Chapter 2. Hydraulic and Hydrologic Recommendations

The following pages contain several detailed illustrations, notes and guidance of Best Practice options for Hydraulic and Hydrologic design of structures impacting Public Waters. Each site will have to be evaluated to ensure that replacement of an existing structure does not result in an increase of flood potential to upstream or downstream properties. Additional information is also provided to improve or repair stream stability and local habitat.

Natural stream geomorphological processes are required to be incorporated into hydraulic and hydrologic design process. (Devil Track River, TH61 Cook County MN)

(TH171 Floodway bridge near St. Vincent, Kittson County MN)

Chapter cover photo, TH61 at Palisade Creek, Lake County, MN)

Things to Consider for Improved Culvert Design

Casual observations of stream characteristics at a crossing can provide definitive information on how an existing culvert has matched (or not matched) the surrounding stream characteristics. This section lists characteristics that road maintenance crews and bridge inspectors should be trained to identify during regular maintenance and inspections. Historical knowledge of how a culvert is interacting with the surroundings will be valuable if the crossing is proposed for replacement.

A redesign should include knowledge of how the existing crossing is functioning, and noted if there are contributing factors as to why an existing crossing is no longer adequate. It is entirely possible that a crossing was sized appropriately at the time of installation, though became insufficient as changes in the watershed occurred. Natural bedload composition can also be expected to have been altered due to land use changes in the watershed, or changes in storm frequency/intensity since the crossing was installed. Regardless of the structural reasons for the need for crossing replacement, there are several observations that can be utilized for determining if an existing crossing size or alignment is inadequate.

Traditional hydraulic design has been the standard requirement for crossing designs since the 1950s. These programs calculate stage increase (water elevations) based on storm event and watershed area/characteristics. Road authorities set thresholds to be met regarding road overtopping (maximum depth of water on the road for a chosen storm event). DNR regulations require that the headwater elevation for the 100yr frequency not exceed 0.5' over the calculated stage when compared to calculations without any crossing. DNR allows exceptions to this rule for replacement of existing crossings that previously had a higher stage increase (A new crossing can be replaced with the up to the pre-existing stage increase as long as there are no structures impacted). These processes typically lead to the smallest opening being chosen for installation. Thus traditional hydraulic design models, by suggesting a smallest opening size, may inadvertently lead to an increased potential for destabilizing natural stream integrity. This can lead to situations that are not good for either the interests of road stability or ecological connectivity.

There are many design objectives, which result in different designs for different settings. Flood elevations, wetland control elevation, ecological connectivity, safety and economics are all pieces being considered when a crossing is to be replaced. Recognizing flaws in the existing crossing will help to prevent duplicating defects in the new design. Currently, DNR regulations allow for replacement of existing crossings 'in-kind' (same size opening and invert elevations) with minimal scrutiny. However this may not be in the best interest of either the road authority or stream ecology.

The DNR and road authorities may have differing missions, though the DNR's responsibility to require ecological connectivity need not be in conflict with a road authorities responsibility to provide for safe travel on the road. A crossing designed with aspects of ecological connectivity can also:

- Minimize the consequences of plugging and overtopping.
- Prevent stream diversion (unstable banks and road slopes).
- Have sufficient hydraulic capacity:
    - Headwater depth does not cause pressurized flow during flood events
    - Culvert hydraulics do not cause scour at the outlet or inlet
- Maximize the life cycle of crossing.

Thus, a properly designed culvert does compliment the interest of both the road authority and the DNR.

Problem indicators on existing crossings:

1. **Plunge pools, stream bank scour, & sediment deposits)**
2. **Debris accumulation.**
3. **Perched outlet**
4. **Change in road overtopping frequency or depth.**
5. **Shallow culverts (but not perched)**

Other issues:

6. **Liners**
7. **Basin Outlets and its control elevation:**
8. **Non Public Waters**
9. **Deficient flood capacity and nearness to critical cultural operations**

1. Plunge pools, stream bank scour, & sediment deposits:
And undersized culvert produces an 'hourglass effect' with the upstream segment widening due to sediment deposition, while at the same time a downstream plunge pool scours a wide area. The formation of a scour hole or streambank erosion on the downstream side of the crossing provides evidence that an existing crossing is undersized and/or not properly aligned (slope or skew). The primary cause of this phenomenon on the downstream is the 'fire-hose' effect of high velocities through the crossing. Scour can also destabilize the end sections and roadbed. If a culvert is not to be replaced, scour hole protections such as riprap and/or grade control should be considered.

The photo above shows upstream aggradation (deposits). This area may look good, but the braided wide shallow channels through sediments is indicative of sediment deposition. Below is the downstream side of the same crossing which show the presence of a large scour hole. Having both features on the same crossing is sometimes called the 'hourglass' effect. (TH56 Freeborn County MN)

Scour holes can often seen in air photo review. They are typical of undersized culverts and found throughout the state in a variety of topography (top left, Mississippi River, Itasca State Park, TH73, TH56, TH23)

The accumulation of sediment on the upstream side of the crossing provides evidence that an existing crossing is undersized. When there is a stage increase of the headwater elevation (ponding) it causes a change in water surface slope. The slower water drops a portion of its load of suspended solids (gravel and silt). Vegetation can also become established on these deposits, thus compounding the adverse impact to the crossing's hydraulics. There are no long term solutions other than replacement with a properly designed culvert. Without replacement, maintenance crews can expect to regularly remove these deposits in order to maintain hydraulic capacity. Failure to do so may increase potential for road overtopping.

Note on location: Crossings on alluvial areas or very low gradient streams should be noted. Alluvial areas may be aggrading naturally, thus sediment deposits may not be the result of an improperly designed crossing. Determining the cause of aggradation can be difficult, and sources could be numerous. Running a Hec Ras model may also provide validation if the sedimentation is natural or not. A survey of the longitudinal profile upstream, and check changes to the stream cross sections may provide the limits of the aggradation. Though where it occurs, a comparison of culvert opening width and stream bankfull width should be noted. On very low gradient streams the deposits may be primarily composed of organic materials (decaying plant matter), not mineral in composition (sand or gravel). A properly designed culvert should take these situations into account.

2. Debris accumulation

A crossing that does not pass debris is vulnerable to plugging and failure during a flood event.   A properly sized crossing will pass debris (including ice).   If there is a history of debris maintenance at a location, it indicates the opening is too small. The replacement crossing should be designed with a properly sized crossing.

Woody debris is a problem in many parts of the state, and ice jams occur throughout the state. 'Debris catchers' are proving to be a short term fix at best.

3. Perched outlet

Perched crossings are those that have a drop of water level at the downstream end of a culvert. These are commonly blocks to all upstream movement of aquatic species. This situation can be due to several reasons, including improper invert elevation at installation. If a culvert has both an upstream aggradation deposit and a perched situation, it is due to an undersized culvert. A streams interrupted bedload capacity due to an undersized opening causes both upstream aggradation (sediment deposits) and causes the stream to perch the outlet when water picks up downstream material as it reestablishes bedload carrying capacity. If a perched culvert has no upstream aggradation, there are velocity issues (downstream scour hole) that have continued unchecked. In flood conditions perched culverts are vulnerable to apron undercutting, and in worse case scenarios can weaken the associated road grade.

Options to reestablish fish passage are either complete replacement with a properly sized culvert, or retro-fitting the outlet pool with grade control such as a rock rapids (series of weirs). Grade control is required to raise the pool elevation up and back through the culvert at normal flow conditions. Retrofitting existing culverts (floor or wall overlays) generally reduce hydraulic capacity or increase velocity of the structure, thus also increase the importance of including grade control structures to aid aquatic organism passage.

Four examples above are all along the North Shore of Lake Superior. Higher gradient streams are more prone to perched conditions, though it can happen throughout the state.

4. Road Overtopping:
Increased frequency or higher than predicted water depths during road overtopping is an obvious indicator that the crossing is no longer functioning within the desired parameters. There are no long term solutions other than replacement with a properly designed culvert.

Extreme example, though valid for pointing out what can happen with overtopping. (TH210, City of Thompson, Carlton County MN)

5. Depth and Velocity barriers
A situation where water depths are much shallower in the culvert than in the downstream channel is indicative of either improper elevation installation, or high velocities. Unchecked, these can lead to a perched culvert. Repairs to the flow line at the outlet should be considered.

This type of flow effect is more common on low gradient streams than on high gradient streams where fully perched conditions are more likely. If the water levels drop this will create too low a depth for fish passage (TH61 Split Rock River and Lake Superior, Lake County MN).

6. Culvert liners

Lining a culvert a common alternative to complete replacement of the structure. Such structures should be noted since it indicates that culvert performance may have changed since the original crossing was installed. Liners reduce culvert diameter and raise the invert. They may of maintained hydraulics by increased velocity with their smoothness, though fish passage may be an issue due to the increased velocities and/or change of invert elevation. See the section on Culvert Liners for more detailed information on concerns with this practice as it relates to ecological issues (Chapter 2 page 38)


The above left is a hard plastic pipe inserted into a failing corrugated metal pipe, diameter is reduced several inches, volume remains about the same though velocities are increased by the loss of roughness (TH210 Aitkin County MN), The example on the upper right, I have no idea why (TH 11 Koochiching County MN).

The above photo represents four iterations. The original timber bridge was replaced with a large culvert, which in turn was lined with a smaller culvert. A third culvert liner proposal was rejected, and a bridge was required to restore navigation (TH8, Lindstrom, Chisago County MN).

7. Basin Outlet and its control elevation:
It should be noted that crossings can act as an elevation control for a upstream wetland or lake. Many roads loop along wetlands and lakes, often crossing the outlet stream. State law prohibits alteration of outlet elevations of Public Waters without DNR authorization. The Minnesota Wetland Conservation Act has oversight of all other wetlands. Any alteration of altering existing invert elevations should include an evaluation of impact to water levels of the upstream basin. Design for sediment transport is generally not an issue on outlets of large waterbodies since it would be expected that the lake/wetland would have acted as a settling basin and removed sediment from stream flow prior to the discharge point. However long shore wave action can result in shoreline deposition, and on smaller waterbodies and wetlands these areas may be depositional zones for sediment and vegetation accumulation. Thus culvert at outlets should be designed to take into account potential for long term aggradation at the inlet.

> **Note on locations:** Crossings on very low gradient streams should be noted. Sediment and/or bedload can be very low, thus sediment movement may not be noticeable. A new design that accommodates bedload may not be necessary (IE recessed inverts). Though an evaluation or risk analysis should be included in the design process.

At outlets and in wetlands, flows may not carry mineral bedload. If desired, it may have to be added during construction, or forgo recessing inverts in order to maintain basin control elevation.

8. Non Public Waters

Crossings of Public Waters are a small portion of the crossings over Waters of the State. The DNR only has jurisdiction over the crossings that are over Public Waters. Public Waters are specifically identified on maps. Public Waters Watercourse (rivers and streams) are generally those perennially flowing streams that have at least 5 square miles of watershed at their mouth, or perennial flowing tributaries to designated trout streams. Crossings of Waters of the State may have design requirements of other entities such as the US corps of Engineers, Watershed districts, the County Ditch Authority, or other local authority.

Not all culverts are Public Waters. DNR Public Waters regulations and/or requirements of Attachment A do not apply to waters that are not Public Waters.

9. Deficient flood capacity and nearness to critical cultural operations

If not done already, identifying crossings for replacement should take into account how essential a road is for connecting critical operations, such a hospitals, schools, commercial districts, factories, power generating facilities, neighborhoods, cities, and such. It is not in the realm of the DNR to determine which road serves these critical functions, nor which roads would have the most detrimental impact if a culvert were to be washed out and lost for even a short period of time. However, any road that has critical functions should have all crossings evaluated to be sure that they can carry emergency services and/or maintain local safety and economies during flood flows. Such roads should be looked at to be certain that all crossings along such roads either meet or exceed current flood design standards or are identified as deficient. Deficient crossings should be replaced with structures that meet the latest design standards to be sure they can pass floodwater without failure. Replacement of deficient structures should be done regardless of their current condition.

Fish Passage

Culverts have a variety of factors associated with the ability for fish to pass through them, including perched outlets, high in-pipe velocity and/or turbulence, inadequate water depth, and excessive pipe length without fish resting space. Any of these can cause difficulties for fish movement and thus adversely affect their habitat, natural range, and ability to spawn. On Minnesota's Public Waters, culverts shall provide for fish movement unless the structure is intended to impede rough fish movement or the stream has negligible fisheries value. The current GP2004-0001 has the following requirement for fish passage:

> Bridges, culverts and other crossings shall provide for fish movement unless the structure is intended to impede rough fish movement or the stream has negligible fisheries value as determined by the Transportation Hydrologist or Area Hydrologist in consultation with the Area Fisheries Manager. The accepted practices for achieving these conditions include:
>
> A. Where possible a single culvert or bridge shall span the natural bankfull width adequate to allow for debris and sediment transport rates to closely resemble those of upstream and downstream conditions. A single culvert shall be recessed in order to pass bedload and sediment load. Additional culvert inverts should be set at a higher elevation. All culverts should match the alignment and slope of the natural stream channel, and extend through the toe of the road side slope. "Where possible" means that other conditions may exist and could take precedence, such as unsuitable substrate, natural slope and background velocities, bedrock, flood control, 100yr flood elevations, wetland/lake level control elevations, local ditch elevations, and other adjacent features.
>
> B. Rock Rapids or other structures may be used to retrofit crossings to mimic natural conditions.

Traditionally, culvert design was based on hydrologic and hydraulic models that predict peak runoff from a watershed, with the culvert sized accordingly to pass a specified design storm. Fish passage was not always addressed with these designs. Several alternative design methods have been developed that focus on matching the natural characteristics, and consider sediment transport and fish passage requirements. These recent improvements to hydraulic design practices may also reduce the frequency of scour at pipe outlets in many areas. Other potential benefits include lower maintenance costs, longer life span, and better sediment and erosion control. Alternative designs or simulation techniques inherently take fish passage into account by addressing issues of low flow, hydraulic variability and sediment transport. A variety of design techniques are being implemented in Minnesota where fish passage is a concern.

Culvert Design Approaches

Open bottom span: Open bottom structures are not considered as restricting flow or impinging upon the channel cross sectional area. These structures are generally not considered an impediment to fish movement in Minnesota.

Conventional Hydraulic Design: Culverts sized to pass a specified design storm event (e.g., 10 years peak flow) with no consideration given to fish passage needs.

Hydraulic Design for Fish Passage: Techniques that create water depths and velocities to meet the swimming abilities of target fish populations. This approach considers the flow requirements (eg: maximum velocity, sustained velocity, flow depth, etc) needed by specific species. The goal is to keep the velocity below a set of thresholds corresponding to a fish's maximum swim speed, sustained swim speed, and related measures. This is the method for meeting the frequent DNR requirement of: 'Velocities of the 2-year 24-hour event shall not exceed 2 feet per second".

FHWA has the publication 'HEC-26' that utilizes the hydraulic design approach to select culvert size and bedload material. HEC-26 presents a mathematical design procedure, methods, and best practices for designing roadway culverts to facilitate aquatic organism passage (AOP).
http://www.fhwa.dot.gov/engineering/hydraulics/pubs/11008/hif11008.pdf.

Hydraulic Simulation: Hydraulic design approaches that simulate natural hydraulics of streams by adding rock or roughness elements to simulate natural hydraulic variation within or adjacent to the culvert. Typically these include placement of rock on the floor of the culvert or placement of rock rapids below the outlet to create pools and riffles, etc.

Stream Simulation (Geomorphic Design): Design approaches that recreate or allow natural channel morphology and sediment transport. In Minnesota, two differing methods are being utilized.

1. '**MESBOAC**' was developed in the northern forested region of Minnesota and is based on principles of fluvial geomorphology rather than individual fish swimming ability. **MESBOAC** aims to match the culvert width with natural stream dimensions, while maintaining sediment balance (sediment in = sediment out). In addition to burying the culvert bottom below the streambed to provide for a natural substrate in the culvert, it also provides a low-flow channel that is important for late season migrations which occur from August to November. MESBOAC assumes that since the natural flow characteristics are maintained, fish passage will occur. See Appendix A for more information on MESBOAC methods.

MESBOAC stands for:

Match culvert width to bankfull stream width.
Extend culvert length through the side slope toe of the road.
Set culvert slope the same as stream slope
Bury the culvert
Offset multiple culverts.
Align the culvert with the stream channel.
Consider headcuts and cutoffs.

2. The Aquatic Organism Passage (AOP) program is a broader ecosystem-based design approach developed by the USDA Forest Service for designing and constructing a channel through the road-stream crossing structure based on physical and ecological continuity along the stream corridor. The premise of stream simulation (AOP) is that the culvert be large enough for a channel to be constructed within the crossing that simulates the dimensions and characteristics of the adjacent natural channel. Therefor, fish and other aquatic organisms should experience no greater difficulty moving through the structure than if there were no road crossing. Identifying a 'reference reach' is a key concept and component of stream simulation as it provides the natural template for designing a channel through the crossing and determining the size and embedment depth of the replacement structure. The manual '**Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings'** is located here: http://www.stream.fs.fed.us/fishxing/aop_pdfs.html.
A copy of the published report on a summary of this program is in Appendix A (Stream Simulation for Aquatic Organism Passage at Road-Stream Crossings, by Cenderelli, Clarken, Gubernick and Weinhold).

Note: The link to the FishXing program that is embedded in the AOP website is a culvert assessment tool for aquatic organism passage. The program models various organisms capabilities against culvert hydraulics across a range of expected stream discharges. AOP methodology does not require a check on velocities since it uses reference conditions in the stream to emulate a crossing that has the proper context with its surrounding profiles.

MESBOAC and AOP are similar in the use of bankfull width determination, though differ in determination of slope and invert elevations for a culvert.

MESBOAC utilizes a line connecting the thalweg riffle elevations from upstream and downstream of the crossing to set culvert slope and elevation.

In addition to utilizing riffle elevations, the AOP program methodology incorporates pool depths, stable control points, and other vertical control points in the steam (bedrock, pool-tailcrests, and large woody debris) to determine a streambeds potential upper and lower vertical adjustment profile (VAP) to which the culvert invert and slope are determined.

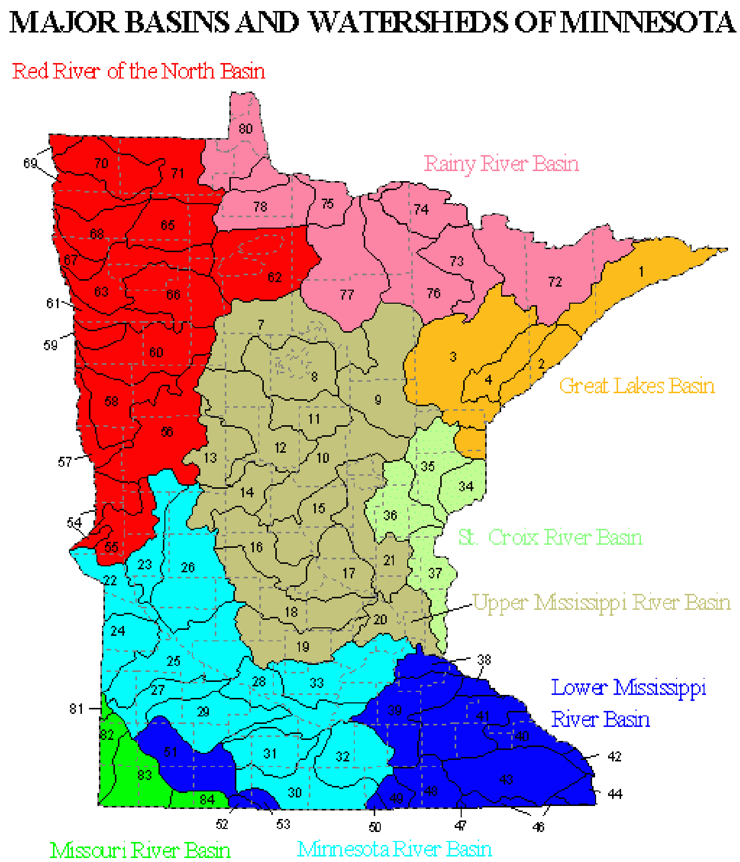
Summaries of both methods are located in Appendix A

Floodplain Connectivity: In addition to the above, there is growing attention in the concept of 'floodplain culverts'. These culverts are set in the floodplain, away from the main channel and are dry, except in flood conditions. It is gaining interest for use within floodplains, and in areas with woody debris or ice issues. An initial study by the DNR is located here: http://files.dnr.state.mn.us/eco/streamhab/geomorphology/reducing-rior.pdf

Please contact the DNR Area Hydrologist for design information at the earliest stages of project development. Determining the appropriate design method is influenced by project objectives. Consideration for fish passage, other aquatic organisms, rare species, invasive species, habitat protection/restoration, wildlife passage, traffic (road safety), funding limits, adjacent property and right-of-way limits, floodplain ordinances and other regulatory requirements (e.g., wetland protection) are to be considered.

Key Fish Populations by Major Watershed*

The figure and chart below show key fish populations that may impact crossing design. * From the 'Final Report - Cost Analysis of Alternative Culvert Installation Practices in Minnesota, June 2009', by B. Hansen, J. Nieber, and C. Lenhart. For the full report see the U of Minnesota, Center for Transportation Studies, report #2009-20, http://www.cts.umn.edu/Publications/ResearchReports/reportdetail.html?id=1796



Major river basins in Minnesota and fish passage issues

Name	Key fish	Geomorphology	Other issues
Great Lakes	Chinook salmon, Lake trout,	High gradient, cobble beds	Fall spawning
Upper Mississippi	Walleye, bass, pike	Mod gradient, sand-gravel bed	
Minnesota River	Catfish, smallmouth bass,..	Low gradient, sand/fines bed	
St. Croix River	Smallmouth bass, sturgeon…	Moderate gradient	
Lower Mississippi	Brook & brown trout, smallmouth bass	High gradient tribs, low gradient in Mississippi	Brook & brown Trout spawn in fall; highest fish diversity of all basins
Red River	Sturgeon, pike	Low gradient	agriculture
Rainey River	Lake trout, smallmouth bass, walleye	Moderate gradient, gravel bed	BWCA wilderness, forestry
Missouri River	Topeka Shiner	Prairie streams	Endangered species

Grade Control

Miller Creek at TH53 crossing, Duluth

Grade control structures may be beneficial to add to a stream crossing design. They can be used to protect: a) single span bridge pilings from scour, b) provide grade control to prevent head-cutting where past undersized and/or perched culverts have caused upstream aggradation and downstream degradation, c) create slower velocity backwater type habitat for fish passage, or d) direct flow away from a bank. There are several sources of information for design of grade control structures.

The development of Rock Rapids (Rock Ramps) in Minnesota has been primarily due to the removal of dams. However, this practice is increasingly being utilized for grade control to retrofit culverts that are perched at the outlet. The DNR publication **'Reconnecting Rivers: Natural Channel Design in Dam Removal and Fish Passage'** provides information on the concept of this practice and has case examples to illustrate technical problems that may be encountered in such design. http://www.dnr.state.mn.us/eco/streamhab/reconnecting_rivers.html.

Other reports:
"Stream Restoration in the Vicinity of Bridges", by P. Johnson, R. Hey, E. Brown, and D. Rosgen.", Journal of the American Water Resources Association Vol 38, No1 February 2002
http://www.wildlandhydrology.com/assets/SRITVOB.pdf

"The Cross-Vane, W-weir and J-Hook Vane Structures, by D. Rosgen."
http://www.wildlandhydrology.com/assets/cross-vane.pdf

The report "**DESIGN METHODS FOR IN-STREAM FLOW CONTROL STRUCTURES"** on the results and recommendations from a study on the performance of in-stream flow control structures, conducted by the St. Anthony Falls Laboratory (SAFL) at the University of Minnesota (UMN) is in the final stages of publication. National Cooperative Highway Research Program (NCHRP) NCHRP Project 24-33 will be published at any time. See: http://apps.trb.org/cmsfeed/trbnetprojectdisplay.asp?projectid=1641

Hydrologic/Hydraulic Data Reporting

A Hydrologic/Hydraulic report will be required for the construction or replacement of Public Waters crossings. If an approved Flood Insurance Study (FIS) exists, the FIS shall be used as a basis for the calculations for the crossing. Any variance shall be approved by the applicable DNR Hydrologist. The Hydrologic/Hydraulic Data should be provided in the format as shown. If a Flood Insurance Study is used as a basis for the report, information including Title and Date of the FIS shall be included.

		When reporting, replace text in this column with project data	
	Vertical Datum	Datum of survey information	ft
*	Stream Name	Name of stream	
	Drainage Area	Area of watershed contributing to the site	mi^2
	Flood of Record	Maximum observed discharge, date of occurrence, and any other notes	ft^3/s
(a)	Maximum observed highwater elevation	Highest recorded water elevation, date of occurrence, and any other notes	ft
*	Design flood ([example:50] year frequency)	Design discharge and design frequency	ft^3/s
(b)	Road sag point elevation	Roadway low point elevation used to determine overtopping flood frequency, note location	ft
	Stage	Water surface elevation (without crossing) taken at location where stage increase is calculated with design discharge	ft
	Total stage increase	Calculated stage increase for proposed structure with design flood	ft
*	Headwater elevation	Calculated headwater elevation for proposed structure with design flood	ft
	Stage increase of the inplace condition	Calculated stage increase for existing structure with design flood	ft
	Minimum Waterway opening		ft^2
	Below elevation		ft
(c)	Low member at or above elevation		ft
	Mean velocity through structure	Calculated mean velocity through proposed structure with design flood	ft/s
	Main channel velocity	Calculated main channel velocity for design flood	ft/s
*	Greatest flood (500-year frequency or overtopping)	500-yr flood discharge or roadway overtopping discharge (if less than 500-year)	ft^3/s
(b)	Road sag point elevation	Roadway low point elevation used to determine overtopping flood frequency	ft
	Stage	Water surface elevation (without crossing) taken at location where stage increase is calculated with overtopping or 500-year flood	ft
	Total stage increase	Calculated stage increase for proposed structure with overtopping or 500-year flood	ft
*	Headwater elevation	Calculated headwater elevation for proposed structure with overtopping or 500-year flood	ft
	Stage increase of the inplace condition	Calculated stage increase for existing structure with overtopping or 500-year flood	ft
	Mean velocity through structure	Calculated mean velocity through proposed structure with overtopping or 500-year flood	ft/s
	Main channel velocity	Calculated main channel velocity for overtopping or 500-year flood	ft/s

*	Basic flood (100-year frequency)	100-year flood discharge (1% annual chance flood)	ft^3/s
	Stage	Water surface elevation (without crossing) taken at location where stage increase is calculated with 100-year flood	ft
	Total stage increase	Calculated stage increase for proposed structure with 100-year flood	ft
*	Headwater elevation	Calculated headwater elevation for proposed structure with 100-year flood	ft
	Stage increase of the inplace condition	Calculated stage increase for existing structure with 100-year flood	ft
	Minimum overflow area above sag point elevation	Overflow area over roadway sag point elevation	ft
	Mean Overflow velocity	Calculated mean velocity over roadway	ft/s
	Mean velocity through structure	Calculated mean velocity through proposed structure with 100-year flood	ft/s
	Main channel velocity	Calculated main channel velocity for 100-year flood	ft/s
**	2-year flood frequency	Flow for the 2-year flood	ft^3/s
**	Average velocity through structure	Calculated velocity at mid-length of structure	ft/s
**	Main channel velocity	Calculated main channel velocity of 2-year flood	ft/s
	Approximate flowline elevation	Elevation of flowline at inlet of structure	ft
	Skew	Angle of structure to roadway	°
	Riprap size	Required class of riprap at outlet of structure	

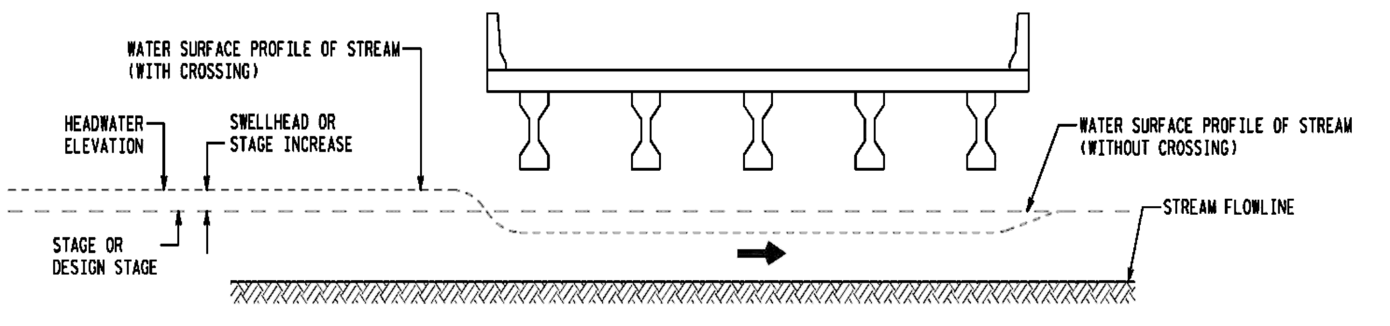
* Items to be shown on grading plan

** Calculations showing velocities through the structure at 2-year peak flow may be required for fish passage considerations (typically only required on culverts).

(a) Any notes on event or location of highest known water elevation

(b) Any notes on location of low point in the road (sag location)

(c) Any notes on low member elevation, required on DNR canoe routes (typically 3' minimum clearance above 50yr for DNR requirements). Also note high-low and low-low elevation points if sloped bridge.



BRIDGE

Reporting Impacts to Flood Elevations

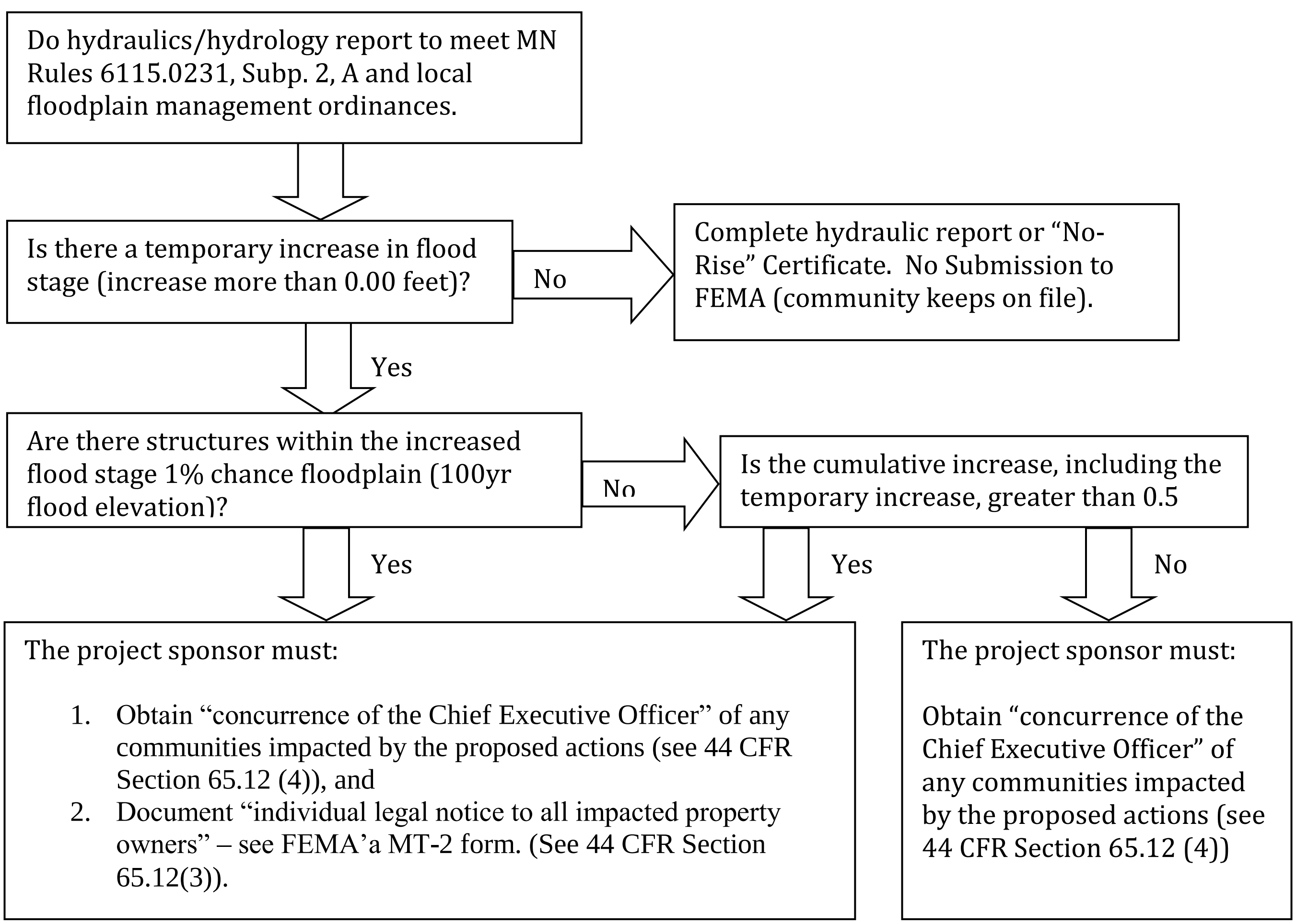
The following flow charts are for use in determining correct forms for reporting impacts within areas designated as 100-year (1% annual chance) floodplain by the Federal Emergency Management Agency (FEMA). These flow charts focus on road crossing hydraulics and not overall floodplain ordinance compliance. Zones A and AE are identified on official FEMA maps as areas subject to inundation by the 1% annual chance flood (100yr flood event). Zone X identifies areas subject to inundation by the 0.2% annual chance flood (500-year flood event) and is not regulated under DNR Public Waters Rules and are not mandated for protection by FEMA. However, some Local Units of Government (LUG's) have chosen to be more restrictive than the federal/state regulations. The LUG zoning administrator should be contacted whenever proposing projects within designated floodplain areas.

The following flow charts, plus more information is located at:
http://www.dnr.state.mn.us/waters/watermgmt_section/floodplain/fp_resource_material.html

Bridges & Culverts
Temporary** stage increase (construction related) in AE Zones

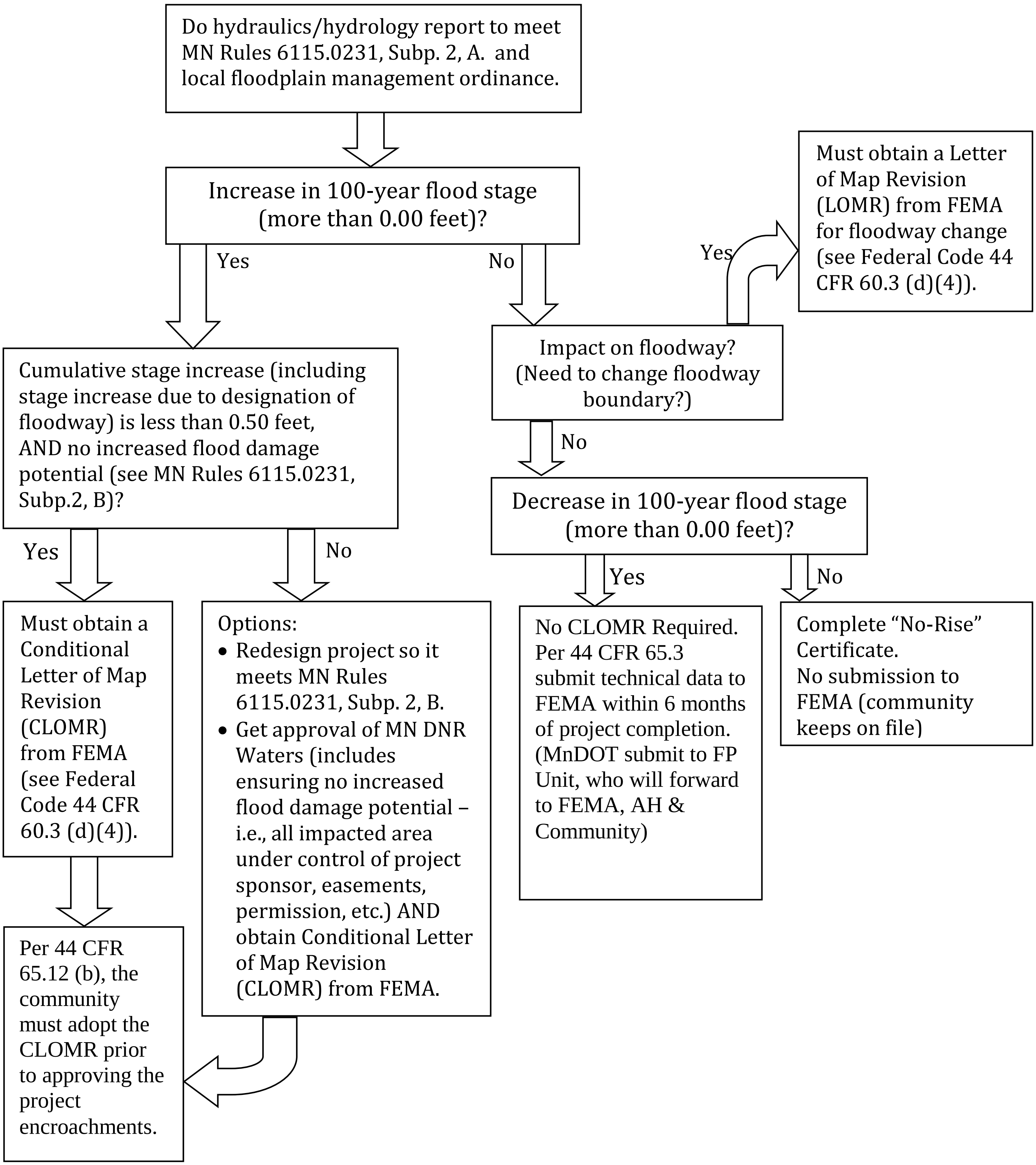
'AE Zones' are designated 100 year (1% annual chance) floodplain areas where an approved detailed flood study has generated flood profiles for various events along with a mapped floodway.

**'Temporary' is typically defined as less than one year.



NEW Bridges & Culverts
Floodplain Reporting Requirements in FEMA's AE Zones

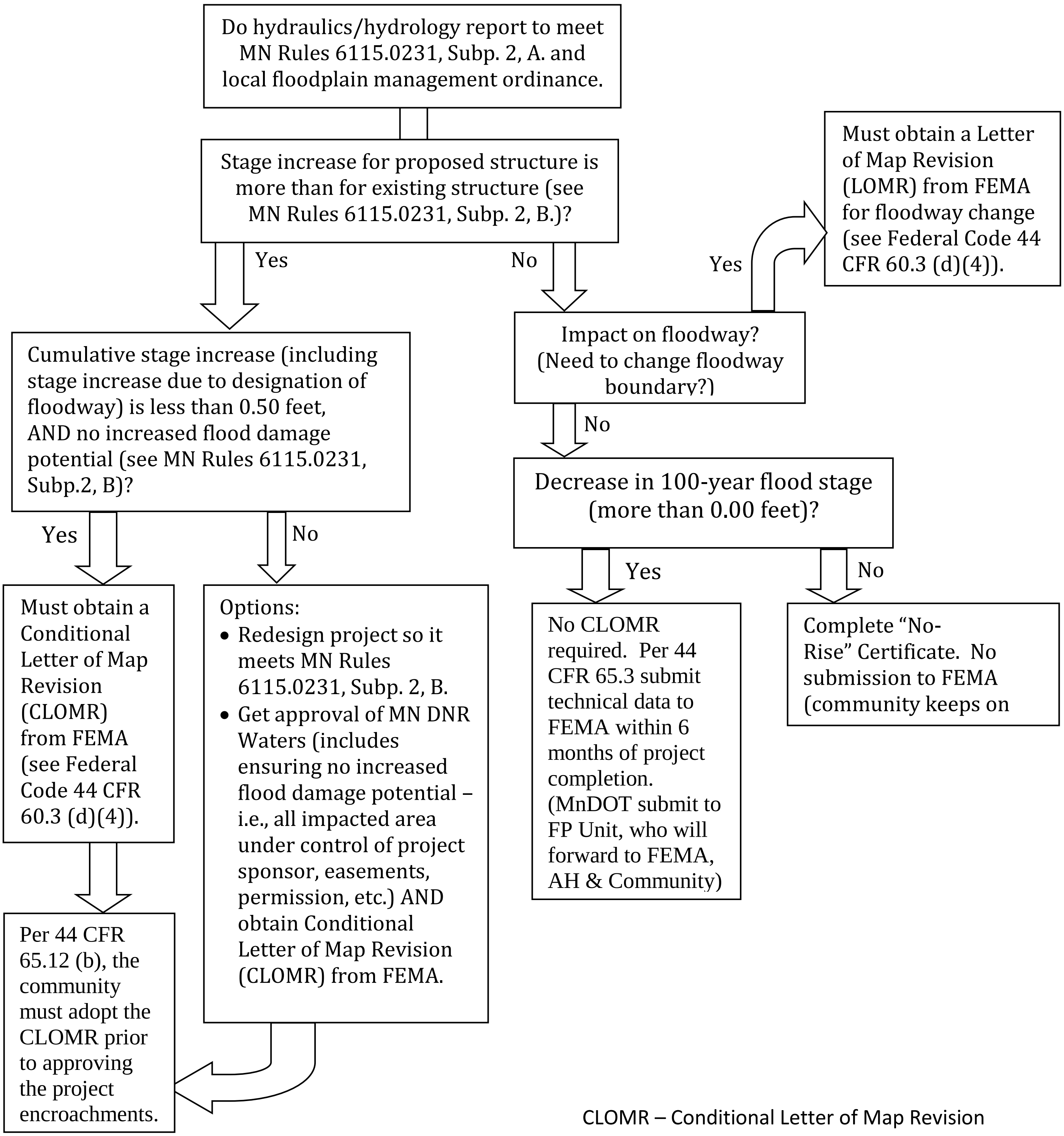
'AE Zones' are designated 100 year (1% annual chance) floodplain areas where an approved detailed flood study has generated flood profiles for various events along with a mapped floodway.



CLOMR – Conditional Letter of Map Revision
LOMR – Letter of Map Revision

REPLACEMENT Bridges & Culverts
Floodplain Reporting Requirements in FEMA's AE Zones

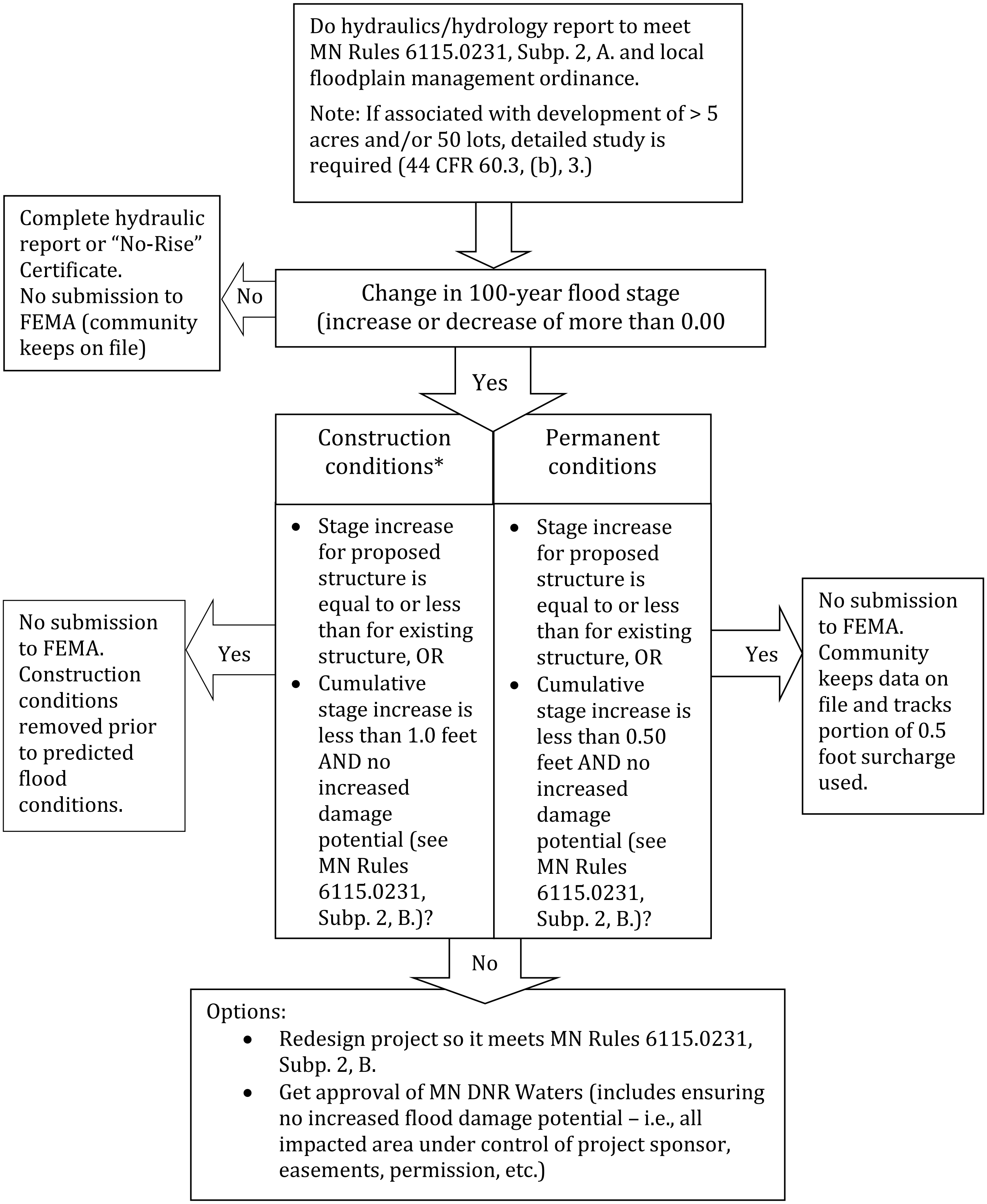
'AE Zones' are designated 100 year (1% annual chance) floodplain areas where an approved detailed flood study has generated flood profiles for various events along with a mapped floodway.



CLOMR – Conditional Letter of Map Revision
LOMR – Letter of Map Revision

Bridges & Culverts – Floodplain Requirements in FEMA's A Zones

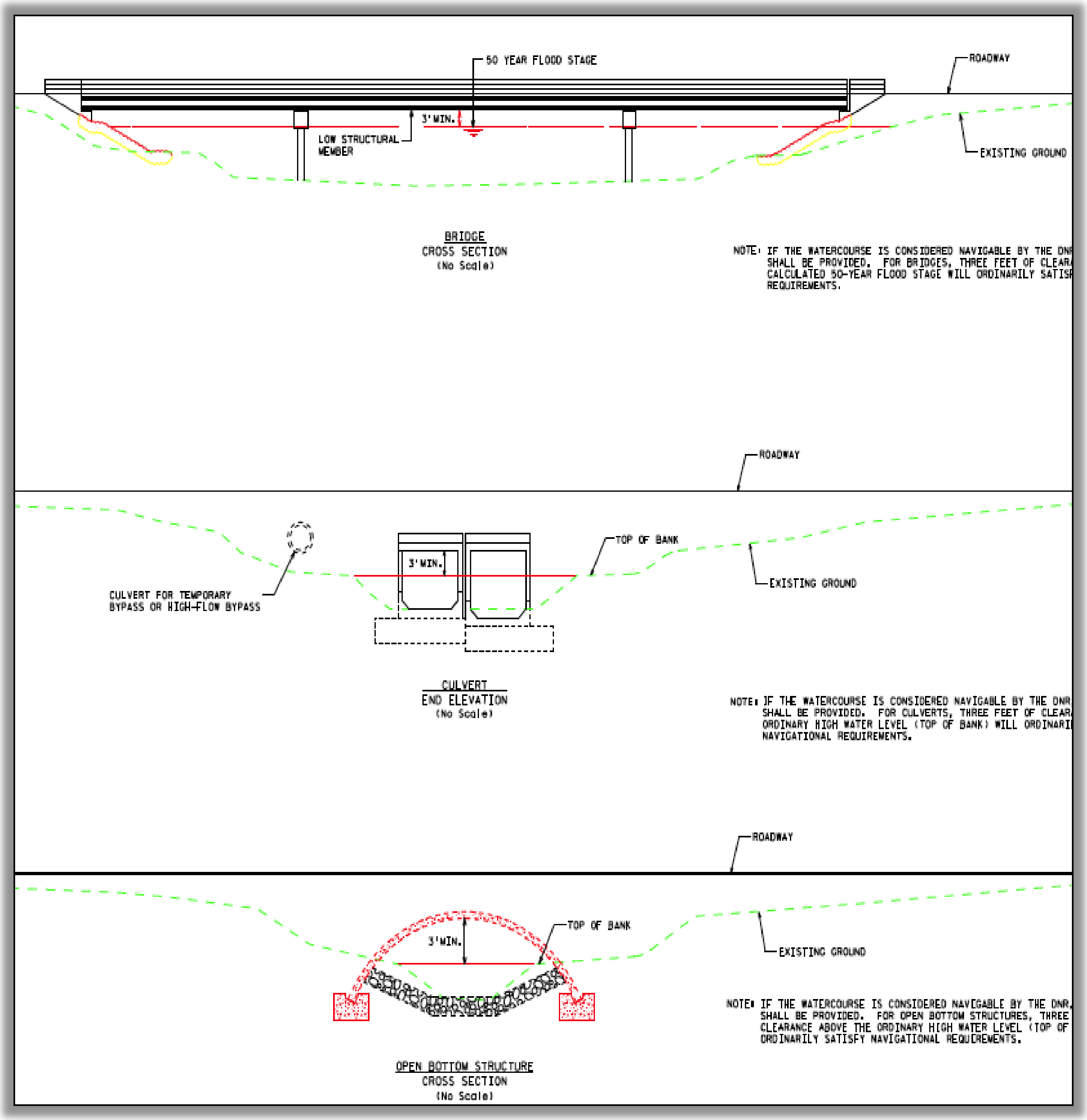
'A zones' are designated 100 year (1% annual chance) floodplain areas where a detailed flood study has not been done.



* Construction conditions are those that are very short in duration, such as where stream blocks, diversions, or temporary crossings, are in place during construction of permanent structures. Construction conditions are removed when the permanent structure is completed, or should a flood be predicted.

Navigation Requirements

For waters with commercial navigation, the DNR defers to the US Corps of Engineers and the US Coast Guard for navigational requirements. For other rivers and lakes and streams, to meet DNR navigation requirements, clearance of three feet above the; 1) Ordinary High Water Elevation (OHW), or 2) top of the adjacent bank, or 3) 50-yr flood stage elevation, will ordinarily satisfy DNR requirements. In no case should waters with navigation be re-designed with reduced clearance



State Water Trails

For an interactive trail map with links to individual canoe route information, go to:
http://www.dnr.state.mn.us/watertrails/location_map.html

Crossings of canoe routes must be evaluated for navigation clearance. Generally 3 ft above the 50 yr event, OHW, or top of the bank is sufficient for recreational navigation (see previous page).

Best Practice: Road Projects near State Parks, State Trails or Public Access's should be considered as opportunities for joint MnDOT-DNR projects, such as improved access and parking facilities.

State Trails

Interactive trail maps are located here: http://www.dnr.state.mn.us/state_trails/map.html

For Public Access locations by county: http://www.dnr.state.mn.us/water_access/counties.html

For snowmobile trail maps, go here: http://www.dnr.state.mn.us/snowmobiling/maps.html

Bridge Scuppers

Scupper definition: A vertical hole through a bridge deck for the purpose of deck drainage. Sometimes, a horizontal opening in the curb is called a scupper.

MnDOT Road Design Manual, Chapter 8 (Drainage Design & Erosion Control) section 8.5.6, provides the following Design information regarding drainage of bridge decks:

> *Drainage of bridge decks is similar to other curbed roadway sections. Deck drainage is often less efficient, because cross slopes are flatter, and small drainage inlets or scuppers have a higher potential for clogging by debris. Because of the difficulties in providing and maintaining adequate deck drainage systems, gutter flow from roadways should be intercepted before it reaches a bridge. In many cases, deck drainage must be carried several spans to the bridge end for disposal.*
>
> *Zero gradients and sag vertical curves should be avoided on bridges. The minimum desirable longitudinal slope for bridge deck drainage should be 0.5 percent. If a sag curve cannot be avoided, the sag should not occur directly over a water body unless it is a treatment pond. Deck drainage can generally not be discharged directly to a water body without providing a pond or other means of intercepting a hazardous spill. Runoff should be handled in compliance with applicable stormwater quality regulations.*
>
> *The use of scuppers should be evaluated for site-specific concerns. Scuppers should not be located over embankments, slope pavement, slope protection, navigation channels, driving lanes, or railroad tracks. For bridges that require deck drains, it may be necessary to provide a drainage system on the bridge to convey water off the bridge.*

Chapter 8 of the MnDOT Road Design manual can be downloaded from:
http://www.dot.state.mn.us/design/rdm/metric/8m.pdf

The above guidance is generally adequate for DNR concerns. However there may be site specific concerns (EG Areas of Environmental Sensitivity) that will require drainage treatment systems. When water is directed off the bridge and back past the abutments, there may be retrofit options in the road ditch prior to discharge to the stream.

Culvert Liners

County 43, Mayhew Creek, Benton County

Lining a failing culvert is a common alternative to complete replacement of the structure. The DNR evaluates culvert projects on Public Waters to ensure there are no adverse impacts associated with this practice. Potential adverse impacts on stream hydrology or ecology are:

a. Permanent changes to velocity, water elevations, or invert elevation may occur due to the reduced culvert size, or
b. Temporary impacts due to discharge of construction precipitate created by the installation process. This could have adverse impacts to fish populations (e.g. fishkill).

Culvert lining projects typically occur on smaller culverts. These tend not to be on Public Waters and are not in DNR Public Waters jurisdiction. However they are occurring on Public Waters with increased regularity. In general, DNR will request a culvert to be assessed for complete replacement (under current design recommendations) prior to authorizing a culvert lining project.

1. There are three general types of culvert lining projects.

    a. Cured in place plastic (CIPP) liners. These are essentially a flexible plastic tube that is inflated inside the pipe (like a balloon). Cured in place liners are thin (about an inch) and are intended to bond with the existing culvert wall.
    b. Hard pipe liners. Smaller diameter pipes are slid through the existing opening and the outside void is filled with expansion foam or other suitable material (e.g. cement slurry). The new pipe material may be plastic, metal or concrete.
    c. Spray on liners or overlays. Either concrete or resin based materials may be applied to existing walls or floors for spot repairs or a complete lining. Thicknesses vary by material and the pre-existing culvert condition.

2. Potential implications of center-line culvert lining projects:

a. Hydraulics (water elevations and velocities) of the stream through a road is altered due to a liners smaller opening. Culvert lining projects should not adversely impact flood elevations or control elevations of upstream water basins. On corrugated metal pipes, a CIPP liner is generally self-mitigating as the slightly smaller diameter is compensated by the liners smoothness (change in Manning's 'n' value). However, an increase of velocity may compromise fish passage on currently marginally passable culverts.
b. Liners will raise the culvert inverts slightly. On culverts with inverts above the stream profile (perched), this will make the perched situation worse and may compromise fish passage,
c. Scour may be an issue. Increased velocity may increase the scour potential at the outfall.

The DNR may ask for hydraulics information to evaluate the concerns above. There are situations where we have not allowed liners because of the increased velocities or changes to invert elevations can turn marginally fish passable culverts into impassable barriers. Total replacement may be required in these situations.

3. Lining projects on culverts that outfall into Public Waters:

   a. If a culvert outfall is not within the stream during normal water levels, fish passage is less of an issue, though #2 above still applies.

4. Liner methods may temporarily alter the chemical or thermal properties in the receiving water during the installation process, curing process, or initial flush. These by-products of installation have potential for adverse impacts to receiving waters. In extreme cases, impacts may result in a localized fish kill. To help assure that suitable containment or treatment prior to discharge to Public Waters is conducted, the following is recommended:

   a. Special Conditions to construction specifications should be written to prevent hot water precipitate or chemical containing precipitate (e.g. styrene or cement waste) from discharging into receiving waters.

   b. The following provision should be included on Public Waters permits for culvert lining projects: CULVERT LINER CONSTRUCTION METHODS: Liquid or other by-product waste resulting from the construction or curing processes of liner installation shall not be discharged into Public Waters.

TH61 Indian Camp Creek (Cook County)

TH61 Carlson Creek at normal flow after floor overlay and grade control installation downstream (Cook County)

(comment: Project was marginally successful, as velocities through the culvert were still very high post project)