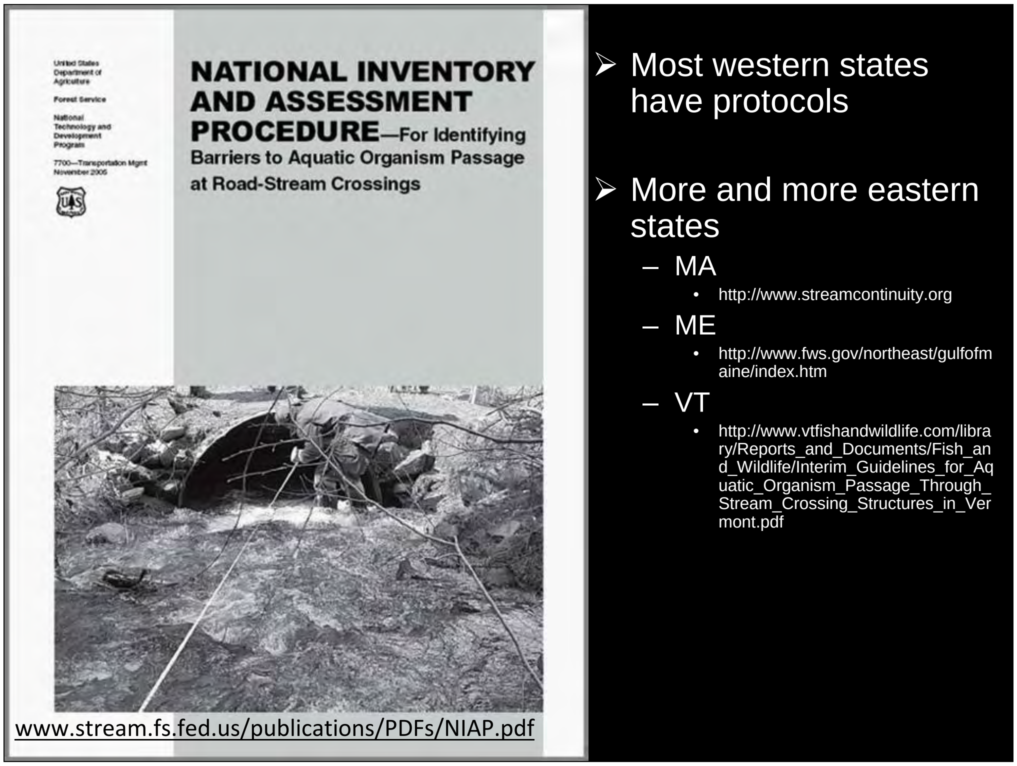
Formalized inventory and analysis methods provide much more information than a coarse filter. In general, these additional details will help you

--quantify passage condition across a full range of flows

--prioritize crossing replacements within a watershed

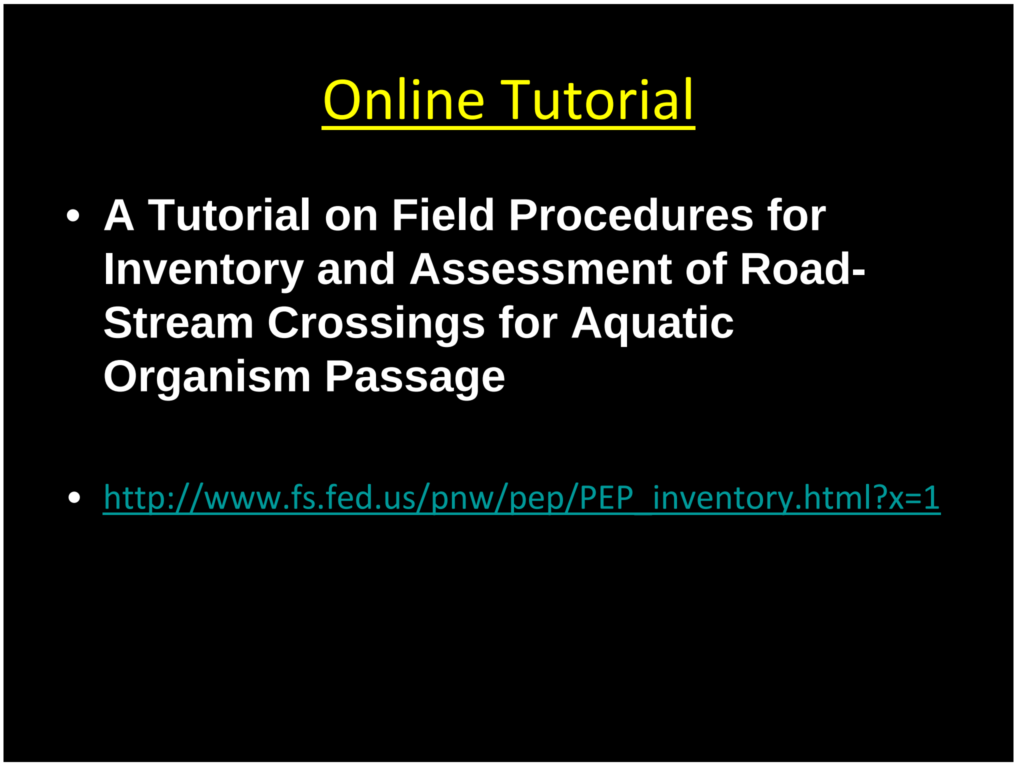
--initiate design

--approximate replacement or construction costs.

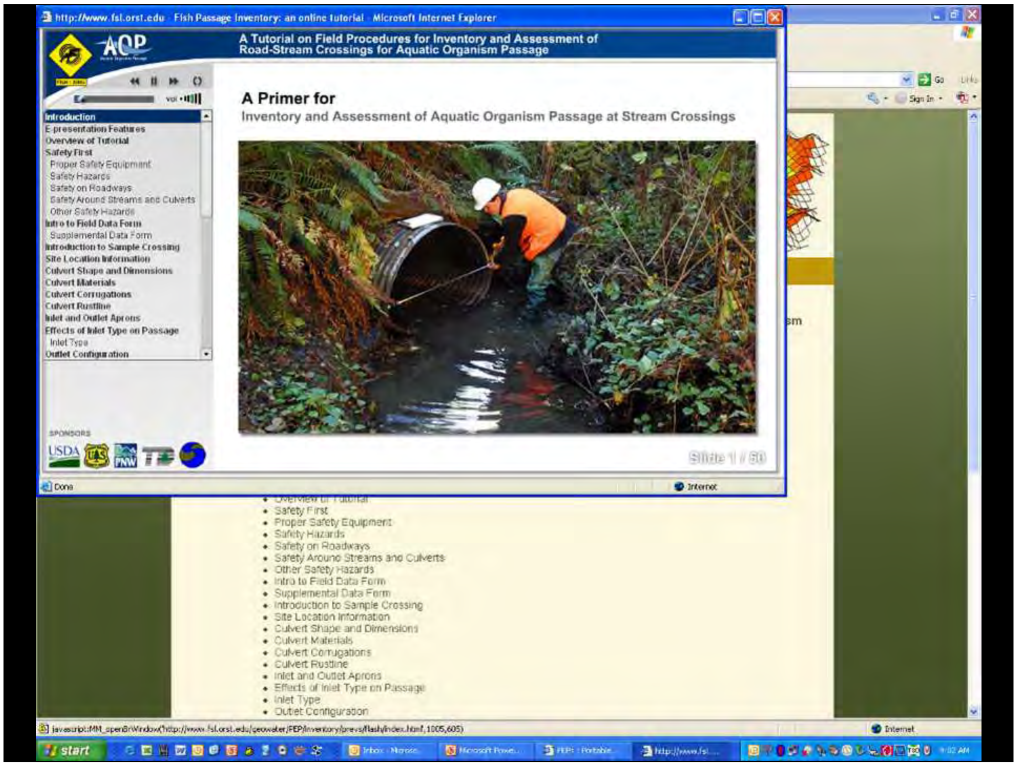


Here’s a great resource to evaluate passage at road-stream crossings published by the Forest Service in 2005.

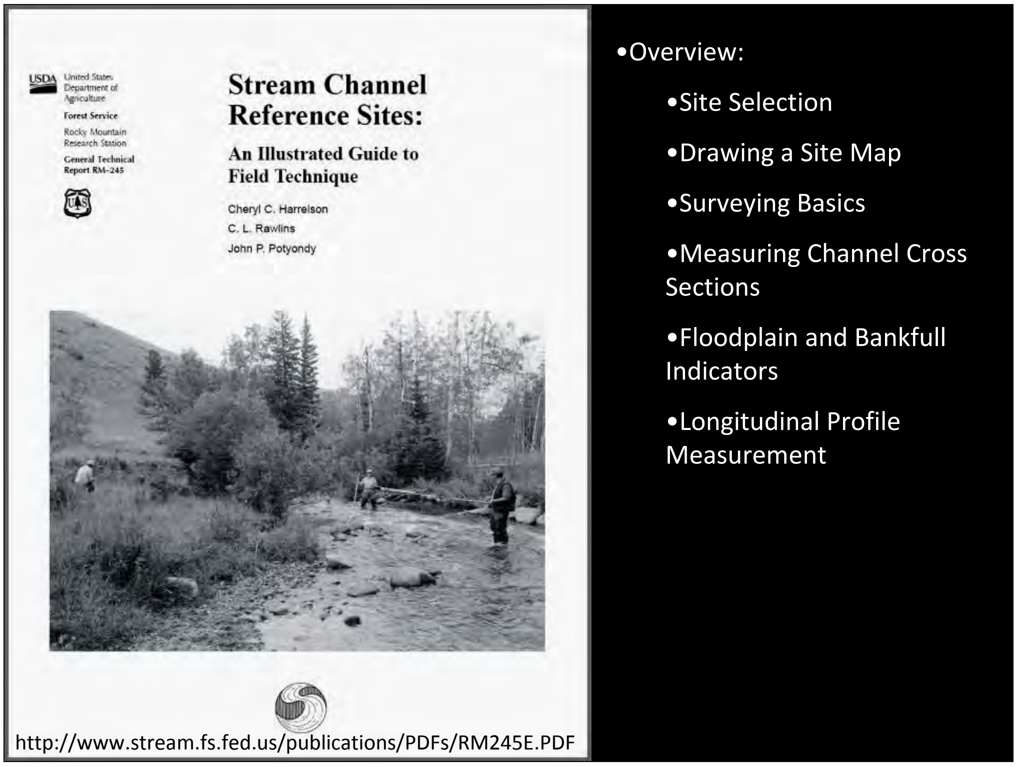
[CLICK] Most western states have some form of a protocol for evaluating crossings, and some eastern states—like MA, ME, and VT—have produced documents in the past few years.



By the way, if you're interested in using the National Procedure, the Forest Service recently completed a 30-minute online tutorial, found at the website shown here.



Its a video primer that covers all of the data collection methods and techniques necessary to complete the procedure. In addition, the tutorial stops after each section and illustrates how to fill out the inventory worksheets.



Most inventory and assessment protocols require various field methods, and this guide covers the most common techniques, including:

-Basic topographic surveying

-measuring channel cross sections

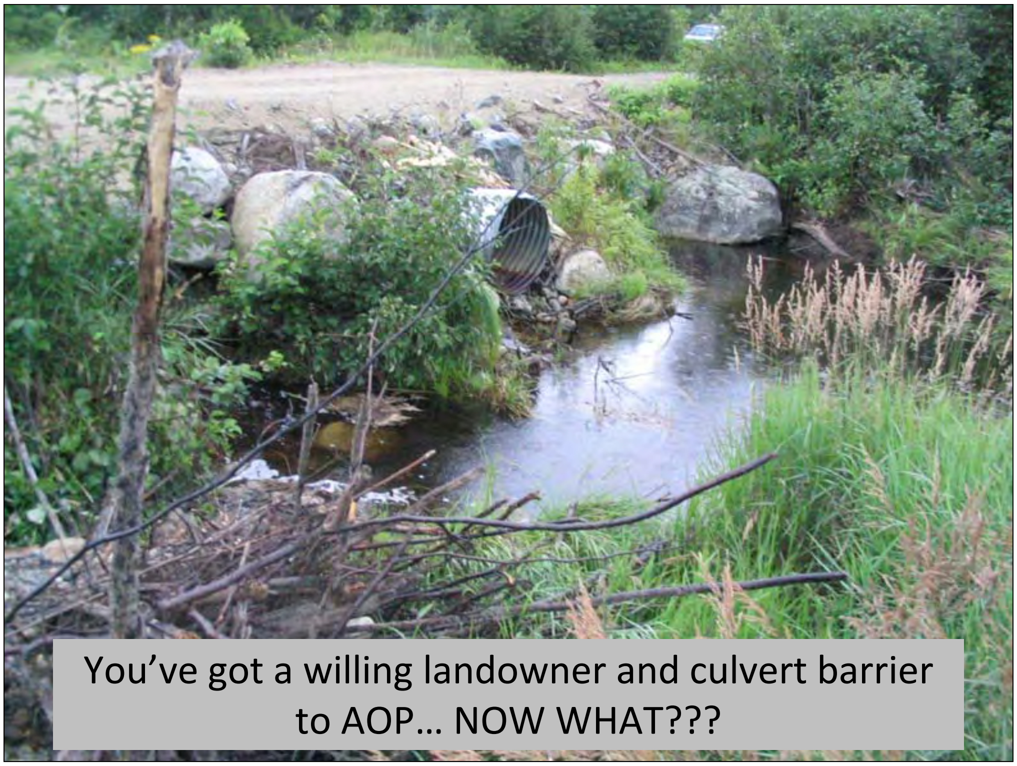
-and longitudinal profile measurement.

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.

OK, so here is a summary slide of the major factors affecting passage at culverts for future reference.

This material was originally developed for guidance issued last spring regarding the measurement and reporting of miles improved under Fish Passage Standard Code 396.


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

READ SLIDE

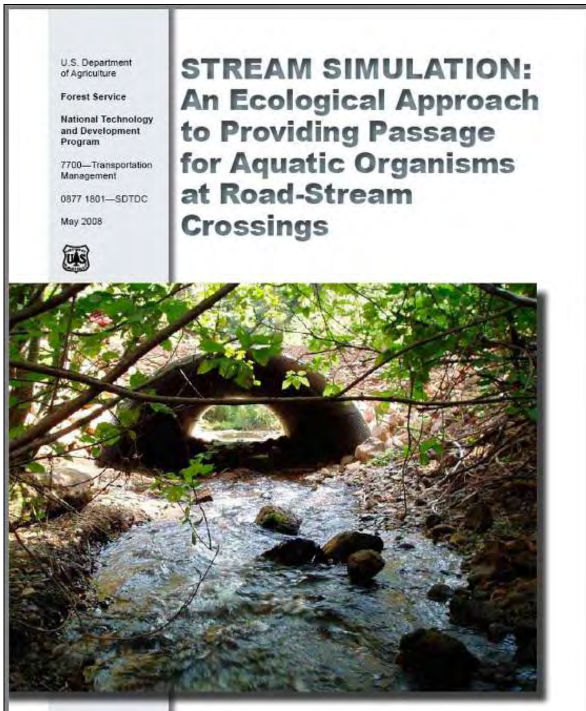
Working With Road Crossings

- 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"

Before jumping right into culvert replacement, I suggest that you talk with a landowner about plans for the road and any stream crossings. Is it possible to close the road and remove all stream crossings??? It never hurts to ask.

If the crossing will remain, and removal and replacement aren't an option, passage can be improved by channel manipulations and baffling—I won't have time to cover these today, but can provide assistance whenever needed.

But, if replacement is on the table, I'd advocate using a stream simulation approach.



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

Another resource from—you guessed it—the USFS was released to the public last May and became available online in August.

This is one of the most outstanding references I've seen—created by the best in the business with a careful eye towards keeping it from being too large and inclusive to be useful or readable. If you only download one of the sources I cover today, this should be it.

This manual provides the best available guidance on reviewing the watershed and stream reach, assessing site conditions, and designing a stream simulation crossing.

Notably, it goes further by providing complete coverage of final design preparation, contracting issues, and project 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

So, what is Stream Simulation??

As the name implies, the basic premise of this design approach is that if we can simulate physical conditions in the culvert that look and function like those in the adjacent natural channel, we've created acceptable passage for aquatic organisms.

READ SLIDE

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

However, because it is a geomorphic design, there are certain conditions where project success may be affected.

In general, these situations will likely be evident when you visit a site—those situations when you way “Whoooa”, when you drive up.

Instability features are often easy to see, but a few of these—like floodplain conveyance, intermittent bedrock, evidence of icing, and the type and extent of depositional features—will require a bit more walking around. I suggest that you get aerial photos of sites whenever possible—and get all dates available.

These channel characteristics and geomorphic settings aren’t always or equally hazardous, and can often be mitigated with careful analysis and design.

But, you definitely need to be aware when working at sites with one or more of these conditions.

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

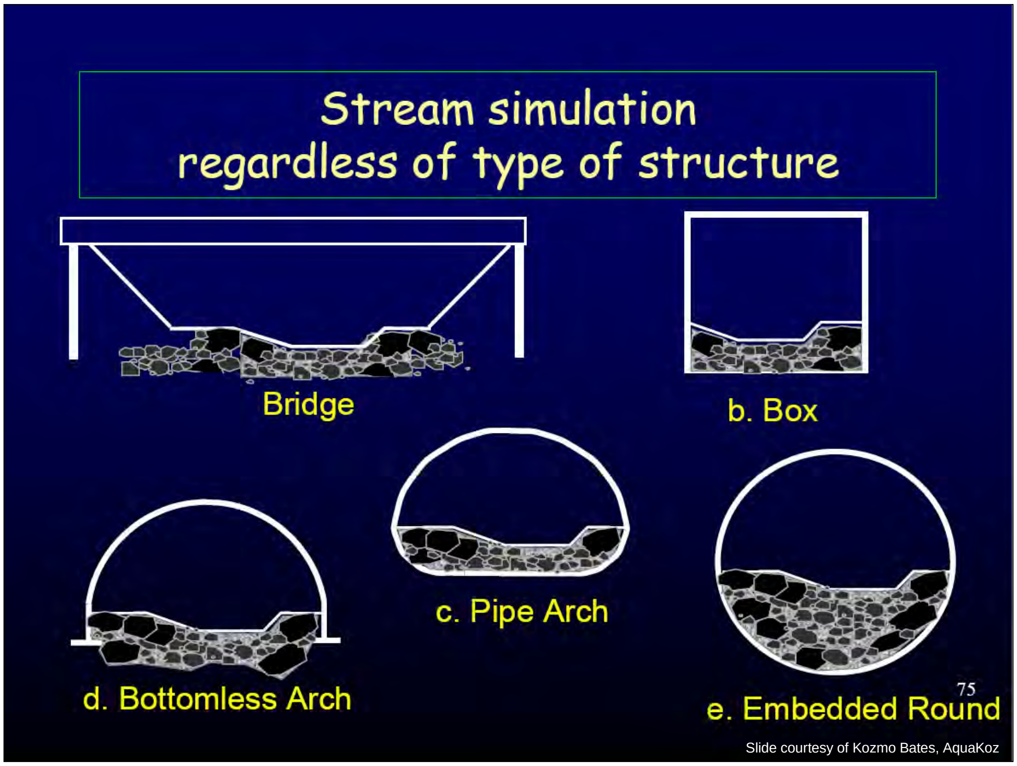
So, with that disclaimer, the basic task is to design a stream channel and then put something around it—like a culvert.

This approach relies on accuracy in characterizing the bankfull channel geometry, slope, structure, and function of a reference reach and rebuilding it within the culvert.

The goal is to construct a conduit for stream processes to function as they would in the absence of a road crossing.

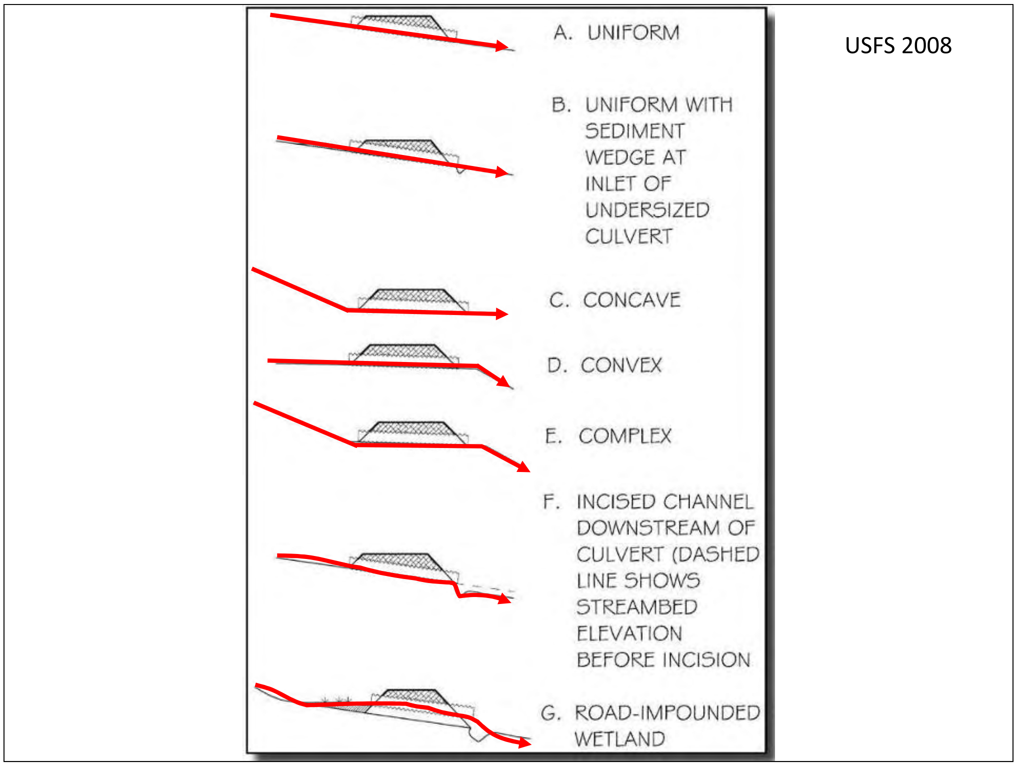
So, here is another shot of a barrier road crossing on Lawrence Brook in Maine taken in August 2007 And here is [CLICK] the same location seen last May after the completion of a project by Maine NRCS and partners.

A bottomless arch culvert was used to cap the intact streambed uncovered when the old culverts were removed and the stream channel was relocated. Stream continuity—with respect to both geomorphology and passage—has been dramatically improved.



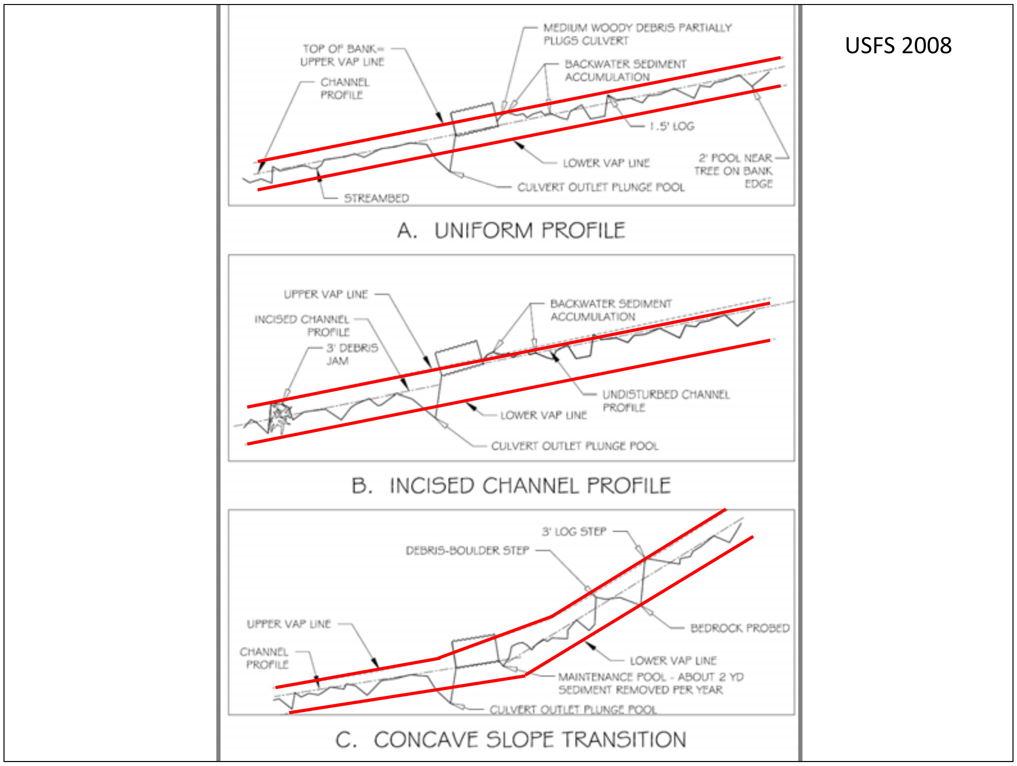
I'll cover a skeletal outline of stream simulation culvert design topics here, and encourage you to consult the new AOP manual for more in-depth treatments of what follows.

Stream simulation approaches to passage at road crossings can be used regardless of what structure carries the load above. Bridges, corrugated metal pipes, or bottomless arches are all commonly used in stream simulation projects.



However, you need to place the crossing in the larger context of the stream reach it bisects.

For example, [CLICK] it is essential to characterize the shape of the longitudinal profile of a culvert crossing to determine the effect geomorphic transitions may have on project alternatives.



Once the overall shape of long profile is known, dialing in the resolution to [CLICK] include local controls on channel profile up and downstream of the road will help you figure out the range of vertical adjustment that might occur when a culvert is removed and replaced with a stream simulation structure.

One of the most important elements of the stream simulation approach is to accurately characterize the streambed of the reference reach. Basically, you need to collect information adequate enough to facilitate mimicking every meaningful factor of the natural, reference streambed.

Numerous methods are available. The one you use is likely going to be a function of familiarity, regional calibration, or speed/ease of use.

Whatever methods you choose, make sure that bed shape and particle diversity are adequately accounted for.

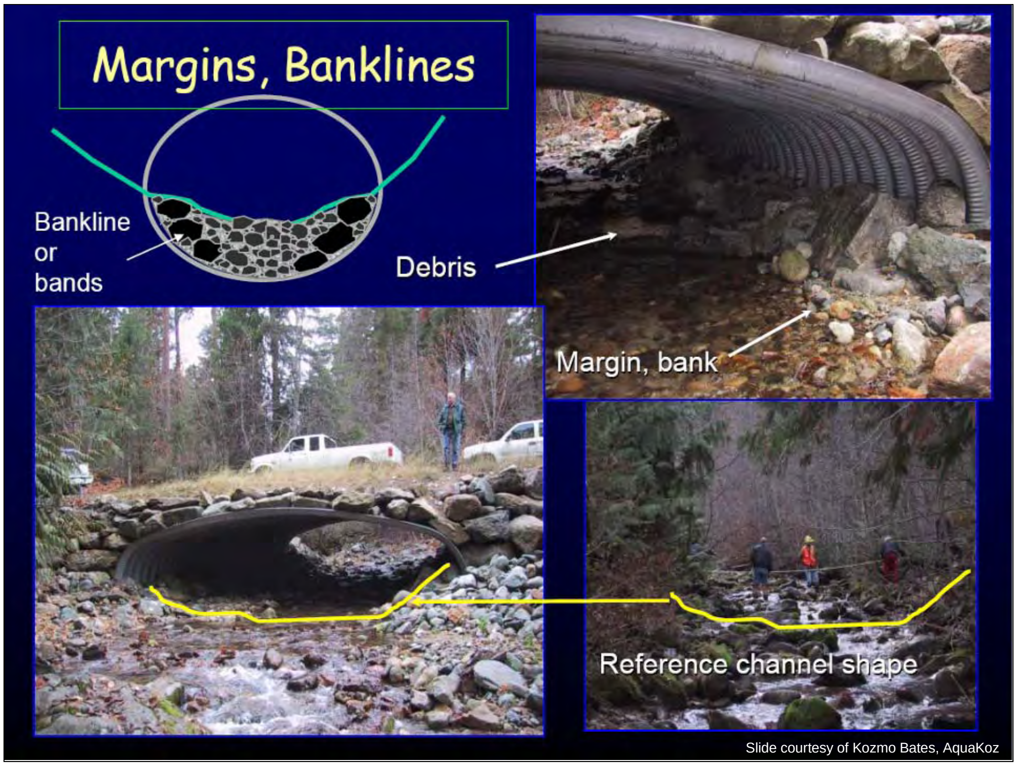
Consider developing your own roughness information if extensive modeling will be used, and try to gain insight into streambed mobility.

In addition, note features that force bed morphology—an important example of this would be boulder-forced steps in mountain channels.

Also, track down any geologic factors that control permeability either in the watershed or that have been affected by transportation corridor construction activities—like compaction or excavation that interferes with shallow groundwater.

Simply filling a bottomless arch culvert with rock does not make it a stream simulation structure.

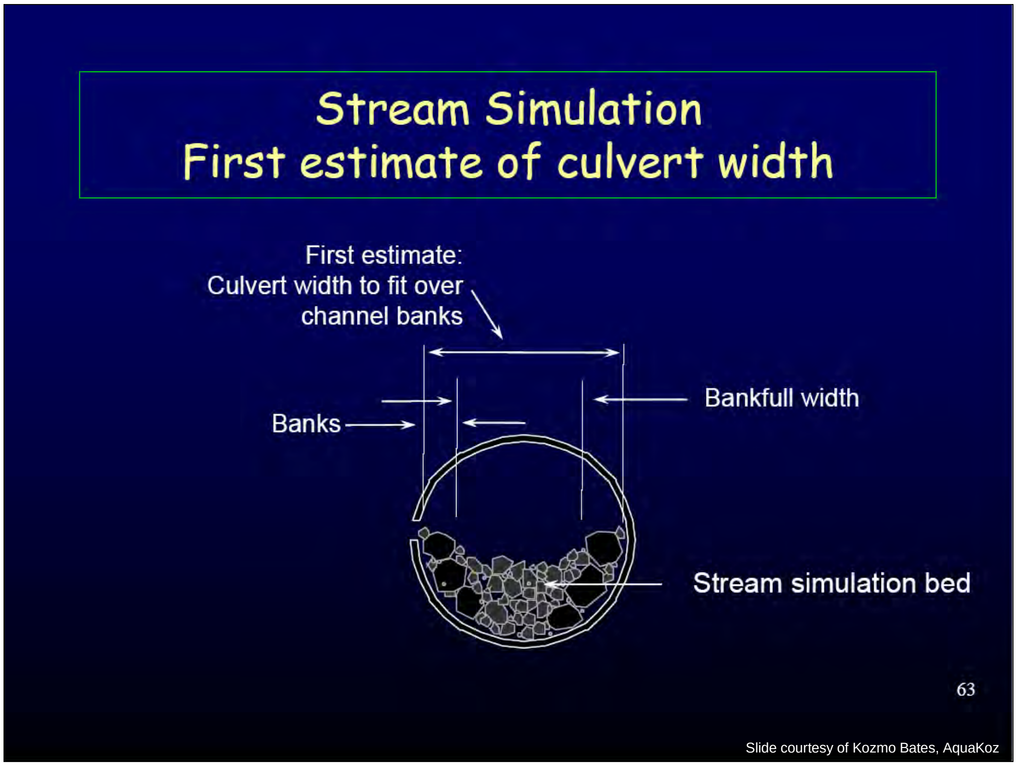
Uniform rock removes bedform diversity that’s important to a whole range of aquatic organisms, and may create turbulence that makes passage conditions even tougher.



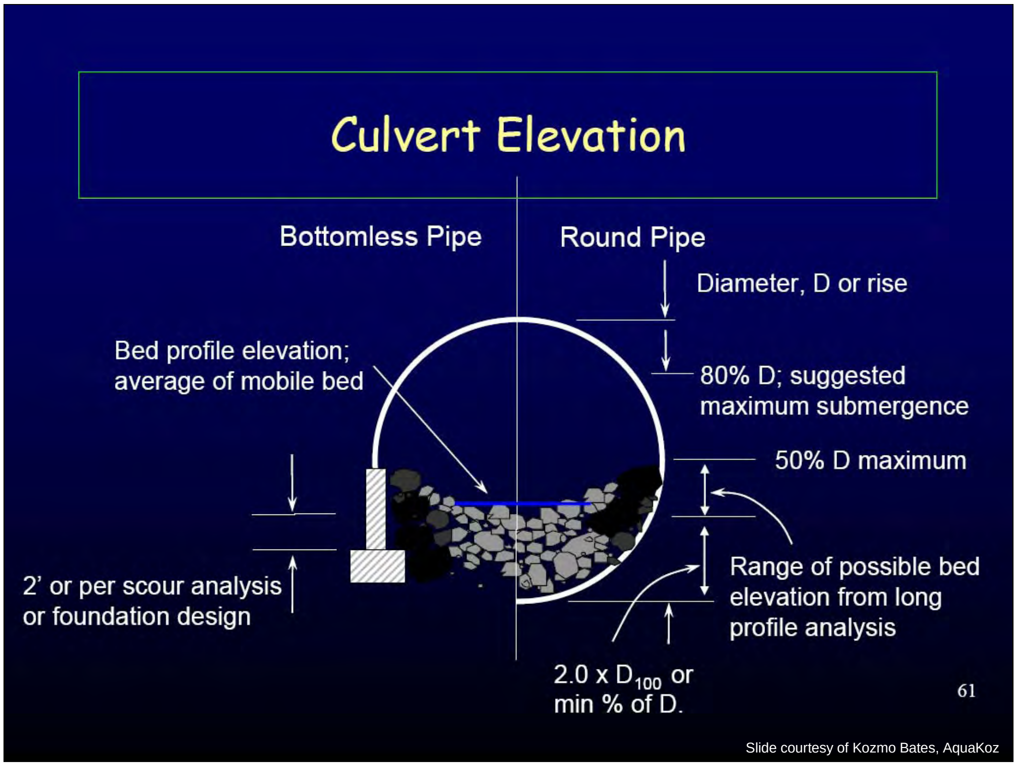
Other elements of the reference channel must be noted and recreated inside the road crossing.

For example, channel margins and banklines are important design features.

From an aquatic passage perspective, recreating banklines helps provide more migration pathways for smaller bodied fish, crawlers, and others.



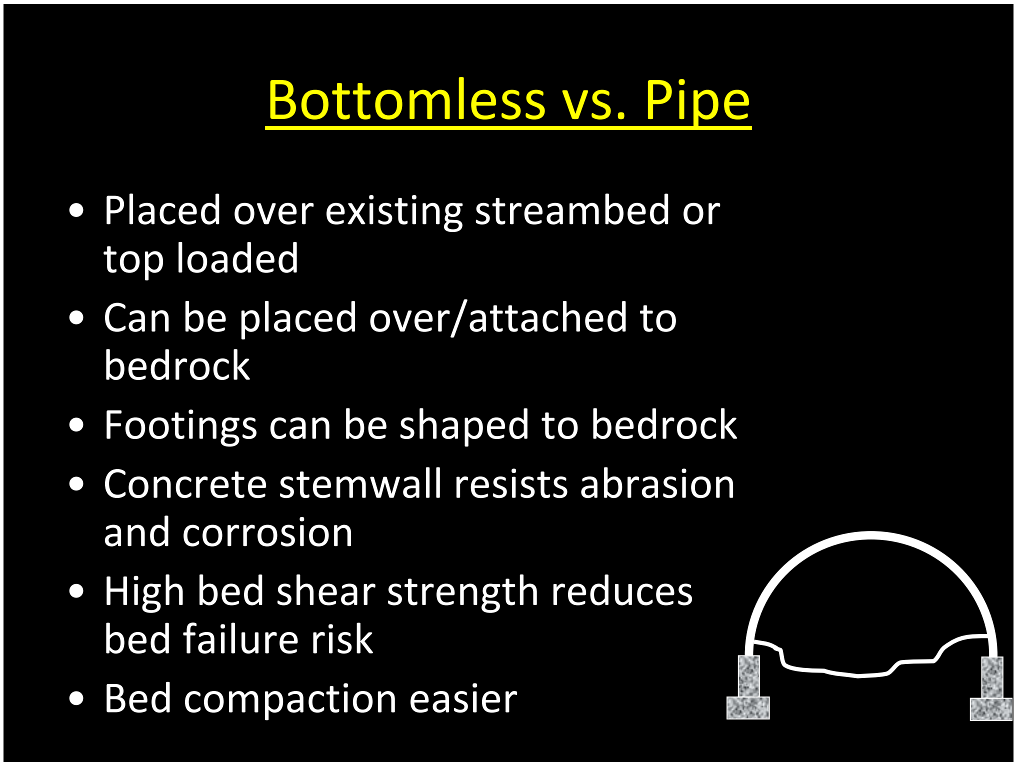
Stream simulation culverts are generally sized to cover the bankfull width of the reference reach plus the width of the streambanks. If streambank width is hard to judge, a good rule of thumb is to add 20% to your field estimate of bankfull width.



After estimating culvert width you need to account for the amount of countersinking necessary if a round pipe is used, or the depth to which foundations or footings should be set if a bottomless arch is planned.

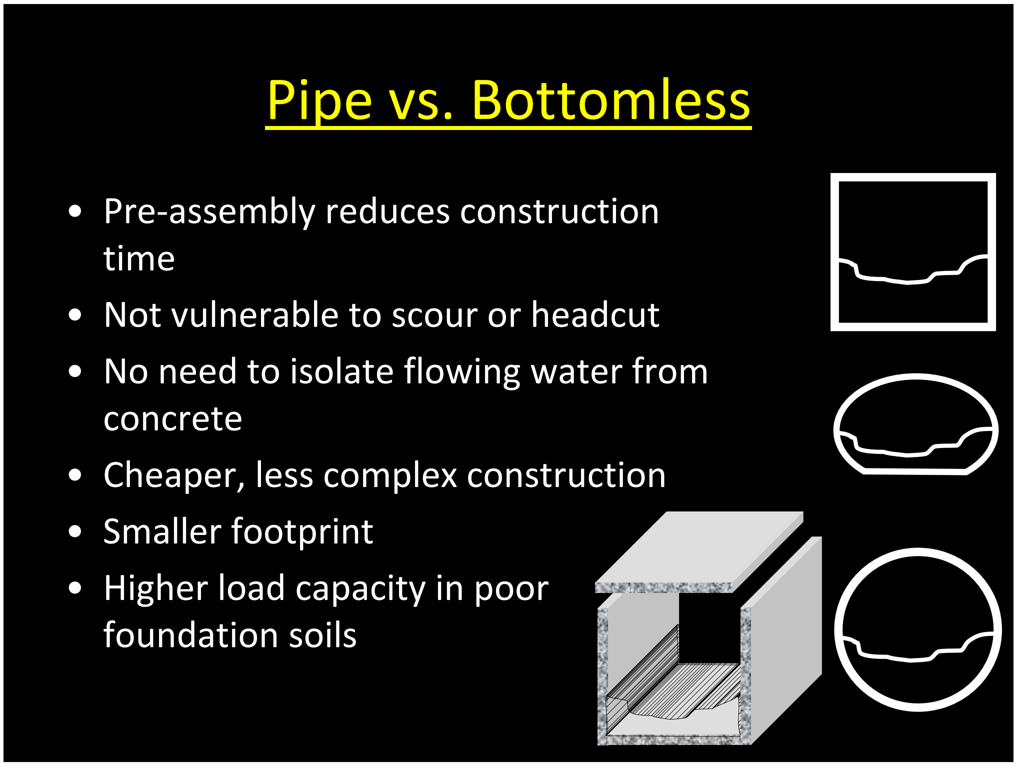
A good estimate for determining the lowest point in the section, or that point on which the floor of the culvert will be set, is go 2 times the D100 determined during bedform analyses performed on the reference reach. This allows for a good foundation on which the stream simulation bed can be built, and should withstand most high flows, unless the culvert becomes pressurized.

The top of the culvert should be set so that high flow water surface elevation is not higher than 80% of the culvert diameter or rise. This elevation is generally derived from either field verified or modeled peakflow estimates.



As I mentioned earlier, stream simulation passages can be contained by a number of different structures. As long as the streambed morphology is right, its all the same to the critters. However, bottomless structures have a few advantages over pipes.

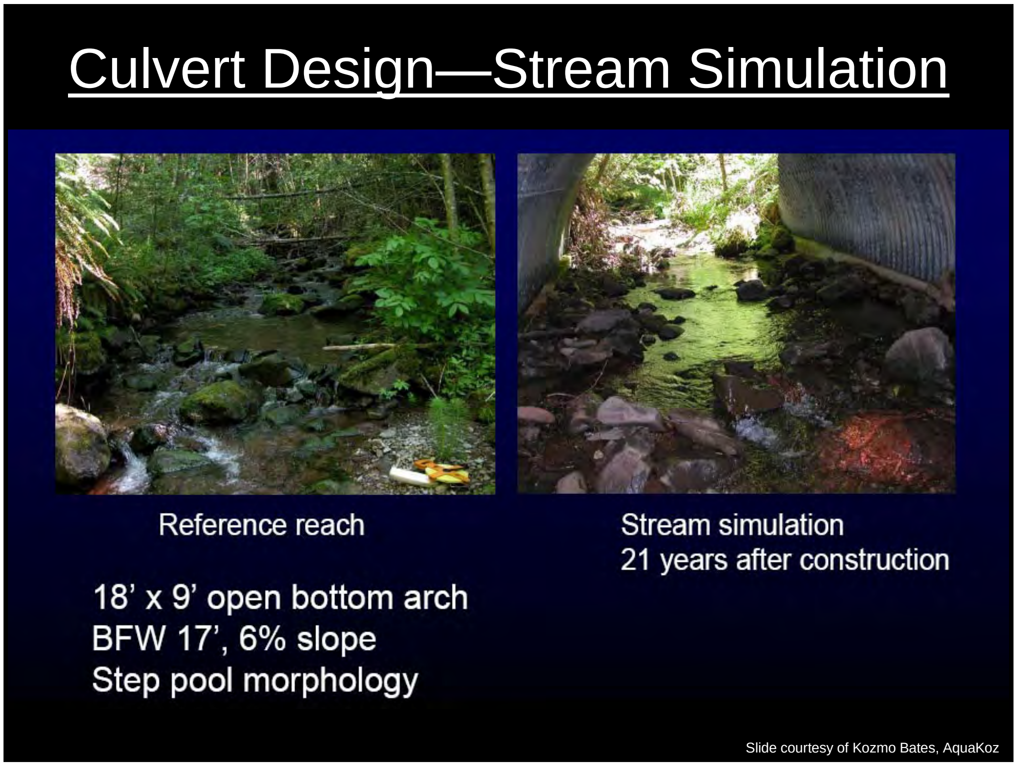
For example, bottomless arches can be placed over an existing streambed or top loaded with a mix. In addition, they can be placed onto bedrock, and make bed compaction at the site easier.



Conversely, Pipes have a few advantages over bottomless structures.

Pipes are often pre-assembled, which can reduce construction time.

They're often not vulnerable to scour or headcut, have a smaller footprint, and offer higher load capacity in poor foundation soils.



The initial cost of stream simulation culverts is usually more than culverts designed with conventional methods.

However, more than 20 years experience with many of these structures in the Pacific Northwest and elsewhere has shown that they persist longer, require far less maintenance, and satisfy the need to pass aquatic organisms.

This slide shows a stream simulation culvert that's been in place for more than 25 years—it's a good sized pipe set at 6% slope in a step-pool stream in Washington state.

Alright, moving on now to low-water crossings.

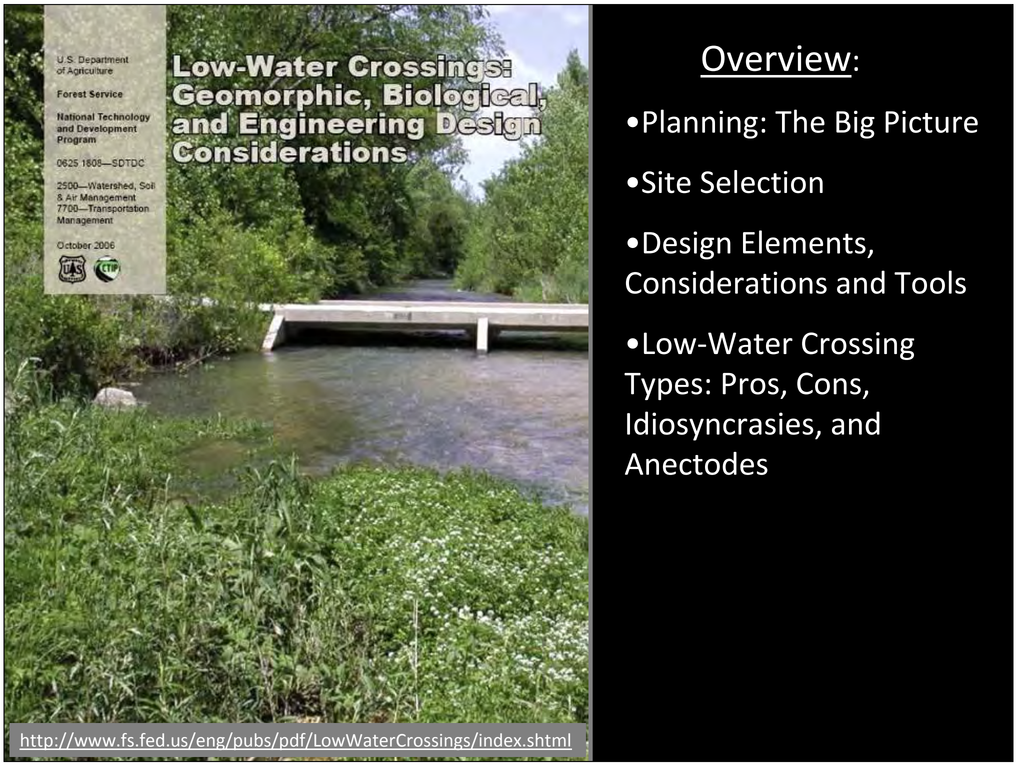
Low-water crossings or fords are often associated with historic sites and trails used by native peoples and early explorers.

Generally, they're found at sites created by hydraulic controls like riffles or bedrock outcroppings that afford a uniform, relatively shallow spot that remains stable over time.

This site, Few's Ford on the Eno River in NC, was associated with a mill and trading trail dating back to colonial times.

Like culverts, improperly designed and built low-water crossings also block passage.

However, unlike culverts, low-water crossings can also pose a risk to livestock and equipment and cause chronic water quality problems.



Here is yet another great reference from the Forest Service for designing low-water crossings with biological, geomorphic, and engineering considerations.

This manual provides a comprehensive review and approach to methods used at a range of different low-water crossing types, with extensive design guidance and a great set of case histories.

Low-Water Crossings

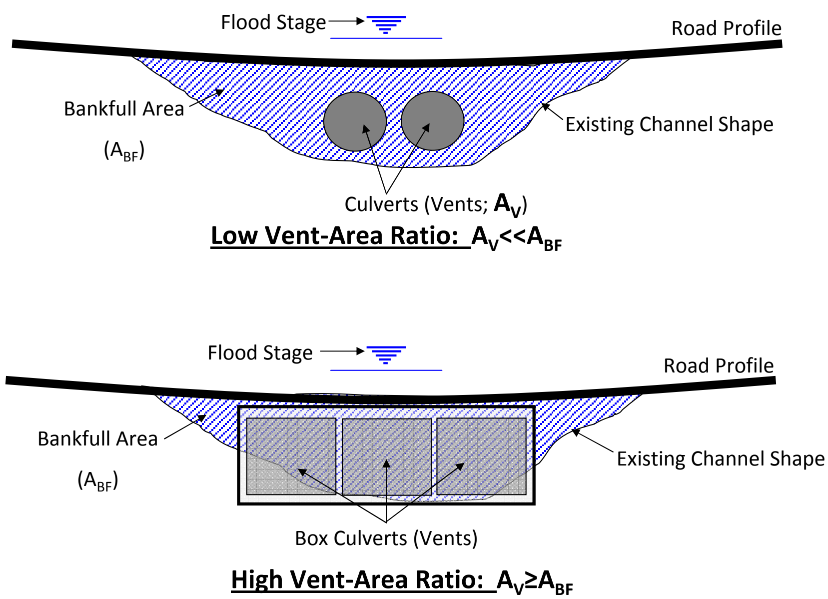
- Usually built on low-volume roads or unimproved roads on private land
- Cost efficient and easily (relatively) maintained
- Can be built to pass debris and sediment somewhat efficiently
- Static section in a dynamic system

In general, low-water crossings are built on low volume roads or on unimproved roads on private lands.

They're attractive because they're generally cost efficient and can be relatively easy to maintain. In addition, they can be designed and built to pass large sediment and debris loads with some efficiency.

However, they're another example of a static structure in a dynamic system, and thus affect river mechanics and aquatic organism passage.

Vent-Area Ratio (VAR)

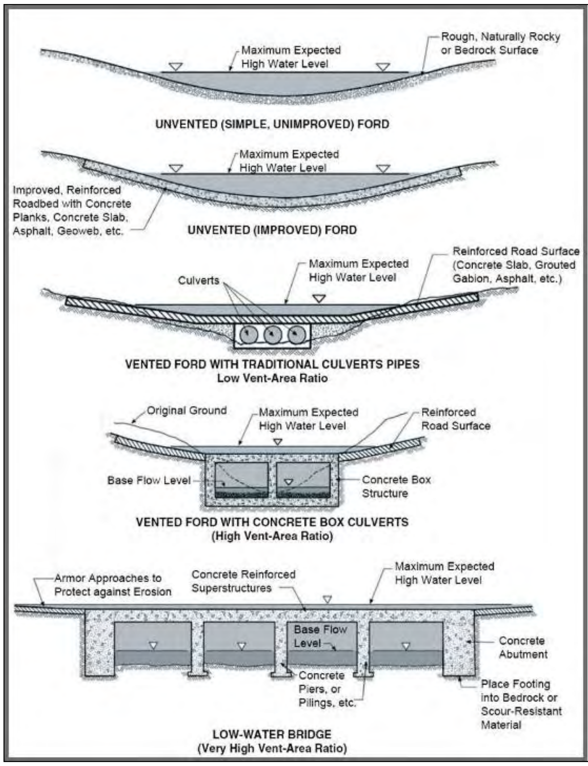


Graphic: Modified from Keller and Clarkin (2007)

One metric that describes the effect a low-water crossing has on stream function is the Vent-Area Ratio—or VAR. VAR is the ratio of the openings of a crossing to the bankfull area of a stream.

Low VAR crossings are those where the area of the vents is much smaller than the bankfull flow area of the stream.

High VAR crossings are those where the area of the vents is greater than or equal to the bankfull flow area of the stream.



Low-Water Crossings: Common Types

Graphic: Keller and Clarkin (2007)

Here are some common types of low-water crossing in use today. They range from simple fords composed of natural streambed material, to low water bridges that can be quite expensive.

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

In general Fords, High VAR crossings, and Low-water bridges all support good river function and passage.

Low VAR crossings and other structures that affect sediment and debris dynamics impair passage in much the same way as culverts—they create sections with shallow depths, high velocities, or elevation drops.

The magnitude of these barriers often scales with streamflow. Often, the more improved a crossing is, the bigger a barrier it creates.

Here are a couple of examples. These crossings in Illinois [CLICK] and Texas are both jump, depth, and velocity barriers to migratory organisms.

By comparison, simple unimproved or improved fords such as this one in northwest Arkansas provide year-round passage and can remain stable for years.

Granted, they won't withstand the same traffic load as the two crossings shown in the previous slide.

Luckily, fords like this represent a good number of the low-water crossings NRCS installs.

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

Low-water crossing design and analysis should roughly follow the same procedures outlined for stream simulation culverts. In fact, the low-water crossing document I mentioned earlier suggests the use of stream-simulation techniques for low-water crossings at high VAR structures.

Consequently, its best to characterize the nature of the reach as either transport or response and account for the flux of watershed materials.

Generally, crossings tend to function the best when they are:

--designed and built to conform to existing channel geometry and slope,

--constructed to match the shape of the existing channel,

--oriented to cross the stream at a 90 degree angle.

For example, each of these unvented improved fords in Oregon, [CLICK] Virginia, and [CLICK] North Carolina match the channel shape and slope and cross at a right angle.

Consequently, the have been relatively long-lived and provide good passage across a range of flows.

Low-water crossings can be improved or hardened in a number of ways. This technique seems to work best on low-energy streams.

Generally, the crossing is overexcavated and the roadway is backfilled with a mixture of well-graded rock up to the elevation of the natural streambed.

Rock size should the smallest needed to remain stable under prevailing flow conditions—bigger isn't better for passage because of turbulence. You may need to add smaller material into the mix to seal the section to ensure that the stream doesn't percolate into the crossing substrate.

Ensuring that the resulting crossing is at-grade will help promote passage and resist erosion or aggradation.

Cable concrete blocks are a cost-effective means to improve a stream crossing in situations where traffic volume or the energy regime might be higher.

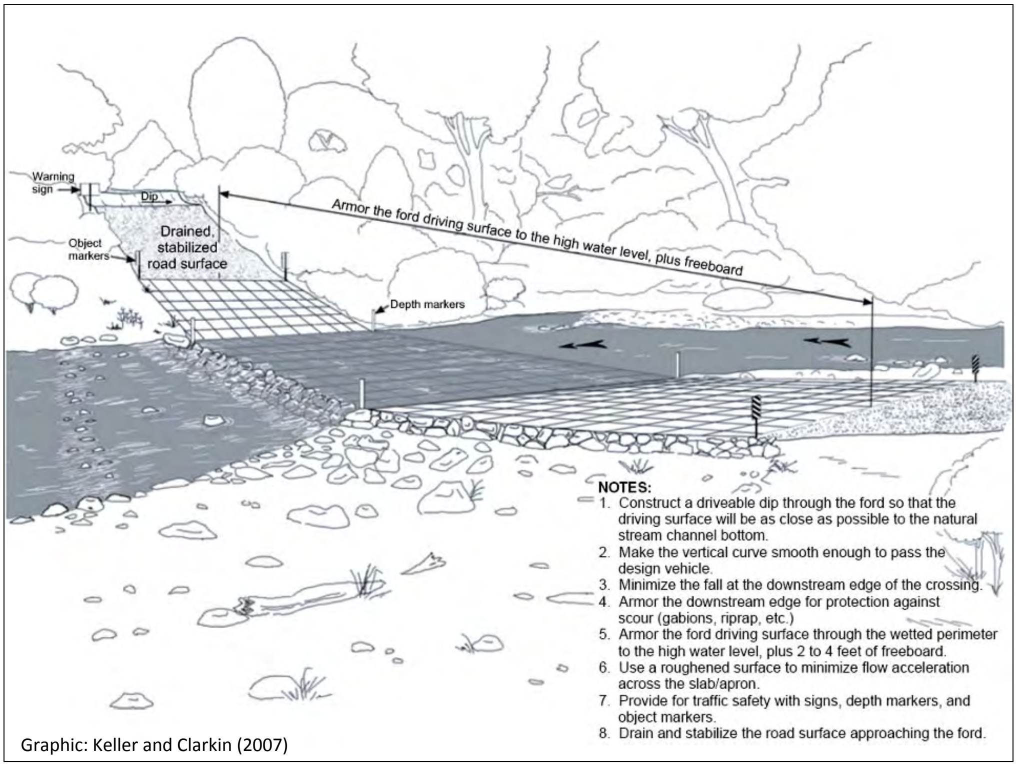
Installation is similar to the previous slide—the section is overexcavated to account for the thickness of the concrete blocks and any necessary subgrade materials.

It is important to ensure that the subgrade is well compacted and protected by geotextile—each block is independent of its neighboring blocks and can settle, rotate or tilt. If this occurs, it can make the crossing rough and endanger its long-term function and integrity.

Here are a few shots of a crossing project in Oregon showing a cable concrete mat and excavator prior to installation, [CLICK] a juvenile chinook moving upstream between the blocks the day after it was built, and [CLICK] the crossing after the first rain-induced high flow event of the fall. [CLICK] Voids between the blocks can be backfilled with smaller material following construction, but they tend to infill naturally.

Here is a shot of a cable concrete crossing in Wyoming where the mat wasn't extended up the bank as high as necessary. In addition, the subgrade at this crossing was not well compacted because of the presence of large boulders.

Erosion and settling at the site has exposed some of the structural cables---HIGHLIGHT WITH MOUSE—which can be a hazard to passing vehicles. It's rough to drive across, but functional from a passage perspective.



Graphic: Keller and Clarkin (2007)

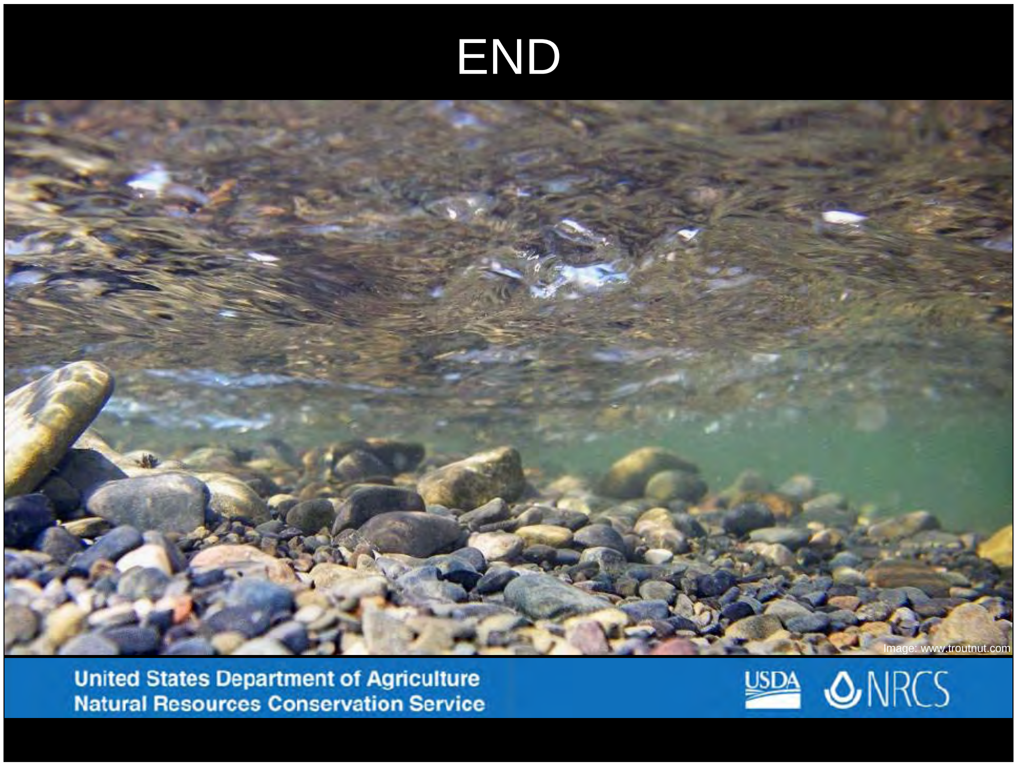
So, its important to extend the driving surface of the crossing to an elevation that exceeds the known high water level.

Keeping the crossing at grade, providing surface roughness, and ensuring that the downstream edge does not produce a sharp drop in water surface is the best way to keep material and animals moving through the system.

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.

Again, a summary slide of the major issues that impede AOP at low water crossings. If you see elevation drops, areas of shallow, fast water, debris accumulations, or crossings where the stream is diving down into the roadway material, you've got passage problems.



That is all I have for today, and I really appreciate your time and attention.

I’ll now turn this back over to David, and would be pleased to hear any questions or comments you have.