KANSAS LOCAL TECHNICAL ASSISTANCE PROGRAM

# Kansas Fish Passage Guide

## A guide for constructing stream crossings on local roads and private drives to provide for fish passage

Johnson County Public Works

2015

Kansas LTAP meets the needs of road and bridge departments in local governments for information, training and technical assistance.


1536 West 15th Street
Room G520
Lawrence, Kansas 66045
phone: (785) 864-5658
fax: (785) 864-3199
http://www.ksltap.org


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The information, findings and conclusions in this document are those of the author and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

—Norm Bowers, L.S. & P.E., Local Road Engineer, Kansas Association of Counties

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Cover photo: This low water crossing has a bottomless precast box that allows for aquatic organism passage.

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## INTRODUCTION TO THIS GUIDE

**Part One** of this publication has been prepared for a target audience of local road officials, farmers, ranchers, and their contractors who install and replace culverts in streams and gullies. Farmers, ranchers and most counties, cities, and townships do not have engineers on staff, yet they replace many culverts every year. Each culvert replaced is an opportunity to improve the stream stability and to provide for fish passage, both now and in the future. There will be simple guidelines to follow for smaller culvert replacement projects, so the culvert will satisfy environmental concerns and in most cases reduce long-term maintenance costs for the culvert.

**Part Two** is aimed at engineers and describes engineering items and principles related to fish passage.

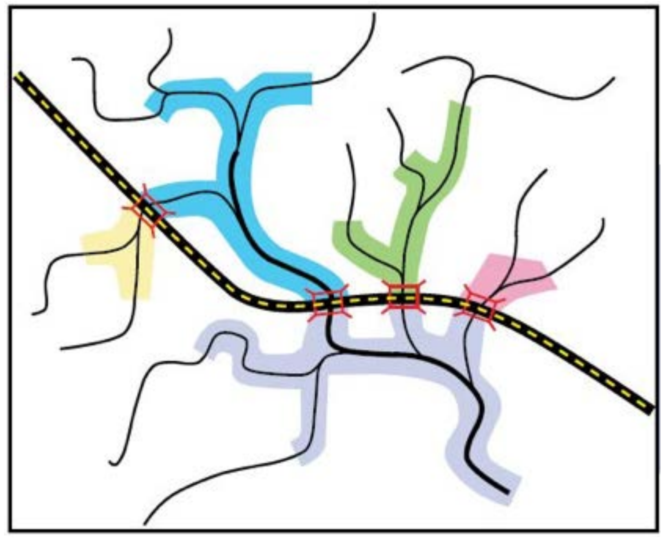



***Figure 1.*** *This illustration of habitat fragmentation shows four substandard culverts (sketched in red) fragmenting an aquatic system into five isolated aquatic populations, each shaded a different color.*

# PART ONE
# GENERAL CONSIDERATIONS:

## HABITAT FRAGMENTATION

***Habitat fragmentation and road crossings.*** A culvert is a discontinuity in a stream that can be a barrier or a hindrance to fish passage if not designed and installed correctly. In Kansas, fish passage issues caused by culverts were not recognized by road officials until about 2010 when a Kansas Department of Transportation (KDOT) funded research that indicated culverts and low water crossings were a significant cause of habitat fragmentation in the Kansas Flint Hills (Bouska, Paukert, and Keane, 2010).

Many of the threatened and endangered fish in Kansas are a type of minnow or minnow-size fish. Small fish typically are not strong swimmers, so waterfalls, water velocity and turbulence can be a barrier to passage upstream. Culverts are dark and have an atypical channel bottom that may also discourage fish passage. Lack of water depth through the culvert can restrict passage during low-flow seasons.

The most common problem is a perched culvert, which is a culvert with the outlet higher than downstream water level. A typical perched culvert is shown in Figure 3, next page. At these locations the stream channel downstream of the culvert is usually significantly larger than upstream. In some cases the design of the culvert may be the issue. In other cases the channel downstream may be incised due to increased runoff or downstream channel work that may have occurred decades ago.

No matter the cause, the perched culvert is significant barrier to most Great Plains fish. These stream barriers reduce or eliminate upstream and downstream movement of fish, which results in what is called "habitat fragmentation." Habitat fragmentation in a watershed is illustrated above in Figure 1.

Stream barriers reduce habitat range and can adversely affect fish populations upstream and downstream of the stream crossing. A severe event like a drought or oil spill in a stream segment can wipe out a species, and the species cannot repopulate the stream because of the barrier. The barrier will also limit genetic diversity.

Research in Kansas and other parts of the United States has demonstrated the detrimental environmental effects of culverts and low water crossings that act as barriers. Habitat fragmentation is a widespread issue and there are many documented locations in Kansas where endangered species habitat declined due to barriers caused by low water crossings and culverts. Any culvert with a bottom can become a stream barrier due to perching or shallow water depth.

Figures 2 and 3, next page, show perched culverts that act as barriers to fish passage.

In summary, fish passage can be restricted at culverts by these conditions: 1) a perched culvert, 2) water velocity and turbulence, 3) atypical channel bottom and darkness, and 4) low-flow water depth. In most cases habitat fragmentation can be reversed when replacing culverts by following relatively simple design and installation practices.

Kansas Department of Wildlife, Parks & Tourism

***Figure 2.*** *A box culvert with a waterfall at the outlet is a barrier to aquatic organisms swimming upstream.*

US Fish & Wildlife Service / Wayne Stancill

***Figure 3.*** *A low water crossing with channel incision or poor design, like this one, creates a barrier to fish and other aquatic organisms.*

## BASIC PRINCIPLES OF STREAM CROSSINGS

While stream morphology and fish passage are complex, fortunately there are some simple basic principles related to stream crossing construction. While more detail will be discussed later in this handbook, the following guidelines will be appropriate in a vast majority of locations.

Fish passage will normally be provided or enhanced at a stream crossing project by following these guidelines:

1. The culvert should be as short as possible.
2. Bottomless structures are preferred. If the structure has a bottom, bury the flowline below the normal channel elevation.
3. The culvert waterway opening should be as large as the approach channel.
4. If the existing culvert is perched or if there is headcutting downstream, then provide channel grade stabilization that will provide fish passage and protect the upstream channel from incision.

More detail is provided in the following sections. For longer and larger culverts, channel substrate material and rock bands may need to be placed to provide adequate water depth and resting areas with lower water velocities. Figure 18 (on Page 14) shows typical rock bands. More information on rock bands is provided in the section on the Stream Simulation Approach to culvert design.

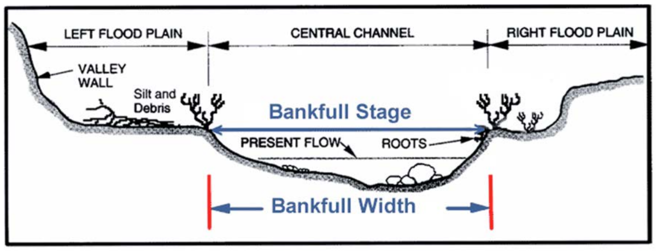
***Culvert length.*** The section of the channel within the culvert is dissimilar to the natural channel; the water velocity and channel bottom material, shape and irregularities will be different within the culvert. During daylight the interior of the culvert may be dark or at least darker than the rest of the stream. Smaller fish may avoid the darkness because darkness can harbor predatory fish. The culvert bottom may not provide resting and hiding places for smaller fish.

From an environmental disturbance standpoint, it is usually desirable to minimize the length of the culvert. Culvert length can be minimized by aligning the road crossing to be perpendicular to the channel. If the road crosses the channel at a skew, the culvert may need to be longer and aligned with the direction of flow in the channel to avoid turbulence at the culvert ends and bank erosion.

***Culvert flow line elevation.*** To provide fish passage, the flowline of the pipe should be embedded below the natural streambed elevation. This burying of the flowline will allow channel substrate material to deposit in the culvert so the channel bottom material will be similar to the natural channel. Burying the flowline will allow for fish passage even if the streambed lowers in the future.

Environmental regulations related to the Clean Water Act require culvert flowlines to be embedded in most cases. This requirement is in *General Guidelines for Stream Crossings Regional Condition 1* that applies to all work in Waters of the U.S. in Kansas[1]—and is good policy for all culverts. This regional condition is shown in the Appendix, see page 16. In Waters of the U.S., culverts must be embedded below the grade of the stream at least 1 foot for culverts greater than 48 inches in diameter. On culverts 48 inches and smaller, the bottom of the culvert must be placed at a depth below or at the natural stream bottom to provide for passage during low flow conditions. Culverts in streams with non-erodible beds (i.e. bedrock or stable clay) must be constructed flush with the stream bed, and do not need to be embedded. Culverts in streams with highly erodible beds must be embedded deeper to lessen the chance of future perching due to downstream degradation and may need supplemental grade-control measures to prevent erosion.

***Culvert waterway opening.*** Engineers normally size a culvert based on flood flows. For instance, on a major county



Newbury & Gaboury (1993)

***Figure 4.*** *This illustration of bankfull stage shows that low gradient streams often have wide, connected floodplains.*


Phil Balch, Wildhorse Riverworks

***Figure 5.*** *Small headcut*


Phil Balch, Wildhorse Riverworks

***Figure 6.*** *Large headcut*

[1] The definition of the Waters of the U.S. is lengthy and complicated, but for stream crossings will include all perennial and intermittent streams as well as ephemeral streams with a defined bed, bank, and ordinary high water line. A complete definition of Waters of the U.S. is in the Clean Water Act, 40 CFR 230.3. http://www2.epa.gov/cleanwaterrule/definition-waters-united-states-under-clean-water-act

road the culvert may be sized assuming the road is flooded on a recurrence interval of 25 years. In FEMA-mapped areas, and where there are improvements upstream, the culvert is sized so flood backwater is within acceptable limits. For fish passage and channel stability the culvert needs to be sized based on what is called "bankfull flow."

***Bankfull flow.*** "Bankfull" is the incipient point of flooding. On a stream that is in dynamic equilibrium, that point is the top of bank; i.e., the point or stage just before water flows onto the floodplain. Figure 4 illustrates the bankfull stage.

For fish passage the culvert waterway opening should be as large as the bankfull channel. In a non-incised channel this will allow "bankfull flow" (discharge) with little or no backwater or increases in velocity or turbulence. For example, in a channel 4 ft. wide and 3 ft. deep the culvert waterway opening should be 12 sq. ft. (4 x 3 = 12).

Regulations related to the Clean Water Act also have requirements for culvert waterway opening. A specific requirement is included in the document *General Guidelines for Stream Crossings Regional Condition 1,* mentioned in the previous section. The requirement applies to all work in Waters of the U.S. in Kansas and is good policy for all culverts. Generally the new or replacement culverts must be designed to convey the geomorphic bankfull flow (return period of 1.01 – 1.7 years) with a similar average velocity as upstream and downstream sections.

Estimating bankfull flow will be discussed in more detail later in this Guide.

***Channel incision.*** Channel incision is the process where a channel flowline deepens. As the channel flowline deepens, the banks erode or become unstable and slough off, making the channel wider. Some channel incisions may be natural, however channel incision is usually caused by either a change in land use upstream or a channel change downstream. A land use change upstream, such as development or converting pasture to cultivated land, increases storm water runoff, and this may cause channel incision as the stream tries to reach an energy equilibrium. A channel change, which usually shortens the channel, causes an increase in the channel slope and water velocity that may cause incision. The process may be very slow, so the cause of channel incision may have occurred decades before it is apparent to an upstream neighbor or at a bridge or culvert. Channel incision is widespread in the eastern two-thirds of Kansas.

In rock, gravel, and clay bed streams, the point where a stream is actively down-cutting is called a headcut or nickpoint. The headcut is a sudden drop in the channel elevation and will be a little waterfall if the stream is running. The headcut can be a few inches high to several feet high. The headcut moves slowly upstream as it erodes the channel bottom with turbulence in the waterfall.

Headcuts in small channels are shown in Figures 5 and 6. The channel is widened by water eroding the banks or by the banks becoming unstable and sloughing off as shown in Figure 7, next page. Downstream of the headcut the channel


***Figure 7.*** *An incised channel with the right bank sloughing.*


***Figure 8.*** *This headcut has reached a box culvert that is now protecting the upstream channel.*


***Figure 9.*** *Channel incision has exposed the bridge footings.*

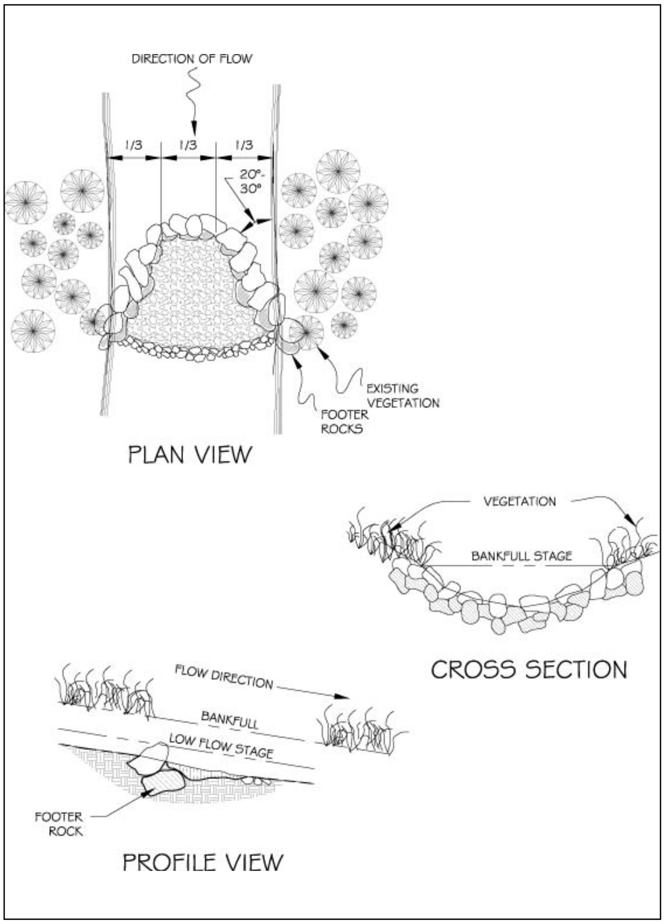

***Figure 10.*** *Many bridge and culvert problems are blamed on age, but actually are caused by undermined footings like on this stone arch culvert.*

is normally deeper and wider, which will carry more flood flow. A normal channel may only carry a 1 or 2 year flood event before water overflows onto the floodplain. In incised channels, the larger channel may carry as much as a 10 year storm event.

Before installing or replacing a stream crossing it is always advisable to check downstream a few hundred feet to see if a headcut is present that may work upstream and affect the crossing. Channel grade stabilization could then be installed at the headcut.

***Channel grade stabilization.*** Channel grade stabilization protects the upstream channel from incision by stabilizing the channel at or near the headcut. Channel grade stabilization is needed if a culvert is to be replaced where the headcut has reached the crossing and has resulted in a perched culvert as in Figure 8. In this situation the culvert is protecting the upstream channel from degrading but it is also retarding fish passage.

Channel grade stabilization is also helpful in protecting existing structures from undermining and eventually collapsing. In most counties in Kansas over half the bridges and culverts are more than 75 years old. Many of these structures were built on shallow-spread footings based on the then-current channel elevation. If the channel deepens it exposes the base of the footing. The bridge in Figure 9 is not being supported by the footing, but by soil friction against the abutment. If the soil is eroded behind the abutment, the bridge will collapse. Head cutting has reached a stone arch culvert shown in Figure 10; undermining of the floor has allowed minor movement of the arch. The culvert is now protecting the upstream area from headcutting, but the drop of water elevation through the culvert will likely lead to more undermining and collapse of the culvert, unless repairs are made first. In this case a repair has to include a downstream toe wall to prevent undermining of the floor of the culvert and a gradual rock ramp grade transition that will provide fish passage.




U. S. Forest Service (2008), Appendix F

***Figure 11.** Typical Newbury Rock Riffle*

The channel grade stabilization is normally constructed at the headcut. Many times that will be at the culvert outfall; however, if the headcut is located farther downstream then the channel stabilization is normally constructed at the headcut. The transition from an incised channel to a non-incised channel is steeper than the normal channel. This steeper slope results in higher water velocities that can erode soil, sand, gravel, and smaller boulders. The typical engineering solution is to line the channel bottom with riprap. While the riprap protects the channel, it may not provide fish passage unless designed properly. Channel lining of riprap or boulders to provide fish passage are usually called rock ramps.

***Rock ramps.*** Rock ramps are boulders or riprap placed on grade with rock riffles. Rock riffles are drop structures that concentrate energy as water plunges over the crest, and turbulence and bed scour dissipate the energy. Figures 11 and 12 show typical Newbury Rock Riffles.

Ficke et al (2011) concluded that rock ramp fishways may represent the best design type for smaller, non-jumping species. These structures incorporate heterogeneous water depths, velocities, and velocity refuges. They are also advantageous in that they can be designed without a well-defined or constricted entrance. Rock ramps can also accommodate a large number of water levels. A rock ramp would have lower water velocities near the edges of the structure; even though the water would be shallow, this would not prevent passage of small-bodied fish.

Great Plains fish are not strong swimmers so the grade control needs to be relatively flat to provide acceptable


Douglas County Public Works

***Figure 12.** A rock ramp consisting of a series of Newbury Riffles of about 0.5 ft. fall each.*

velocities. Generally the following rock ramp guidelines will accomplish this:

1. For up to 1 ft. of fall: Place riprap on a 1:20 slope.
2. For more than 1 ft. of fall: Install Newbury Rock Riffles with 0.5 ft. fall.

These guidelines take into account both sustained and burst speed of Great Plains fish. Variations from these guidelines will normally require an engineering analysis. Bed scour can undermine the structure, and bank erosion can cut around the ends. Outflanking is one of the most common modes of failure. Designing the structures with a V-shape in both plan view and cross-section view helps prevent these types of failures.

***Soil savers.*** In the past soil savers were installed at the upstream end of culverts to protect the upstream channel from incision. Figure 13 shows a typical soil saver. Soil savers do not allow for fish passage and are not now allowed where fish passage needs to be provided. Generally, use a soil saver only where there is no defined channel upstream, perhaps just a grassed waterway or where the farmer tills across the low area. Upstream from a farm pond and in dry channels near the top of a watershed might also be locations where a soil saver will be allowed.

***Low water crossings.*** There are many traffic safety and environmental issues with low water crossings on public roads. These issues include steep vertical alignments, driving hazards when the crossing is flooded, construction difficulties, long term maintenance, and environmental issues related to fish passage. This section only discusses environmental issues related to fish passage.

Because a low water crossing is designed to flood, by their nature their culverts (vents) are undersized compared to bankfull flow. Undersized vents can have velocity and turbulence that may be a restriction to Great Plains fish. Also, since the vents are relatively small, a slight channel bed incision can result in perched openings as shown on Page 6.

On new crossings, velocity, turbulence and potential headcutting can be overcome with proper design. Larger vents with the flowlines well below the channel bottom as shown in Figure 14 will function better than small pipes. A more desirable structure is a large bottomless box as shown on the front cover of this Guide.

While a bridge is sized based on flood flows, the vents in a low water crossing are sized for normal flow conditions. If the crossing is not designed properly, turbulence and excess velocity will hinder fish passage during normal flow conditions. In Kansas there are not a lot of data on normal flow rates in streams. Higher normal flows occur in the Spring. Where normal flow rates are not available, some measurement estimates will need to be made by an engineer based on normal flow in the Spring. Designing for the normal flow in the Spring will also accommodate the lower flow expected in other seasons.

Sedgwick County Public Works

***Figure 13.*** *A typical soil saver, above, does not provide fish passage.*

Miami County

***Figure 14.*** *This low water crossing has larger vents that were set well below the channel elevation. This might be acceptable where there is little danger of channel incision for the life of the structure.*

***Unvented fords — farm & ranch low water crossings.*** For occasional-use crossings, the most economical and probably the most environmentally-friendly stream crossing is an unvented ford. An unvented ford does not have pipes to carry the low flow.

A natural ford is a crossing at a rock ledge where the water is not too deep and vehicles simply drive through the water if present. Where the channel bottom is not hard enough to support vehicles, the channel bottom should be over-excavated and large rocks (or concrete) placed in sufficient thickness to support the weight of vehicles. These types of fords are sometimes referred to as hardened crossings. Hardened crossings are difficult to construct when water is running, as the excavation will need to be kept dry while the rock is placed. To provide fish passage, the top of the placed rock needs to be at or below the natural stream channel level. Unvented fords are most suitable where streams are usually

Paul Ingle

***Figure 15.*** *Unvented ford (or hardened stream crossing) under construction. Note the use of geotextile.*

Paul Ingle

***Figure 16.*** *Example of an established hardened stream crossing.*

dry or at low flow during the time of year when the crossing is most likely to be used. Figures 15 and 16 show typical construction and a completed unvented ford.

***Construction considerations.*** Culvert construction work can have both a temporary and permanent effect on water quality and stream stability. The greatest potential for pollution is sediment from the work area and contamination from litter and construction debris. Environmental issues can be minimized by following these construction guidelines:

1. Minimize work in and near the channel.
2. Do not make channel changes.
3. Protect the grass or wooded buffer strip near the channel.
4. Stockpile dirt, construction debris, and materials away from the channel in areas unlikely to flood.
5. One- or two-day projects should not be started unless they can essentially be completed prior to forecasted rain. For longer projects, erosion control measures should be placed and checked each day before leaving the job site.
6. Complete the project as fast as possible, including seeding and mulching of all disturbed areas. Native grass and plants will provide the best long-term cover and are usually specified if an environmental permit is required.

# PART TWO
# ENGINEERING CONSIDERATIONS:

## MORE ON BANKFULL FLOW

Bankfull flow is an important consideration for sizing culverts for fish passage. Some of the physical characteristics of determining bankfull flow (discharge) were discussed in a previous section, but more discussion is needed for determining bankfull flow in incised channels.

"Bankfull" is the incipient point of flooding of an undisturbed, self-forming natural channel—the water level just before water flows onto the floodplain. Physical characteristics that may indicate the bankfull stage include:

- In stable streams, the location where water exits the channel onto the floodplain
- The elevation associated with the top of the highest depositional features such as pointbars and midchannel bars
- Changes in bank slope
- Changes in bank materials (coarser to finer)
- Changes in vegetation types along stream margins.

The bankfull stage is usually considered equivalent to the Ordinary High Water (OHW) Level. The Ordinary High Water Level in streams is the limits of Waters of the US. In 2005 the U.S. Army Corps of Engineers (USACE) issued *Regulatory Guidance Letter 05-05* as an aid to determining the OHW. The guidance letter states a clear preference for the use of on-site physical indicators of the OHW Level. If downcutting (channel incision) has occurred, the stream is entrenched and actual channel capacity may be much larger than bankfull flow. As a channel downcuts, or degrades, runoff that previously spread over the floodplain is now confined to the larger-deeper channel. If downcutting has occurred, physical characteristics are not a reliable indicator of the bankfull flow, and an engineer will need to calculate the bankfull flow based on recurrence intervals.

Engineers have compared physical channel characteristics with discharge frequency and have found that the recurrence interval or frequency for bank full flow is approximately 1.2 – 1.7 years. The range of frequency may vary from state to state. In Kansas the common methodology is defined in *Bankfull Discharge for Kansas Natural Alluvial Channel Design,* a 2009

ASCE publication authored by Shelly, Young, and McEnroe.

In September 2014 a new research report was published by KDOT titled *Discharge for Ordinary High Water Levels in Kansas* (Report No. K-TRAN: KU-13-1 by Young and McEnroe from the University of Kansas). The report determined that the reliable physical indicators of the Ordinary High Water Level map directly to indicators of bankfull flow. The report further stated that it was evident that these two water levels are one and the same, and that the discharge responsible for bankfull flow is equal to the discharge responsible for the OHW Level.

This report provides two methods for the hydrologic estimation of the discharge responsible for the Ordinary High Water Level in Kansas. The regression-based approach developed in Chapter 3 of the report uses watershed area, a characteristic rainfall intensity, and the mean annual precipitation to estimate the OHW Level. Chapter 4 presents a HEC-HMS flood hydrograph simulation method for estimating the OHW Level. The hydrologic methods can be used as a check on field estimates, or in lieu of field determination where physical indicators are absent, misleading, or inconclusive.

## CULVERT DESIGN FOR FISH PASSAGE

***Basic variables that limit fish passage.*** Three basic hydraulic design variables limit fish passage.

- Velocity
- Turbulence
- Minimum depth.

Limiting values are based on the swimming abilities of the target fish species. Vertical jump distance is also a factor in steep terrain where water velocities are high and fish are by necessity strong swimmers and jumpers. On the Great Plains, streams are relatively slow-flowing and fish are not strong swimmers and jumpers, so perching will significantly restrict fish passage. Design approaches for fish passage either physically mimic the natural channel or are designed based on water velocity, turbulence and depth during critical periods.

The U.S. Forest Service has developed “FishXing” software, pronounced “fish crossing,” which is a learning system for fish passage through culverts. This software is intended to assist engineers, hydrologists, and fish biologists in the evaluation and design of culverts for fish passage. It is free for download. FishXing provides much more detail than is provided in this Guide. The FishXing website is listed in the References.

***Three basic design approaches.*** Three basic culvert design approaches provide for fish passage:

- No Slope
- Stream Simulation
- Hydraulic Design.

The choice of the design approach will depend on the site conditions and the proposed culvert size related to the bankfull width or bankfull discharge.

***No Slope Approach.*** This approach applies to relatively short culverts that are as wide as the bankfull width, or can carry the bankfull flow with little or no backwater. Culverts that are designed to carry flood flows are usually wider than bankfull width and are prime candidates for the No Slope Approach.

The No Slope approach is based on the premise that the culvert is so short and the waterway opening is so large that the culvert will not affect normal channel flows and fish passage. This approach is basically the same as described earlier in the section on Basic Principles of Stream Crossings. No fish passage engineering is required as fish passage is provided by depressing the flow line of the culvert and providing a waterway opening equivalent to the bankfull channel waterway area.

The engineer will first size the culvert based on standard road engineering that will include allowable backwater and frequency of road flooding. Bankfull width will need to be determined based on physical conditions at the site. If the channel is incised the bankfull width can be determined by calculations based on the geomorphic bankfull discharge. If the culvert is wider than the bankfull width, no additional fish passage engineering is required. Guidance for culvert embedment and waterway opening is listed in *General Guidelines for Stream Crossings Regional Condition 1* which applies to all work in Waters of the U.S. in Kansas. This regional condition is included in the Appendix on Page 16.

***Stream Simulation Design Approach.*** The Stream Simulation Approach applies to longer culverts on steeper slopes (<3% on the Great Plains) as compared to the No Slope approach. This approach maintains fish passage by mimicking the natural channel stream processes within the culvert. The stream simulation approach is usually applicable to a longer culvert that can carry the bankfull flow with little or no

*On the Great Plains it’s usually easy to design and construct a stream crossing for a two-lane road to provide fish passage.*

MN Dept of Natural Resources / Konrad Schmidt

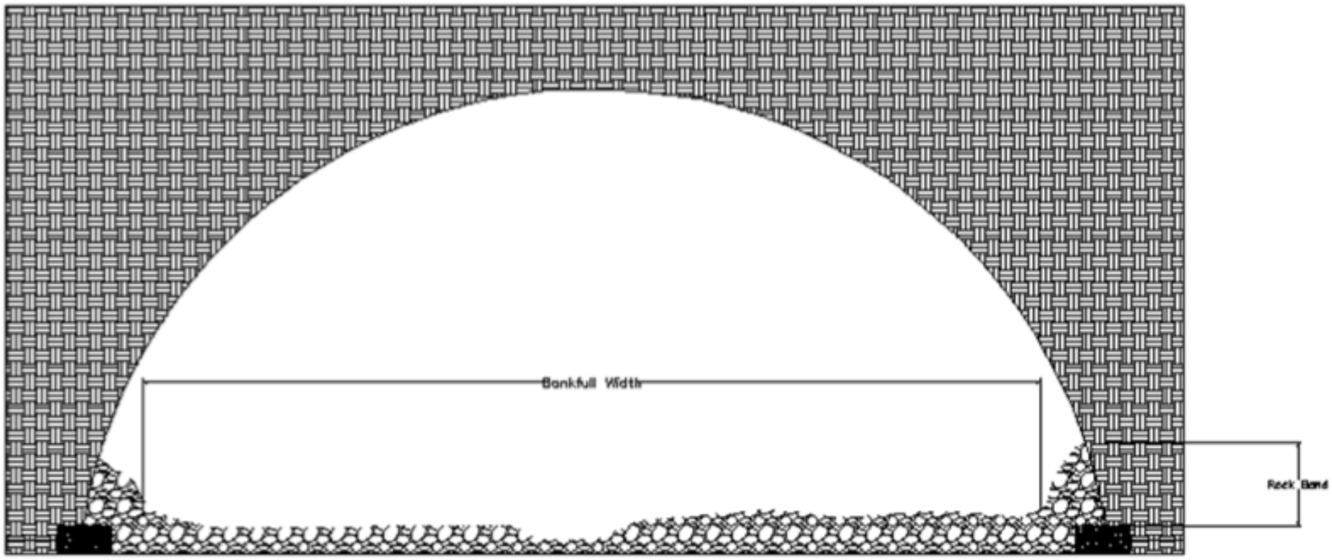



***Figure 17.*** *Illustration of typical channel bottom in a stream approach.*

backwater. Because of the longer length and steeper slope, rock bands and channel substrate material are usually required to mimic the natural channel.

The Stream Simulation Approach works by providing a structure within the culvert that has streambed diversity similar to natural channel. The water level, depths, velocities, and resting areas are similar to the natural channel. These items make the culvert almost transparent to fish and most aquatic animals except during periods of flood flow where velocities may be higher.

For the Stream Simulation Approach to be applicable, the following conditions generally need to be met.

- Culvert width at least channel bankfull width or the waterway opening meeting the criteria of the USACE regional conditions for stream crossings
- Slope at natural grade, or if providing channel grade control within the culvert not more than 3%
- Most applicable for lengths 100 feet or shorter
- Bed stability analysis indicates the bed material is "dynamically stable" (no net erosion or deposition)
- Embed to a depth approaching design scour depth.

If these criteria are met, no further hydraulic analysis is needed to support fish passage.

If the culvert is set at the natural slope of the stream, the natural channel material should be stable. If the site conditions necessitate a slope steeper than the natural channel, the velocities will be higher and the natural channel material may not be stable. Bed material has to be sized to prevent washout, so higher velocities will require larger rock material. Sheer-stress analysis will be required to size the material. Design procedures are provided in the *Natural Channel Design Manual* listed in the References. The engineer may want to seek technical assistance from the U.S. Fish & Wildlife Service or a stream restoration professional when first using this design approach. The larger material will aid fish passage through the structure by reducing channel velocities and provide holding locations for the fish as they move though the structure.

The Stream Simulation Approach requires additional channel profile information than has been traditionally required for road crossings. A longitudinal channel profile should be obtained for 20 to 30 channel widths both upstream and downstream. The profile identifies length and spacing of channel units such as pools and riffles. The profile also identifies the length and depth of accumulated sediment upstream of an existing crossing, as well as length and depth of channel scour downstream. With this information the natural channel gradient can be determined by calculating the slope between grade controls such as riffles. When calculating the natural channel gradient, the horizontal distance is the length of the channel along the deepest part of the channel (thalweg), which is often longer than the apparent channel centerline. Natural pool depths provide a guide on the vertical adjustment potential that could occur in the future. Headcuts in the vicinity of the culvert are also apparent on a channel profile.

The cross section through the culvert below normal water elevation should be roughly equivalent to the natural channel. This requires the culvert to be about as wide as the bankfull width. Natural channel substrate material should be placed to the design channel grade. Additional material should be placed up the culvert wall to simulate bankline roughness as shown in Figure 17. Rock bands are usually placed in longer culverts to simulate the diversity of a natural channel. Fish will rest in the reduced-velocity areas adjacent to the rock bands during high flow events. Rock bands also reduce trench erosion that occurs along smooth walled culverts. See Figure 18, next page.

In gravel and cobble bed streams natural bed material is normally placed where mechanical equipment can be


Wayne Stancill

***Figure 18.*** *Rock bands reduce flow velocity in a culvert.*

operated in the culvert. Walk-behind equipment can place material in culverts as small as 72" in diameter. In smaller culverts it is not practical to place bed material and the culvert will usually fill naturally over a period of years. If bed material is not placed in the culvert, it should be designed so the water depth will be adequate for fish passage when construction is completed. In sand bed streams it is typical to allow culvert beds to fill naturally. In longer culverts in sand bed streams, rock bands can be placed to create some bank roughness when hydraulics will not be compromised.

Monitoring indicates that fish passage failure using the Stream Simulation Approach is most commonly due to:

• Erosion of bed material during flooding where the culvert itself or bed material was undersized.

• Low water depth during low flow periods due to lack of bed material which results in the flow spreading out across the culvert bottom at depths too shallow for fish to move through. A low flow channel forms in bed material deposited in the culvert.

The culvert may also fail like any crossroad culvert due to poor bedding material, poor backfill compaction and unstable material below the culvert. In bottomless culverts structural failures have occurred due to scour at shallow footings.

There is engineering involved in setting the grade of the culvert and determining the stability of the channel substrate material. From an engineering standpoint the advantage of the Stream Simulation Approach is that it is not necessary to compare velocities in the culvert to acceptable velocities for target fish. Target fish are typically the weakest swimmers of the fish in the stream.

***Hydraulic Design Approach.*** The Hydraulic Design Approach applies to short or long culverts that will have significant backwater at bankfull flow—including the vents of low water crossings and culverts that are designed to carry flood flows with higher velocities due to backwater. Culverts constructed with the Hydraulic Design Approach will not usually provide fish passage during high flows, but are designed to provide fish passage during normal flows and critical times of the year for spawning and fish migration. This approach is the most engineering-intensive, as the control velocities are based on the swimming ability of target fish.

On the Great Plains, because streams typically have relatively flat gradients and slow flows, culverts sized for flood flows should qualify for the simpler No Slope or Stream Simulation design approaches. Sometimes the Hydraulic Design Approach is used where the No Slope or Channel Simulation approaches are not practical from a cost or engineering perspective. However, due to uncertainties that can affect design effectiveness when using Hydraulic Design Approach, it should be the method of last resort.

The uncertainties associated with the Hydraulic Design Approach include the following:

• Swimming ability and timing of target species

• Doesn't address turbulence and perhaps other hydraulic characteristics

• Hydrology simulations have large standard errors

• May affect stream processes such as sediment transport and debris loading.

The Hydraulic Design Approach matches the hydraulic performance of a culvert with the swimming capabilities of a target species of fish. This is a traditional approach in some areas that is widely accepted by regulatory agencies. The inherent assumption is that fish passage will not be provided at high flow conditions due to excess velocity and turbulence in the culvert.

The major decision then is on which flow is used for the design criteria. There are a number of options:

• Satisfy fish passage criteria 90% of the time during the fish passage season

• Median flow during the migration season

• 1% annual exceedance

• Spring base flow

• Flows that fill the active channel (bankfull width).

There are roadway safety issues involved with low water crossings being flooded for a number of days. Engineers are likely to first size the culverts based on how long the road can be flooded then check the velocities for fish passage.

## FISH PASSAGE VELOCITIES

***Research.*** Research by Ficke et al, published by the American Fisheries Society in 2011, studied the swimming and jumping abilities of brassy minnow Hybognathus hankinsoni, Arkansas darters Etheostoma cragini, and common shiners Luxilus cornutus. Based on swimming trial results, current velocities in fishways should not exceed 2 ft./sec. for brassy minnow or common shiners and 1 ft./sec. for Arkansas darters. Based on the results of this laboratory study, water velocities of less than 2.5 ft./sec. and avoidance of fishways with vertical drops or weir type structures will increase the probability of successful passage of small-bodied fishes. FishXing software has a listing of swimming speeds of many fish species but does not currently include the above listed species.

***Target species design velocity.*** The target species for fish passage design is site specific and may be a minnow, shiner or darter. If unsure the design engineer should check with U.S. Fish & Wildlife Service and the Kansas Department of Wildlife, Parks and Tourism. FishXing software has a listing of swimming speeds of many fish species and should be checked if the target species is not listed above. Once the target species is identified that species' physiology will determine the control velocities and perhaps the spawning and migration period for the design. When velocities exceed the sustained swim speeds, rock bands are required to provide rest areas. Rock bands are not practical in small diameter pipes, so the control velocity will be the sustained swim speed.

## CONCLUSION

On the Great Plains it's usually easy to design and construct a stream crossing for a two-lane road to provide fish passage. The two basic principles are:

- Submerge the flow line, and
- Size the culvert for bankfull flow.

On larger projects, low water crossings and more critical areas, there are three design approaches depending on the situation: a) No Slope, b) Stream Simulation, and c) Hydraulic Design.

Headcuts and perched culverts are barriers to fish passage. Rock ramps with Newbury Rock Riffles are the preferred treatment to restore fish passage. For more information on providing for fish passage when designing and placing culverts, consult the following references.

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## APPENDIX

***Regional Condition 1.*** There are numerous requirements when working in Waters of the U.S. The following Regional Condition was developed specifically for stream crossings in Kansas, and became effective in 2012. Regional Condition 1 is reprinted below and can be accessed online at the U.S. Army Corps of Engineers portal. See the link below.

### General Guidelines for Stream Crossings
### Regional Condition 1

For all Nationwide Permits that involve the construction/installation of culverts and low water crossings, measures will be included in the construction, design, and installation that will allow for the passage of flows and promote the safe passage of fish and other aquatic organisms. The following General Guidelines are required to supplement General Condition (2) Aquatic Life Movements and General Condition (9) Management of Water Flows.

**Culverts:**

• Culverts must be designed, sized, and placed correctly. Culverts perched above the grade of the stream are not allowed. This includes other in-stream structures placed at the inlet with the purpose to reduce sedimentation within the stream crossing. Culverts must be the shortest length necessary to meet the project purpose.

• New or replacement culverts must be designed to convey the geomorphic bankfull discharge (return period of 1.01 – 1.7 years) with a similar average velocity as upstream and downstream sections. A single culvert is encouraged. The following basic guidelines shall be used when designing the culvert area for similar average velocity:

| ***Stream Type*** | ***Culvert Area*** |
| --- | --- |
| Perennial | Similar to upstream and downstream preconstruction bankfull area (approximate minimum area of 85%) |
| Intermittent | Similar to upstream and downstream preconstruction bankfull area (approximate minimum area of 50%) |
| Ephemeral | Sized to convey geomorphic bankfull discharge |

• For permanent crossings, the culvert must be embedded and backfilled below the grade of the stream ≥ 1 foot for culverts >48 inches. On culverts ≤ 48 inches the bottom of the culvert must be placed at a depth below or at the natural stream bottom to provide for passage during low flow conditions. Culverts in streams with non-erodible beds (i.e. bedrock or stable clay) must be constructed flush with the stream bed, but do not need to be embedded. Culverts in streams with highly erodible beds must be embedded deeper to lessen the chance of future perching due to downstream degradation and/or may be accompanied with other grade control measures as needed to prevent erosion.

**Low Water Crossings:**

• The applicant must notify the District Engineer when repairing, rehabilitating or replacing low water crossings when discharges of dredged or fill material would raise or lower the lowest elevation of the crossing or when removing the structure.

• When replacing or removing low water crossings the applicant must propose and employ measures to mitigate for and minimize the potential of streambed headcutting where channel incision has occurred downstream of the structure and the structure is providing grade control that is preventing channel incision from migrating upstream.

Source: http://www.nwk.usace.army.mil/Portals/29/docs/regulatory/nationwidepermits/2012/KSRC1Streams.pdf