STREAM CROSSING INVENTORY AND BARRIER RANKING GUIDELINES

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The content of this publication is a synthesis of current literature and expertise provided by a group of highly experienced MN DNR professionals that work directly with streams, stream crossings and stream restoration.

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PROJECT GOALS

Recognition of the need for assessing the impacts of culverts on our watersheds and prioritizing restoration efforts is growing among natural resource professionals across the state of Minnesota. The MN DNR Stream Habitat Program developed and field tested a culvert survey protocol and ranking procedure to begin to address culvert impacts. The purpose of this document is to present this field and ranking protocol and provide a case example which demonstrates how data collected using this methodology can be used to determine a barrier ranking for each culvert.

This document specifically describes data collection parameters, procedures and barrier ranking assignment. A complete inventory of all (public and private) stream crossings in the Root River Watershed was collected to demonstrate how these guidelines can be applied.

INTRODUCTION

Stream crossings, including bridges, culverts and fords, are abundant across the landscape. However, their individual and cumulative impacts are unknown. For example, in the Great Lakes Basin there are 38 times more stream crossings than there are dams (Januchowski-Hartley et al. 2013) yet their combined impacts on stream stability and fish passage have not been assessed. The abundance and effect of crossings are important when analyzing and evaluating watershed health. To assess the impacts of stream crossings on stream systems, we must understand:

1) how crossings impact stream systems,
2) which crossings have the most impact and
3) why they are problematic.

Currently in Minnesota, there is no statewide inventory of stream crossings. The random data that has been collected is scattered across the local scale by various organizations so it is not consistent, centrally organized or shared. This lack of consistent and consolidated data makes it difficult for decision makers, especially those at the watershed or state level, to identify and prioritize the replacement of structures that are negatively impacting river ecosystems. For those that are taking a strategic approach to stream restoration, a consistent, collective and complete inventory is critical to making informed decisions that will make the most progress towards improving stream and watershed health. As stated by Kemp and O'Hanley (2010), having a complete inventory will allow for the maximization of positive benefit resulting from barrier remediation.

Of the various types of stream crossings, culverts are typically more affordable so they are the most widely used. However, culverts can be particularly problematic. Design issues in both publicly and privately owned culverts include culverts that are too narrow, too wide, set too high and/or poorly aligned (see Appendix G for graphic illustration). Poor culvert design can be a result of inadequate knowledge or training, lack of funding, lack of an appreciation of the ecological consequences and/or deficient permitting regulation authority. As a result, culverts continue to have negative impacts to all five components of our stream systems - connectivity, biology, geomorphology, hydrology and water quality.

The purpose of the review below is to describe how culverts impact all five components directly and indirectly. The impacts of culverts reviewed below are by no means comprehensive.

CONNECTIVITY

Improperly sized and/or placed culverts can significantly decrease lateral (between the channel and its floodplain) and longitudinal (along the length of the stream) connectivity within a watershed. Both lateral and longitudinal connectivity are critical for stream function and stability and to overall stream health.

Longitudinal connectivity in streams, as it pertains to fish, is typically measured as distances between dams because most dams are complete or near-complete barriers to fish movement. Culverts however, can also be considerable obstacles for fish migration (Jackson 2003; MacPherson et al. 2012) that function like seasonal or year-round barriers that further fragment watersheds. Because culverts commonly function like barriers, research has shown that when compared to bridges and fords, culverts pass the least amount of fish (Warren and Pardew 1998).

Longitudinal connectivity also significantly affect freshwater mussel communities because they depend on freshwater fishes to complete their life cycle and to distribute their young. The tiny larval mussels, called glochidia, are released by the females, which then attach to the gills of a host fish. Once mature they detach from the fish and begin their lives as free living mussels. The distribution of the various native mussel species is directly dependent on the distribution of the host fish. Therefore, culverts that inhibit host fish movement and migration also impede mussel movement.

Lateral connectivity between the channel and its floodplain can be altered by culverts. Undersized culverts can result in constriction of the stream during high and flood flows. Undersized culverts essentially channelize stream flow through a narrow culvert thereby inhibiting lateral migration onto the floodplain (Vaughan 2002).

Over-wide culverts have excessive channel widths and change flow continuity (Zytkovicz and Murtada 2013). Over-wide culverts can cause critically low water depths at lower flows. As a result, over-wide culverts can function like seasonal fish barriers during low flow times of the year or during drought events.

BIOLOGY

Biologically, free-flowing rivers are important for migratory fishes and are necessary to sustain populations. Various Minnesota fishes have been observed to migrate upstream anywhere between just over 100 miles (walleye and sauger) up to nearly 3,500 miles (America eel; Aadland 2010). Research suggests that lake sturgeon need 155-186 miles of connected habitat and have been estimated to migrate as far as 620 miles (Auer 1996). Lake sturgeon migrate to their to spawning grounds and females only spawn once every 4-9 years (USFWS 2015). Culverts can disrupt spawning by blocking access to spawning grounds. As a result or interrupted spawning cycles, only 10-20% of adult lake sturgeon spawn during a given season (USFWS 2015).

Improperly sized and/or placed culverts that function like barriers force aquatic populations to live independently of each other which can lead to long-term genetic changes (Jackson 2003). The long-term persistence of fish populations are potentially compromised as a result of genetic and demographic isolation (Wofford et al. 2010).

In addition to altering the genetic make-up, culverts can also change community structure within a stream system. Research has found that stream reaches just below culverts have altered species composition and decreased abundance of macroinvertebrates (Kahn and Colbo 2008; Peterson 2010).

Culverts can degrade habitat and disrupt important ecological processes, such as flow of energy, nutrient and sediment downstream (Jackson 2003). Culverts can modify riffle to pool ratios and thereby decrease the amount of critical habitat types necessary at different stages of fish development (Dane 1978). Culverts that create backwatering upstream can increase sedimentation rates resulting in buried aquatic habitat and organisms (Frizzell et al. 2004).

GEOMORPHOLOGY

The alteration of erosion and sedimentation rates caused by improperly sized and/or placed culverts can have a variety of impacts on the geomorphology of the stream.

In general, over-wide culverts cause changes to stream systems by altering flow continuity and sediment transport dynamics (Zytkovicz and Murtada, 2013). Over-wide culverts decrease depth, velocity and sheer stress leading to increased sedimentation rates and the formation of mid-channel bars (Frizzel et al. 2004).

In contrast, undersized culverts constrict the stream and cause backwatering at higher flows resulting in upstream lateral erosion of the road prism and in-stream sediment deposition. The outflow from undersized/constricted culverts will have higher velocities and cause both lateral (bank and road prism) and vertical erosion downstream.

Culverts with slopes steeper than the natural stream slope will increase velocities and turbulence at the culvert outlet resulting in downstream lateral and vertical erosion.

Culvert placement and alignment can have additional impacts to geomorphology. Traditionally culverts were placed perpendicular to the road to minimize culvert length disregarding the natural pattern of the stream. The consequences of poor placement or alignment are decreased stream sinuosity and resulting decreased length; this results in steeper slopes and higher velocities ultimately causing more downstream erosion (MN DNR 2013).

HYDROLOGY

Improperly sized, placed and aligned culverts alter flow regimes, velocity and depth. Absence of a low flow channel and insufficient water depth through the structure (Jackson 2003) are a result of an over-wide culvert design.

Conversely, a variety of hydrological problems are the result of undersized culverts such as: 1) the reduction of water conveyance which results in water detention and longer residence times of flows, 2) the constriction of the stream resulting in flow contraction at the inlet that causes excessive turbulence (Jackson, 2003) and 3) a decreased roughness coefficient of stream bed which leads to increased water velocities.

Additionally, undersized culverts can become inundated during high flows and overtop the roadway (Merril and Gregory 2007). When flows exceeds the culvert capacity, the culvert is essentially acting as a dam to retain water and impede flow.

WATER QUALITY

By altering flow patterns and water velocity, culverts can degrade water quality. Upstream and downstream erosion caused by improper culverts can increase stream turbidity. Turbidity can have many deleterious impacts on freshwater fish including: mortality, decreased growth rates, reduced resistance to disease, prevention of egg and larval development, modification of natural migration movements and reduction of available food (MPCA 2008).

Culverts can alter in-stream temperature regimes (MacPherson et al. 2012). Backwatering increases residence time of the water, allowing for higher absorption of the suns energy and thus higher temperatures. This could be particularly problematic for fish species that require cold water environments.

DATA COLLECTION - SCALE AND PURPOSE

There are two main components to the stream crossing data collection initiative: 1) creating an inventory of culvert data and, 2) examining the assessment and usefulness of that data.

When thinking about inventories and assessments, there are different levels of data collection necessary depending on the goals and scope of the project (i.e. smaller scale efforts will allow for more detailed collection of data). A number of datasheets (Appendix A-D) have been generated within the DNR to serve varying degrees of data collection intensity, ranging from basic crossing information to detailed survey information.

All data collection is valuable. However, it is intent of the Stream Habitat Program (SHP) that the methodologies outlined in this document become part of a collaborative effort to compile: 1) a statewide inventory of stream crossings and 2) the associated data necessary to rank culverts for replacement and/or restoration. To apply the ranking guidelines detailed in this document, a standardized minimum level of data is needed (Table 1, Appendix A). The data collected in the SHP Culvert datasheet (Appendix A) is used to characterize, rank and assist with diagnosing the possible problem(s) for each culvert (Table 1).

The information collected at the intended statewide scale is only meant to be a quick and basic indicator of condition upon which to rank stream crossings for restoration. Identified barriers will require more in-depth data collection for design.

The SHP datasheet (Appendix A) differs from the Full Assessment datasheet (Appendix D) in that it requires collection of all parameters necessary for culvert ranking. On the Full Assessment datasheet, substrate depth and water depth are listed as optional data and there is no mention of headwater or tailwater surface elevations. These optional or omitted parameters (headwater and tailwater surfaces, substrate depth and water depth) are critical components used for ranking according to the guidelines detailed in this document. Without these data there is no way to determine what the water slope, headloss, and flow depth are through the culvert and if the crossing is countersunk (Table 1).

Another main difference between the two datasheets (SHP and the Full Assessment) is that the SHP version allows for different methodologies of bankfull estimation (Appendix E-F). Working at a statewide scale would require undue manpower or time to measure bankfull width at each site. In past experience, requiring an onsite bankfull measurement can often times quadruple the amount of time at each site. The use of bankfull, when assigning a barrier ranking, is to determine if a culvert is too narrow/constricted or over-wide. Getting an estimate from LiDAR or an aerial photo will give a coarse estimation of whether the culvert crossing width falls within the range of the stream's bankfull width. Further, precise bankfull information is not necessary for ranking problem culverts (at this stage).

Using the SHP datasheet will provide all the minimum data required for the statewide database and allow for assignment of a barrier ranking. All "required" data detailed in the Full Assessment datasheet has been incorporated into the SHP's datasheet (Appendix A). This was done to supplement other stream crossing/culvert work being done within the DNR.

Table 1: Purpose description and calculations of all data collection parameters on the Stream Habitat Program Culvert Datasheet (Appendix A). Data collection parameters are categorized as 1) basic site characterization (grey), 2a) measurements used for ranking calculations (blue), 2b) quantitative measurements not requiring calculations for ranking (blue) or 3) qualitative analysis used to help diagnose problems at each culvert (green).

1.) Site Characterization Parameters	*Crossing ID, Date, Collected By, County, Township, Section, Range, Roadway, Watersheds, Elevation Method, Lat/Long, Stream, Structure Type, Number of Culverts, Culvert Material, Structure Interior, Structure Shape, Inlet Type, Outlet Type and General Condition*	
2a.) Measurements for Ranking Calculations	***Applicable Ranking Variable*** *(Culvert Slope, Water Slope Bed Slope, Headloss, Perching, Countersunk, Flow Depth, Sizing Width Ratio)*	***Calculation***
Headwater Surface Elevation (HWS)	Water Slope, Headloss	Water Slope = (HWS-TWS)/CL*100 Headloss = HWS-TWS
Tailwater Surface Elevation (TWS)		
Identification of the Thalweg Culvert[1]	Culvert Sizing, Countersunk	*See calculations for Countersunk, Bed Slope, Culvert Slope*
Sediment Depth	Countersunk[1]	≤10 foot wide culverts need ≥1.0 feet of sediment in thalweg to be countersunk >10 foot wide culverts need ≥2.0 feet of sediment in thalweg to be countersunk
Bankfull Width (BKFW)	Culvert Sizing	CHW=Sum of all culvert widths (not including embankment width in between culverts) Sizing Width Ratio[3]= CHW/BKFW
Crossing Hydraulic Width (CHW)[2]		
Perched	Perching	Degree of structure perching (none, 0.5-2.0 feet or >2.0 feet
Culvert Length (CL)	Culvert/Water/Bed Slope	*See calculations for water slope, bed slope and culvert slope*
Inlet Bed Elevation	Bed Slope[1]	Bed Slope = (Inlet Bed Elevation – Outlet Bed Elevation)/CL*100
Outlet Bed Elevation		
Inlet Invert Elevation	Culvert Slope[1]	Culvert Slope = (Inlet Invert Elevation – Outlet Invert Elevation)/CL*100
Outlet Invert Elevation		
Inlet Water Depth	Flow Depth[1]	Determine if flows are >0.2 foot of depth
Outlet Water Depth		
2a.) Quantitative Measurements not used for Calculations	***Applicable Ranking Variable***	***Reason for Data Collection***
Downstream Scour Pool	Culvert Sizing, Culvert Slope	Extent of downstream scour pool may indicate degree of sizing issue and/or problematic culvert slope
Upstream Pool	Culvert Sizing	Extent of upstream pool may indicate degree of sizing issue
Culvert Height[4]	Countersunk	Culvert height can be used to determine if a culvert is countersunk (e.g. MESBOAC; this document does not use it for that)
3.) Diagnosis	Alignment, Bank Erosion, Backwatering, Upstream Deposition, Downstream Incision, Substrate Type, Plugged, Crushed and Rusted	

[1] Culvert Slope/Bed Slope, Countersunk and Flow Depth are calculated based on the structure's thalweg culvert.
[2] Crossing Hydraulic Width is the sum of culvert widths not including the width of the embankment between the culverts.
[3] If the culverts are offset then the Sizing Width Ratio is based on only the thalweg culvert width versus the total hydraulic crossing width.
[4] Culvert height was initially used to calculate if a culvert is countersunk. However after reviewing the MN and MI General Permits, a better analysis to determine if a culvert is countersunk involved looking at crossing hydraulic width instead of height. Height is still collected as measurable site characteristic and it is required on the Full Assessment datasheet (Appendix D).

STUDY SITE

The Root River watershed is in the "Driftless" area of southeastern Minnesota (Fig. 1). This 709 square mile watershed (MN DNR, 2014) lies within the Mississippi River basin and has 2,471 miles of stream (NRCS, 2014).

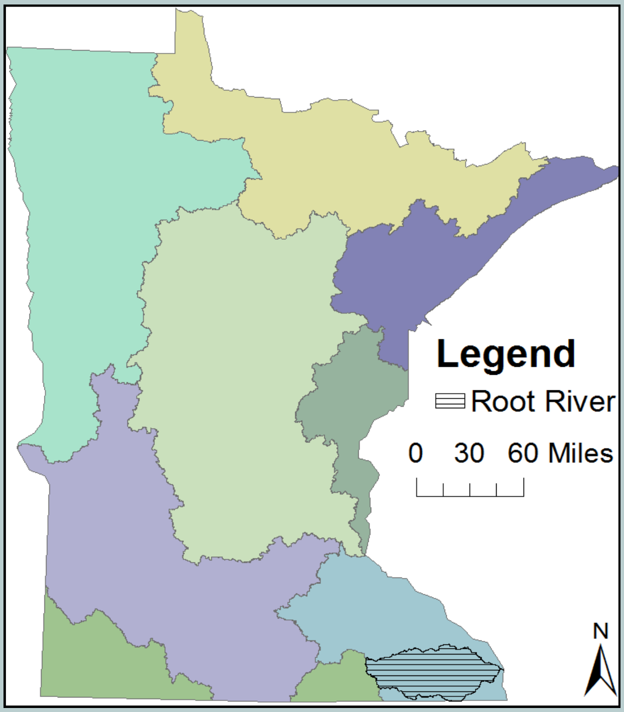


Figure 1: River basins in Minnesota. The Root River watershed is located in the Lower Mississippi River basin (blue) in southeastern Minnesota..

Characteristic of this area is the karst topography (Fig. 2) which is a result of dissolving limestone. In comparison with other areas of Minnesota, this watershed has steeper terrain and is often referred to as Minnesota's "little Switzerland" (Waters, 1977).

Figure 2: Karst landscape in the Root River Watershed.

This watershed suffers from frequent, flashy floods. Historically, large flood events in 1865 and 1876 plagued farming operations and resulted in several deaths (Waters, 1977). In 2013, during the first year of this inventory, a large flood event did severe damage within the watershed (Fig. 3). Following that event, Governor Dayton requested a declaration of Public Assistance from FEMA at the rate of $94.37 per capita in Fillmore County and $339.55 per capita in Houston County for damages to roads and bridges (FEMA 2013).

Figure 3: Impacts of the 2013 flood in the Root River watershed: A) flood flows carried a recreational vehicle downstream, B) a bridge was damaged due to flows overtopping the structure and C) a stream crossing was washed out.

METHODS

Stream Crossing Inventory

Digitizing Site Locations

The first step in creating a stream crossing inventory was to identify the locations of all stream crossing in the watershed. There are two approaches to identifying stream crossings - road-based and stream-based inventories. The road based inventories approach will exclude a number of crossings including dams, diversions and crossings on side streams (WDFW, 2000). Due to this limitation of the road-based approach, this inventory of stream crossings locations is a stream-based approach that used the entire perennial stream system within the watershed. As a result, all intersections between stream and infrastructure are identified as stream crossings.

For this case example, a comprehensive inventory of stream crossings was completed, including both public and private crossings, on all 24K Perennial Streams (MN DNR Quick Layers) in the Root River Watershed[1]. Crossing locations were identified using ArcMap 10.1 by simultaneously consulting FSA 2010 aerial imagery and MN DOT's inventory of public bridges and culverts. Each perennial stream was visually inspected (at a 1:2500 scale) and all crossing locations were digitized in a new data layer.

Figure 4: Illustration of a pipe-arch culvert to demonstrate that crossing refers to the entire structure (red circle) and a culvert (yellow circle) refers to one section within the crossing.

Structure Type Definitions

The Minnesota Department of Transportation (MNDOT) has very specific definitions for whether a structure is a bridge or a culvert. According to MNDOT standards, a multiple barrel structure is considered a bridge "when multiple pipes convey the flow, the gap between the pipes is less than half the interior diameter of the smallest pipe and the pipes together are greater than 10 foot span" (2011).

For the purpose of this study, culverts and bridges were more simply defined. A stream crossing was considered a culvert if it had a hard or confined bottom. If there were multiple sections to a hard bottomed crossing, each section was labeled as a culvert (Fig. 4; i.e. culvert can refer to the crossing type overall or a single barrel within a crossing.). Bridges were defined as stream crossing with open bottoms while fords were defined as shallow stream crossing with no overhead structure.

Table 2: Levels of Data Quality

Level of Data Quality	Description of Data Analyzed	Access Scenario
1	Quantitative datasheet (Appendix A) Pictures Aerials	Full Access
2	Onsite qualitative datasheet (Appendix B) Pictures Aerials	Sites that were inaccessible (e.g. fenced out)
3	Pictures Aerials	No one available to ask for permission (e.g. driveway)
4	Aerials	Permission denied

[1]Digitizing of stream crossing locations of Minnesota watersheds is currently an ongoing effort. The following is a list of other HUC8 watersheds that have been completed: Buffalo River, Chippewa River, Cottonwood River, Crow Wing River, Des Moines River Headwaters, Lac Qui Parle River, Leech Lake River, Little Sioux River, Lower Big Sioux River, Minnesota River Headwaters, Minnesota River Yellow Medicine, Mississippi River Brainerd, Mississippi River Grand Rapids, Mississippi River La Cresent, Mississippi River Sartell, Mississippi River St. Cloud, Mississippi River Winona, North Fork Crow River, Otter Tail River, Pine River, Pomme de Terre River, Red Lake River, Red River of the North Marsh River, Red River of the North Sand Hill River, Redeye River, Redwood River, Rock River, Root River, Snake River, Upper Big Sioux River, Upper Iowa River, Upper Mississippi River Reno, Upper Red River of the North, Watonwan River and Wild Rice River.

Figure 5: A) image of structure looking downstream, B) image of structure looking upstream, C) image of stream looking downstream and D) image of stream looking upstream. Note that there is indication of flow direction in each picture.

<u>Data Quality Levels</u>

Due the various situations encountered in the field, four different levels of data quality were established (Table 2). The highest level of data was collected at each site based on the extent of access.

- The data quality level 1 quantitative datasheet (see Appendix A) was used when the site was completely accessible.
- The data quality level 2 datasheet (see Appendix B) was used when we could get to the site but could not get into the culvert to obtain measurable data (i.e. high flows, fencing etc.). In these cases, only qualitative data based on a visual assessment was recorded.
- Data quality level 3 data was recorded at sites where we intended to ask permission onsite (mostly for driveways) but no one was around to give permission. Since we were already onsite, pictures were taken.
- Data quality level 4 was based on gathering information available on Google Earth's most recent aerial photography. Typically this level was used when access was denied by the landowner or there was no reasonable access point to the crossing.

<u>Data Collection</u>

The methodologies detailed in this document are a more basic version of the Great Lakes Stream Crossing Inventory Instructions (GLSCII, USFS *et al*. 2011). The GLSCII methods were modified in order to be more applicable to the large scale of this inventory effort.

1.) Photos

A minimum of four photos are taken at each site (culverts, bridges and fords) to provide visual documentation of conditions at the time of site visit. (Note: something was used to indicate direction of flow). These included two pictures of the structure itself, one from upstream and the other from downstream, and two pictures of the stream/riparian zone from on top of the crossing, one looking upstream and the other looking downstream (Fig. 5).

2.) Site Information

Location details are recorded at each site including: crossing ID, roadway name, township/section/range (T/S/R), county, stream name, watershed and latitude/longitude.

3.) Qualitative Data for Culverts

A visual qualitative assessment is completed to document: year built, materials, number of culverts, structure type, structure interior, structure shape, inlet/outlet type, general condition, substrate, plugged, crushed and rusted through.

The culvert crossing is also visually assessed to determine if it: has offset culverts, has downstream incision, has an upstream pool/backwatering, is aligned properly, generates bank erosion and/or has upstream deposition/bars.

Figure 6: A typical stamp seen on cement culverts identifying the year it was constructed and culvert dimensions.

Year built: If a marking can be found on the inside of the culvert (see Fig. 6), then record the year built.

Culvert Material: Document if the culvert is made out of metal, concrete, plastic or wood.

Number of culverts: Record the number of separate culverts comprising the crossing as defined above.

Structure type: Record if the crossing is a culvert, bridge, dam, ford or other.

Structure interior: Record if the culvert(s) are smooth or corrugated.

Structure shape: Document if the culvert(s) are pipe arch, round, square/rectangle or ellipse (Fig. 7). NOTE: GLSCII also has "open-bottomed square/rectangle" and "open bottom arch" as options for shape types so they were included on the datasheet). However neither these options were ever selected since we defined open bottomed structures as bridges.

Inlet type: Record inlet type for each culvert: apron, mitered, headwall, projecting, wingwall or trash rack (Fig. 8)

Figure 7: Examples of structure shapes including A) pipe arch, B) round, C) square/rectangular and D) elliptical.

Figure 8: Inlet types include: A) apron - culvert extends beyond the pipe, B) mitered - top of the culvert is angled back toward road, C) headwall - a wall around the inlet , D) projecting - culvert protrudes from embankment, E) wingwall - side walls angled from the inlet and (F) trash rack - mesh cover over inlet to catch debris (no image available).

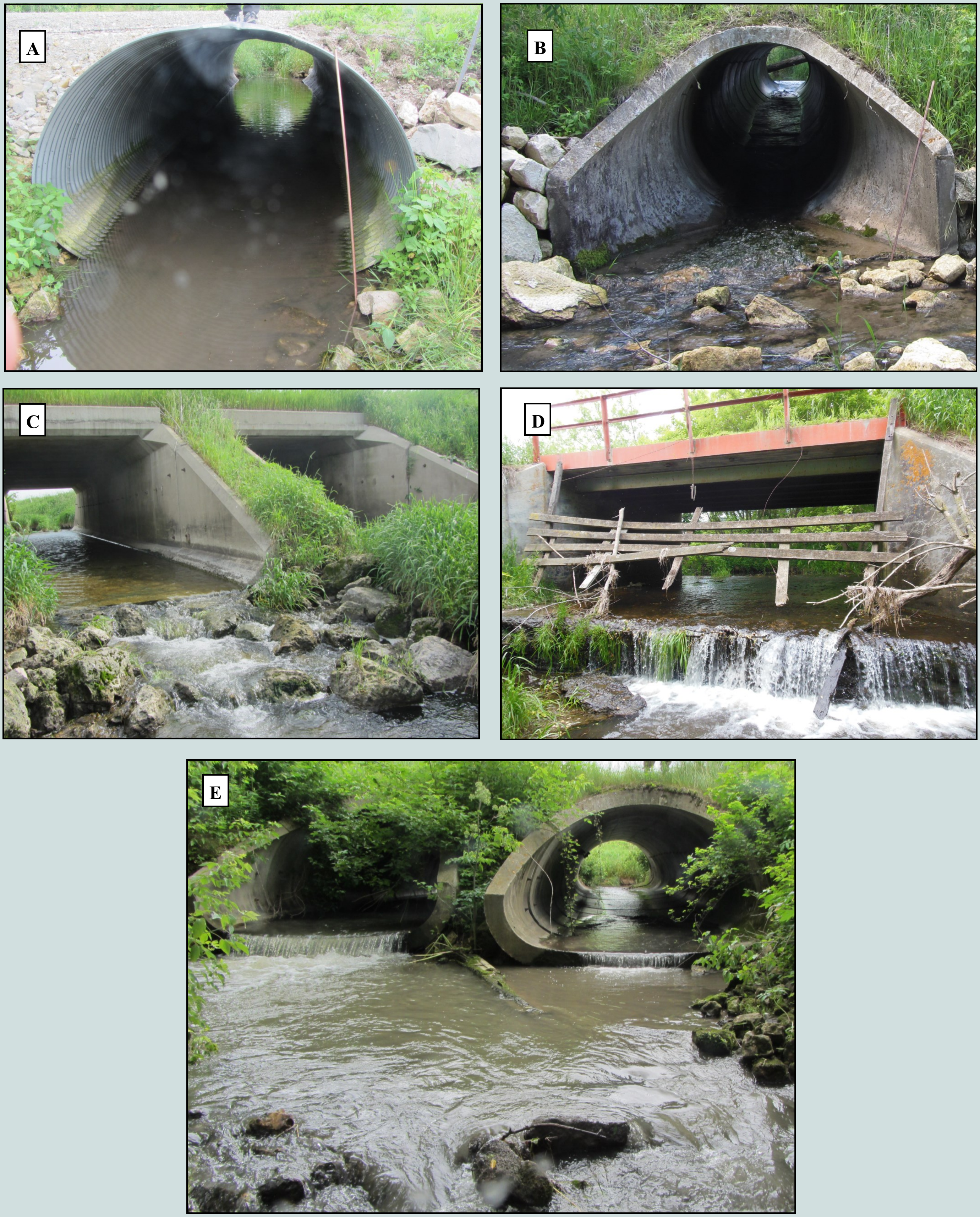


Figure 9: Outlet types include: A) at stream grade - bottom of culvert is at or below stream bed, B) apron - extension of culvert beyond pipe, C) cascades over rip rap, D) free falls into pool and E) free falls onto rip rap.

Figure 10: Illustration of A) channel incision downstream and B) the upstream pool of a backwatered culvert during high spring flows.

Outlet types: Document the type of outlet for each culvert: at stream grade, apron, cascades over rip rap, free falls into a pool, or free falls onto rip rap (Fig. 9).

General Condition: Record the general condition of the culvert as new, good, fair or poor.

Substrate: Document what type of natural stream bed material(s) are in each culvert. Choose none, sand, gravel, rock or mixed and note if substrate is in the upstream and/or downstream end of the culvert.

Plugged: Estimate what percent of the cross-sectional area is plugged for each culvert and note if it is in the inlet, outlet or inside culvert.

Crushed: Estimate what percent of the cross sectional area of each culvert is crushed and note if it is at the inlet, outlet or inside the culvert.

Rusted through: Record if any of the culverts are rusted through and note if it is at the upstream and/or downstream end.

Offset Culverts: If multiple culverts exist, document if there is >0.5 feet of elevation difference in the culvert inverts.

Downstream Incision: Determine if there is evidence of incision downstream of the crossing (Fig. 10a).

Upstream Pool (backwatered): Look for and upstream pool or signs that the crossing gets backwatered during high flows (Fig. 10b).

Proper Alignment: Alignment should follow the natural pattern of the river (Fig. 11).

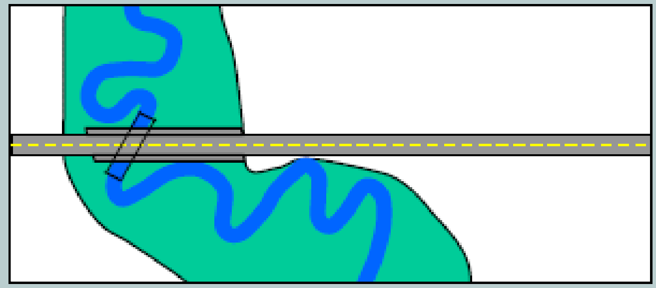


Figure 11: A correctly aligned culvert (MN DNR 2013)

Bank Erosion: Document if the culvert is causing stream bank erosion.

Upstream deposition/bars: Look for upstream indicators of deposition, such as mid-channel bars. Excess deposition indicates constriction and backwatering caused by the crossing.

4a.) Quantitative Data for Crossing

Upstream (US) Pool: Estimate length, width and depth of the upstream pool (if one exists). An upstream pool indicates that the culvert is undersized.

Downstream (DS) Scour Pool (Fig. 12): Estimate length, width and depth of the downstream scour pool (if one exists). Evidence of a scour pool indicates the crossing could be constricted or have a high slope.

Water Surface Elevations (Fig. 13): Record the elevation reading at the headwater surface (HWS) and tailwater surface (TWS). Take these readings out of the direct influence of the culvert. For example, the tailwater surface reading should be taken where the river is flowing, not where plunging or cascading over rip rap. Be sure to take the tailwater surface elevation downstream of any hard armoring that may exist (Fig. 14).

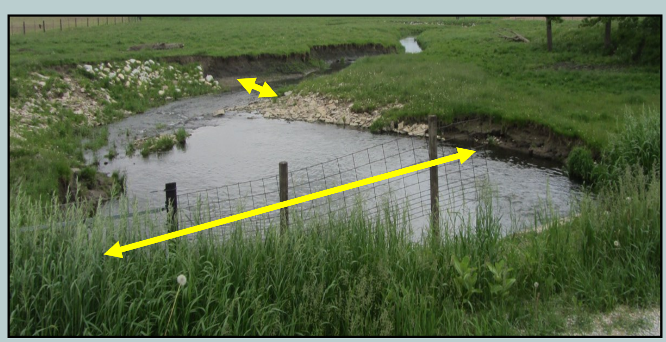


Figure 12: Example of downstream scour pool width in relation to the stream width.

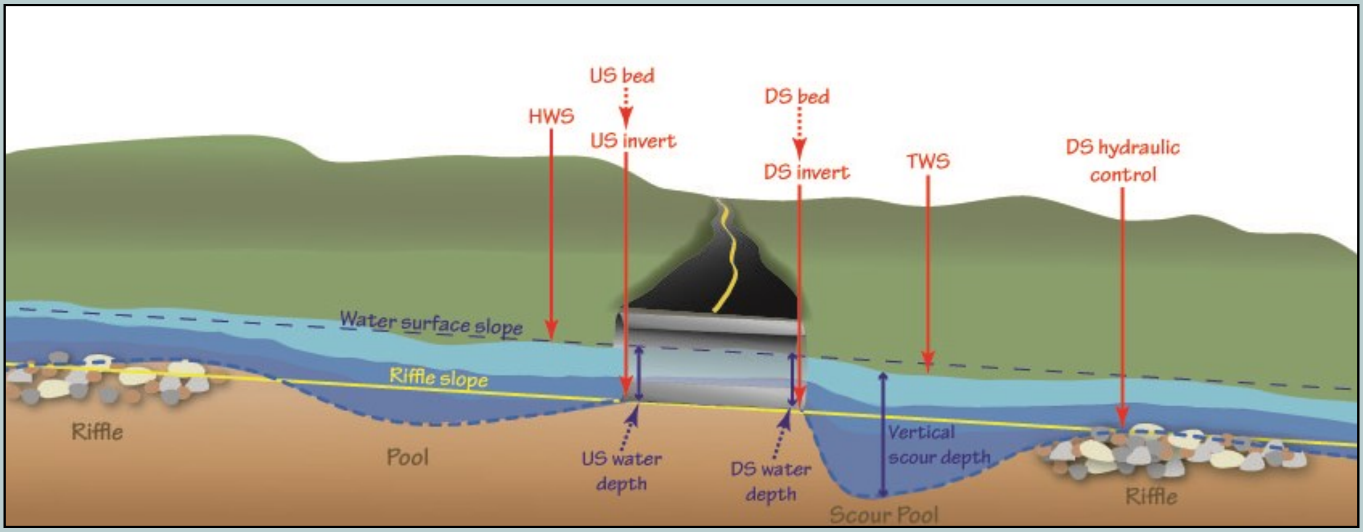


Figure 13: General locations of survey points (**elevations** and **water depths**). Measurements include: headwater surface (HWS), tailwater surface (TWS), upstream (US) and downstream (DS) invert elevations, US and DS stream bed elevations, DS hydraulic control, US and DS water depths in the deepest part of each opening, and vertical scour water depth.

Bankfull Width: For the purposes of this inventory, the bankfull width was used to calculate the sizing ratio (the ratio between the crossing hydraulic width and the bankfull width of the stream). Due to the quantity of sites surveyed for this inventory, Method 3 described in Appendix E, estimating bankfull from aerial photos, was used. Appendix E outlines three methods for determining bankfull depending on the scale of the project and accessibility. Choose the most accurate and applicable method for your purposes.

Thalweg: Record which culvert is the thalweg.

Sediment: In the thalweg culvert only, use a copper rod with 1 and 2 foot markings to measure the depth of sediment at the deepest point in the inlet and outlet. Record if there is <1.0 foot, 1-2 feet or >2 feet of sediment.

4b.) Quantitative Data for Culverts

Elevation Method: Record the appropriate elevation method: Benchmark (BM) when using a relative set elevation (e.g. 100 feet), Monument when recording actual elevations based on a monumented control, Real Time Kinematic (RTK) when using GPS based survey equipment or LiDAR when extrapolating elevations from LiDAR data.

Benchmark Elevation: For this case study, all elevations were based on a relative benchmark with a set elevation of 100 feet at each site (BM Method). An "X" was marked on the top of all concrete culverts using a chisel and hammer. For culverts that couldn't be marked (plastic or metal) the benchmark location was typically the top of the corrugation on the inlet/outlet or the top of the road. Document the location of the "X" or where the benchmark was taken and record the elevation.

Bed and Invert Elevations (Fig. 13): For each culvert record the upstream (inlet) and downstream (outlet) inverts and stream bed elevations. The invert is the bottom surface of the culvert whereas the stream bed elevation is taken on top of any deposited sediment in the culvert acting as stream bed. *Note: it may be difficult to get at the invert elevations depending on how much sediment has been deposited. If the invert cannot be reached, record the elevations of the top of each culvert upstream and downstream. This option is not ideal but can provide an estimate of culvert slope.

Downstream Hydraulic Control Elevation (Figure 13): If accessible, locate the head of the nearest riffle downstream from the culvert. Record the elevation of the head of the riffle which serves as the downstream hydraulic control.

Water Depths (Fig. 13): Measure upstream and downstream water depths in all flowing culverts. These measurements are to be taken in the deepest part of each culvert. Do not record non-flowing water as water depth.

Perched (Fig. 14): Determine if each culvert is perched. If perching exists, estimate the degree of perching by measuring the height between downstream water surface and the water surface in the culvert outlet.

Culvert dimension: Record the length, width and height for each culvert. Round culverts only require the diameter and length. Measure dimensions depend on culvert shape (Fig. 15.) *Note: Culvert length measures the total length of the hard bottom.

Figure 14: Perched culvert with hard armoring downstream.

5.) Onsite Diagnosis

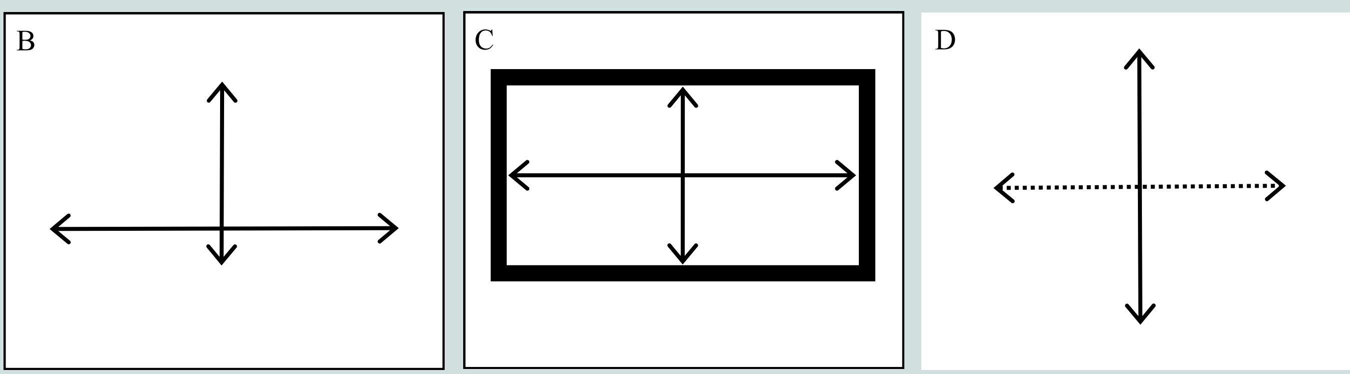
Barrier to Fish Passage: Document if the crossing inhibits fish passage. Consider all flows.

Limiting Factor for Passage: If the onsite diagnosis determines there is an issue for fish passage, record what specific obstacle is the limiting factor: outlet drop, velocity, depth or substrate.

Stream Stability Impact: Record if the crossing is having an impact of geomorphic stability of the stream.

Recommended Corrective Actions: Provide suggestions on how to resolve the observed fish passage obstacle(s) and impacts to stream stability.

Figure 15: Illustration on where proper culvert dimension should be taken. A) Do not include the culvert thickness in the height or width dimensions. B) For pipe arch culverts take the height in the center and the width near the bottom. C) For box culverts, dimensions can be taken anywhere but ideally in the centers. D) Round culverts only need one diameter dimension taken through the center.



Barrier Ranking

Culverts were ranked into three degrees of barriers or were considered passable based on the collected site data (Table 3). Parameters used to determine passability include: degree of perching, sizing width ratio (crossing hydraulic widthto bankfull width), if countersunk, water slope, culvert slope, headloss, depth of flow, upstream pool/ backwatering and downstream scour pool. These parameters were chosen because they are indicators of what the predominant passability issue(s) are: high velocities, water depth, and outlet drop.

Ranking Parameters

Perch height: the difference between water surface in the culvert outlet and tailwater surface of the stream. *Note - if hard armoring is present downstream, make sure to estimate perching downstream of armoring (Fig. 14).

Countersunk: the degree to which the thalweg culvert invert is set below the streambed (both inlet and outlet). The crossing hydraulic width is used to determine how much sediment needs to be present to be considered countersunk. Culvert crossings greater than 10 feet wide are considered countersunk if there is more than 1.0 foot of sediment and culvert crossings greater than 10 feet wide are considered countersunk if there is more than 2.0 feet of sediment maintained in the thalweg culvert (MN DNR 2013, Michigan DEQ 2014).

Sizing width ratio: the ratio of crossing hydraulic width to bankfull width. Culverts with a ratio of less than 0.8 are considered constricted while culverts with a ratio of greater than 2.0 are considered over-wide.

Water slope: the calculated water slope is based on culvert invert length and the difference in headwater and tailwater surface elevations. Water slopes over 1% are considered possible barriers.

Culvert slope: the calculated slope of the culvert is based on culvert invert length and the difference in invert elevations from the inlet and outlet. Culvert slopes over 1% are considered possible barriers when ranking sites. **NOTE: Water and culvert slopes of 1% were selected based on literature to provide a way to rank sites. These slopes would need to be reassessed in the context of the stream slope if considering the site for restoration.*

Headloss: the difference in elevation between headwater and tailwater surfaces. Culverts with greater than 1.0 foot of headloss are considered possible barriers.

Depth of flow: the depth of flow in both the inlet and outlet of the thalweg culvert. The reading is taken at the maximum water depth from stream bed in the thalweg. Culverts with less than 0.2 foot of flow are considered to be a limiting factor for fish passage.

Upstream pool (backwatering): is assessed based on current upstream pool conditions or evidence of backwatering at high flows. If ponding is observed during site visit or if the channel is noticeably wider upstream, then the site is considered to have an upstream pool. If there is evidence of upstream lateral scour and the crossing is likely to backwater at higher flows, then it is assumed to have an upstream pool.

Downstream scour pool: If there is a noticeably wider and deeper pool just downstream of the culvert. **NOTE: the size of the downstream scour pool could be used to sort crossings by degree of severity. For this protocol, all crossings with a downstream scour pool (regardless of severity) were included to obtain a Level 3 ranking.*

Table 3: The Barrier Ranking Categories and Parameters used for each level.

Ranking	Degree of Barrier	Parameters Characterizing Barrier Type
1	Complete	>2.0 ft perched (Aadland, personal communications, September 9th, 2014)
2	Significant	0.5-2.0 ft perched (WDFW 2000, USFS et al. 2011) <0.8 sizing width ratio (constricted) Not countersunk and one or both: •Water/Culvert Slope >1% (WDFW 2000) •Headloss of >1.0 ft
3	Partial/ Seasonal	Water depth <0.2 ft (USFS et al. 2011) Upstream Pool or evidence of backwatering (USFS et al. 2011, Verry 2011) Downstream scour pool (USFS et al. 2011) >2.0 sizing width ratio (overwide)
4	Passable	No parameters exceed set limits
5	Dry	No data collected at dry crossings

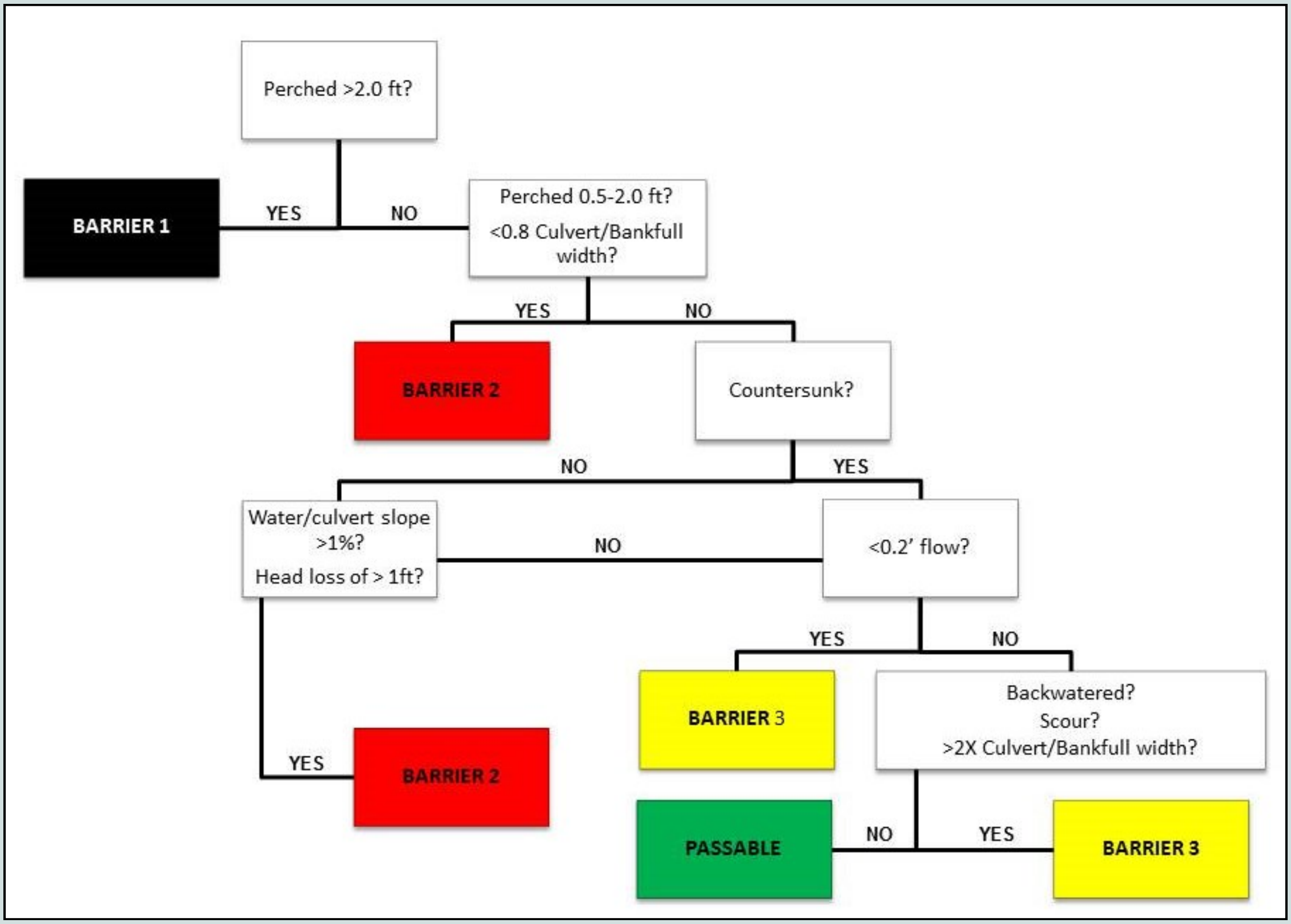


Figure 16: Flowchart of culvert ranking analysis. *In black box, complete barrier, red, significant barrier, yellow partial or seasonal barrier and green passable crossing.*

Barrier Ranking Definitions

The following barrier ranking levels were assigned based on the degree of impassibility for native fish species: complete barriers, significant barriers and partial/ seasonal barriers. A flowchart to assist with ranking assignment has been provided (Fig. 16.)

Complete barriers (Table 3; Fig. 17a): completely block native fish passage because they were perched more than two feet.

Significant barriers (Table 3; Fig. 17b): block passage for most native fish species and life stages at most flows. These crossings were ranked as a significant barrier if one or more of the following criteria were met: a) perched 0.5-2 feet, b) not countersunk and water or culvert slope over 1%, c) not countersunk and more than 1 foot of headloss and/or d) constricted with a sizing width ratio of <0.8.

Partial or seasonal barriers (Table 3; Fig. 17c): block passage for some species and life stages at most flows or are barriers at extreme high or low flow conditions.

Passable (Table 3; Fig. 17d): had no measured conditions that indicate fish passage issues.

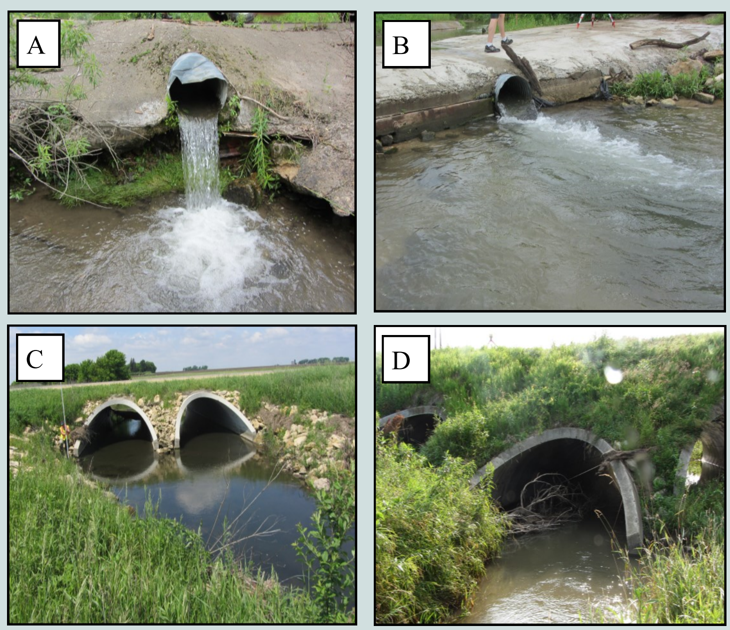


Figure 17: Examples of each barrier ranking level: A) a Level 1 or complete barrier that is perched over two feet, B) a Level 2 or significant barrier with a sizing ratio (hydraulic width to bankfull width) of <0.8 and 0.5 feet of perching, C) a Level 3 or partial/seasonal barrier that is over-wide and has a downstream scour pool and D) a passable crossing with a thalweg culvert, in the middle, set lower than the floodplain culverts on both sides.

RESULTS

Overall, 622 stream crossings were located in the Root River watershed. Of those, 300 were photo documented bridges that accounted for 48% of the total sites visited (Table 4). The other 52% were non-bridge crossings including culverts, dams, fords and undetermined sites (Fig 18, Table 4). The most extreme fish passage barriers include 10 dams and 8 Level 1 (complete) barriers, or 5.6% of all non-bridge crossings (Table 4). From a watershed perspective, these results identify 18 locations that are complete or near complete barriers for most native fish and are sites that are likely to have significant impacts on stream stability, hydrology, water quality and biology.

The Root River system is further fragmented by 88 significant barriers and 147 partial/seasonal barriers (Table 4). Together these crossing categories account for 73% of all the non-bridge crossings in the watershed. Conversely, only 5.9% of the non-bridge crossings were considered passable (Table 4).

These results demonstrate the degree and extent of fragmentation caused by stream crossings. Ultimately there is need for: 1) restoration of high priority sites (such as dams and complete barrier crossings) and 2) incorporation of geomorphic and ecological principals into culvert design, permitting and on the ground implementation.

Table 4: Stream Crossing Ranking Summary for the Root River Watershed

Ranking Level	Number of Sites	Percent of all Non-bridge Crossings
1	8	2.5
2	88	27.3
3	147	45.7
4	19	5.9
5	24	7.5
DAM	10	3.1
UND	26	8.1
Bridges	300	NA

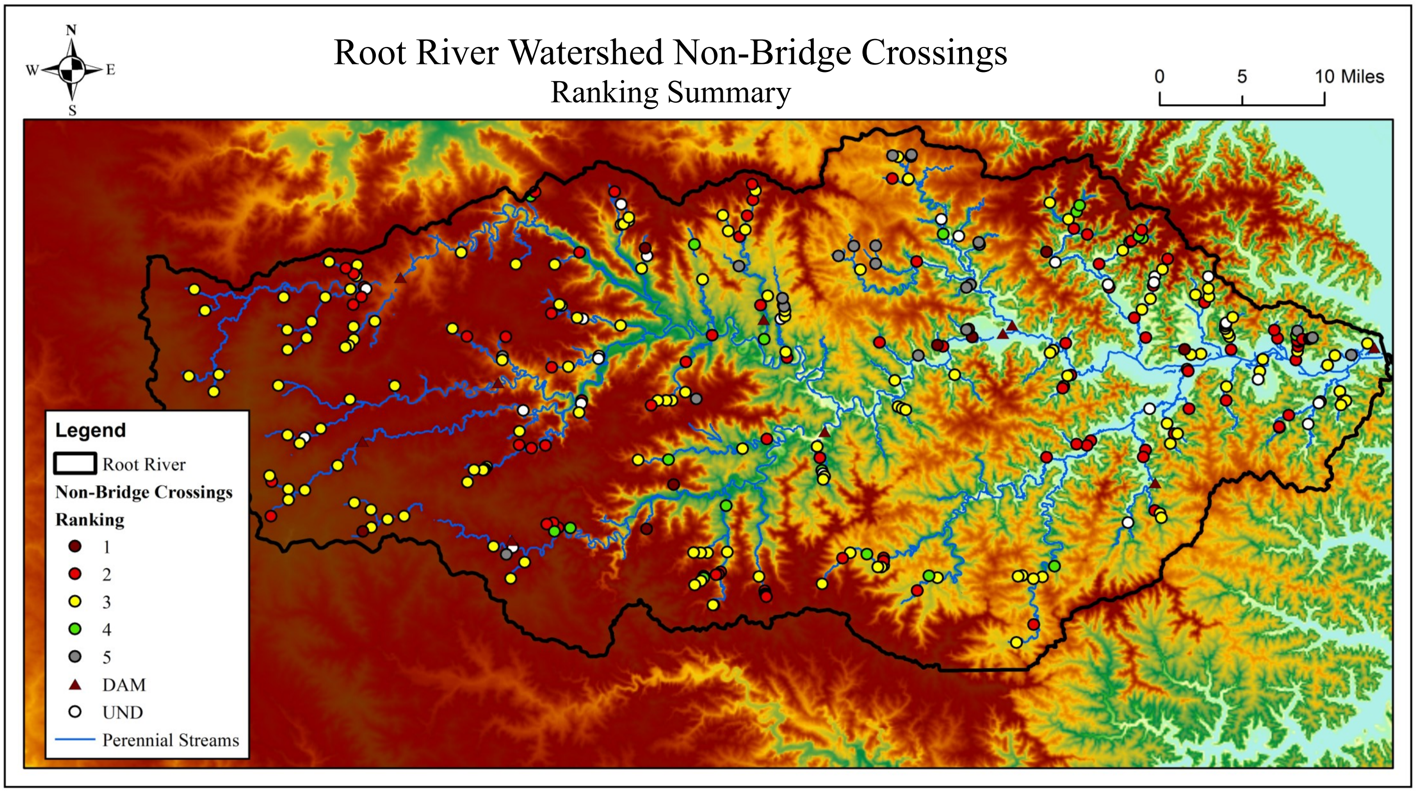


Figure 18: The non-bridge stream crossings within the Root River watershed. Non-bridge stream crossings include culverts, fords, dams and sites that could not be determined. Rankings include: complete barriers (1), significant barriers (2), partial/seasonal barriers (3), passable structures (4), dry structures (5), dams (DAM) and undetermined sites (UND).

Table 5: Barrier ranking parameters and the percent of culverts in exceedance.

Barrier Ranking Parameters	% Culverts
Perched >2 feet	3.2
Perched 0.5-2 feet	10.0
<0.8 sizing width ratio (constricting)	10.7
>2.0 sizing width ratio (over-wide)	78.9
*Water slope >1%	32.5
*Culvert slope >1%	21.0
Headloss >1 foot	24.9
<0.2' water depth in thalweg culvert	12.6
Evidence of upstream pool or backwatering	29.1
Downstream scour pool (lateral and/or vertical scour)	50.8

*These parameters were only considered if the culvert was not countersunk. To be considered countersunk, crossings with <10 feet hydraulic width had to have at least 1 foot of sediment in the thalweg culvert while culverts >10 feet hydraulic width required more than 2 feet of sediment in the thalweg culvert.

Noteworthy percentages of culverts in the Root River watershed were found to meet one or more of the ranking parameters (Table 5). In total 13.2% of culverts were perched to some degree. Sizing width ratios found that 10.7% of culvert crossings constrict bankfull or higher flows while 78.9% were overwide. Only 10.4% of the culvert crossings have the appropriate hydraulic width (sum of culvert widths not including embankment width between the culverts). Exceedances in water slope, culvert slope and headloss parameters were found in 32.5%, 21.0% and 24.9% of sites, respectively. In culvert water depth was a limiting factor in 12.6% of sites. Finally an estimated 29.1% of sites showed evidence of an upstream pool or backwatering and 50.8% of sites had lateral and/or vertical scour identifying a downstream scour pool.

Another noteworthy statistic is that 26.9% of the surveyed sites were located on privately owned land. In some cases, privately owned structures had the worst design and passability issues (e.g. Fig 17a and b are privately owned structures). This demonstrates the importance of including privately owned structures in stream crossing inventories. This will ensure a complete systemic assessment of watershed impacts from stream crossings.

SUMMARY

In conclusion, the results from this watershed demonstrate:

1) a methodology that can be replicated to rank stream crossings for watershed planning and restoration,
2) there is need for a complete (public and private) stream crossing inventory across the state and
3) the necessity for improved culvert design and permitting regulation.

Moving forward, there is recognition of the need to compile an inventory of all stream crossings. Accomplishing a statewide inventory will require a multi-agency effort. The use of the Stream Habitat Program Culvert Datasheet (Appendix A) and these ranking guidelines will ensure that necessary data will be collected and that all crossings will be categorized using the same ranking system.

Application of these guidelines result in a ranking scheme upon which we can begin strategically targeting stream crossings for replacement and/or restoration. Implementing this strategic approach will serve a critical role in improving stream connectivity, biology, geomorphology, hydrology and water quality, and in restoring impaired watersheds and streams.

EQUIPMENT LIST

Field Equipment

- Laser level (Trimble LL500)
- Receiver (Trimble HL700)
- Tripod
- Leveling Rod (in 10ths)
- Chisel
- Hammer
- Measuring tape (in 10ths)
- Copper Rod

Data Collection and Identification of Site Location

- GPS (Garmin 650t)
- Camera
- Clipboard
- Pens
- Datasheets
- Extra Batteries
- Plat Books (optional but helpful when dealing with private property)
- 2-way Radio (optional)

Safety

- PFD
- High Visibility Vest
- Traffic Cone
- Sunblock
- Bug Spray

QUICK REFERENCE TERMINOLOGY

- **Bankfull Width:** BKFW
- **Bed:** top of deposited sediment in the culvert
- **Benchmark:** BM
- **Bridge:** open bottomed crossings
- **Countersunk:** the degree to which the thalweg culvert invert is set below the streambed (both inlet and outlet)
- **Crossing:** any structure at the intersection between a stream and roadway
- **Crossing Hydraulic Width (CHW):** sum of culvert widths not including the width of the embankment between the culverts
- **Culvert:** a) a type of crossing consisting of a hard bottom and/or 2) a single barrel within a hard bottomed crossing
- **Culvert Length (CL):** length from upstream invert to downstream invert
- **Culvert slope:** calculated slope of the culvert based on culvert invert length and the difference in invert elevations
- **Downstream:** DS
- **Ford:** stream crossing with no overhead structure
- **Great Lakes Stream Crossing Inventory Instructions:** GLSCII
- **Headloss:** the difference in elevation between headwater and tailwater surfaces
- **Headwater Surface (HWS):** water surface elevation upstream of the crossing
- **Invert:** bottom surface of the culvert
- **Length, width and depth dimension:** L/W/D
- **Perch height:** difference between water surface in the culvert outlet and tailwater surface of the stream
- **Real Time Kinematic (RTK):** GPS Grade Survey Equipment
- **Sizing width ratio:** the ratio of crossing hydraulic width to bankfull width
- **Stream Habitat Program:** SHP
- **Tailwater Surface (TWS):** water surface elevation downstream of the crossing
- **Township, Section Range:** T/S/R
- **Upstream:** US
- **Water depth (depth of flow):** the depth of flow in both the inlet and outlet of the thalweg culvert
- **Water slope:** calculated water slope based on culvert invert length and the difference in headwater and tailwater surface elevations

APPENDICES

- Appendix A: Stream Habitat Program Culvert Datasheet
- Appendix B: Stream Habitat Program Inaccessible Culvert Datasheet
- Appendix C: MNDNR Basic Assessment Datasheet
- Appendix D: MNDNR Full Assessment Datasheet
- Appendix E: Methods for Determining Bankfull Width
- Appendix F: Minnesota Regional Curves for Bankfull Width and Cross-Sectional Area
- Appendix G: Proper and Improper Culvert Design Graphics

Crossing ID:		**County:**	**T/S/R:**
Date:	**Year Built:**	**Roadway:**	**Watershed:**
ElevationMethod:BM/Monument/RTK/LiDAR/Other		**Collected by:**	
# of Culverts: 1 2 3 4 5 6		**Lat/Long:**	
Structure Type: Culvert / Bridge / Dam / Ford / Other		**Stream:**	
Culvert Material: Metal / Concrete / Wood / Plastic		**Structure Interior**: Smooth / Corrugated	
Structure Shape: Round / Pipe Arch / Square/Rectangle / Open Bottom SR / Open Bottom Arch / Ellipse			
Inlet Type: Projecting / Mitered / Headwall / Apron / Wingwall / Trashrack / Other			
Outlet Type: At stream grade / Cascade over riprap / Freefall to pool / Freefall to riprap / Outlet apron / Other			
General Condition: New / Good / Fair / Poor		**Downstream Incision:**	□Yes □No
Benchmark Elevation:	**BM Location:**	**Upstream Pool (backwatered):**	□Yes □No
Offset Culverts: □Yes □No □N/A		**Proper Alignment:**	□Yes □No
Headwater Surface Elevation:	**Tailwater Surface Elevation:**	**Bank Erosion from Crossing:**	□Yes □No
DS Hydraulic Control*:		**Upstream Deposition/Bars:**	□Yes □No

US Pool (L/W/D):				**DS Scour Pool (L/W/D):**			

Bankfull Width (ft):_____________	**Confidence:** □High □Med □Low	**Method:** □Field □LiDAR/Aerial
Thalweg Culvert: 1 2 3 4	**US Sediment:** □Yes □No	**Depth of Sediment:** □<1 □1-2 □ ≥2
Thalweg Culvert: 1 2 3 4	**DS Sediment:** □Yes □No	**Depth of Sediment:** □ <1 □1-2 □ ≥2

	Culvert 1 (RL)			**Culvert 2**			**Culvert 3**			**Culvert 4**		
Perched	No	Drop _____		No	Drop _____		No	Drop _____		No	Drop _____	
Substrate												
% Plugged(**inlet/outlet/inside**)												
%Crushed(**inlet/outlet/inside**)												
Rusted through? Y/N												
Culvert Length (ft)												
Height/Diameter (ft)												
Culvert width (ft)												
Inlet Bed Elev												
Outlet Bed Elev												
Inlet Invert Elev												
Outlet Invert Elev												
Inlet Water Depth												
Outlet Water Depth												

Barrier to fish passage: □Yes □No **Limiting Factor for Passage:** Outlet Drop / Velocity / Depth / Substrate

Stream Stability Impact: □Yes □No

Recommended corrective actions:

Appendix B: Stream Habitat Program Inaccessible Culvert Datasheet

Crossing ID:		**County:** T: S: R:	
Date:	**Year Built:**	**Roadway:**	**Watershed:**
		Collected by:	
# of Culverts: 1 2 3 4 5 6 **Thalweg:**		**Lat/Long:**	
Structure Type: Culvert / Bridge / Dam / Ford / Other		**Stream:**	
Culvert Material: Metal / Concrete / Wood / Plastic		**Structure Interior**: Smooth / Corrugated	
Structure Shape: Round / Pipe Arch / Square/Rectangle / Open Bottom SR / Open Bottom Arch / Ellipse			
Inlet Type: Projecting / Mitered / Headwall / Apron / Wingwall / Trashrack / Other			
Outlet Type: At stream grade / Cascade over riprap / Freefall to pool / Freefall to riprap / Outlet apron / Other			
General Condition: New / Good / Fair / Poor		**Aligned Properly:** □Yes □No	
Upstream deposition/bars: □Yes □No		**Bank Erosion from crossing:** □Yes □No	
Downstream Incision: □Yes □No		**Upstream Pool (backwatered):** □Yes □No	
Thalweg Culvert: 1 2 3 4 **US Sediment:** □Yes □No **Depth of sediment:** □ <1 □1-2 □ ≥2			
Thalweg Culvert: 1 2 3 4 **DS Sediment:** □Yes □No **Depth of sediment:** □ <1 □1-2 □ ≥2			
Bankfull width (ft):____________	**Confidence:** □High □Med □Low	**Method:**□Field □LiDAR/Aerial	

	Culvert 1 (RL)	**Culvert 2**	**Culvert 3**	**Culvert 4**
Perched (No, >2.0 feet or 0.5-2.0 feet)				
Less than 0.2 feet of flow? (Yes/No)				
Sediment in Culvert? (No, <1.0 feet, 1.0-2.0 feet or >2.0 feet)				

Barrier to fish passage: □Yes □No **Limiting Factor for Passage:** Outlet Drop / Velocity / Depth / Substrate
Stream Stability Impact: □Yes □No
Why was culvert inaccessible?:
Other Notes:

Appendix C: MNDNR Basic Assessment Datasheet

Location: Observer*:______________________Date*:____/____/_____County:________T___R___S___
Stream name*:___________________ Stream mile:____ UTM:* N_________________E________________
Alt. name:___________________ Stream Kittle or AUID (circle which)*:_____________________________
DNR Major watershed/HUC 8*(circle which):_____________ Road/Path/Railway name*:_________________
Elevation method*: ☐ Monument ☐ RTK ☐ Benchmark/LiDAR ☐ Handheld GPS Accuracy:______________
HI:_________Notes:____
Crossing: Benchmark location:_______________________________
Crossing type*: ☐ Span Bridge
☐ Culvert(s) Num. (if multiple):____ Offset*?: ☐ Y ☐ N
☐ Ford
Other:______________________
Total span* (sum of culverts):______
Outlet drop*:___
Crossing properly aligned*? ☐ Y ☐ N
Year built:________

Openings* (left to right, facing downstream)

	Opening 1		Opening 2		Opening 3		Opening 4	
Type*	☐ Thalweg ☐Offset ☐Floodplain		☐ Thalweg ☐Offset ☐Floodplain		☐ Thalweg ☐Offset ☐Floodplain		☐ Thalweg ☐Offset ☐Floodplain	
Shape*	☐ Circular ☐ Box ☐ Pipe Arch ☐ Ellipse ☐ Open bottom arch		☐ Circular ☐ Box ☐ Pipe Arch ☐ Ellipse ☐ Open bottom arch		☐ Circular ☐ Box ☐ Pipe Arch ☐ Ellipse ☐ Open bottom arch		☐ Circular ☐ Box ☐ Pipe Arch ☐ Ellipse ☐ Open bottom arch	
Material*	☐ CMP ☐ SMP ☐ Concrete ☐ Wood ☐ Plastic		☐ CMP ☐ SMP ☐ Concrete ☐ Wood ☐ Plastic		☐ CMP ☐ SMP ☐ Concrete ☐ Wood ☐ Plastic		☐ CMP ☐ SMP ☐ Concrete ☐ Wood ☐ Plastic	
Length*								
Width *								
Height*								
Inlet invert	FS	El.	FS	El.	FS	El.	FS	El.
Outlet invert	FS	El.	FS	El.	FS	El.	FS	El.
Benchmark el.	FS	El.	FS	El.	FS	El.	FS	El.
Water depth								
Substrate present?*	☐ Y ☐ N		☐ Y ☐ N		☐ Y ☐ N		☐ Y ☐ N	
% plugged*								

Stream:
Bankfull width*:______________ Bankfull estimate confidence*: ☐ High ☐ Medium ☐ Low
Scour Pool*: ☐ Y ☐ N Upstream pool*: ☐ Y ☐ N Upstream bars/deposition*: ☐ Y ☐ N
Bank erosion caused by crossing*: ☐ Y ☐ N
Summary:
Barrier to fish passage at some flows*? ☐ Y ☐ N Stream stability impact*: ☐ Y ☐ N Priority: ☐ High ☐ Med. ☐ Low
Limiting factor for passage*: ☐ Outlet drop ☐ Velocity ☐ Depth ☐ Substrate
Recommended corrective actions*: ____
Photos: Crossing, upstream and downstream views; Stream, upstream and downstream views from crossing

Appendix D: MNDNR Full Assessment Datasheet

Location: Observer*:______________________Date*:____/____/_____County:________T___R___S___
Stream name*:___________________ Stream mile:____UTM:* N__________________E________________
Alt. name:____________________ Stream Kittle or AUID (circle which)*:_____________________________
DNR Major watershed/HUC 8*(circle which):_____________ Road/Path/Railway name*:_________________
Elevation method*: ☐ Monument ☐ RTK ☐ Benchmark/LiDAR ☐ Handheld GPS Accuracy*:_____________
HI:_________ Water level ☐ High ☐ Baseflow ☐ Low Velocity method: ☐ Meter ☐ Surface

Crossing: Benchmark location:_______________________________
Crossing type*: ☐ Span Bridge Total span* (sum of culverts):______
☐ Culvert(s) Num. (if multiple):___ Offset*?: ☐ Y ☐ N Outlet drop*:___
☐ Ford Crossing properly aligned*? ☐ Y ☐ N
Other:______________________ Year built:________
Inlet type: ☐ Projecting ☐ Mitered ☐ Headwall ☐ Apron ☐ Wingwall ☐ Trash rack ☐ Other:_______________
Outlet type: ☐ At stream grade ☐ Cascade over riprap ☐ Freefall into pool ☐ Freefall onto riprap ☐ Apron
Bridge condition: ☐ Good ☐ Fair ☐ Poor Condition issues:_______________________ Road Fill depth:____

Openings (left to right, facing downstream)

	Opening 1		Opening 2		Opening 3		Opening 4	
Type*	☐Thalweg ☐ Offset ☐ Floodplain		☐Thalweg ☐ Offset ☐ Floodplain		☐Thalweg ☐ Offset ☐ Floodplain		☐Thalweg ☐ Offset ☐ Floodplain	
Shape*	☐ Circular ☐ Box ☐ Pipe Arch ☐ Ellipse ☐ Open bottom arch		☐ Circular ☐ Box ☐ Pipe Arch ☐ Ellipse ☐ Open bottom arch		☐ Circular ☐ Box ☐ Pipe Arch ☐ Ellipse ☐ Open bottom arch		☐ Circular ☐ Box ☐ Pipe Arch ☐ Ellipse ☐ Open bottom arch	
Material*	☐ CMP ☐ SMP ☐ Concrete ☐ Wood ☐ Plastic		☐ CMP ☐ SMP ☐ Concrete ☐ Wood ☐ Plastic		☐ CMP ☐ SMP ☐ Concrete ☐ Wood ☐ Plastic		☐ CMP ☐ SMP ☐ Concrete ☐ Wood ☐ Plastic	
Flow restriction	☐ Y ☐ N Type:____________		☐ Y ☐ N Type:____________		☐ Y ☐ N Type:____________		☐ Y ☐ N Type:____________	
Length*								
Width *								
Height*								
Inlet invert*	FS	El.	FS	El.	FS	El.	FS	El.
Outlet invert*	FS	El.	FS	El.	FS	El.	FS	El.
Benchmark el.	FS	El.	FS	El.	FS	El.	FS	El.
Water depth								
Substrate?*	☐ Y ☐ N		☐ Y ☐ N		☐ Y ☐ N		☐ Y ☐ N	
Subst. depth								
Subst. size	☐ Cobble ☐ Gravel ☐ Sand ☐ Silt ☐ Bdrk		☐ Cobble ☐ Gravel ☐ Sand ☐ Silt ☐ Bdrk		☐ Cobble ☐ Gravel ☐ Sand ☐ Silt ☐ Bdrk		☐ Cobble ☐ Gravel ☐ Sand ☐ Silt ☐ Bdrk	
% plugged*								
Max. velocity	fps		fps		fps		fps	
% at max vel.	%		%		%		%	

Stream:

Bankfull width*:____________ Bankfull estimate confidence*: □ High □ Medium □ Low
Riffle max. water depth:______ Riffle max. velocity:______ Riffle dominant substrate:______
Scour Pool*: □ Y □ N Depth:____ Width:____ Length:____ Upstream pool*: □ Y □ N
Upstream deposition*: □ Y □ N Bank erosion caused by crossing*: □ Y □ N Channel gradient:_____
Floodprone width:_____ Sedimentation from road grade or embankment (circle)

Road/Rail/Path:

Ownership:_____________________________ Surface materials: □ paved □ gravel □ native Road width:____
Upstream fill depth:_____ Downstream fill depth:____

Summary:

Barrier to fish passage at some flows*? □ Y □ N Stream stability impact*: □ Y □ N
Priority: □ High □ Med. □ Low Limiting factor for passage*: □ Outlet drop □ Velocity □ Depth □ Sub-strate
Recommended corrective actions*:

Notes and comments: ____

Photos:

Crossing, facing upstream
Crossing, facing downstream
Stream, facing upstream from crossing
Stream, facing downstream from crossing

Sketch:

Method 1: Field determination of bankfull upstream of the stream crossing – This method will most likely to be used on smaller scale efforts where more time can be spent at each site and more precise bankfull data is needed (e.g. catchments)

1. Find an area upstream where a bankfull call can be made using aerial photo or in the field by walking up the channel. Obtain permission from the landowner to access the land adjacent to that reach of the river.
2. In the field, make an informed bankfull call using available indicators (e.g. depositional flat). Please refer to the US Forest Service videos if you need further assistance with bankfull determination (http://www.stream.fs.fed.us/publications/bankfull_west.html)
3. Measure the bankfull width (feet), distance from observed bankful indicator to the other side of the channel (perpendicular to bankfull flow) at the same height above water surface. Be sure to rate the level of confidence in the call.

Method 2: Bankfull determination using cross-sectional area – This method can be used when the bankfull call is questionable (e.g. incised channels, ditched channels, etc.) or when working on a large scale efforts (e.g. HUC 8 watersheds and larger regions) where site visits must be time efficient.

In the field:

1. Locate the nearest upstream riffle (outside of the crossing influence) and note the GPS coordinates.
2. Stretch a tape across the channel from bank to bank (perpendicular to bankfull flow) at the height where bankfull is approximated to be. Record the width from bank to bank.
3. Using a 25 foot rod, record the height (to the nearest 0.1ft) of the tape from the stream bottom at three to five spots along the cross-section while note the stationing.
4. If possible, lay the rod along the tape (that is still perpendicular to flow) and take a picture.

In the office:

1. Calculate cross-sectional area by summing the area of each trapezoid -
   - Averaging the two heights at stations on the sides of each trapezoid.
   - Then multiple that average height by the cell width to get an area for that cell.
   - Add up the sum of all the cells to get total cross-sectional area
2. With the calculated cross-sectional bankfull area use the regional curve data (Appendix F) to estimate the drainage area.
   - For Western MN Streams: $y=4.7456x^{0.6102}$ (x=cross sectional area and y=drainage areas)
   - For Eastern MN Streams: $y=5.3096x^{0.7054}$ (x=cross sectional area and y=drainage area)
3. Lastly, use the regional curve data to estimate bankfull width from the drainage area (Appendix F).

- For Western MN Streams: y=drainage area and x = bankfull width)

$$x = \sqrt[0.4534]{(y/6.6316)}$$

- For Eastern MN Streams: (y=drainage area and x = bankfull width)

$$x = \sqrt[0.3867]{(y/5.7926)}$$

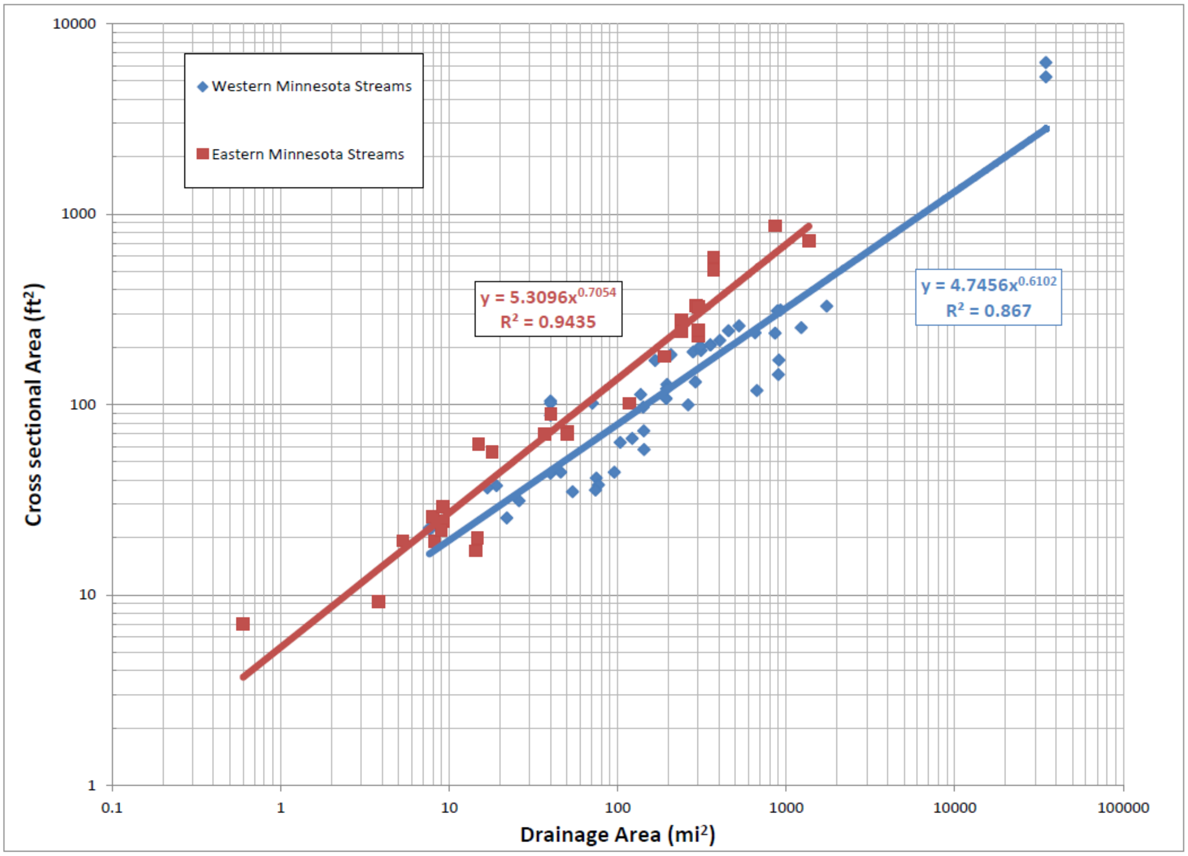
*Note: Use Western MN Stream curves for the Red River, Minnesota River and Missouri River basin streams. Use Eastern MN Stream curves for Rainy River, Great Lakes, St. Croix River and Mississippi River basins.

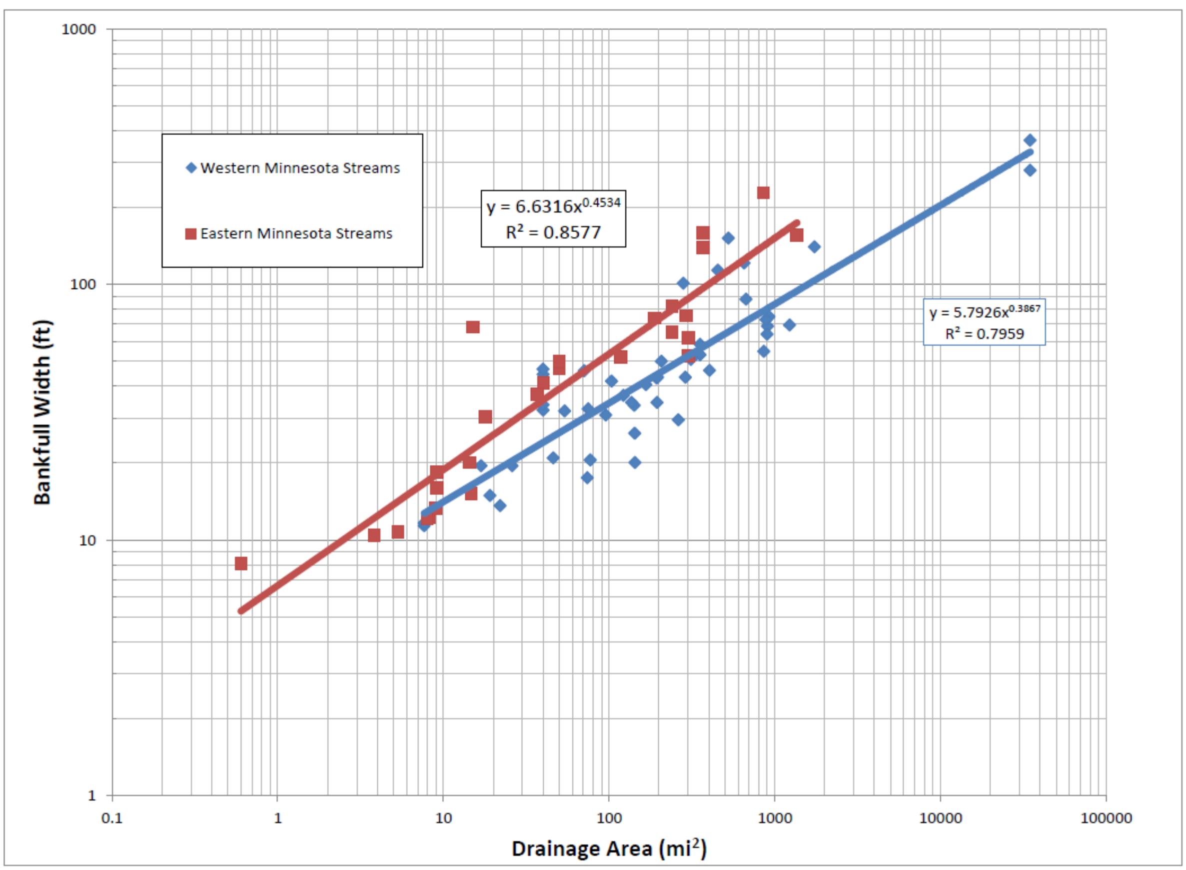
Method 3: Use aerial photos or LiDAR to estimate bankfull when:

- Sites are inaccessible, such as gates blocking access, landowner permission denied or unobtainable or water is too high or fast to safely survey.
- No bankfull indicators are present in the vicinity of the crossing.

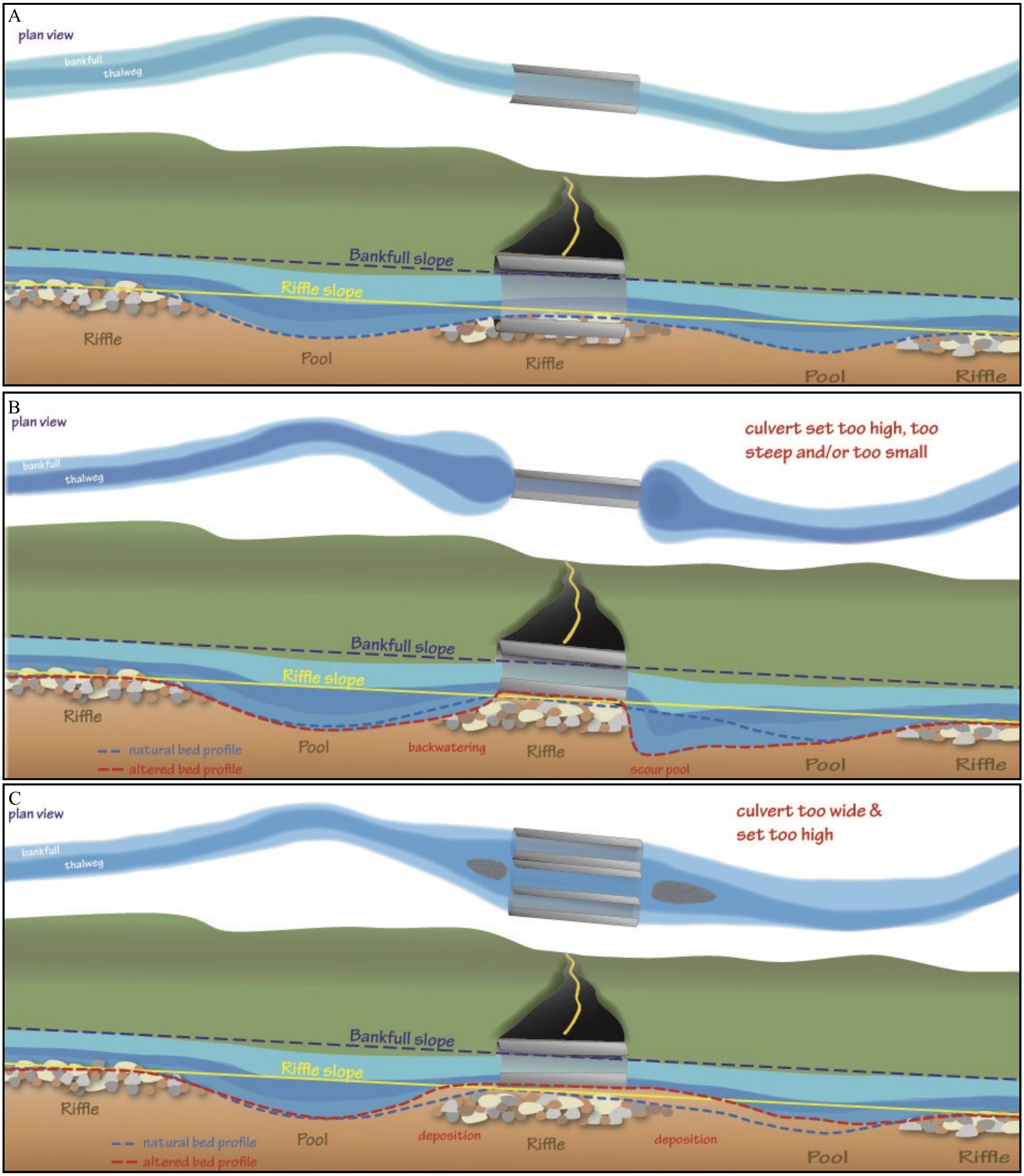
*Note: when scanning aerial photos for places to measure/estimate bankfull width look for stable representative reaches with well defined riffles (generally located between the straight reaches between the meanders).

Appendix F: Minnesota Regional Curve - Cross Sectional Area





Appendix G: Proper and Improper Culvert Design Graphics



Panel A illustrates a properly placed culvert that is aligned with the natural stream pattern and located on a riffle. This proper design also has a sizing ratio of 1, a culvert slope that matches the riffle slope, and countersunk inverts. Panel B illustrates an improperly designed culvert that is too high, too steep and/or too small. It shows the resulting negative impacts to the stream, which includes upstream backwatering and upstream and downstream scour. Panel C illustrates an improperly designed culvert that is too wide and set too high. It shows the lack of water depth through the culvert at low flows, inverts that are set above the natural riffle stage and the altered bed profile that is a result of deposition and mid channel bar formation.

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