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3.2.2 Stream and river crossings

Stream and river crossings require the designer to consider the waterway in detail and, in some cases, obtain permits for the bridge. The topics listed below are to be considered in design of bridges over streams and rivers and are discussed in sub-articles that follow.

- Hydrology
- Hydraulics
- Backwater
- Freeboard
- Roadgrade overflow
- Streambank Protection
- Scour

As a general rule, the design discharge for rural structures on Iowa's primary highway system is the 50-year flood. For bridge locations where the upstream flood damage potential is high or where the site is located in a detailed Flood Insurance Study (FIS) area, the 100-year flood should be the design discharge. When a project is located in a detailed FIS area, the published peak discharges and flood elevations are used for design. The average velocities (Q/A) through a bridge waterway opening typically should range between 6 and 8 feet/second (1.8 and 2.4 m/s) for the design discharge. The designer should calculate the following discharges and stage for each bridge.

- Q_{50} - to determine velocity through bridge opening, backwater, and freeboard to the low superstructure elevation
- Q_{100} - to determine backwater and velocities through the bridge opening
- Q_{200} – to determine design scour
- Q_{500} or $Q_{Overtopping}$ - to determine check (maximum) scour

Stage is the water surface elevation for a given discharge. Stage for the purpose of the hydraulic data block is the engineer’s best estimate of the PROPOSED water surface elevation at the downstream toe of the road embankment.

3.2.2.1 Hydrology

Reliable estimates of flood-frequency discharges are essential for the economical planning and safe design of bridges and other structures located over streams. Hydrology for bridges should include the following peak discharges for design: Q_{50}, Q_{100}, Q_{200} and Q_{500} or $Q_{overtopping}$. In special cases the designer may need to determine additional discharges for the project.

Drainage area should be determined by using the USGS web based program called Iowa "StreamStats". This method supersedes the Bulletin 7 (Red Book) for determining drainage areas at bridge sites.

"StreamStats" is capable of delineating a watershed from a point and computing the drainage area in square miles. The engineer may use LiDAR or other more accurate information to check the results for accuracy and to make and document appropriate corrections.

The designer has several methods for determining estimated discharges, which are listed below.

- **Federal Emergency Management Agency (FEMA) Flood Insurance Studies (FIS)**
  Many cities and counties in Iowa have detailed FISs. Typically, a community with an FIS has adopted regulations that can prohibit increasing the 100 year flood elevation or encroaching upon a regulated floodway. The discharges and flood elevations in an FIS are usually legally binding and are used by the Iowa Department of Natural Resources when issuing flood plain development permits. If different design discharges are proposed, prior approval from the DNR is required. When a project is located outside the detailed area of an FIS but could impact flood elevations or flood prone properties of an FIS community, the FIS information should be used for analysis.

  It should be noted that when a project involves development within a regulatory floodway (including bridge piers), the analysis must show that the project will not cause an increase in the 100 year flood elevation. If a "no rise" condition cannot be obtained when encroaching upon a regulatory floodway, the designer may need to apply to FEMA for revisions to the FIS by means of a Conditional Letter of Map Revision (CLOMR). After a CLOMR is issued and construction is completed a Letter of Map Revision (LOMR) is obtained by submitting as-built plans.

  For Iowa DOT projects, a "No-Rise" certification is not required.

  Information from an FIS, if available, is preferred over other sources. The designer should check the FEMA website to determine the current status of a community's FIS.

  Projects located in communities that are mapped by the National Flood Insurance Program as flood prone but do not show the 100-year flood elevation are not subject to the same requirements as a project located in a detailed FIS area. If a community does not have an adopted floodway or established base (100 year) flood elevations, it may be possible to construct a structure smaller than the existing structure as long as the upstream damage potential is low. Sound engineering judgment should be used when downsizing an existing structure.

- **U.S. Geological Survey (USGS) and U.S. Army Corps of Engineers (USACE) stream gage information**
  Stream gage data may be used for estimation of peak discharges when the structure site is at or near a gaging station and the streamflow record is fairly complete and of sufficient length. Information for stream gages in Iowa is available from USGS and USACE web sites as follows:

  USGS - Iowa Water Science Center:

  USGS - StreamStats - Annual Exceedance-Probability Discharge (AEPD) per Scientific Investigations Report (SIR) 2013-5086. May be updated in the future to use Open File Report 2015-1214:

USGS - SIR 2013-5086 - Methods for Estimating Annual Exceedance-Probability Discharges for Streams in Iowa - Based on Data through Water Year 2010. Provides Expected Moments Algorithm/Multiple Grubbs-Beck (EMA/MGB) and Weighted Independent Estimates (WIE) AEPD's for gage data through water year 2010:

USGS - Statistical summaries of selected Iowa streamflow data through September 2013. Open-File Report 2015-1214 provides EMA/MGB and WIE AEPD's for gage data through water year 2013:

USACE – Rock Island District

USACE – Omaha District

If the drainage area at the project site is within 50% of the drainage area of the gage, the gage discharges should be used and transferred to the project site per the method specified in USGS SIR 2013-5086. Generally a regression-weighted estimate should be utilized to ensure a smooth transition from gage-weighted to regression equation discharge estimates for a stream. When the project site falls between two stream gages (within 50% of gage drainage area per above) an area-weighted estimate should generally be utilized. The gage parameters used for weighting (gage site regression equation discharge or drainage area) should be reviewed for consistency with the project (ungaged) site estimate.

The Iowa DOT AEPD spread sheet, addressed in more detail in the following section, includes estimation of AEPD's at ungaged sites on gaged streams per SIR 2013-5086. A future version of the USGS StreamStats web site will also provide this functionality. Refer to the Iowa DOT AEPD Spread Sheet Usage Guide, Section 4, for additional information on gage weighting methodologies for ungaged sites on gaged streams.

A thorough review of gage derived AEPD estimates at gaged and ungaged sites should be performed. Generally the published gage AEPD estimates per SIR 2013-5086 will be adequate (data through 2010) . AEPD estimates per Open File Report 2015-1214 (data through 2013) can be utilized and may be preferable for sites with limited years of uncensored records (less than 30 yrs.). A request can be made to the USGS through the DOT for updated statistics as required at a gage. Considerations would be limited years of record or significant recent floods not captured by the above reports.

For gaged sites USGS guidelines advise use of the WIE estimate. Since the WIE estimate makes use of a Regional Regression Equation (RRE) AEPD estimate per SIR 2013-5086, applicability of the RRE AEPD used in the WIE estimate should be determined. For gage sites with 25 years or more of uncensored record, preference (weight) should be given to the EMA/MGB estimate in the event of a significant discrepancy between the EMA/MGB and WIE AEPD estimates. Uncensored data represents actual observed values, whereas censored data reflects historical or otherwise estimated data values. Statistics developed using only uncensored data will generally be presented as 'period-of-record' whereas statistics that include censored data generally be presented as 'historical period'.

For ungaged sites the gage weighted AEPD estimate should be reasonably consistent with the gage AEPD estimate, particularly for gage sites with 25 years or more of uncensored record. For example, that the ungaged site downstream of gaged site has an AEPD estimate greater than gaged site estimate, etc.

- **USGS Scientific Investigation Report 2013-5086 RRE estimates**
  If a project site is not located in a detailed FIS, and AEPD estimation using stream gage data is not possible, the Regional Regression Equation (RRE) methodology contained in USGS Scientific Investigation Report (SIR) 2013-5086 should be used to estimate Annual Exceedance-Probability

Discharge (AEPD) for the design of bridges and culverts. A copy of the report can be obtained at the USGS web site per the link provided in the previous section.

The USGS has developed a web based program called “StreamStats” that calculates the estimated AEPD’s per SIR 2013-5086. Refer to the StreamStats web link per the above section.

The Iowa DOT has developed an AEPD spread sheet which provides an alternative method to StreamStats for calculating AEPD’s per SIR 2013-5086. The variables for each regression equation, including the Main-Channel Slope (MCS) variable, must be calculated by the StreamStats program. AEPD’s per past USGS Regional Regression Equation (RRE) procedures (USGS WRIR 87-4132 & WRIR 00-4233) can also be calculated.

The Iowa DOT currently recommends that for drainage areas of 2 square miles or less, the Iowa Runoff Chart should be used for calculating peak discharges.

The AEPD spread sheet should be used as a tool for comparing the different methodologies to determine if any outliers are present in estimating the AEPD’s per SIR 2013-5086. In general, USGS SIR 2013-5086 provides higher peak discharges than the previous regression equations, particularly WRIR 87-4132. If the AEPD spread sheet determines that AEPD’s calculated per SIR 2013-5086 are significantly different from those estimated using previous RRE procedures (USGS WRIR 87-4132 & 00-4233), then engineering judgment can be used to adjust SIR 2013-5086 AEPD estimates for the design of bridges and culverts in Iowa.

USGS SIR 2013-5086 has defined three different flood regions for the state and utilizes a multi-variable equation for each region. For basins that cross region boundaries (multi-region basins), StreamStats will provide a SIR 2013-5086 RRE AEPD estimate for each region falling in the basin, and a weighted AEPD estimate per SIR 2013-5086 based on the ratio of the area of each contributory flood region to the total basin area.

The AEPD spread sheet can calculate AEPD’s for basins that cross region boundaries per the above. In addition, the AEPD spread sheet allows for alternate weighting of flood regions in multi-region basins.

For multi-region RRE estimates, IaDOT recommendation/policy is to use an additional weighting factor in the RRE estimate for the region where the site is located (outfall region). IaDOT recommendation is to use an outfall region weighting of 2. Refer to the AEPD Spreadsheet Usage Guide referenced above, Section 5, for guidelines on weighting of RRE AEPD multi-region estimates.

- **USGS WRIR 87-4132 and USGS WRIR 00-4233 RRE estimates**
  The regression equations contained in USGS WRIR 87-4132 & WRIR 00-4233 have been superseded. However, the previous reports can be utilized for comparative purposes when engineering judgment is used to estimate peak discharges for the design of bridges and culverts in Iowa. See commentary for Q50/Q500 Chart to be used with WRIR 87-4132 analysis.

- **USGS flood reports**
  Open file flood reports by the USGS have been developed and can be valuable supplemental information when evaluating discharges and water surface elevations. The reports are listed and, in some cases, available for download as follows.
  Iowa Water Science Center Publications
  Chronology of Iowa Flood Reports

- **Urban Hydrology**
  When development/urbanization is located within the drainage basin, other hydrologic methodologies should be considered to account for the higher runoff potential due to additional

impervious areas and the decreased travel time. In general, urban hydrology for a basin should be considered when 25% or more of the watershed has been developed.

For urban basins with less than 160 acres, the Rational Method may be used for determining peak discharges. For urban basins larger than 160 acres, and for some complex basins that are less in size, the design storm runoff may be analyzed by other methods such as TR-55 for watersheds up to 2000 acres. For areas larger than 2000 acres TR-20 may be used or other methodologies such as HEC-HMS or other programs.

Hydrologic analysis that use precipitation/frequency relationships should use NOAA Atlas 14, Volume 8: Precipitation-Frequency Atlas of the United States, Midwestern States.

Engineering judgment should be used when determining design discharges for basins that have development/urbanization within its watershed.

3.2.2.2 Hydraulics

Once the peak discharges are determined for design, the structure must be analyzed to determine the hydraulic capacity or conveyance of the bridge waterway opening. Bridge hydraulics (freeboard and backwater) can be analyzed by utilizing various hydraulic programs such as HEC-2 or HEC-RAS, which are available from the Corps of Engineers or other sources; the Iowa DOT Bridge Backwater program based on the publication *Hydraulics of Bridge Waterways, HDS 1*; or WSPRO, which is available from FHWA. For complex hydraulic situations, 2-D models such as TUFLOW, SRH-2D, HEC-RAS2D, MIKE FLOOD, etc. may be used. The designer should be aware of the assumptions and limitations for using the methodology in any hydraulic analysis program.

- **HEC-2 or HEC-RAS analysis**
  When a bridge is located within a detailed Flood Insurance Study (FIS) area, or the upstream flood plain has a high damage potential (such as a residence or business located in the upstream flood plain), the designer should perform a HEC-2 or HEC-RAS analysis to determine the impacts on flood elevations.

- **Iowa DOT Bridge Backwater program analysis**
  For bridges located in a rural area where the flood plain has a low damage potential, the designer may use the Iowa DOT Bridge Backwater program to analyze backwater and freeboard provided the conditions listed below are met.

  (1) The channel is relatively straight.
  (2) The floodplain cross section is fairly uniform.
  (3) The stream slope is approximately constant.
  (4) The flow is free to contract and expand.
  (5) There is no appreciable scour hole in the bed at the constriction.
  (6) The flow is in the sub critical range (Type I, non-pressure flow)

- **WSPRO analysis**
  For bridges located in a rural area where the flood plain has a low damage potential, the designer may use WSPRO program to analyze backwater and freeboard.

- **2-Dimensional hydraulic analysis**
  For complex hydraulic locations, a 1-D hydraulic analysis may not adequately capture the effects of flooding and backwater. These locations may include overflow bridges, flood plains with flank or lateral levees and roadways that are significantly skewed to the flood plain. In those situations, 2-D hydraulic models such as TUFLOW, SRH-2D, HEC-RAS2D, MIKE FLOOD, etc. may be more appropriate for analyzing the impacts associated with a bridge project.

3.2.2.3 Backwater

Bridge backwater is caused by the encroachment of the road embankment onto the floodplain which constricts flood flows through the bridge opening. This constriction causes an increase in the normal stage (flood elevation without a bridge and roadgrade in place). The maximum backwater typically occurs one or two bridge lengths upstream.

Iowa DNR backwater criteria are listed in Table 3.2.10.1-2. In general, bridges should be designed to meet the backwater criteria even when a project does not require Iowa DNR approval. Variances to the backwater criteria can be obtained when it is not economical to meet the backwater criteria and when flowage easements are obtained for low damage potential areas.

Manning's Equation is used to determine normal depth and a stage-discharge relationship (rating curve) for analyzing bridges. Typical roughness coefficients for the equation are given in Table 3.2.2.3.

Table 3.2.2.3. Manning's Roughness Coefficients for natural stream valleys (n-coefficients)

Description	Detailed Description	Manning's Coefficient
Channel, small to medium drainage areas	Irregular section, meandering channel, rocky or rough bottom, medium to heavy growth on bank and side slopes	0.04-0.05
	Uniform section, relatively straight, smooth earthen bottom, medium to light growth on bank and side slopes	0.03-0.04
Channel, large drainage area	---	0.025-0.035
Overbank flood plain, pasture land	No brush or trees	0.05-0.07
	Light brush and trees	0.06-0.08
Overbank flood plain, crop land	---	0.07-0.09
Overbank flood plain, brush and trees	Heavy weeds, scattered brush	0.08-0.10
	Medium to dense brush and trees	0.09-0.12
	Dense brush and trees	0.10-0.15
	Heavy stand of timber, a few downed trees, little undergrowth	0.07-0.10

~~Table note:~~

~~The table is from the Iowa DNR's Bridge Review Checklist.~~

~~3.2.2.7~~3.2.2.4 Freeboard

Freeboard is the vertical clearance measured between the regulatory low beam and the 50-year stage with the proposed bridge in place. Typically this clearance is measured in the middle of the channel at the downstream edge of bridge.

The purpose of freeboard is to provide adequate clearance for passage of debris and ice during high flows and to reduce the potential of superstructure submergence. Debris and ice jams can create horizontal and buoyant forces on the bridge superstructure and can reduce the bridge waterway opening resulting in increased velocity, scour, and upstream flood levels. If the 100-year stage with the proposed bridge in place is above the operational low beam, consult the section leader for guidance.

When hydraulic modeling predicts that a span in a pretensioned prestressed concrete beam (PPCB) bridge will be inundated by the 100-year or lesser floods, the designer should recommend that beams in the span be vented to prevent buoyancy forces. (See BDM 5.4.2.4.2 for beam vent details.) The designer also should recommend venting a steel superstructure with integral abutments that will be inundated from abutment to abutment by the 100-year or lesser floods [BDM 5.5.2.4.2].

For streams draining more than 100 square miles in rural (unincorporated) areas and for streams draining more than 2 square miles in urban (incorporated) areas, the required Iowa DNR clearance between a 50-year flood and the low superstructure is 3.0 feet of freeboard. For streams draining less than 100 square miles in rural areas and streams draining less than 2 square miles in urban areas, no Iowa DNR permit is needed, so freeboard of 3.0 feet is not required but still is desirable.

Occasionally, a variance to the Iowa DNR freeboard criteria can be requested where one or more of the following conditions are present:

- The bridge is a floodplain overflow structure,
- Ice or debris is not expected to be a problem,
- Roadgrade overflow readily provides relief in the event the bridge opening is obstructed, or
- Raising an existing grade will result in excessive costs or damages, as in heavily developed urban areas.

~~3.2.2.8~~3.2.2.5 Road grade overflow

New primary road profile grades generally should be designed to ensure that the 100-year flood elevation including backwater is not greater than the outside edge of shoulder. However, the designer should recognize that if the road grade is much higher, road grade overflow will not serve as a relief valve for the bridge during an extreme flood.

Changes to existing primary road profile grades on bridge replacement projects also need careful consideration. The designer should ensure that raising profile grades in areas with a history of roadway overtopping does not have a negative impact to adjacent property owners.

Coordination of the road grades with the Office of Design may be required.

~~3.2.2.9~~3.2.2.6 Streambank protection

Streambank erosion is a natural process in which the stream adjusts to changing conditions within its channel and watershed. The main factors contributing to streambank erosion are the velocity of water, angle of attack, soil type, lack of vegetation, and changes in land use.

When stream velocities exceed 8 to 10 feet per second, riprap may be considered. Past aerial photos should be examined to determine an approximate rate of erosion.

There are many streambank stabilization practices used by the engineering profession. A detailed description of the different methods is beyond the scope of these guidelines. However, because 75% of the streambank failures are caused by toe scour, a common design practice for bank protection with riprap is to provide adequate protection at the toe of the bank: a minimum 6-foot from the toe or to the maximum scour elevation. The riprap should be a minimum 2-foot thick layer of Class E Revetment [IDOT SS 2507.03]. The bank slope generally should be 2 horizontal to 1 vertical. The designer should identify the limits of the riprap by station and offset on the TSL sheet.

As a general rule, any streambank protection design should not extend more than 25% of the width of the eroded channel, which includes the sandbar. The streambank protection design should be sufficiently keyed into the bank to prevent undercutting. For a bank toe protection example see the commentary for this article.

A good streambank stabilization resource is the Iowa DNR's manual *How to Control Streambank Erosion*.

~~3.2.2.10~~3.2.2.7 Scour

Scour calculations should be made for all new and replacement bridges. The most common cause of bridge failure is from floods scouring bed material from bridge piers and abutments. Bridge scour is the engineering term for the movement of soil caused by the erosive action of water. Bridge scour is a complex process and difficult to analyze but very important in terms of bridge safety and maintenance cost. For guidance on calculating bridge scour the office generally relies on the Federal Highway Administration (FHWA) publication *HEC-18 Evaluating Scour at Bridges, 5TH Edition* and the recommendations and guidelines published in "Iowa DOT Bridge Scour Guidelines." See the commentary for this article.

The effects of scour should involve a multidisciplinary review of hydraulic, geotechnical, and structural engineers to assess the stability of a structure.

"Iowa DOT Bridge Scour Guidelines" is derived from *HEC-18*. The main difference between the FHWA publication and the Iowa DOT methodology is the way pier scour is calculated. For most cases pier scour in Iowa has been calculated using the research performed by Laursen under "Iowa Highway Research Board Bulletin No. 4, Scour Around Bridge Piers and Abutments." *HEC-18* recommends the Colorado State University (CSU) equation for calculating pier scour. The Laursen equations and the CSU method give comparable results.

~~3.2.2.10.1~~3.2.2.7.1 Types

There are two types of bridge scour: general or contraction scour and local scour.

- General or contraction scour is the decrease in streambed elevation due to encroachment of the road embankment onto the flood plain causing a contraction of flood flows, and
- Local scour is the loss of material around piers, abutments, wing dikes, and embankments.

There are two conditions for contraction and local scour: clear water and live-bed.

- Clear water scour occurs when there is little to no movement of the bed material of the stream upstream of the crossing. Typical situations include most overflow bridges without a defined channel, coarse bed material streams that could be found in northeast Iowa, flat gradient streams during low flow, and bridges over main channels with a significant overbank length.
- Live-bed scour occurs when velocities are high enough to move the bed material upstream of the crossing. Most Iowa streams experience live-bed scour since they consist of sands and silts.

The designer should calculate the individual estimates of contraction, pier, and abutment scour. The designer should also consider long-term degradation when determining the total contraction scour depth. Local scour should be added below the contraction scour at each pier and abutment for evaluation. The designer should also apply engineering judgment when comparing results obtained from scour computations with available hydrologic and hydraulic data to achieve a reasonable and prudent design.

~~3.2.2.10.2~~3.2.2.7.2 Design conditions

The design scour is determined for the 200-year or lesser flood, depending on which results in the most severe scour conditions. Usually the overtopping flood results in the worst scour, so evaluate this discharge if it is less than the 200-year flood. This scour depth is used by the final designer to check pile capacity and stability using load factors for the strength limit state.

The check scour is based on the occurrence of a 500-year or lesser flood, depending on which results in the most severe scour conditions. Bridge foundations will be evaluated by the final designer to ensure that they will not fail at the extreme event limit state due to the check (maximum) scour.

The preliminary situation plan hydraulic data block and longitudinal section shall show the design and check scour elevations.

~~3.2.2.10.3~~3.2.2.7.3 Evaluating existing structures

When evaluating an existing bridge for scour, the designer should be aware of the procedures to evaluate the structure by engineering judgment to determine if it is scour-safe. A "Bridge Scour Stability Worksheet" and "Intermediate Scour Assessment Procedures" evaluation should be performed before proceeding with a calculated *HEC-18* scour analysis. This may significantly reduce the cost of analyzing structures for scour that could be considered scour-safe.

The "Bridge Scour Stability Worksheet" was developed in the early 1990s to assess structures based on the type of structure, observed conditions, and stream geomorphics. The structures were considered stable or scour-critical based on the point total determined from the worksheet.

The "Intermediate Scour Assessment Procedures" were developed in 1997 to provide additional assessment of existing structures that have not been evaluated for scour. A flowchart was developed to assess those bridges that could be considered scour-safe.
If the structure is not determined to be scour-safe after assessment by the "Bridge Scour Stability Worksheet" or the "Intermediate Scour Assessment Procedure," a full computational analysis (*HEC-18*) must be performed.

~~3.2.2.10.4~~3.2.2.7.4 Depth estimates

{Text for this article will be added in the future.}

~~3.2.2.10.5~~3.2.2.7.5 Countermeasures

{Text for this article will be added in the future.}

~~3.2.2.10.5.1~~3.2.2.7.5.1 Riprap at abutments

{Text for this article will be added in the future.}

~~3.2.2.10.5.2~~3.2.2.7.5.2 Riprap at piers

{Text for this article will be added in the future.}

~~3.2.2.10.5.3~~3.2.2.7.5.3 Wing dikes

The use of wing dikes (also called spur dikes or guide banks) shall be considered at any bridge site that has appreciable overbank discharge (25% or more of the total Q in an overbank area). Wing dikes help minimize backwater and scour effects. See the commentary for a table on selecting appropriate lengths of wing dikes and the Office of Design's manual [OD SRP EW-210] for construction details. The riprap should typically be extended through the end of the wing dike.

~~3.2.2.10.6~~3.2.2.7.6 Coding

{Text for this article will be added in the future.}