Hydraulic Analysis Guidelines

2015

Nebraska Department of Roads
Bridge Division – Hydraulics

Last updated: February 2015

GENERAL GUIDANCE

The Bridge Division – Hydraulics section is responsible for:

- Hydrologic and hydraulic analyses at state bridge sites to develop the preliminary bridge data sheets that define bridge design parameters.
- Administering, managing and providing quality assurance review for hydrological bridge design studies by consultants on state and federal-aid projects.
- Providing an Interdisciplinary Scour Assessment Team (ISAT) for the Scour Critical Bridge Evaluation Program.
- Evaluating and developing design details for hydraulic related maintenance issues.
- Providing technical assistance to other NDOR divisions and the Attorney General's Office.

The hydraulic analysis will satisfy requirements of the FEDERAL–AID POLICY GUIDE, 23 CFR 650A (Location and Hydraulic Design of Encroachments on Flood Plains) and Federal Highway Administration Publication No. FHWA–HIF–12–003 (Hydraulic Engineering Circular No. 18, Evaluating Scour at Bridges).

Reference: (http://www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm)

The hydraulic engineer is required to define the most practical design for all hydraulic related issues. The analysis process evaluates, assesses and documents the impacts and consequences an encroachment has on the floodplain environment. The proposed design, countermeasure design and hydraulic related design parameters are defined by considering hydraulic constraints including, but not limited to, cost, risks, regulatory requirements, channel behavior, environmental impacts, environmental mitigation, superstructure requirements, substructure requirements, engineering requirements and social concerns.

The proposed structure is selected by hydraulically assessing natural, existing and alternate conditions. Structure sizing is based on hydraulic requirements for floods up to the 100-year flood. High risk sites may require sizing based on the 500-year floods. Bridge foundation designs are checked for scour to verify the structure has a reasonable chance of surviving a 500-year flood.

The hydraulic study is based on surveyed cross-sections that define the 100-year floodplain. Normally, a minimum of one upstream cross-section, one downstream cross-section and one encroachment (bridge opening/road grade) cross-section is required. For minor action projects with minimal hydraulic risks, such as culvert extensions, approximate hydraulic calculations based on preliminary road survey data is acceptable. High risk, very complex sites may require the use of additional floodplain cross-sections and/or total station survey data.

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Existing Hydrologic and Hydraulic Data

Research and document historic and current data that is relevant to the performance of the existing structures. Documents may include Federal Emergency Management Agency (FEMA) studies, United States Geological Survey (USGS) gaging stations and existing hydraulic studies.

Hydrologic Analysis

Develop flood flow magnitude–frequency relationships and/or flood hydrographs for the drainage basin at the encroachment.

Typically, the hydrologic evaluation is based on discharges up to 100-year discharge. For bridge scour evaluations and high-risk areas (i.e. urban areas) discharges up to 500-year discharge are required.

A partial list of hydrologic resources:

- FEMA Study
- Gaging Station Records (Log Pearson III Analysis)
- USGS Regression Equations
- University of Nebraska – Lincoln (UNL) Regression Equations
- Rational Method
- TR-55, Urban Hydrology for Small Watersheds (SCS)
- Regional Data (County Hydrology Charts)
- Other Agency Data:
    - U.S. Army Corps of Engineers (USACE)
    - Nebraska Department of Natural Resources (NDNR)
    - Others

For a practical hydrologic evaluation, assess the channel and floodplain geomorphology.

Figure 1 details the hydrologic analysis process that is typically followed by NDOR bridge hydraulics. If regression equation analyses are required, users are encouraged to verify the drainage area size falls within the limits for each set of regression equations. The drainage area limits for the regression equations currently used by NDOR bridge hydraulics may be verified as follows:

- Magnitude and Frequency of Floods in Nebraska
    - USGS Water Resources Investigations Report 76-109 (Beckman)
        - Drainage Area > 0.1 square miles
            - Applies to Regions 1, 3, 4, 5
        - Drainage Area > 10 square miles
            - Applies to Region 2
- Design Discharge of Culverts
    - NDOR Research Project Number RES-1(0099) P466 (Cordes & Hotchkiss)
        - Verify drainage area by reviewing Table 5.3 in manual
- Peak-Flow Frequency Relations and Evaluation of the Peak-Flow Gaging Network in Nebraska
    - USGS Water Resources Investigations Report 99-4032 (Soenksen et. al.)
        - Verify drainage area limits on Tables 2, 3, 4, 5, 6, 7, and 8 in manual
- Regression Equations

- o NDOR Research Project Number SPR-1(2) P541 (Strahm & Admiraal)
    - ▪ Verify drainage area limits for small and large basin analyses on Tables 4.2, 4.3, 4.5, 4.6, 4.8, 4.9, 4.11, 4.12, 4.14, 4.15, 4.17, 4.18, and 4.20

Include information related to hydrologic analysis on BR Form 14.

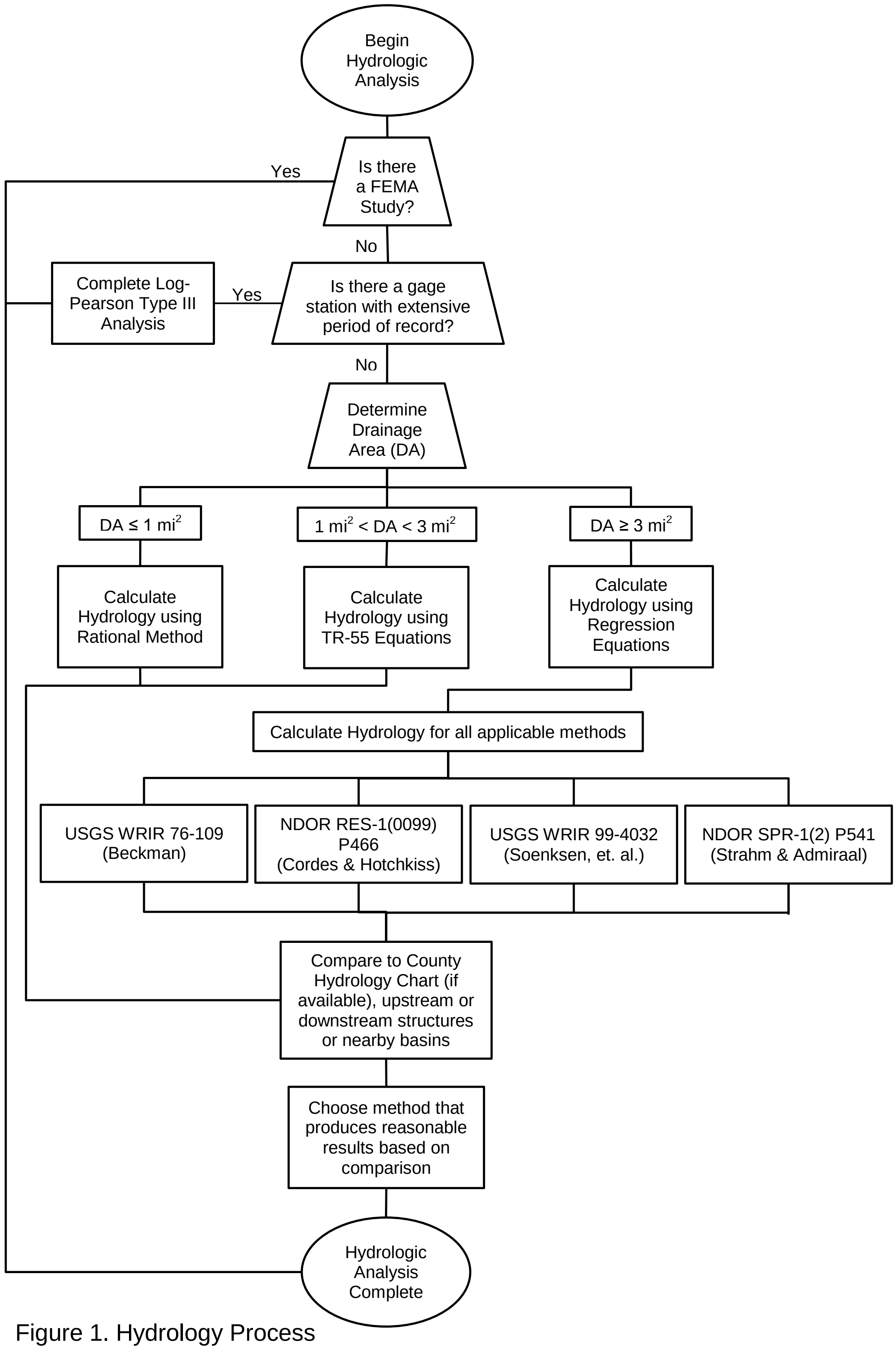

Figure 1. Hydrology Process

Typical Hydraulic Survey

One-Dimensional Model

Typical floodplain cross-sections for a HEC-RAS analysis are surveyed left to right facing downstream and extend out to the 100-year flood limits. The cross-sections are normal to the high-water floodplain and low water channel.

Locate the upstream floodplain cross-section approximately one bridge length upstream from the bridge. Use a minimum upstream distance of 100 feet and a maximum distance of 500 feet

Locate the bridge opening cross-section at the immediate downstream side of bridge from left abutment to right abutment. Include low structure elevation and existing bridge deck grade elevations at both abutments. For new alignments, obtain a channel cross-section at project centerline extending up to high bank.

Locate the downstream floodplain cross-section approximately one-half of the floodplain width downstream from the bridge. Use a minimum distance of 300 feet and a maximum distance of 1,500 feet

Hydraulic controlling features, such as natural contractions, downstream confluent streams, railroad structures, adjacent hydraulic structures, head cuts, and other obstructions, have a variety of survey requirements. Obtain the appropriate data to hydraulically evaluate obstruction impacts.

There are situations that may warrant an additional upstream cross section to accurately reflect changes occurring in the floodplain and to ensure the upstream-most cross section is far enough upstream that the water surface profiles no longer experience influences due to the hydraulic structure. Specific examples of these instances include wide floodplains transitioning to narrow hydraulic structure openings and developed property located within 1,500 feet upstream.

Hydraulic study limits are site specific. The floodplain study reach extends upstream and downstream sufficiently to analyze impacts of the encroachment. For complex floodplain analysis obtain additional cross-sections and/or total station survey.

Two-Dimensional Model

Survey for a two-dimensional model typically consists of LiDAR survey supplemented with ground survey, to incorporate more detailed flowline and high bank information into the survey data used for the two-dimensional model. In general, LiDAR coverage should extend approximately three floodplain widths upstream and downstream. However, an investigation of upstream or downstream controls, such as roadway or railroad embankments or bridges, should be conducted to ensure the topographic information extends far enough that these controls will not have any influence at the structure site. The LiDAR survey boundaries shall cross any inflow points, including the main channel and tributaries, perpendicular to the flow path.

Supplemental ground survey may include the following:

- Detailed roadway information in the vicinity of the structure.
- Detailed channel data in the vicinity of the existing structure, both upstream and downstream.
- Flowline elevations approximately 300 feet to 500 feet upstream and downstream of the existing bridge.
- Channel cross sections, high bank to high bank, every 500 feet to 1,000 feet, upstream and downstream of the bridge, wherever there is a significant change in channel geometry or slope.
- Representative cross section, for uniform channels.

- Channel profile at elevation breaks.
- Top of bank profile on both banks.
- General bridge geometry of upstream or downstream structures.

Hydraulic study limits and supplemental ground survey are site specific. Each site should be investigated using these guidelines, but there may be instances where additional survey needs will be required in order to properly model the site.

Hydraulic Analysis

Natural, existing, alternate and proposed conditions are analyzed to evaluate flood hazards, determine flood risks, assess structure adequacy and to select a practical, cost-effective design. The hydraulic analysis evaluates the impacts and consequences an encroachment has on the floodplain environment.

Hydraulic models are utilized to evaluate the floodplain over a range of flows. Two types of hydraulic analyses may be performed; one-dimensional and two-dimensional.

The majority of hydraulic analyses are performed using one-dimensional programs. These programs rely on the assumption that the velocities, conveyances, and associated forces are only significant in the stream direction (i.e. upstream and downstream). The programs use these assumptions to perform a standard-step backwater analysis, based on the Manning's equation, to solve the one-dimensional energy equation.

In some instances, the assumption of one-dimensional flow is not accurate and a one-dimensional model may not provide reasonable results. These situations may include:

- Flow moving in multiple directions, with flows being split between moving downstream in the channel and moving out of the channel into the floodplain
- Floodplain flows being disconnected from the channel or exchanged at multiple locations
- Areas of flat terrain, where runoff occurs as shallow flow over the floodplain

In these scenarios, a two-dimensional model may be preferred. Two-Dimensional models account for flow in the stream and transverse dimensions by solving depth-average equations of motion using grid, or mesh, based finite difference or finite element methods.

Calibration of a two-dimensional hydraulic model must be performed to ensure that hydraulic parameters and output are reasonable. Calibration shall be performed by comparing historical data to model output results and adjusting energy loss coefficients accordingly. Historical data may include:

- Measured water surface profiles
- Reliable high-water marks
- Stream gage information

The calibration process shall be fully documented and explicitly measureable input values should not be adjusted unless justifiable. Aerial photos of flooding may not be used to directly calibrate a hydraulic model; but may be used to demonstrate the model results are reasonable.

Submission of a Technical Methods memorandum detailing the proposed hydraulic models and methodology will be required for a project requiring two-dimensional modeling. Coordination with the FEMA Regional Office may be required when using a two-dimensional model in a mapped area.

A list of nationally accepted one-dimensional and two-dimensional hydraulic models may be found on the "Numerical Models Meeting the Minimum Requirement of NFIP" page on FEMA's website.

Further guidance on hydraulic analysis may be found in "Appendix C: Guidance for Riverine Flooding Analyses and Mapping" of the "Guidelines and Specifications for Flood Hazard Mapping Partners" also located on FEMA's website. More specifically, section C.3 discusses Hydraulic Analyses and section C.3.3.3 expands on two-dimensional modeling.

In general, HEC-RAS is the preferred bridge hydraulic analysis program. Although complex designs may require a two-dimensional model analysis. In either situation, the analysis shall address the following items:

- Type, size, location and elevation of the structure
- Road grade elevation requirements across the floodplain
- Road alignment with floodplain
- Backwater and associated flooding risks
- Flow distribution and elevation variances during rising/falling stages
- Freeboard relative to low superstructure, low road and high bank
- Channel geology and geomorphology
- Scour and erosion that affect the bridge foundation and/or channel stability
- Channel geometry, modification, training and stabilization countermeasures
- Sediment transport
- Debris
- Ice jams and relief requirements
- Flood Frequency
- Flood hydrograph and flood wave storage
- Construction parameters that are hydraulically related
- Floodplain permit requirements
- Environmental impacts and mitigation
- Subsurface water impacts
- Historic flood data

Bridge Scour

Scour is the removal of bed material through the bridge opening due to the contraction of the natural flow. The abrupt reduction of the stream's cross section at a bridge causes increased velocity and bed shear through the bridge opening. The bridge waterway area increases until a relative equilibrium is reached.

Bridge scour analysis is used to define bridge design parameters for:

- Structure type
- Structure location
- Length and span arrangements
- Low superstructure elevation

- Road grade elevations
- Abutment design
- Pier/bent design

Bridge general (contraction) scour, local pier/bent scour and abutment scour are analyzed per Publication No. FHWA-HIF-12-003, Hydraulic Engineering Circular No. 18, EVALUATING SCOUR AT BRIDGES and by using engineering judgment. NDOR acknowledges that there are issues with the abutment scour calculations and these results are typically not included in the local scour values. Abutment scour is generally only an issue in wide floodplains on larger streams. NDOR also recognizes that the general (contraction) scour calculations produce unrealistic values in some cases. NDOR uses the continuity equation (Q = V*A) and a scouring velocity of five (5) feet/second for sandy soils and seven (7) feet per second for cohesive soils to ensure that the general (contraction) scour computations produce reasonable results.

Assess the impacts of channel geomorphology, aggradations and degradation on scour potential per Publication No. FHWA-HIF-12-004, Hydraulic Engineering Circular No. 20, STREAM STABILITY AT HIGHWAY STRUCTURES.

Perform a scour analysis on the existing structure in conjunction with an assessment of maintenance history to define deficiencies. Utilize this data to assess the proposed design parameters to ensure the selected design is practical.

A proposed design is required to withstand the effects of scour up to a 500-year flood with minimal risk of failing. The 500-year scour elevation is based on calculation, debris impact assessment, long term aggradations/degradation, ice jam impacts, attack angle variations and channel behavior.

The minimum 100-year general (contraction) scour, used for bridge design, is three (3) feet for cohesive soils and six (6) feet for sand bed streams. The minimum 500-year scour elevation is six (6) feet below flowline for cohesive soils and 12 feet below flowline for sand bed streams.

Structure Design Parameters

The structure consists of the superstructure and substructure. Superstructure design parameters include bridge length, span arrangement, low superstructure and stationing. Substructure design identifies abutment type, back wall design and interior support (piers/bents) based on hydraulic requirements. Structures must not restrict the passage of in-channel flows to the maximum extent practical.

- Superstructure
  - Bridge Length
    - Typically, the minimum bridge length spans the natural stream channel plus five (5) feet of berm width adjacent to each abutment. For larger rivers, increase the berm width to a minimum of ten (10) feet.
    - The final bridge length requirements are based on hydraulic calculations that assess the scour, channel behavior, backwater, road grade requirements, freeboard, debris transport and design constraints.
  - Bridge Low Superstructure
    - Typically, the superstructure is designed to be above the 100-year flood elevation with one (1) foot of freeboard when practical.
    - Actual freeboard clearance is defined by an assessment of the risks associated with backwater, low road elevation, flood relief, debris, ice effects, channel behavior, Coast Guard regulations, and hydrologic variances.

        - When ice jams are an issue, additional freeboard of up to four (4) feet is appropriate when flood relief is not available.
        - When it is not practical to provide freeboard, submergence of the bridge superstructure must be justified and documented.
    - Spans
        - Single span bridges should be used when practical. Multi-span structures are used when bridge length exceeds single span design requirements, or if road grade constraints are an issue.
        - Piers and bents are to be located outboard of the ordinary high water channel. If this is not practical, minimize the numbers that are located within the ordinary high water channel.
    - Bridge Rail
        - In general, open rail shall be used. For guidance on when to specify closed rail please refer to the "Bridge Office Policies and Procedures" Manual, Section 3.6.2 "Concrete Rail Policy".
        - When closed rail or concrete barrier are specified for a bridge, hydraulic calculations determining whether deck drains are warranted must be provided. See the "Bridge Office Policies and Procedures" Manual, Section 3.1.6 "Floor Drain Policy" and Section 3.6.2 "Concrete Rail Policy" for additional information.○
    - Stationing
        - Typically, the structure is centered over the channel. Actual stationing is determined by assessing hydraulic and design requirements.
        - Non-symmetrical floodplains and road grade requirements are several items taken into consideration in the assessment.

- Substructure
    - Abutment
        - Typically sheet pile wall abutments are preferred.
        - Concrete wall abutments are acceptable if they meet the 500-year scour requirements.
        - Define critical berm elevation requirements for final abutment design.
            - Where the critical berm elevation is the soil line at the abutment after considering 100-year scour and channel behavior.
            - For concrete wall abutments the bottom of concrete elevation is the critical berm elevation.
            - For sheet pile walls, estimate the bottom of wall elevation and verify that the 500-year scour elevation is above the bottom of wall elevation.
            - Typical abutment design has the critical berm elevation approximately five (5) feet below the berm and 14 to 15 feet below bridge grade.
            - The maximum economical concrete wall depth is 15 feet.
            - The maximum economical sheet pile length is approximately 30 feet.
    - Pier/Bent
        - Use concrete encased piers or bents when debris is significant, to protect piling from rust or for un-braced piling length requirements.
        - Typically low concrete is at stream flowline, which takes into account potential channel degradation.
        - For Piers the low concrete is defined as top of footing.

        - Define special pier/bent designs when necessary for debris or ice.

Countermeasures

Countermeasures are methods used to prevent bridge failure resulting from channel behavior, general (contraction) scour and local scour.

- Abutment Countermeasures
    - Alignment
        - Proper structural alignment with the channel and floodplain to minimize scour.
    - Berms
        - Berms along sheet pile walls are used to reduce the probability of voids forming behind the abutments due to repeated saturation of the approach fill.
        - Armor berms to counteract the effects of scour and channel meandering.
            - Berms adjacent to sheet pile walls are armored to stabilize them from eddying flow along the irregular surface.
            - Use a minimum armor width of five (5) feet.
        - Construct artificial berms above the normal high bank to stabilize the abutment walls when wall height is excessive.
            - The minimum artificial berm width is five (5) feet with a two to one (2H :1V) slope to natural high bank.
            - Armor, extend and transition around the road fill to the end of wings.
    - Guide Banks/Spur Dikes
        - When flow depth and volume are excessive, use guide banks to transition flow smoothly through the bridge opening and minimize scour.
    - Channel Stabilization
        - Stabilize the channel bank as necessary to prevent the channel from shifting/meandering into the abutment.
        - Do not encroach into the natural channel.
    - Utilizing Buffer Areas
        - When appropriate, utilize high bank buffer areas to reduce transitioning floodplain velocities at the abutment and to minimize abutment scour.
    - Relief Structures
        - Use relief structures on wide or skewed floodplains to reduce flow through the main bridge when practical.
    - Channel Change
        - Channel change is allowed only when there is no other practical alternative.
        - Channel change limits and length changes shall be minimized and designed to be the least environmentally damaging, practicable solution.
- Pier/Bent Countermeasures
    - Alignment
        - Align pier/bent with the high flows to minimize local scour.

        - Encasement
            - Encase piers/bents when debris transport is significant, pile rust protection is necessary or pile bracing is required
            - Typically, minimum bottom of concrete encasement elevation is 2 feet below flowline; which provides protection from channel degradation.
    - Tapered Pier/Bent
        - Design ice breaker pier/bent when channel has ice effects.
        - Channels with excessive debris may require a tapered pier/bent that causes debris to ride up the taper on the upstream side, thus reducing local scour.
- Open Rail Countermeasures
    - Open Rail Drip Line Countermeasures
        - Armor unprotected areas under the drip line and outboard of the channel to prevent rutting
        - When distance from grade to ground is ten (10) feet or less, armor a ten (10) foot wide strip centered below the drip line
        - Consider additional drip line protection width when distance from grade to ground exceeds ten (10) feet
        - The drip line protection is trenched to prevent the reduction of water way area (WWA)

Road Grade Elevation Requirements

Flood overtopping of roadways is acceptable if the action is reasonable and prudent. Determine the preliminary road grade across the floodplain and coordinate final design with the roadway design engineer.

Minimum overtopping justification:

- Overtopping of all roads from floods less than the 100-year flood will require justification by hydraulic computations that consider existing conditions, constraints, risks associated with the action, roadway design requirements and economics.
- Four lane interstate highways will be designed for a minimum 50-year overtopping.
- Six lane interstate highways will be designed for a minimum 100-year overtopping.
- When practical, expressways will be designed to the same standards as interstate highways.
- Typically, highways are designed for a minimum 50-year overtopping. Coordination with roadway design is required when it is not practical to meet the minimum.

Channel Behavior

The process of selecting the most practical bridge design requires an assessment of channel reach behavior. Channels are dynamic and naturally adjust to climate and man-made changes. Channel adjustments usually occur very slowly when reacting to natural, environmental change. When the channel is subjected to man-made alterations, such as dredging or straightening, changes can occur rapidly.

The dominant parameters that influence channel adjustments are water discharge, channel slope, sediment transport and the average size of the channel bed material. A change in any of these four parameters causes the channel to readjust. The rate of change varies with each basin hydrograph for ephemeral, intermittent and perennial streams. Ephemeral channels have flowing water only from precipitation events. Intermittent channels have flowing water from rainfall events and ground water return but do experience dry periods during the year. Perennial channels have flowing water year-round.

The six stages of channel evolution, used to understand how a channel reach adjusts when it is subjected to alterations, are:

STAGE I – PRE-MODIFIED

When a channel is in the pre-modified, natural state, it is relatively stable and properly designed bridges experience few channel behavior scour problems.

STAGE II – CONSTRUCTED

This phase identifies channels recently modified by channel straightening and usually has a short duration before adjustments occur. The artificial channel becomes unstable after a major runoff event.

STAGE III – DEGRADATION

Channel degradation occurs due to a series of headcuts that progress in an upstream direction. Bank slopes become steeper as channel depth increases.

STAGE IV – THRESHOLD

Degradation has ended and headcuts are not evident. Alternate bars start to form and mass wasting of the bank is the dominant channel shaping process that widens the top of the channel.

STAGE V – AGGRADATION

Stream meandering occurs and the elevation of the flowline increases.

STAGE VI – RESTABILIZATION

Channel equilibrium is achieved, channel capacity is reduced and channel adjustments are minimal.

Environmental

The hydraulic design of a structure over a waterway must provide connectivity through the structure for all wildlife to facilitate long term population viability.

The channel aquatic ecosystem and corridor should be maintained to provide vital habitat for fish and wildlife. An appropriate structure design is based on the site's unique situation. Avoid negative long- and short-term environmental impacts unless it is not practicable.

Long term environmental impacts are minimized by spanning the entire natural stream channel and providing adequate berms for wildlife. Minimize the number of piers/bents that are located within the ordinary high water area when it is not practical to span the channel.

Short term environmental impacts occur during construction and flooding. Consider constructability issues when designing a structure to minimize short term impacts. During significant floods the natural channel shape is altered due to increased channel velocity and depth. At the bridge opening, flow contraction creates scour forces that add to the natural channel changes. As flood waters recede, the channel returns to its natural condition, which is typically formed by a 2-year event.

Assessment of Alternates and Risk

The hydraulic study includes an assessment of alternates and the risks associated with each alternate to arrive at the most practicable design.

The general assessment is based on:

- Constraints
- Hydraulic requirements (Refer to Section 4 – Hydraulic Analysis)
- Bridge parameters
- Roadway alignment and profile
- Traffic issues
- Economics
- Social concerns
- Constructability
- Environmental issues and mitigation
- Flood hazards to the natural and beneficial floodplain values

A detailed risk analysis is necessary when the assessment is inadequate to define the most practical encroachment design.

Hydraulic Stability Categories

The hydraulic stability of structures is determined by assessing channel behavior, scouring of the bridge waterway area, and structural design parameters. Field observations and hydraulic analyses of these factors are used to evaluate how floods impact structures.

The structures are separated into four categories:

1. Stable

   Structure has a reasonable chance to survive a 500-year flood. A 100-year flood will have minimal impact to berm stability, substructure stability, and approach integrity.

   - **Channel Behavior** – Structure is not at risk
   - **Scour** – Minimal impact
   - **Structural** – Designed to withstand hydraulic concerns

2. Low Risk

   Structure will survive a 100-year flood. Scour damage is within design limits and will not impact the substructure and/or approach integrity. Scour at berm will not impact abutment stability.

   - **Channel Behavior** – No significant risk to the structure, monitor during routine inspections
   - **Scour** – Within design limits
   - **Structural** – Substructure has minimal concerns

3. Scour Susceptible

   Assessment indicates failure is possible during floods if a change in channel behavior occurs. Monitoring, structure replacement, substructure modifications, or channel countermeasures are required to minimize scour risks.

   - **Channel Behavior** – Long-term risks for foundations, monitor during routine bridge inspections
   - **Scour** – At or near scour limits
   - **Structural** – Substructure is at risk from floods

4. Scour Critical

   Failure of the structure is probable due to flooding. Plan of Action (POA) required.

   - **Channel Behavior** – Berm failure
   - **Scour** – Scour limits exceeded
   - **Structural** – Substructure near failure

Each structure assessed is unique. In some cases, a single hydraulic concern will place the structure into a specific category. For others, one must consider a combination of hydraulic problems. Areas to consider for channel behavior, scour and structural issues are:

- Channel Behavior
  - Meander belt stability
  - Channel reach stability
  - High bank buffer
  - Channel depth
  - Channel vegetation
  - Debris transport
  - Ice effect/jam
  - Countermeasures
  - Degradation
  - Aggradation
- Scour
  - General (contraction) scour
  - Local scour
  - Abutment
  - Pier/bent
  - Berm stability
  - Waterway adequacy
  - Abutment wall turbulence
  - Flood relief
- Structural
  - Superstructure

- Superstructure type
- Vertical alignment
- Structure spans
- Structure low steel
- Freeboard
- Structure alignment
- Substructure
- Abutment design and location
- Critical berm
- Pier/bent design and location

Permit Requirements

Impacts due to floodplain encroachments require specific permitting on a site-to-site basis. Typical requirements include:

- Nebraska law

  A floodplain easement is required from the land owner if the 100-year flood elevation is raised more than one (1) foot at any location.

- Clean Water Act

  A USACE Section 404 permit is required for the placement of fill material into the waters of the United States.

- FEMA Zone “A” Floodplain

  Construction within a floodplain requires a Certification of Compliance, from a licensed Engineer, verifying that the 100-year flood elevation was not raised more than one (1) foot at any location. Minor action projects, defined as modification of existing encroachment, require only a Certification of Compliance. Major action projects, defined as new construction, require a copy of the hydraulic report with the Certification of Compliance.

- FEMA Floodway

  Construction in a floodway requires a Certification of Compliance, from a licensed Engineer, verifying there is no-rise to the 100-year floodway elevation based on the existing FEMA model. A copy of the existing, duplicate effective, corrected effective and proposed models are provided with the Certification of Compliance, as required.

- Local Agencies

  Verify local permit requirements

Temporary Road Design

Hydraulic designs of temporary road structures are typically based on the 2.33-year flood and are designed to cause no adverse impacts. Reducing the design to as low as a 1-year flood is acceptable if proper justification is provided and the site is monitored during an overtopping event. The structure is required to meet USACE Section 404 permit requirements.

Contractor Access Crossing

Contractor access crossings are designed to allow the contractor to complete bridge work with minimal impact to the channel. Contractor access crossings should be designed to pass the ordinary high water flows with minimal backwater and should fit the natural channel. Typically, corrugated metal pipes are used for the crossing, however if pipes do not provide adequate conveyance, a temporary bridge may be appropriate.

When using culvert pipes, the following items will be reported:

- Size of pipes
- Number of pipes
- Fill over pipes (minimum of 1 foot of fill is required)

When using a temporary bridge, the following items will be reported:

- Length of temporary bridge required to span ordinary high water.
- Low structure elevation required to obtain 3 feet of freeboard above the ordinary high water elevation.

Ditch Drop Structures

The hydraulic design of ditch drop structures is the roadway designer's responsibility. Notify the roadway designer when an assessment by the bridge hydraulic engineer indicates a ditch drop structure may be required.

Documentation

Hydraulic reports are arranged in an organized, consistent format. The content is subdivided into categories that include:

Preliminary Design Data

- Preliminary Data Sheet
  - BR Form 359A – Preliminary Bridge Data Sheet
  - BR Form 359B – Culvert Data Sheet (*Culvert to Culvert*)
  - BR Form 359C – Culvert Data Sheet (*Bridge to Culvert*)
- Bridge TS&L sheet (11 x 17 size sheet)
- Plan and Profile Across Floodplain (11 x 17 size sheet)
- Floodplain Certification
  - Floodplain Certification Memo
  - DR Form 266 - Certification of Compliance
  - Flood Insurance Rate Map showing site (FIRMette)

Field Inspection Photographs

- Bridge Opening – identify if looking upstream or downstream
- Upstream Channel View
- Downstream Channel View
- Scour and Flood Related Observations

Project information and Assessment

- USGS topographic map – site location identified
- Aerial Photograph of Site (typical scale at 1 inch per 500 feet)
- Hydraulic Survey Request
- Executive Summary
- Existing Bridge Plan
- Existing Plan and Profile
- FEMA Information
  - Summary Table
  - FIRMette
- Contractor Access Crossing Information

Proposed Condition

- Detailed Contour Plot of Immediate Area
- Cross-Section Location Sketch – Aerial photograph to scale
- Cross-section plot of upstream bridge opening including:
  - Deck elevation
  - Low superstructure
  - Abutment back wall details
  - Bent/pier locations
  - Q_{100} water surface
  - Calculated Q_{100} scour
- Water Surfaces and Flowline Profile Plot
- Upstream Cross-Section Rating Curve
- Computer Model Output Table, including:
  - Total flow in cross section (Q Total)
  - Calculated water surface from energy equation (W.S. Elev)
  - Average velocity of flow in main channel (Vel Chnl)
  - Flow in left overbank (Q Left)
  - Flow in main channel (Q Channel)
  - Flow in right overbank (Q Right)
  - Top width of the wetted cross section (Top Width)
  - Top width of the main channel (Top W Chnl)
  - Total area of cross section active flow (Flow Area)
  - Area of main channel active flow (Flow Area Ch)
  - Conveyance of total cross section (Conv. Total)
  - Froude number for the main channel (Froude # Chnl)
- Computer Model Input
- Cross-section Plots, to common scale (include all water surface profiles)
- Q_{100} and Q_{500} scour computations (include $Q_{Overtopping}$ if less than Q_{100})

Existing Conditions

- Detailed Contour Plot of Immediate Area
- Cross-Section Location Sketch – Aerial photograph to scale
- Cross-section plot of upstream bridge opening including:
    - Deck elevation
    - Low superstructure
    - Abutment back wall details
    - Bent/pier locations
    - Q_{100} water surface
    - Calculated Q_{100} scour
- Water Surfaces and Flowline Profile Plot
- Upstream Cross-Section Rating Curve
- Computer Model Output Table, including:
    - Total flow in cross section (Q Total)
    - Calculated water surface from energy equation (W.S. Elev)
    - Average velocity of flow in main channel (Vel Chnl)
    - Flow in left overbank (Q Left)
    - Flow in main channel (Q Channel)
    - Flow in right overbank (Q Right)
    - Top width of the wetted cross section (Top Width)
    - Top width of the main channel (Top W Chnl)
    - Total area of cross section active flow (Flow Area)
    - Area of main channel active flow (Flow Area Ch)
    - Conveyance of total cross section (Conv. Total)
    - Froude number for the main channel (Froude # Chnl)
- Computer Model Input
- Cross-section Plots, to common scale (include all water surface profiles)
- Q_{100} and Q_{500} scour computations (include $Q_{Overtopping}$ if less than Q_{100})

Hydrology – Frequency Data

- Hydrologic Frequency Distribution Plot to Q_{500}
- BR 14 – Hydrologic Reference Information
- Hydrology Comparison Chart
- Regression Spatial Analysis and Basin Delineation
- County Hydrology Chart

Field Inspection

A final field inspection of the project site is conducted after the office evaluations are completed and a detailed design is defined. Consider conducting a preliminary field inspection to improve design efficiency and help assess the hydraulic risks.

Field Inspect and verify the following:

- Structure location
  - Centerline
  - Abutments
  - Piers/Bents
  - Skew
  - Channel alignment
- Flood calculations by visualizing flood height, limits, and flow distribution
- Hydraulic coefficients
- Berm and flowline elevations
- Bed and bank material
- Upstream buffer effectiveness
- Channel geomorphology and expected impacts to structure
- Countermeasure requirements, location and limits
- Need for a ditch drop
- Ordinary High Water line
- Photographs
  - Structure opening
  - Hydraulic deficiencies
  - Upstream channel
  - Downstream channel
  - Ordinary high water line
  - Alignment of proposed structure
  - Flood risks
- Constructability impacts

Preliminary Bridge and Final Culvert Sheet

The preliminary bridge and final culvert data sheets summarize the hydraulic related design requirements for a structure. A preliminary data sheet is used for bridge structures and a final culvert data sheet is used for bridge-size culverts. Submit completed data sheet to the Bridge Engineer for review and approval.

The following information is to be documented on DR Form 359A through 359C:

- Site Description and Disposition
- Existing Structure
- Proposed Structure
- Proposed Grade
- Design Hydraulic Data
- Channel Data/Channel Shaping
- Permits
- Traffic Options

- Contractor Access Crossing
- Hydraulic Design Details/Sketch

Distribution of the approved preliminary bridge and final culvert data sheets for review and comments on state projects:

- Design Manager, Roadway Designer
- cc: District Engineer, Bridge Designer, Environmental Permits Coordinator, Project Development Engineer, Geotechnical Engineer, Construction Engineer, and Bridge

  Management
- Original to bridge hydraulic file

Quality Assurance Review

Verify the hydraulic design report satisfies NDOR Hydraulic Analysis Guidelines and the Federal Aid Policy Guide 23 CFR 650 A.

Categories to Review are as follows:

- Project identification and location
  - Current project identification (Project, Structure and Control Number)
  - Location map (County or Topographic map showing proper location)
- Hydrologic data
  - Drainage Area verification
  - Hydrologic justification
  - Frequency Distribution Plot
- Hydraulic survey data
  - Hydraulic Cross-section location sketch (acceptable length and location)
  - Detailed contour plot of proposed conditions
  - USGS datum identified (1929 or 1988)
- Existing hydraulic analysis
  - Cross-section plots (no obvious survey errors)
  - Input data (Verify reach lengths, “n” values and channel slope)
  - Output data (Includes necessary information)
  - Water Surface profile plot (reasonable profiles)
  - Bridge Scour assessment (Compare natural and scoured velocities)
  - Hydraulic category identification (hydraulic data assessed correctly)
  - Field inspection photographs documenting existing conditions
  - Entire bridge opening (direction identified)
  - Upstream and Downstream channel view (direction identified)
  - Evidence of scour (as needed)
  - Flooding risks (as needed)
  - Ordinary high water and high water marks (as needed)

- Proposed hydraulic analysis
  - Cross-section plots (no obvious survey errors)
  - Input data (Verify reach lengths, “n” values and channel slope)
  - Output data (Includes necessary information)
  - Water Surface profile plot (reasonable profiles)
  - Bridge Scour assessment (Compare natural and scoured velocities)
  - Hydraulic category identification (hydraulic data assessed correctly)
  - Design parameters
  - Structure length (satisfies minimum channel and berm requirements)
  - Superstructure (appropriate skew, type and depth)
  - Low Structure (justifiable freeboard for Q_{100}, low road and high bank)
  - Design flood (justifiable overtopping frequency and flood distribution)
  - Abutment Type (critical berm and bottom of wall satisfies Q_{100} and Q_{500} requirements)
  - Pier/Bent Type (appropriate span arrangement, type and bottom of encasement)
  - Bridge WWA (correct channel cross-section)
  - Countermeasures (berm, channel banks and drip line protection)
  - Channel changes (justified)
- Hydraulic alternates (summary of hydraulic, economic and risk comparisons)
- Constructability (practical structure, countermeasures and traffic options)
- Information sheets (adequate details)
- Final hydraulic report (verify content and organization)
  - Preliminary/final data sheet (verify content and organization)
  - Plan and profile
  - TS&L (per preliminary/final data sheet)

Bridge Scour Inspection and Analysis

The bridge scour inspection and analysis procedure assesses the vulnerability of existing bridge-size structures failing due to flood events. Hydraulic data is used in conjunction with structural data to manage bridges in an efficient, effective and continuous manner for safe public travel. Trained bridge inspectors, para-professional bridge personnel and bridge engineers combine their special skills to prioritize and inspect bridges, assess channel behavior and evaluate the structures for scour.

Continuous visual screening of bridges is completed by National Bridge Inspection Standards (NBIS) trained personnel. They make scour related observations to monitor and document hydraulic changes for bridges over waterways as part of their normal two-year inspection cycle. An Interdisciplinary Scour Assessment Team (ISAT) utilizes the NBIS data to evaluate bridge scour.

The following NBIS Items and ISAT process are used to determine the vulnerability of the bridge due to scour.

Bridge Inspector Scour Observation

The screening process uses the “Nebraska Data Items – Scour Related” in the Nebraska Department of Roads Bridge Inspection Program Manual and knowledge of channel behavior.

300 SERIES SCOUR CRITICAL ITEMS

344	Abutment walls undermined	Y – N
346	Stream bed degradation	Y – N
347	Noticeable Contraction of Stream	Y – N
348	Local Scour at Piers/Abutments (refer to coding guide for details)	______
350	Stream shifted from center	Y – N
353	Potential debris upstream	Y – N
354	Bents/Piers in channel	Y – N
355	Alignment with flow (9 – 0)	______
357	Drop from upstream deck to ground Abut-1 (__), Flowline (__), Abut-2 (__)	
358	Is there a SCOUR PROBLEM	Y – N
358C	Scour Plan of Action effective date	

Interdisciplinary Scour Assessment Team Process

Bridge scour assessment requires multidisciplinary inputs. Hydraulic engineers involve structural and geotechnical engineers in the evaluation process. A licensed engineer supervises the Interdisciplinary Scour Assessment Team (ISAT) process.

Scour Assessment Analysis

A five-step evaluation/calculation process is used by ISAT to assess bridges for scour.

1. Hydraulic data and Hydrologic analysis
    - Assemble existing hydraulic related information for the specific bridge. Reference the available hydraulic data from the immediate region.
    - Review the hydrologic analysis for the bridge site. Verify the flood frequency data for discharges up through the 500-year discharge. The hydrologic analysis is based on appropriate regression equations and available regional data.
2. Field inspect bridge site
    - Update scour and channel behavior data (DR Form 385, DR Form 385B)
    - Identify voids and undermining of abutment/approaches (sound/probe)
    - Establish depth of abutment backwalls. (plans/probe)
    - Probe for evidence of scour immediately upstream of piers/bents
    - Categorize bed material: granular, cohesive or non-erodible
    - Categorize bank material: granular, cohesive or non-erodible
    - Assess channel behavior and determine channel evolution stage
    - Assess the NBIS 300-series Scour items
    - Observe structural features to assess the structure's reaction to scour and channel behavior
    - Document hydraulic observations and provide digital photos that show:
        - o bridge deck relative to low Road grade

    - Upstream and downstream channel views
    - Bridge profile showing waterway area
    - Wings, abutment walls, berms, natural banks
    - Piers/bents
    - Countermeasures, scour related problems and recent high water marks
  - When the bottom of the abutment wall is exposed the NBIS Item 113 coding is typically a "2"

  NOTE: Report any critical condition that requires immediate action to bridge owner.

3. Field survey for Scour Calculations
  - Review road profile and typical floodplain cross section, update as needed.
  - Hydraulic surveys should be taken from left to right as viewed looking downstream
  - Reference the elevations to USGS 1988 NAVD datum
  - For remote areas, approximate USGS datum is acceptable.
  - Use a bridge benchmark or approximate datum based on topographic map data
  - Road Profile from left floodplain to right floodplain limits.
  - Identify bridge grade at abutment 1 and abutment 2.
  - Typical floodplain cross-section, minimum of one (1) required.
  - Record the typical channel top and bottom widths.
  - Cross-section at downstream side of bridge opening.
  - Record superstructure depth.
4. Hydraulically evaluate the bridge site for scour
  - Review the bridge scour based on HEC-RAS hydraulic analysis and update as needed
  - Use the following HEC-RAS input data identification format:
    - NEW PROJECT TITLE - use <u>Structure Number</u> Scour Study
    - FILE NAME - use <u>Structure Number</u>.prj
    - Reference the cross section "River sta.:" to bridge centerline (typically the river station of the bridge is 1,000)
    - Reference the river cross section stations to bridge centerline in the "Description" data field (e.g.: 100 feet upstream, 30 feet upstream, 30 feet downstream, 400 feet downstream)
    - Combine the field information and hydraulic analysis to make an assessment of channel behavior and scour impacts on the bridge
  - Update the 300 series scour items on form (DR Form 385)
  - Update "Item 113" code on forms (DR Form 385, DR Form 385B)
  - Scour study report (folder) includes the following:
    - Correspondence
    - Bridge site photographs
    - Project Information:
      - Background data
    - Existing Structure
      - Report cover with PE seal

- Cross-section plot of (downstream) bridge opening (HEC-RAS controlling Scour Plot), including:
  - Q_{100} water surface
  - Bottom of abutment back-walls (if known)
  - Identify depth of probing (if available)
  - Critical Berm (if known)
  - Low superstructure
  - Deck
  - Bents/piers
  - Calculated scour limits
- Bridge opening section history
- Hydraulic data forms (DR Form 385, DR Form 385B)
- USGS contour map showing bridge site encircled
- Typical floodplain or survey cross-section location on an aerial photo
- HEC-RAS:
  - Stream profile plot showing Q_2, Q_{10}, Q_{25}, Q_{50}, Q_{100}, Q_{500} and ($Qo_{vertopping}$ if less than Q100)
  - Rating curve for cross-section immediately (downstream)from structure.
  - Summary Table showing:
    - Total flow in cross section (Q Total)
    - Calculated water surface from energy equation (W.S. Elev)
    - Average velocity of flow in main channel (Vel Chnl)
    - Flow in left overbank (Q Left)
    - Flow in main channel (Q Channel)
    - Flow in right overbank (Q Right)
    - Top width of the wetted cross section (Top Width)
    - Top width of the main channel (Top W Chnl)
    - Total area of cross section active flow (Flow Area)
    - Area of main channel active flow (Flow Area Ch)
    - Conveyance of total cross section (Conv. Total)
    - Froude number for the main channel (Froude # Chnl)
  - Bridge Details for Q_{100}, $Q_{500,}$ and (Q_{OT} if less than Q_{100})
  - HEC-RAS Report
  - Floodplain cross-section plots showing “n” values and all flows
  - Scour plot and calculation output for Q_{100}, Q_{500}, and (Q_{OT} if less than Q_{100})
  - Back cover with PE seal

- Scour Field Assessment
  - Field inspection data

- Hydrology
    - BR 14 – Hydrologic Reference Information
    - Regression Data
    - County Hydrology Chart
    - Stream slope plot
    - County map with structure location identified

5. Perform a Quality Control check to verify evaluation/report adequacy.

Scour Assessment Follow-up

Send a copy of the Report to the bridge owner and scan for electronic file;

(Do not include: Correspondence, Field data, Background data, Hydrologic calculations, and Stream slope plot).

Plan of Action Requirements for structures determined to be Scour Critical.

A Plan of Action (POA), DR Form 385C, is required to provide for public safety when a structure is rated scour critical. A scour critical bridge is a structure which is rated 3 or lower under *Item 113 "Scour Critical Bridges*" as defined by the *NDOR Bridge Inspection Program Manual.* ISAT assigns the Item 113 rating following inspection, calculation and assessment. The bridge owner is informed of scour critical findings, provided a copy of the scour study and is responsible for the development of a POA.

The POA may require increased inspections, periodic monitoring, installation of scour countermeasures, conditional closure, and/or bridge replacement. A POA includes a schedule for implementation of the various actions prescribed. Details for monitoring, maintenance and areas of responsibility are identified. Guidance for POA preparation is contained in *FHWA Hydraulic Engineering Circular (HEC) 18, 20 and 23*.

Action

The actions prescribed in the POA document the immediate action required, restrictions associated with the actions and if a structure replacement is needed.

Monitoring

The monitoring frequency of NBIS inspections and the supplemental hydraulic inspections between, during or after flood events are identified. NBIS inspectors monitor the site during routine inspections. Supplemental routine and/or special inspections focusing on the hydraulic issues are normally required. A high risk site may require an inspector to be at the site prior to flood arrival. Pre-storm parameters are identified to define when to initiate an on-site visit. A visit to the site may be defined by rainfall parameters and/or flooding information and/or road overflow reports.

Closure Plan

Criteria for closing the structure are identified. A closure plan and detour route is required. The plan defines equipment needs (barricades etc.), instructions on how to close the road, and defines a detour route. The POA identifies the agencies and/or people that may need to be notified immediately after a closure.

Reopening Bridge

Criteria for reopening the structure is to be determined by certified personnel. The authorized inspector identified on the form is responsible for assuring the safety inspections and/or repairs are completed prior to the structure being reopened.

Maintenance

Maintenance proposed to minimize scour related failure risk is identified and the time schedule is listed.

POA QC/QA

Signatures and dates

The POA shall be submitted to NDOR Bridge Division within 30 days of the date that the bridge owner is notified that a bridge is scour critical. Direct questions regarding the POA request to NDOR Bridge Division – Hydraulics.

NDOR Bridge Division shall conduct quality control of the POA and its requirements.

Bridge owner shall maintain a log that documents POA related actions taken and the responsible party for each action (DR form 385E).

Scour studies/ratings are updated as conditions warrant.

Hydraulic Forms

Hydrologic Reference Information	BR Form 14
Preliminary Data Sheet	BR Form 359A
Culvert Data Sheet (*Culvert to Culvert*)	BR Form 359B
Culvert Data Sheet (*Bridge to Culvert*)	BR Form 359C
FEMA Certification of Compliance	DR Form 366
Bridge Scour Report	BR Form 385
Culvert Hydraulic Report	BR Form 385A
Bridge Scour Assessment	BR Form 385B
Bridge Scour Plan of Action	BR Form 385C
Bridge Scour Worksheet	BR Form 385D
POA Monitoring Log	BR Form 385E
Supplemental Hydraulic Findings and Maintenance for Scour Critical Bridges	BR Form 385F