How to establish, document, then apply basic land form (geomorphology) into Infrastructure design

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I. Introduction

There is little doubt that the design of our infrastructure plays a critical role in the stability of our water resource systems. When stable, both floodplain and channel are in balance with the water and sediment delivered to them and channel and floodplain form (i.e., dimensions) change very little through time. However, a recent inventory by the River Ecology Unit discovered very few of our infrastructure designs correlate well to known "stable" channel and floodplain metrics.

From DNR's original study, reference throughout this document, and many applied site assessments and design modifications, this standardized procedure on how to establish and apply landform metrics and the enclosed excel tool were created. Improvements to proposed site designs were able to be quantified through application of this approach on several sites throughout Minnesota. Using this approach, a reduced negative impact to the natural valley reach was always achieved for all Sites; improvement ranged between 20%-80% less impact when compared to proposed designs.

The outlined methodology requires two clear definitions:

Land form: locally measured land information for a given **Site**.
Site: The general area of infrastructure location

To establish the least impactful design for a Site which intersects a valley and a channel (i.e., Landform) a Site Assessor is required to determine a minimal amount of land measurements by completing the enclose excel spreadsheet. By performing this Geomorphic Assessment of the Site to be designed, the information gathered and documented can then be applied into Site design. When correctly performed and applied a reduction of infrastructure impact to the natural channel and floodplain will be achieved. Iterative design configuration to model results should be performed to optimize the Site design to local conditions.

The approach assumes that every stable natural channel has an associated stable natural floodplain.

Where to use this approach?

This approach can be used at anywhere a defined channel exists on the landscape.

Underlying Principles:

To gain a historical understanding on how and why this approach was developed, please read Reducing Impact of Roads at Road/River Intersections; it can be downloaded from this website:
http://www.dnr.state.mn.us/eco/streamhab/geomorphology/index.html

This document outlines a procedure to establish and document basic landform for a design Site. Through additional research and monitoring advanced applications and technical documents will be developed.

II. How to establish geomorphic metrics at road/river intersections

There are many variables in landform that can be applied into road/river Site design. This packet attempts to standardize a process for establishing and documenting a minimum amount of landform metrics to be considered for application into site design. This approach does not replace standard engineering and hydrology sciences; but it enhances the 'standard' design by providing a basic understanding of local land form. The procedure requires a Land Form Assessor to establish stable land form metrics at a Site and a Designer to apply the land form metrics into the Site design.

For the Land Form Assessor: This document outlines how to establish land form metrics. This is accomplished by performing the outlined procedures in conjunction with the Geomorphic Assessment at Road/River Intersection form (ver. 1.0); an interactive excel spreadsheet. When attempting this exercise, some channel and floodplain metrics may be difficult to accurately decipher, so when in doubt the best estimate should be made. The estimates will likely be adjusted through **Step 4: Correlation of Land Form Metrics** to best represent known stable land form at the site.

For the Designer: Application of land form metrics into site design is still relatively infant. For those new to applying land form metrics to their design we suggest following the prioritized land form metrics as outlined in this document. Through experience, you can expand to use additional land form metrics for the site design. Although frequently discussed throughout, guidance on how to apply the land form metrics into Site design is specifically discussed in **II. b. Step 5. Application of Land Form Metrics into Site Design** with additional discussion on application and design refinement can found in **Section IV. Hydraulic Modeling and Analysis.**

For Both the Assessor and the Designer: Through experience more confident design improvements can be expected, and this process has tried to incorporate flexibility to the assessor and designer. Please provide feedback to the authors on this guidance so the approach can be refined and updated. Through ongoing research where application of land form occurs, Site design refinement and reporting will occur.

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II a. The Geomorphic Assessment of Road/River Intersection form (version 1.0)

The Geomorphic Assessment at Road/River Intersection form (ver. 1.0) is designed to be a basic land form assessment. Improvement and refinements are anticipated through user feedback. The metrics chosen in this version (1.0) were established by applying this approach in Minnesota and provides a basic understanding of local landform metrics that can be applied into site design.

The Geomorphic Assessment at Road/River Intersection form Version 1.0 documents the results of Site landform metrics. It provides designers a more complete understanding of site conditions to improve their design. The spreadsheet is designed to be interactive. Once the assessor populates all the yellow cells, channel form metrics should be reviewed and adjusted to best represent the natural site conditions.

Geomorphic Assessment at Road/River Intersection

DEPARTMENT OF NATURAL RESOURCES

Site Name:				
MPARS Number:				
Assessor(s):				
	UTM X	*UTM Y*	Assessment date	
Site Location:				

Road/River Intersection Site Information

		Notes:		
			Required Fill over floodplain culverts	0.5
Required Cross Sectional Area		*As per designer*		
Road Top Elev:		*Top centerline of road at channel*		
Road Sag Elev:		*lowest roadtop elevation - within valley*	-0.5	Available Embankment Height
Channel Flowline Elevation:		*channel bottom elevation into culvert*		
Downstream Floodplain Elevation:		*Avg. DS elevation of floodplain*		
Drainage Area (Mi^2):				

	Site Metrics	*Ratio's / Estimates*			*Design Guidance*
Floodplain Determinations					**Floodplain**
Floodplain Width:			Incoming watershed		Available XSA
Floodplain Slope:					Floodplain Width
Upstream Flooplain Elevation:			MN-Regional		Slope
Bankfull Channel Determinations			West	East	**Preferred Channel Opening**
Width:		Depth of incision			Opening Width
Mean Depth:					High Chord
Slope:					Slope
Sinuosity:					Road Cover
Largest Particle:					

Channel Materials	Silt/Clay	Sand	Gravel	Cobble	Boulder	Bedrock	debris concern?	
Percentage of channel bed material								
USGS StreamStats or Modeled	Q1.5yr	Q2yr	Q5yr	Q10yr	Q25yr	Q50yr	Q100yr	Q500
Discharge:								
Slope (ft/mi):								

Figure 1: BASIC GEOMORPHIC ASSESSMENT FORM – Version 1.0

Interactive Spreadsheet Notes:

- Programming improvements are in the works, please populate All YELLOW cells before fully trusting the Ratios/Estimates and "Design Guidance" section results.
- "Design Guidance" section of the spreadsheet is not complete at this time. It was included to expose users to minimal site derived metrics to apply into design. We need feedback as to what designer's desire from this assessment. It is anticipated in time there will be many more uses of this assessment
- Unless otherwise noted, **all cell units of measure are in English units**.

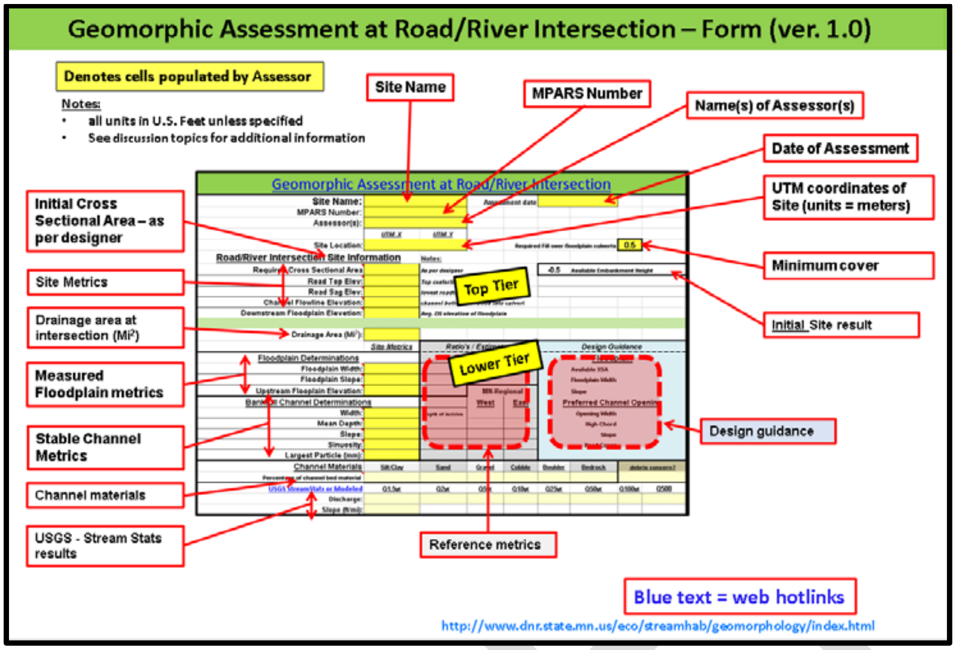


Figure 2: GENERAL LAYOUT, BASIC GEOMORPHIC ASSESSMENT FORM – Version 1.0

The layout of this form is designed into two separate tiers of site information separated by a shaded horizontal line (green, when viewed in color). Each tier is explained below and descriptions of the information to be entered are included.

Top Tier – This tier is used for General Site information and a quick assessment. The quick assessment is to determine if sufficient road fill exists to apply floodplain connectivity into Site design. The Available Embankment Height value is calculated by populating the yellow cells. Once generated, it is up to the designer to determine if sufficient fill is available to design floodplain connectivity into the Site.

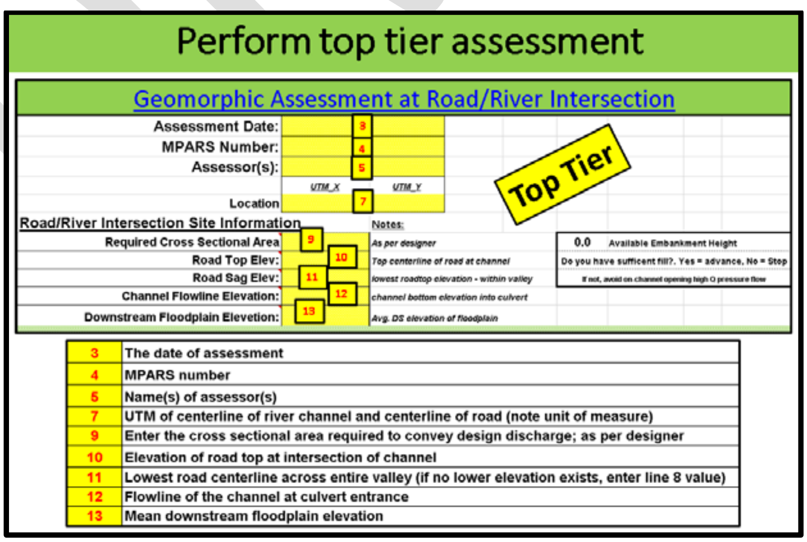
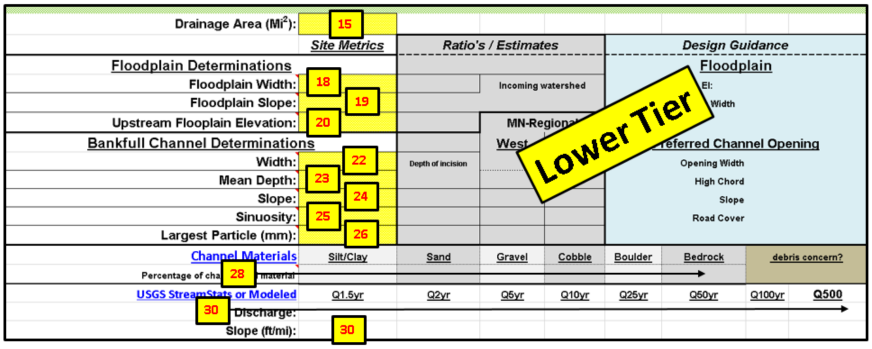


Figure 3: Top Tier of Geomorphic Assessment at Road/River Intersection Form (ver. 1.0)

Lower Tier – Defines additional local land form metrics. Each cell is explained in more detail below.



15	Drainage area of channel at road intersection (Mi^2)
18	Floodplain Width (established from correslated cross sections)
19	Straight line fall slope along VALLEY centerline (long baeline)
20	Mean upstream floodplain elevation (established from cross section)
22	Bankfull Channel Width - the width of a natural, stable channel (use many resources)
23	Mean Depth; (commonly obtained from Regional Curves)
24	Water surface slope of CHANNEL (long baseline)
25	Sinuosity: Channel Length divided by Valley Length (begin and end a same locations; use long baseline)
26	Largest Non-placed particle - Established from Site field data or designer knowledge (optional)
28	Active channel bed materials size distribution (optional)
30	Recurrence discharges - Established from USGS StreamStats or modeled (optional)
31	Watershed Slope - Established from USGS StreamStats or modeled (optional)

Figure 4: Lower Tier of Geomorphic Assessment at Road/River Intersection Form (Ver. 1.0)

Cell Descriptions:

9. **Required Cross Sectional Area:** This is the designed cross sectional area for the Site. This value is established through standard engineering procedures.
10. **Road Top Elevation:** This elevation is the road top elevation at the intersection of the channel centerline.
11. **Road Sag Elevation:** This elevation is the lowest point in the along the road centerline, within the defined valley width and is used to gain insight on the Site's ability to avoid on-channel pressure flow. On channel pressure flow should be avoided but is ok for floodplain connectivity openings; research forthcoming. *(see Figure xx: Land Form perspective view of road design)*
12. **Channel Flowline Elevation:** This elevation is the channel flowline elevation (bottom) where it enters the culvert.
13. **Downstream Floodplain Elevation:** Commonly derived from a downstream valley cross section but should be well correlated with the floodplain profile.
    a. Many roadways inhibit natural floodplain aggradation and cause a slope imbalance of the floodplain at the road. For difficult sites to establish this elevation, it may be required to field survey the tops of channel depositional flats above and below, then plot that down valley slope through roadway and choose appropriate elevation for the Site. When in question, use as many resources to correlate this elevation. Best fit trend lines through valley cross sections have also been useful to establishing this elevation.
    b. NOTE: Minnesota has many incised and entrenched channels, therefore Bankfull and Floodplain elevations are commonly different; use the floodplain elevation for this value.
15. **Drainage Area:** This value should in square miles of drainage area above the Site. StreamStats is useful to establish this value.

18. **Floodplain Width:** Defined by a flat horizontal line, it is the width from valley wall to valley wall on the downstream side of roadway. It should be established from the alluvium surface.
    a. To establish and align 3 valley cross sections:
        i. Along the top center of the road
        ii. Just upstream of the road; upstream of road embankment (i.e., placed fill material)
        iii. Just downstream of the road; downstream of road embankment (i.e., placed fill material)
    b. Review the natural valley cross sections near the road. When assessing this value, visualize the flood moving though the upstream and downstream cross sections and note where that flood elevation would be, then make a call as to how wide the floodplain is at that elevation. Plotting additional floodplain cross sections above and below the Site may prove helpful in determining this value.
19. **Floodplain Slope:** Defined as a sloping line on top of the floodplain, through the road; expressed in decimal degrees. (example: 0.0020 is equal to a 0.2% slope)
    a. This value is established from the top of the floodplain (not channel) through the road Site. It is common to have long baselines to create, then extract/compute elevation from this profile.
14. **Upstream Floodplain Elevation:** Derived from both the valley cross section and correlated with the floodplain profile.
    a. Commonly derived from an upstream valley cross section, together with a valley profile through the road to establish a correlated floodplain elevation. Many roadways amplify natural floodplain deposition on the upstream side which causes an energy slope imbalance. For difficult Sites, it may be best to field survey the tops of depositional flats above and below the road.
22. **Bankfull width:** the width of a natural stable channel at Site.
    a. This is the most critical metric to accurately establish. It defines the width of the on-channel opening for Site design. The most time should be allotted to establishing this value to best represent your Site. Experience has shown that the best resource to establish channel width uses a combination of the following data resources to best correlate the metric:
        - Geomorphic site survey
        - High resolution aerial photography
        - A series of channel cross sections above and below the Site
        - Ratio's/Estimates
        - Discussion with water resource professionals
23. **Mean Depth:** the average bankfull channel depth; the natural "stable" channel depth for the Site
    a. Without a geomorphic channel survey, use the value assigned in the Ratio's/Estimates.
24. **Slope:** the average water surface slope going through road fill prism at the Site.
    a. Water Surface slope is best determined from field survey but can be achieved through a long centerline of channel extracted from LiDAR. For smaller drainage area channels (i.e., drainage areas less than 25 Mi^2) Lidar may not work well to establish this value. When this situation occurs, value can be derived by dividing the valley slope with sinuosity.
25. **Sinuosity:** the curviness of the channel when compared to the valley; measured from above to below the Site.
    a. This value is established by dividing the channel length by the valley length. Using a long, representative reach of the channel going through the roadway. Measure both channel length and straight line fall length of the valley using the same beginning and ending points. Sinuosity is commonly altered through channelization or the design of infrastructure; a critical eye should seek channels in the area that appear unaltered, then compute a sinuosity

from those reaches. Note: sinuosity values are (commonly) inversely related to slope; if the valley steepens the sinuosity goes down, when slope flattens, sinuosity increases.

26. **Largest Particle:** The largest natural particle being transported at this Site; expressed in millimeters.
    a. Often requiring a Site visit, look upstream and downstream for the largest non-quarried particle near-by, on the channel bed, then measure it. Do not be fooled by placed bank armoring (i.e. riprap) and look for smoothed, well rounded particles (i.e. non quarried/placed material). Although this is not essential to this Assessment, it is a critical long term monitoring component to this work. It is ok to leave this cell blank.

28. **Active channel bed materials:** by percentage, the material sizes on the channel bottom.
    a. There are many methods to establish these size percentages and is included to provide some critical insight to channel conditions. The most probable estimate should come from a visual estimate of the bed at the site. Through a site visit or pictures the assessor estimates the percentages of the channel bed materials. It is ok to leave this cell blank

30. **Discharge:** anticipated recurrence discharges for the Site
    a. These discharges values can be obtained in many ways. The suggested method for this Assessment is using the United States Geological Survey (USGS) – StreamStats website. Once procedures are understood on how to operate the web service, recurrence discharge estimates can quickly be obtained. It is ok to leave these cells blank, but will provide valuable insight to the Sites hydrology.

31. **Watershed Slope:** contributing watershed slope (incoming slope)
    a. This value is included in the results of Step 30 a. This estimate can be obtained through various models but the recommended method is through the United States Geological Survey – StreamStats website. It is ok to leave this blank.

Ratios / Estimates Box

This box is used to correlate your initial results of the metrics explained above. Review the values you established in the yellow cells to the values, in this box, immediately to the right. As you adjust the yellow cell values, the values in this Ratio's/Estimates box will change. The goal is to have the values similar for yellow and Ratio's/Estimates. The Assessor should apply a weighted confidence factor the values to establish correlated values. For example, if Assessor is more confident about sinuosity, then adjust the floodplain slope more until correlation is achieved.

Note: do NOT refer to these values until all the yellow cells are populated.

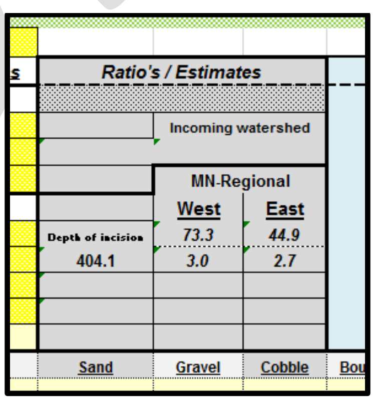


Figure 5: Ratios / Estimates box – example

Design Guidance Box

This is the most DRAFT portion of the Geomorphic Assessment Form Ver. 1.0. The goal is to promote tools for the designer as to how to apply this hydraulic geometry into the Site design. The authors do not claim to be roadway designers so all comments and suggestions are encouraged to help improve this box. <u>This box should be considered very Draft and will change as feedback is received and applied into creating additional tools.</u>

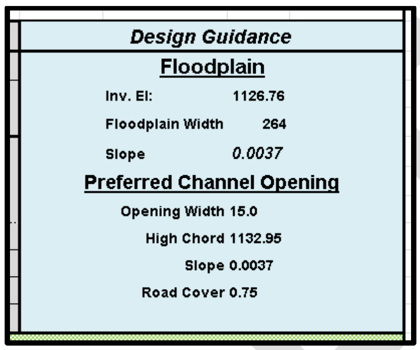


Figure 6: Design Guidance box - Example

II b. The 6 Steps to Assessing and Applying landform into Site design

The following Steps outline a procedure for completing the Geomorphic Assessment at Road/River Intersection form version 1.0. and guides the Designer on how to apply the results into Site design:

Step 1: Answer question, Does sufficient road fill exists to install floodplain connectivity culverts?

Use the Top Tier to determine if floodplain connectivity is achievable at the specific Site; Designer determined. Assessor should populate all Yellow cells:

Top Tier

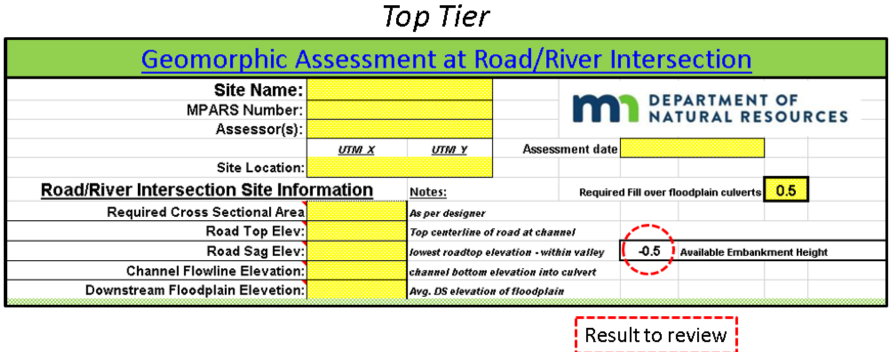


Figure 7: Geomorphic Assessment at Road/River Intersection

Step 2: Establish Site Specific Information

Using available on-line and preferred software, Initial Site specific information is generated and documented in this Step. The results of this Step provides the Assessor with broad understanding of the Site. An important aspect of establishing these landform values is to not get overwhelmed with exact values. Experience has demonstrated that close works for this Step; close being + or – 0.5 feet. Once all cells are populated, the yellow cell values will be correlated to each other in Step 3. As experience grows, Assessors will gain the ability to establish precise metrics using preferred routines. Although this routine uses standard Lidar to establish land form information, Site specific field survey data can improve both Site understanding and Assessment accuracies for this work. Using many data resources this Step establishes essential Site specific land form metrics to be utilized in Site design. Assessor should populate all the yellow cells in the Lower Tier (note: the lighter shaded yellow is not mandatory, but can provide useful information to the designer):

Lower Tier

Drainage Area (Mi^2):								
	Site Metrics	*Ratio's / Estimates*			*Design Guidance*			
Floodplain Determinations					Floodplain			
Floodplain Width:			Incoming watershed		Available XSA			
Floodplain Slope:					Floodplain Width			
Upstream Flooplain Elevation:			MN-Regional		Slope			
Bankfull Channel Determinations			West	East	Preferred Channel Opening			
Width:		Depth of incision			Opening Width			
Mean Depth:					High Chord			
Slope:					Slope			
Sinuosity:					Road Cover			
Largest Particle:								
Channel Materials	Silt/Clay	Sand	Gravel	Cobble	Boulder	Bedrock	debris concern?	
Percentage of channel bed material								
USGS StreamStats or Modeled	Q1.5yr	Q2yr	Q5yr	Q10yr	Q25yr	Q50yr	Q100yr	Q500
Discharge:								
Slope (ft/mi):								

Figure 8: Establish Site Specific Information

Step 3: Correlation of Land Form Metrics

For this Step, data correlation should occur on the following metrics:

- Width
- Mean Depth
- Floodplain slope
- Channel Slope
- Channel sinuosity

Using many resources, along with the Ratio's/Estimates that are on the form, this critical step allows the Assessor to review and modify all the results to achieve a correlated data for the Site. When performing this critical correlation of the data, the Assessor will begin to understand that the many data values relate to each other. This step will allow the many established land form metrics to 'make sense' before final documentation of the results

Using the ratio's/Estimates portion of the form, Assessor should correlate channel width, mean depth, floodplain & channel slopes, and sinuosity. The values should correlate with the values to the right using a priority based upon data consilience.

The Geomorphic Assessment at Road/River Intersection form (ver. 1.0) is designed to be a Basic Assessment. It is anticipated the Ratio's / Estimates will be expanded and refined through much feedback. This area will likely be regionalized for Minnesota. The values in this version (1.0) were chose to establish a basic Site understanding of critical landform components to apply into Site design. Though feedback improvements are likely, please refer to our website for the most up-to-date version.

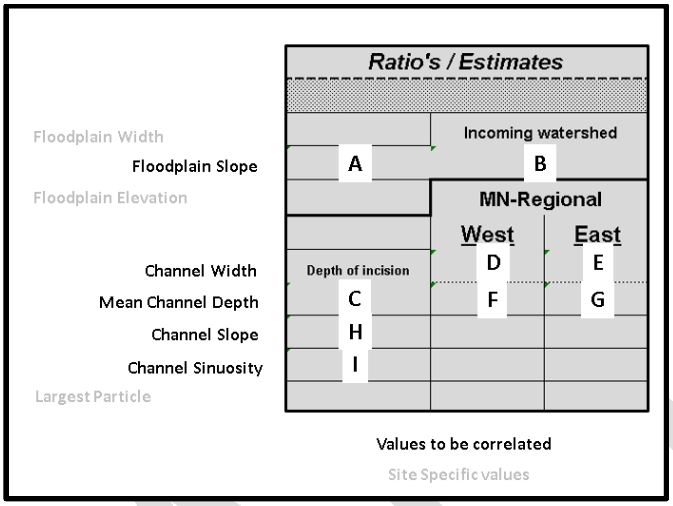


Figure 9: Ratios / Estimates

A. This is the slope of the floodplain at the road centerline; iteratively adjusted from channel sinuosity and bankfull slope as the Assessor correlates the Site geomorphic data.
B. Although not used in data correlation, this value is computed from lowest yellow cell input. Input as Feet-Per-Mile of drop, this provides the designer with additional understanding of the contributing watershed to the Site. it is commonly established through the USGS StreamStats on-line application. This computed value will also provide a critical role to future monitoring of system response to the Site design imposed.
C. Depth of channel incision - when compared to mean channel depth provide insight as to incised, or entrenched the channel is at the Site. This understanding of channel incision poses much concern as to what the design elevation the floodplain culvert inverts should be. Additional research & documentation is underway to provide additional guidance on best elevation. Common design practice has been to lower the channel to reduce stage, but if the channel is already incised, or entrenched, a stable channel will never be achieved; it is recommended to raise the floodplain to the highest elevation; yet still pass the required design flows.
D. Depending upon the Site location (East or West half of Minnesota) use this value to best determine the width of the natural channel at the Site.
E. See D.
F. Depending upon the Site location (East or West half of Minnesota) use this value to best determine the mean depth of the natural channel at the Site.
G. See F.
H. Channel slope is related to sinuosity and floodplain slope. Adjust this value when low confidence is presumed when establishing this value
I. Channel sinuosity is related to floodplain and channel slope. Adjust this value when low confidence is presumed when establishing this value

As an example, review the established with the Ratio's/Estimates and compare yellow cell values with values to the right:

	Site Metrics	Ratio's / Estimates		
Floodplain Determinations				
Floodplain Width:	380		Incoming watershed	
Floodplain Slope:	0.0026 ↔	0.0033	0.0020	
Upstream Flooplain Elevation:	683.1		MN-Regional	
Bankfull Channel Determinations			West	East
Width:	65.0 ←	Depth of incision →	87.5	52.3
Mean Depth:	3.2 ←	→	3.4	2.9
Slope:	0.0020 ↔	0.0016		
Sinuosity:	1.64 ↔	1.30		
Largest Particle (mm):	2			

Figure 10: Correlative metrics displayed by arrows

Begin by adjusting the lowest confidence established value in the yellow cells and watch the changes to the right. It is an iterative process until the values become similar. Once close, the Assessor may want to contact the Regional Clean Water Legacy staff to validate / refine results. Once correlated, generate a PDF, print out a hard copy for the file and, if a design is established and applied using these values, submit back to the authors of this approach for long term monitoring & reporting the applied road design to Site.

Step 4: Apply Land Form Metrics into Site Design

This approach documents some minimal metrics to use in Site design of Infrastructure. Once a decision is made to use this in Site design, the designer can quickly become overwhelmed when trying to apply the many Assessment results into a Site design. It is recommended to begin with a few land form metrics then expand into additional land form metrics as experience grows. Using the Assessment results, the suggested priority to apply into Site design is as follows:

1. Channel Width
2. Floodplain Elevation
3. Floodplain Width
4. Mean Channel Depth
5. Additional land form metrics and considerations will follow through monitoring, research and reporting.

Design consideration: There is much learning through monitoring to come as various Sites get constructed on the land.

This monitoring and reporting can only improve if you notify us with a copy of your results and information and the design.

Our goal is to improve this work and provide open dialog on the issues regarding successfully applied design. From our limited experience in monitoring the few Sites, the following specifics should be considered for your Site design.

- Separate the channel and floodplain metrics and design conveyance openings independently for each by using the values in yellow cells.
- Try to avoid the channel openings to enter into pressure flow at design discharge

- Its 'ok' to allow pressure flow in floodplain… get the floodplain culverts conveying sooner than later, across the entire floodplain width.
- For steeper slopes, or wide roads, have the outlet (top of culvert) above the inlet invert (bottom) to avoid plugging.
- The design likely will require adjustment to best fit the Site. The influences can be many but goal is to optimize the flood flows over the entire floodplain.
- Once established, this information should be fitted then optimized through modeling into your road/river intersection site design (e.g., the sizes and locations of bridges & culverts).
- More design criteria to come as on-going monitoring and reporting continues and valley type inventories are created.

A goal of this effort is to initiate adaptive management into the design of infrastructure through documenting and designing for local land form metrics. The Assessment Form (ver. 1.0) provides a documentation methodology and reporting of basic channel and floodplain and land material information for a Site. It is anticipated that the designer, through application of this assessment, will discover that river systems (channel and floodplain) are predictable and, through time will establish a stable channel and floodplain.

Due to the variability of both Site land metrics and available construction materials the designer must best apply somewhat of an artistic approach to best applying the values into the Site design. The application of the land form values should be applied using the principles outlined in the original study found here.

Step 5: Optimize Site design through hydraulic modeling

Based on the design criteria and objectives, hydraulic modeling can be used to run several design iterations to achieve the optimum solution. Criteria may include meeting the no-rise limit in order to comply with the local, state and FEMA floodplain regulations. Another criteria may include achieving an allowable range of shear stress values in the channel by re-sizing and changing the floodplain culvert spacing, in order to control bank erosion. Furthermore, hydraulic modeling and analysis are very effective in quantifying the benefits of floodplain culverts and assessing the impacts of confining the floodplain flow to an over-widened on-channel culvert. Hydraulic modeling is covered in the Section IV.

Step 6: Record/Report land form Site design information for future access (MPARS?)

Pending discussion with the MPARS staff

III. An example Geomorphic Assessment at Road/River Intersection using the Geomorphic Assessment at Road/ River Intersection form (Ver. 1.0):

The Section gives an example on how to use the Geomorphic Assessment of Road/River Intersection form (Ver. 1.0) to establish land form metrics for a Road/River Intersection Site, then apply those results into the Site design of infrastructure. *Note: Some duplication of above descriptions were included to provide clarity.*

Related Study: http://files.dnr.state.mn.us/eco/streamhab/geomorphology/reducing-rior.pdf

Time Required: time will vary depending upon proficiency, allow minimum 20 minutes to 1 hour for completion.

Essential tools:

- USGS Stream stats (click here)
- GIS or CAD with land topography
  - Lidar or 2 foot contour data
  - Site Survey (click here)

III a. A common Site example outlining a procedure to establish baseline geomorphic metrics

Begin with a Road/River intersection **Site** and fill out the site information on the Geomorphic Assessment Form:

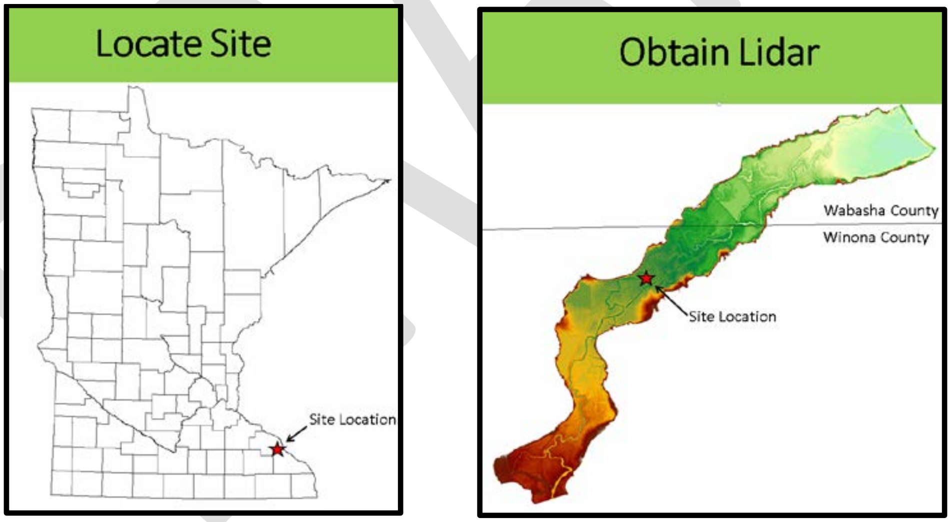


Figure 11: Obtaining LiDAR for the Site

Obtain Lidar of complete floodplain above and below road Site, and/or field data for Site:

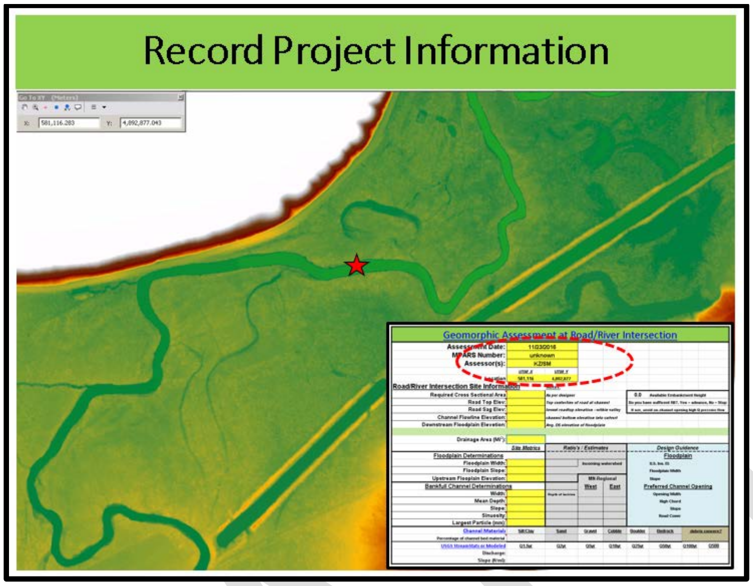


Figure 12: Project Information

Example of a proposed roadway crossing at star. Fill in the Site Assessment information on the excel form

Step 1: Answer question, "Does sufficient road fill exists to install floodplain connectivity culverts?"

To determine the answer fill in Top Tier of this form:

Road/River Intersection Site Information		Notes:	
Required Cross Sectional Area		*As per designer*	0.0 Available Embankment Height
Road Top Elev:		*Top centerline of road at channel*	Do you have sufficent fill?. Yes = advance, No = Stop
Road Sag Elev:		*lowest roadtop elevation - within valley*	If not, avoid on-channel opening high Q pressure flow
Channel Flowline Elevation:		*channel bottom elevation into culvert*	
Downstream Floodplain Elevetion:		*Avg. DS elevation of floodplain*	

Figure 13: Top Tier Information

To begin the Top Tier, extract three (3) valley cross sections from your Site and overlay:

1. On the road top, along centerline across the complete valley
2. Just upstream of road, across the un-impacted (from the road) valley
3. Just Downstream of road, across the un-impacted (from the road) valley

The three, or more cross sections should be extracted and overlaid to represent looking down the valley. In many larger river systems it can be aligned on the channel, but for smaller sites it may be necessary to use reference stationing along the roadway, to accurately correlate the 3+ cross sections to each other (as viewed looking downstream).

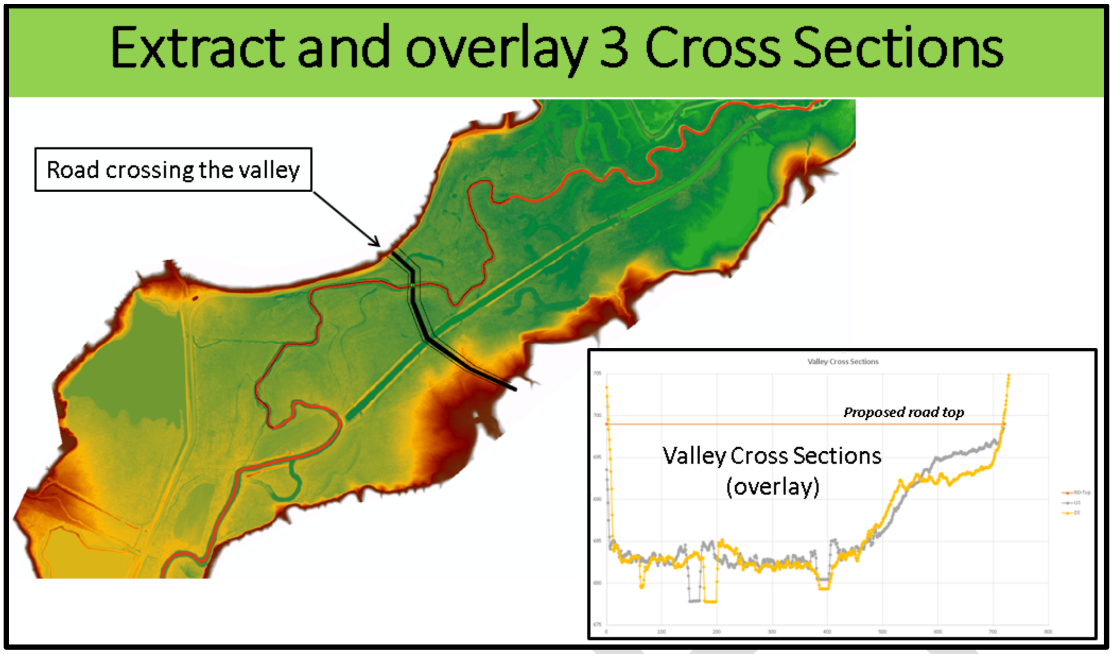


Figure 14: Valley Cross-sections

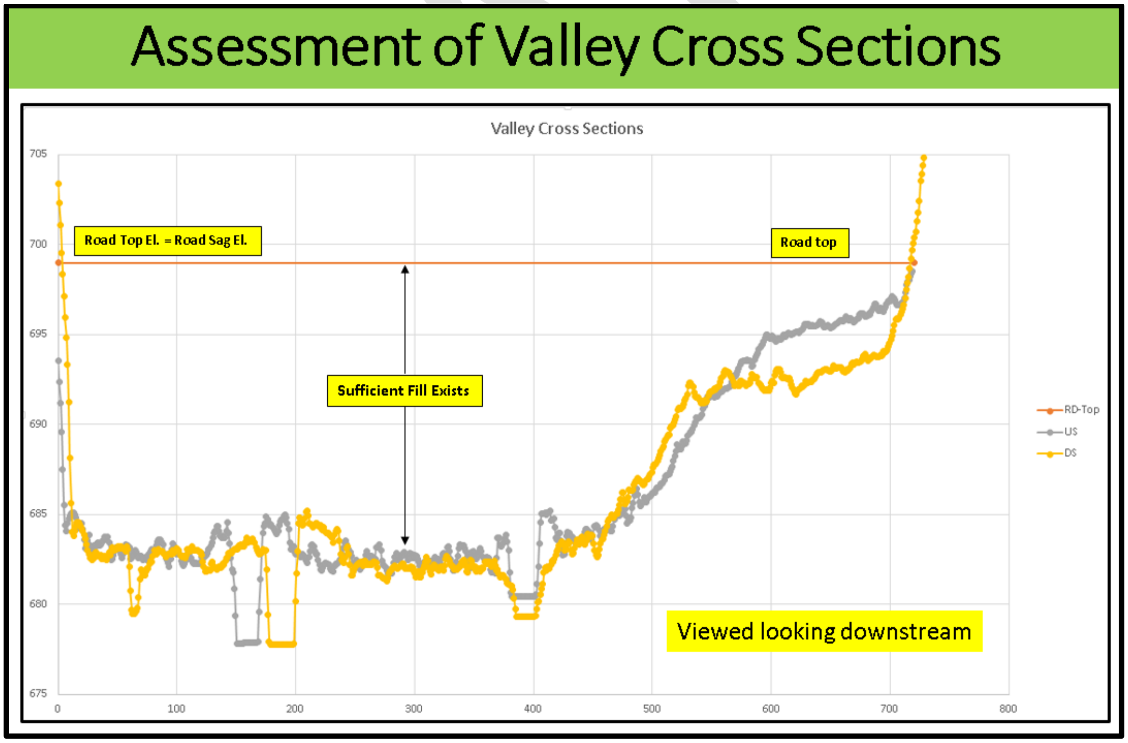


Figure 15: Assessment of Valley Cross-sections

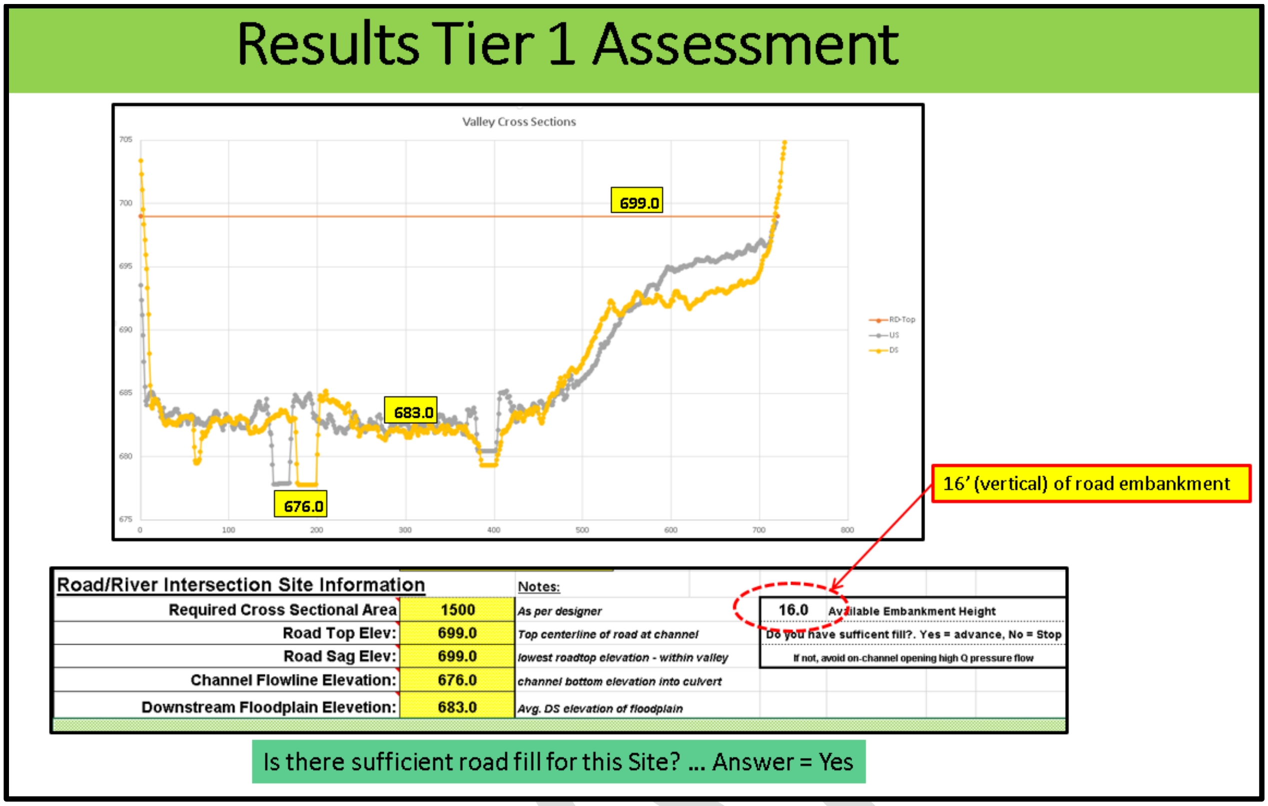


Figure 16: Tier 1 Assessment

Regardless of the answer to the Top Tier question, it is highly recommended to continue onto Lower Tier of this form to gain critical landform understanding to utilize in Site design. When insufficient fill exists to install floodplain culverts it may become difficult to apply the study principles into the Site design. Additional research is underway to establish design guidance for the Site condition when there is insufficient fill; future reports will include findings. Information gained by performing this will improve Site design, please review the application of land form into site design section.

Advance to Lower Tier of the Geomorphic Assessment at Road/River Intersection form – (ver. 1.0)

Drainage Area (Mi^2):	
	Site Metrics
Floodplain Determinations	
Floodplain Width:	
Floodplain Slope:	
Upstream Flooplain Elevation:	
Bankfull Channel Determinations	
Width:	
Mean Depth:	
Slope:	
Sinuosity:	
Largest Particle (mm):	
Channel Materials	Silt/Clay
Percentage of channel bed material	
USGS StreamStats or Modeled	Q1.5yr
Discharge:	
Slope (ft/mi):	

Figure 17: Lower Tier

Step 2: Establish Broad Level Site Information:

Drainage Area: **The contributing land area, in square miles, and slope coming into the Site**

Hydrology Data: **Recurrence discharge information**

A recommended tool for Step 2 is the USGS – Streamstats web application. The application requires a small learning curve to use populate the required cells, and instructions on how to use the web application are given on the website.

https://water.usgs.gov/osw/streamstats/minnesota.html

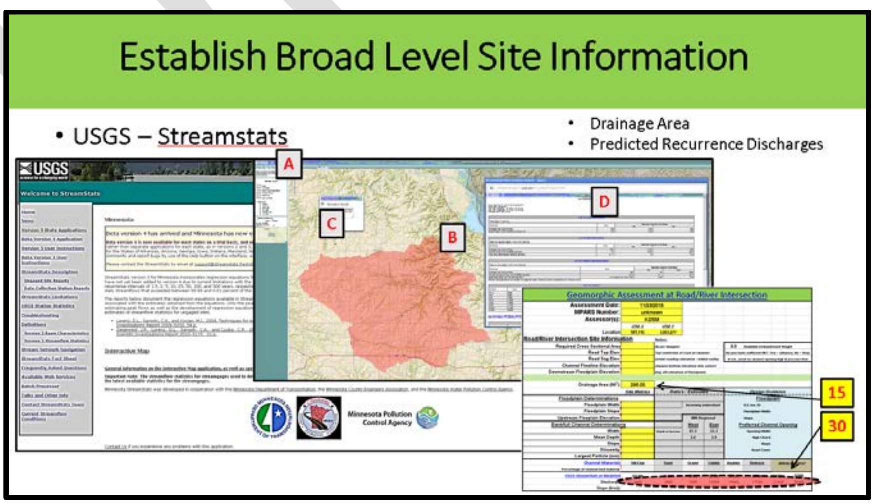


Figure 18: Site Information

Broad Level data completed on form:

Drainage Area (Mi^2):	296.00
	Site Metrics
Floodplain Determinations	
Floodplain Width:	
Floodplain Slope:	
Upstream Flooplain Elevation:	
Bankfull Channel Determinations	
Width:	
Mean Depth:	
Slope:	
Sinuosity:	
Largest Particle (mm):	
Channel Materials	Silt/Clay
Percentage of channel bed material	
USGS StreamStats or Modeled	Q1.5yr
Discharge:	2680
Slope (ft/mi):	10.8

Figure 19: Broad Level Data

Step 3: Establish Site specific land form metrics:

The Site's channel and floodplain metric determination requires populating the following cells:

Floodplain Determinations	
Floodplain Width:	
Floodplain Slope:	
Upstream Flooplain Elevation:	
Bankfull Channel Determinations	
Width:	
Mean Depth:	
Slope:	
Sinuosity:	
Largest Particle (mm):	

Figure 20: Site Specific Land Form Metrics

Floodplain determinations:

Floodplain Width: Using the cross sections above and below the roadway, Assessor is required to perform a visual assessment, comparing all available resources to establish width of the floodplain (flat) at the Site.

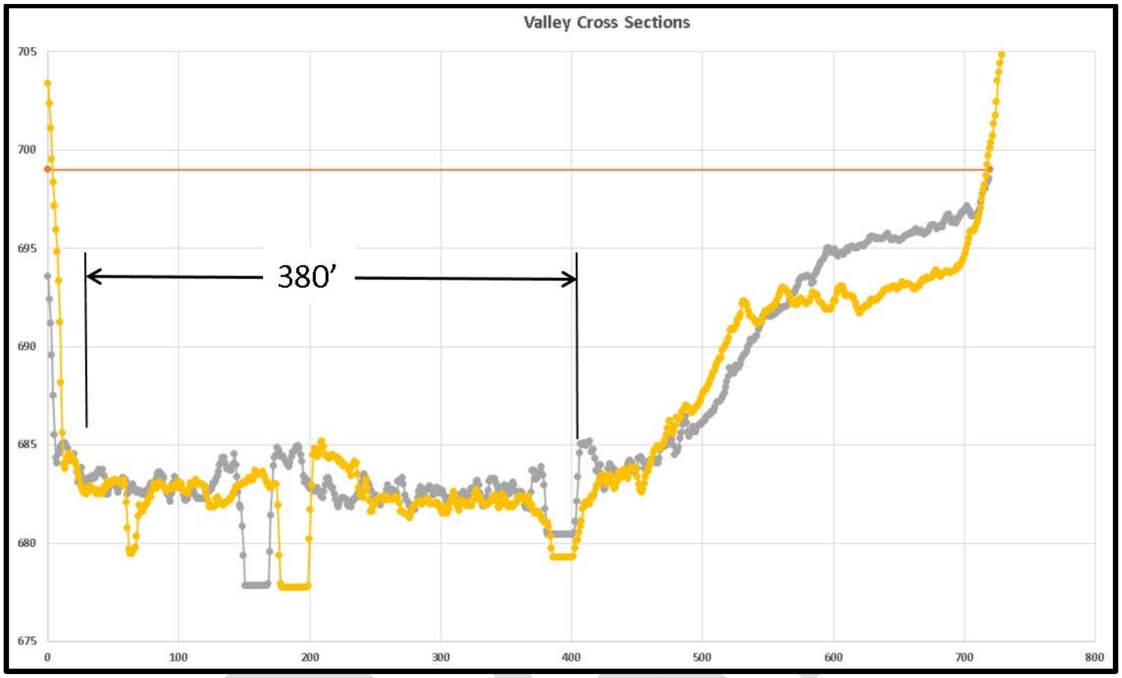


Figure 21: Floodplain Width Cross-section

Floodplain Width:	380

n Slope: Using a long baseline that extends from well above to well below the Site, extract a surface profile in a straight line along the fall of the channel (as shown as black line below). Choose points in a downstream direction, on inside meander flats that are considered to be on top of the floodplain.

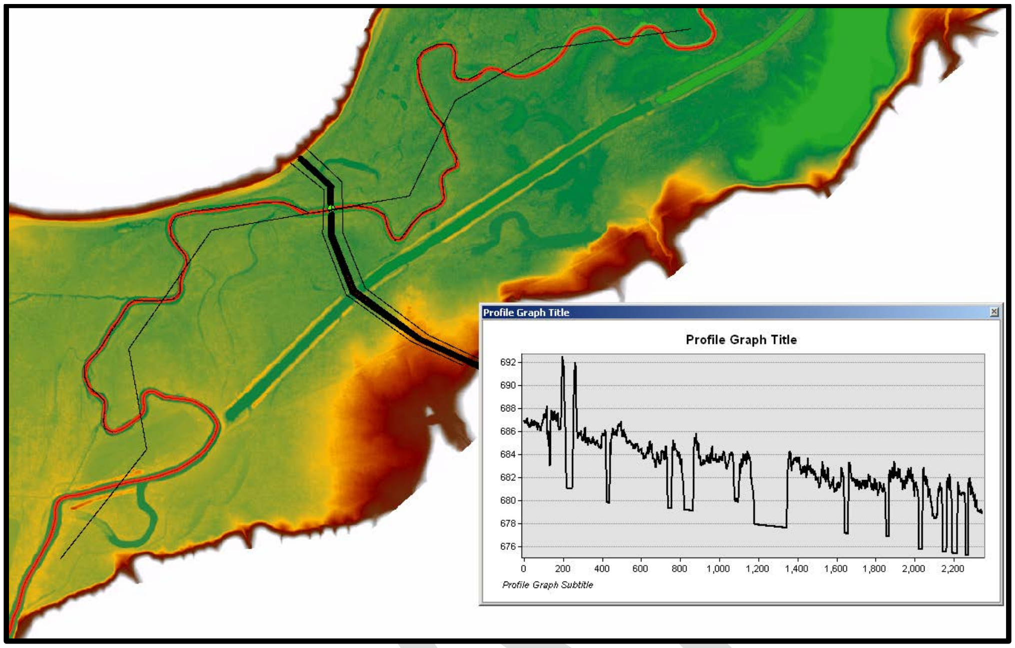


Figure 22: Floodplain Slope Determination

Remove channels and levee's from dataset, apply linear trend line and obtain slope.

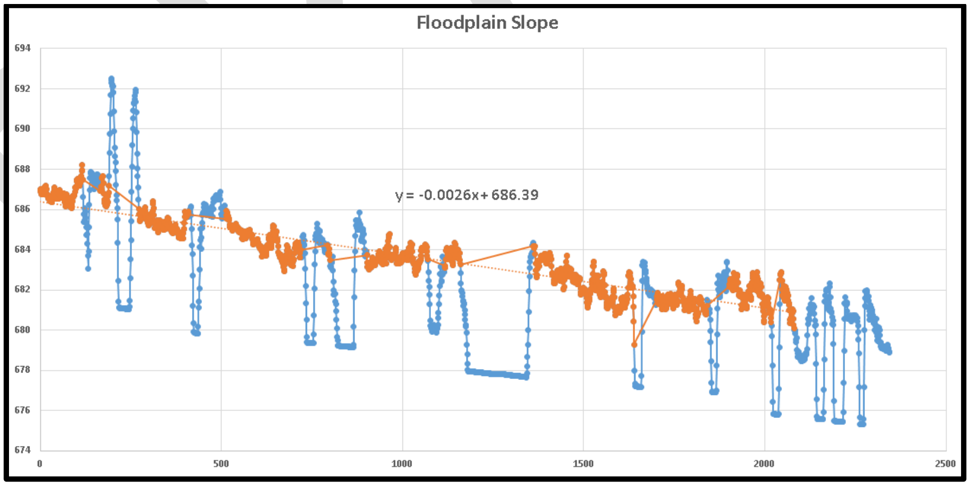


Figure 23: Floodplain Slope

Floodplain Slope:	0.0026

Upstream Floodplain Elevation: From the upstream cross section, establish an elevation of the floodplain. Always cross reference the floodplain profile when establishing this elevation.

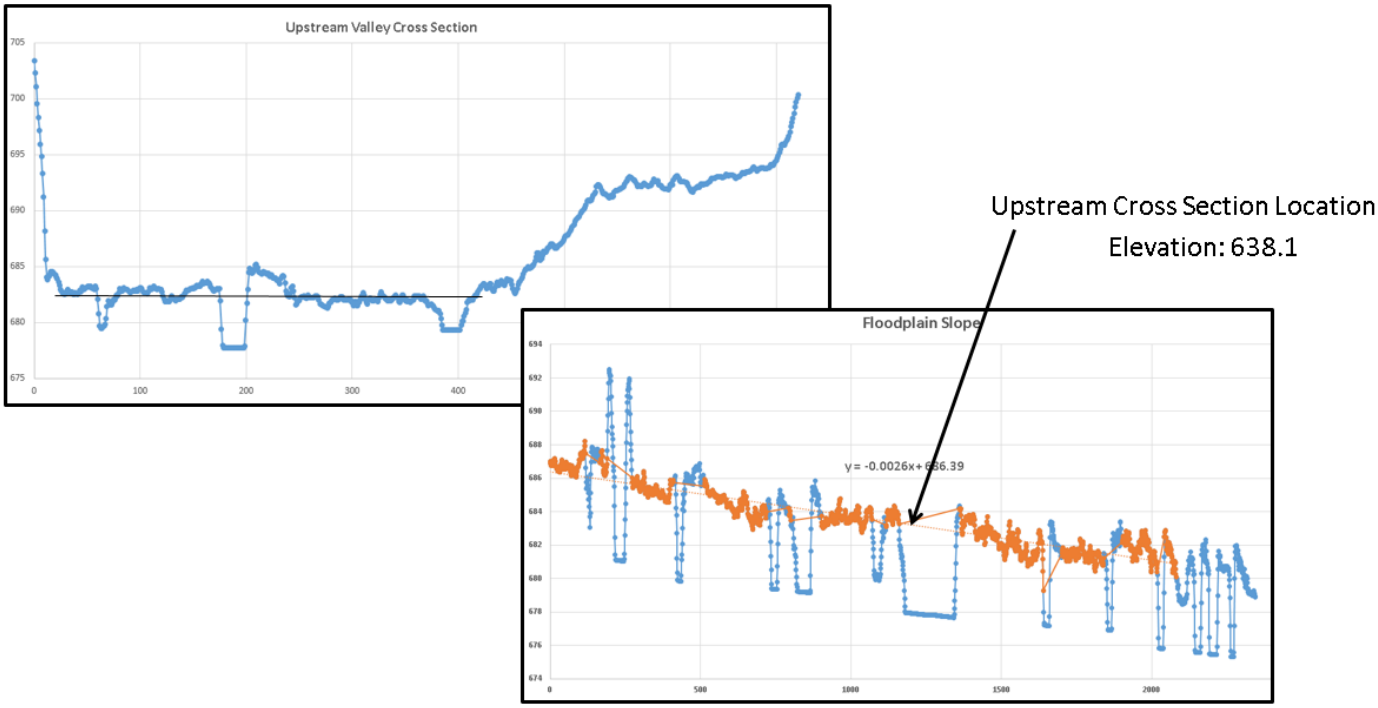


Figure 24: Upstream Floodplain Elevation Determination

Upstream Flooplain Elevation:	683.1

Floodplain Determinations complete:

Floodplain Determinations	
Floodplain Width:	380
Floodplain Slope:	0.0026
Upstream Flooplain Elevation:	683.1

Figure 25: Floodplain Determination

Channel Determinations:

A goal of Assessor should be to keep moving toward completion and not get too worried about the initial accuracy of the Assessment. As proficiency is gained, Assessor accuracy and improved application into design can be expected.

Width: Due to channel succession, it is common to extract an over wide channel from lidar. The stable width should be established through correlation of many data & resources available:

- Overlaid cross sections
- Field survey determination
- high resolution aerial photography (Bing Birds eye)
- DNR Regional Clean Water Specialist

Cross section overlay: Extract as many cross sections upstream and downstream of Site, align the many cross sections and establish a width metric from these data as shown:

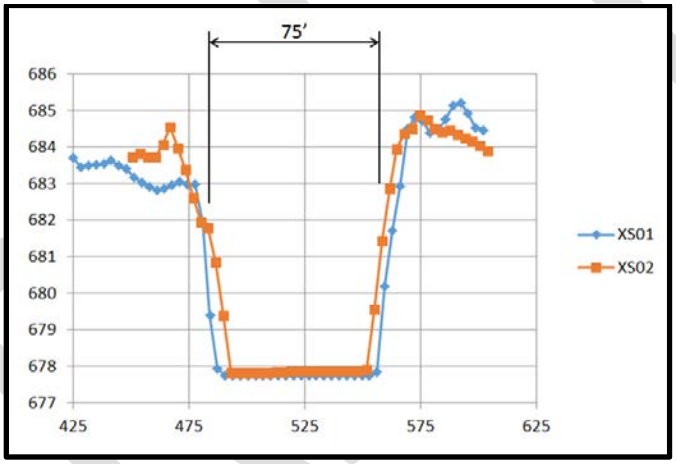


Figure 26: Cross-section Overlay

Cross section overlay indicates channel width is < 75'

No field data exist for this data – not performed.

High resolution aerial photography:

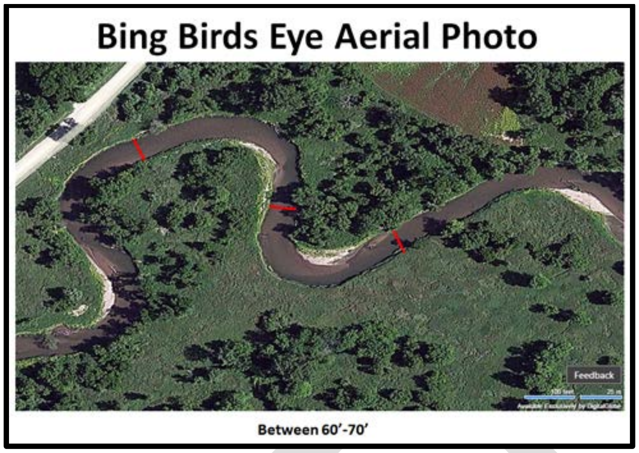


Figure 27: Aerial Image

Bing aerial image suggests channel width is between 60' and 70'

Given all your resources make a determination.

Width: 65.0

Mean Depth: The mean depth's primary purpose is for monitoring. Given there is no field data and the range of this value is very low, when no field data available use the value in the Ratio's/Estimates section of the form.

Mean Depth: 3.2

Slope: Channel slope is the same value as water surface slope. Extract a long baseline from water surface to establish a long consistent profile through the Site. For smaller channels, where water surface is not easily identifiable, this value can estimated.

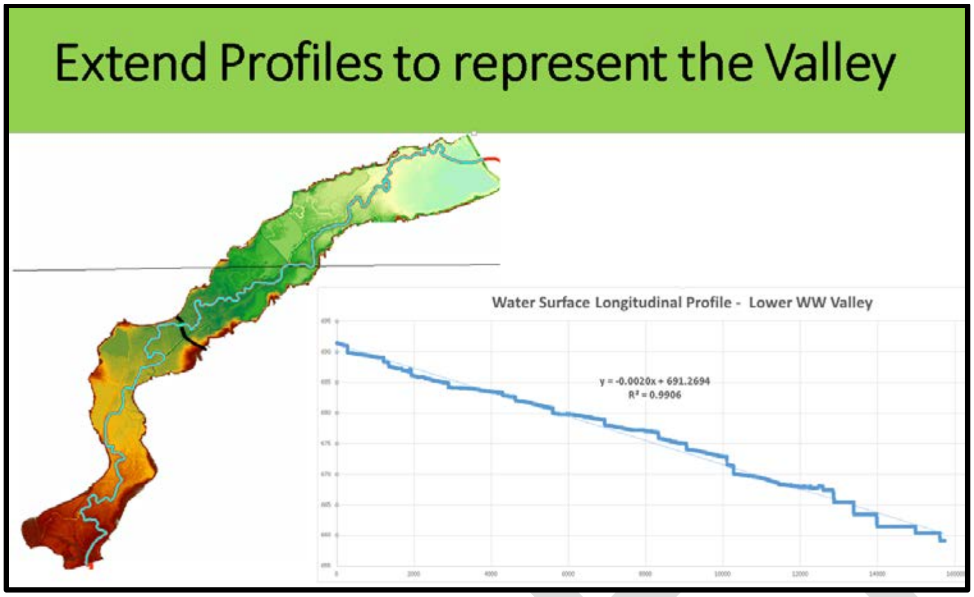


Figure 28: Valley Profile

Extract Water Surface Slope from long baseline

Slope:	**0.0020**

Sinuosity: This value represents how curvy the channel going through the Site. Beginning and ending with the same points, divide the channel length by the straight line valley length.

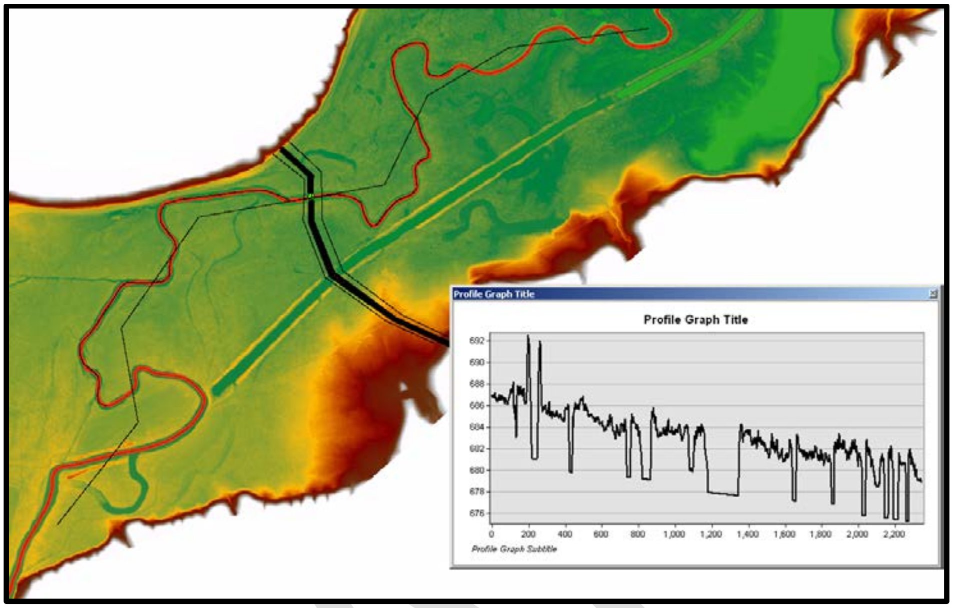


Figure 29: Sinuosity Determination

Alignment of floodplain centerline is shown as straighter line along channel centerline

Sinuosity: 1.64

Largest Particle: This value is the largest naturally place particle on the channel bed in the area. It provides a present condition value and can be estimated. If unknown/unavailable, leave blank but many Site's estimate can be established through aerial photo and/or Site pictures.

This reach is a sand bed channel:

Largest Particle (mm): 2

Initial Results on Lower Tier:

Drainage Area (Mi^2):	296.00
	Site Metrics
Floodplain Determinations	
Floodplain Width:	380
Floodplain Slope:	0.0026
Upstream Flooplain Elevation:	683.1
Bankfull Channel Determinations	
Width:	65.0
Mean Depth:	3.2
Slope:	0.0020
Sinuosity:	1.64
Largest Particle (mm):	2

Figure 30: Results of Lower Tier

Step 4: Correlation of land form metrics:

Using the ratio's/Estimates portion of the form, Assessor should correlate channel width, mean depth, floodplain & channel slopes, and sinuosity. The values should correlate with the values to the right using a priority based upon data confidence.

This Geomorphic Assessment at Road/River Intersection form (ver. 1.0) is designed to be a Basic Assessment. It is anticipated the Ratio's / Estimates will be expanded and refined through much feedback. The values chosen in this version (1.0) were chosen to establish a basic understanding of critical landform components to apply into Site design. Please provide feedback on what changes you believe could be helpful for a Basic Assessment.

To begin, review the established with the Ratio's/Estimates:

	Site Metrics	*Ratio's / Estimates*		
Floodplain Determinations				
Floodplain Width:	380		Incoming watershed	
Floodplain Slope:	0.0026	↔ 0.0033	0.0020	
Upstream Flooplain Elevation:	683.1		MN-Regional	
Bankfull Channel Determinations			**West**	**East**
Width:	65.0	↔ Depth of incision	87.5	52.3
Mean Depth:	3.2	↔	3.4	2.9
Slope:	0.0020	↔ 0.0016		
Sinuosity:	1.64	↔ 1.30		
Largest Particle (mm):	2			

Figure 31: Land Form Metrics Correlation

Correlative metrics displayed by arrows

To Correlate landform metrics begin adjusting the yellow cell values while reviewing the related Ratio's/Estimates columns. Begin by adjusting the lowest confidence established value. It quickly becomes an iterative process as the values become similar. At this point the Assessor may want to reach out to a water resource professional to validate this information.

Although there are unique conditions, the final established values should commonly correlate to the Ratios/Estimates very well.

Geomorphic Assessment at Road/River Intersection								
Assessment Date:	11/23/2016							
MPARS Number:	Original Study Stie							
Assessor(s):	KZ/SM							
	UTM X	*UTM Y*						
Location	581116	4892877			Required Fill over culverts		1	
Road/River Intersection Site Information		Notes:						
Required Cross Sectional Area	1500	*As per designer*			15.0	Available Embankment Height		
Road Top Elev:	699.0	*Top centerline of road at channel*			Do you have sufficent fill?. Yes = advance, No = Stop			
Road Sag Elev:	699.0	*lowest roadtop elevation - within valley*			If not, avoid on-channel opening high Q pressure flow			
Channel Flowline Elevation:	876.0	*channel bottom elevation into culvert*						
Downstream Floodplain Elevetion:	683.0	*Avg. DS elevation of floodplain*						
Drainage Area (Mi^2):	296.00							
	Site Metrics	*Ratio's / Estimates*			*Design Guidance*			
Floodplain Determinations					**Floodplain**			
Floodplain Width:	380		Incoming watershed		Available XSA			
Floodplain Slope:	0.0033	*0.0033*	*0.0020*		Floodplain Width	1056		
Upstream Flooplain Elevation:	683.1		MN-Regional		Slope	*0.0033*		
Bankfull Channel Determinations			West	East	**Preferred Channel Opening**			
Width:	60.0	Depth of incision	*87.5*	*52.3*	Opening Width	60.0		
Mean Depth:	4.0		*3.4*	*2.9*	High Chord	699.05		
Slope:	0.0020	*0.0020*			Slope	0.0020		
Sinuosity:	1.64	*1.65*			Road Cover	-0.05		
Largest Particle (mm):	2							
Channel Materials	Silt/Clay	Sand	Gravel	Cobble	Boulder	Bedrock	debris concern?	
Percentage of channel bed material		100						
USGS StreamStats or Modeled	Q1.5yr	Q2yr	Q5yr	Q10yr	Q25yr	Q50yr	Q100yr	Q500
Discharge:	2680	3480	7400	10300	14400	17700	21400	30800
Slope (ft/mi):	10.8							

Figure 32: Complete Geomorphic Assessment

A complete Geomorphic Assessment at Road/River – form (ver. 1.0)

Once this is achieved through applying a confidence value to all your metrics, you are complete with Step 4. It is highly recommended to establish a PDF file of it and print out a version for the files.

Step 5: Apply land form data into Site design

Due to the variability in Site design and construction constraints it is up to the designer how the landform is applied into Site design. Previous work has demonstrated consistent Site improvement when applying this priority to established metrics:

1. Channel Width
2. Floodplain Elevation
3. Floodplain Width
4. Floodplain Slope
5. Mean Channel Depth + more

Design considerations:

- Try to avoid the channel openings to enter into pressure flow condition
- it is 'ok' to allow pressure flow on the floodplain
- The design likely will require adjustment to best fit the Site. The influences can be many but goal is to optimize the flood flows over the entire floodplain.

The goal of this effort is to begin to understand and document the various land form metrics essential for a stable river channels through roadways. This assessment assigns land form values to both channel and floodplain's dimension, pattern, slope and local materials for a specific Site. Once established, this information should be fitted then optimized through modeling into your road/river intersection site design (e.g., the sizes and locations of bridges & culverts). It is anticipated that the practitioner, through application of this assessment, will discover that river systems (channel and floodplain) are predictable and can be managed based upon watershed size and stream type/valley type conditions.

Landform Site design diagrams:

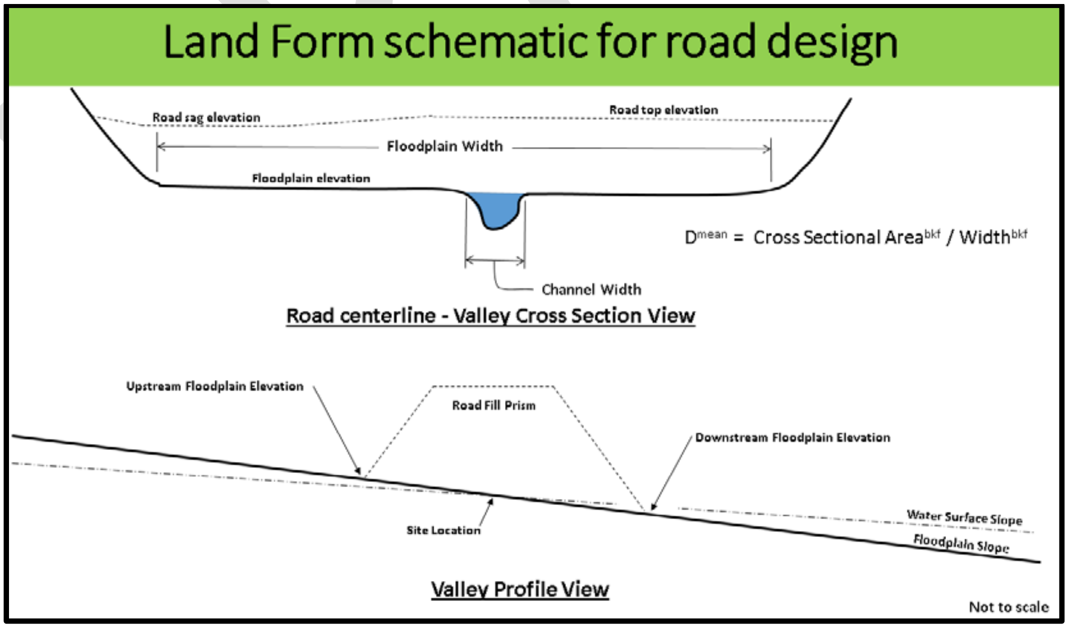


Figure 33: Land Form Schematic

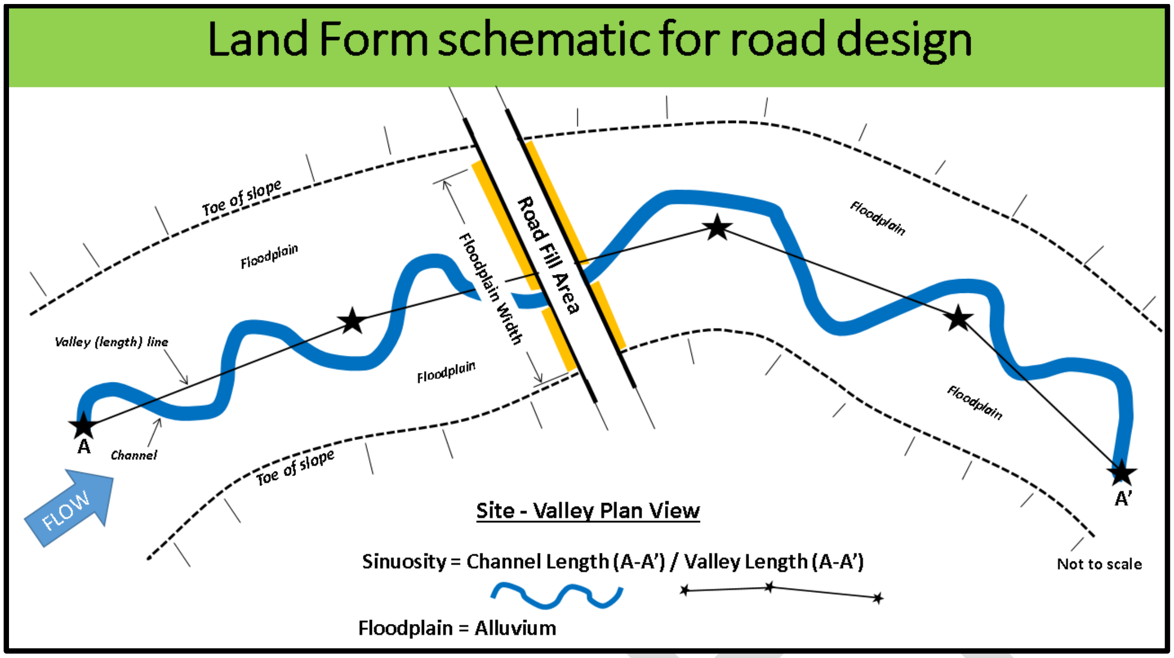


Figure 34: Land Form Schematic

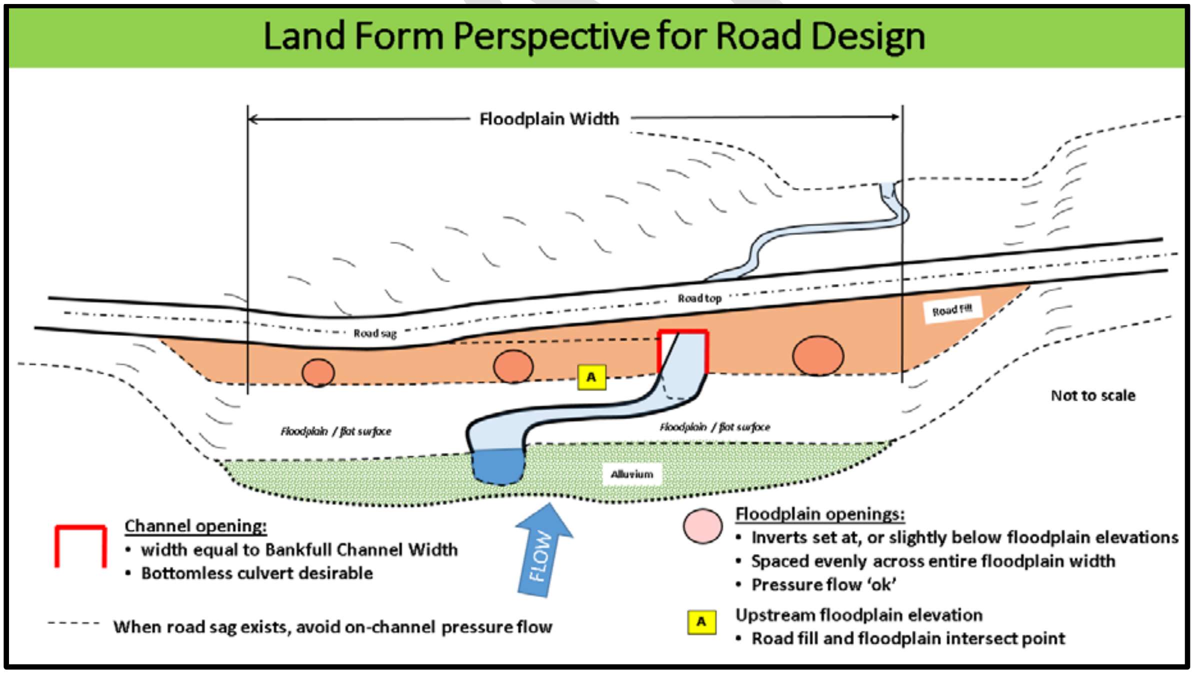


Figure 35: Land Form Perspective

Step 6: Quantify improvements and adjust design through modeling, as described in Section IV, Hydraulic Modeling and Analysis: *See Section IV – Hydraulic Modeling and Analysis (below)*

Step 7: Finalize design report land form assessment… *See included examples of other project reports.*

IV- Hydraulic Modeling and Analysis

a. Introduction to Modeling:

The section provides guidance on hydraulic analysis; hydraulic modeling; and related State and FEMA floodplain requirements for Site design. Hydraulic modeling is very effective in quantifying the benefits of floodplain culverts and assessing the impact of floodplain confinement. Through performing hydraulic modeling, this section illustrates how the modeling results and hydraulic analysis can produce a convincing argument in favor of designing for floodplain connectivity, rather than confining all design discharges to the channel. Furthermore, hydraulic modeling may be needed to address the FEMA, state and local floodplain requirements.

This section is written with the assumption that the user has basic understanding and use of hydraulic modeling programs, such as 1D (one dimensional) HEC-RAS. While 1D steady state modeling might be adequate in addressing the related floodplain connectivity issues, the section does discuss more advanced modeling methods and tools involving unsteady state modeling, 2D (two dimensional) modeling, and sediment transport using BSTEM. As illustrated in Section IV(b), 2-D modeling does a better job simulating the interactions between the floodplain and its channel. Furthermore, the upcoming MNDOT Drainage Manual will recommend using 2-D hydraulic models.

It is up to the modeler to select the appropriate tool. However, we encourage the modeler to learn more about the various hydraulic modeling capabilities to better represent the interactions between the floodplain and its channel and to more accurately quantify the benefits of improving floodplain connectivity.

After establishing and correlating land form metrics using the Geomorphic Assessment at Road/River Intersection form, the designer should incorporate the documented metrics into the modeling effort. The following derived parameters are needed for building the model:

1) Bankfull width
2) Floodplain elevation
3) Floodplain slope
4) Floodplain width
5) Height of embankment

The table below summarizes why each parameter is needed in building the model.

Table One: Summary of Geomorphic Assessment parameters for hydraulic modeling

Geomorphic Assessment	To help with Bridge/Culvert Design
Bankfull width	To determine width of on-channel opening (± 10% of bankfull width)
Floodplain elevation and top of bank	To set the invert elevation of floodplain culverts
Floodplain width	To select the horizontal placement of floodplain culverts
Existing floodplain slope	To set the slope of culverts
Height of embankment	Used to fit the floodplain culverts

The application of the established site based land form metrics are further discussed in the Reducing Impact of Roads at Road/River Intersections study, downloadable here:

http://www.dnr.state.mn.us/eco/streamhab/geomorphology/index.html

b. Hydraulic Modeling:

Many hydraulic models can simulate multiple channel openings and floodplain culverts. For this manual, we have chosen the following industry standard modeling software packages. For each model, at least one example is provided, as summarized in Table Two.

- HEC-RAS (5.03) (steady and unsteady, 1D only)
- HEC-RAS-BSTEM sediment transport features
- 2D-SRH (SMS).

Table Two: List of examples used for each hydraulic modelling method

Hydraulic Model	Condition	Example: site used
HEC-RAS 5.03	Steady state	- CSAH 7 and Redwood, Lincoln County
HEC-RAS 5.03	Unsteady state (1D)	- Whitewater, lower reach Winona County
2D-SRH (SMS)	Unsteady state	- Whitewater lower reach, Winona County - Sciota Trail, Dakota County
HEC-RAS 5.03	BSTEM –quasi-steady state	- Whitewater, lower reach Winona County

Note: When the project requires a FEMA submittal, the hydraulic model(s) must be approved by FEMA. For a list of the approved FEMA hydraulic and hydrologic models, please refer to the following link: https://www.fema.gov/software

HEC-RAS 1D (steady and unsteady)

Figures IV-1 through IV-3 illustrate the culvert configuration for two cases: over-widened on-channel culvert and the distributed floodplain culverts. For the confined flow case, please note the following:

a. Ineffective flow limits upstream and downstream of the road embankment are placed for flow conditions not overtopping the road. Non-permanent ineffective flow limits can be used if the model is running several flow profiles, whether as part of an unsteady state or steady state flow conditions.
b. Note that in Figure IV-2, sediments deposited beyond the limits of the natural channel width may be represented as depth blocks or obstructions up to a specified depth equal to the top of bank or the bankfull depth, as provided in the geomorphic assessment.
c. The ineffective flow limits are determined from the expansion and contraction of flows upstream and downstream of the road embankment. Typically, 1:1 and 1:2 contraction and expansion coefficients are used upstream and downstream respectively. But consult the HEC-RAS manual and use professional judgement for your project.
d. Figure IV-4 illustrates the ineffective flows for confined on-channel flows.

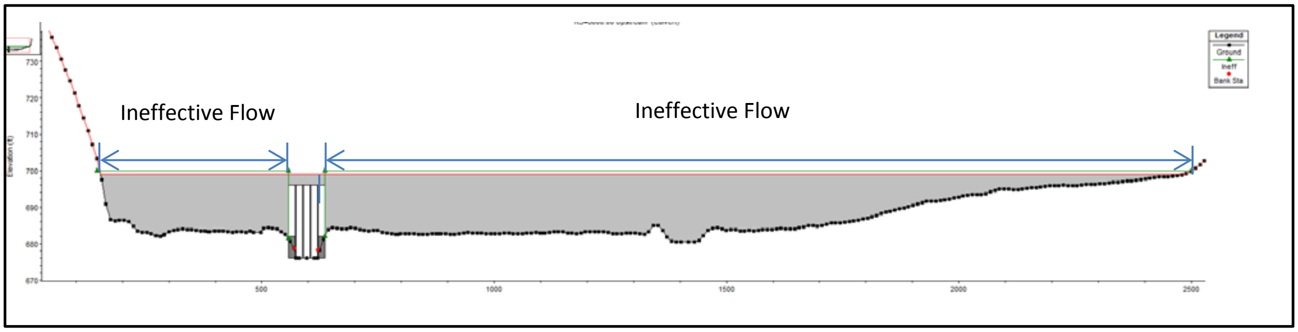


Figure IV-1: Illustration of culvert configuration for floodplain confined flows

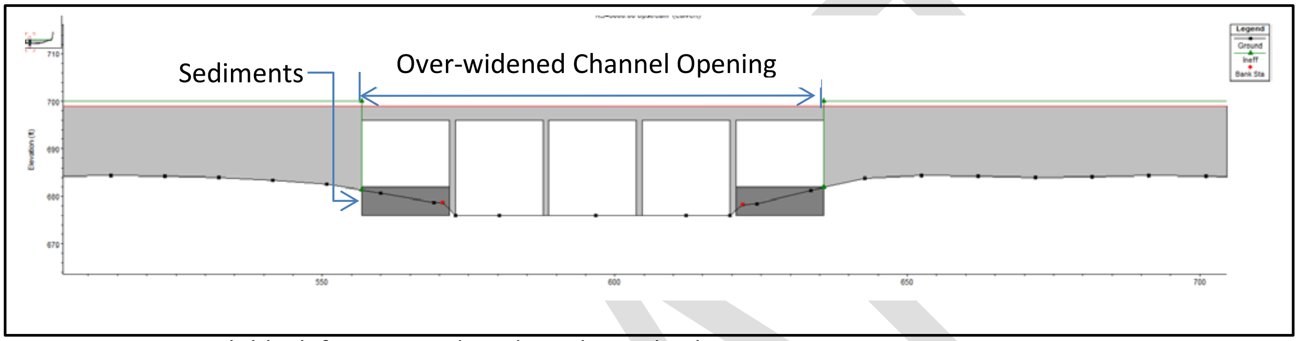


Figure IV-2: Depth block for over-widened on-channel culverts

For the floodplain culverts, please note the following:

a. Ineffective flow limits are determined for each floodplain culvert, the result of which will allow more conveyance through the floodplain. The spacing of floodplain culverts should be specified in a manner that maximizes this conveyance based on the contraction and expansion limits upstream and downstream of the crossing respectively. However, the field conditions and limitations will ultimately control the final spacing.
b. Since the on-channel opening is limited to the bankfull width of the channel, the whole opening would be considered contributing to flow without the need to add any depth blocks due to sediment.
c. Figure IV-5 illustrates the ineffective flows for floodplain culverts. Since the downstream ineffective limits control the culvert spacing, use them to determine the culvert spacing and then check with the upstream locations. As shown in the figure and in contrast to Figure IV-4, placing floodplain culverts “opens-up” the floodplain allowing it to convey more flows through the crossings.

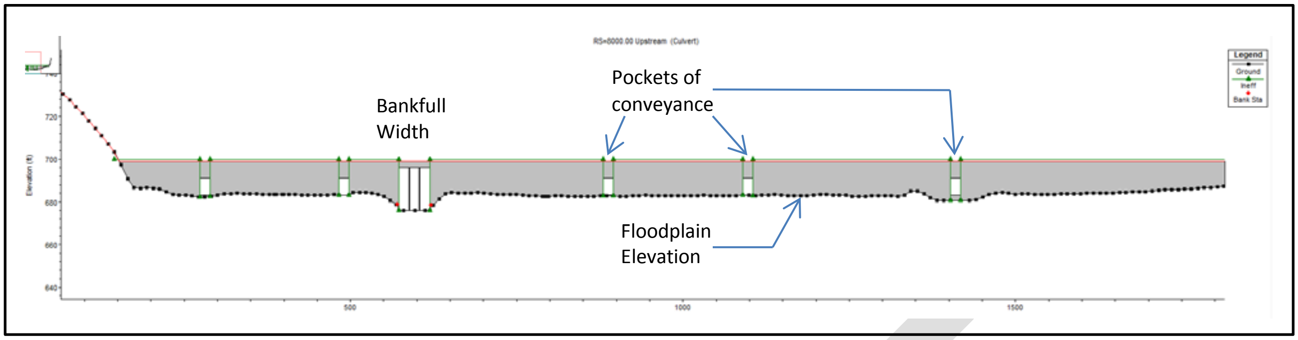


Figure IV-3: Illustration of culvert configuration for distributed floodplain flows

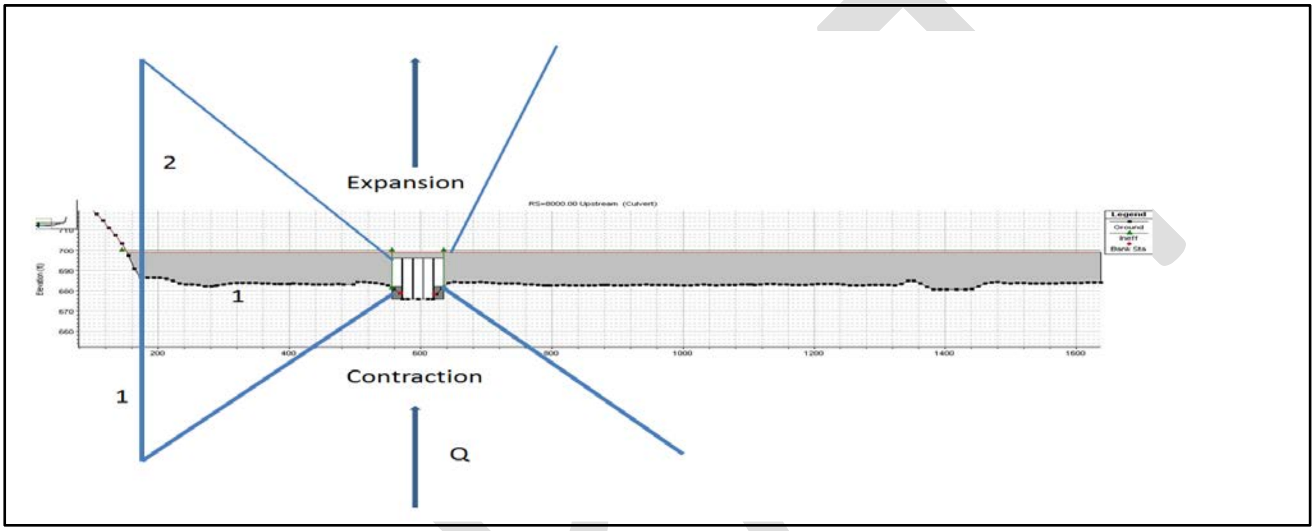


Figure IV-4: Ineffective flow limits for over-widened on-channel culverts

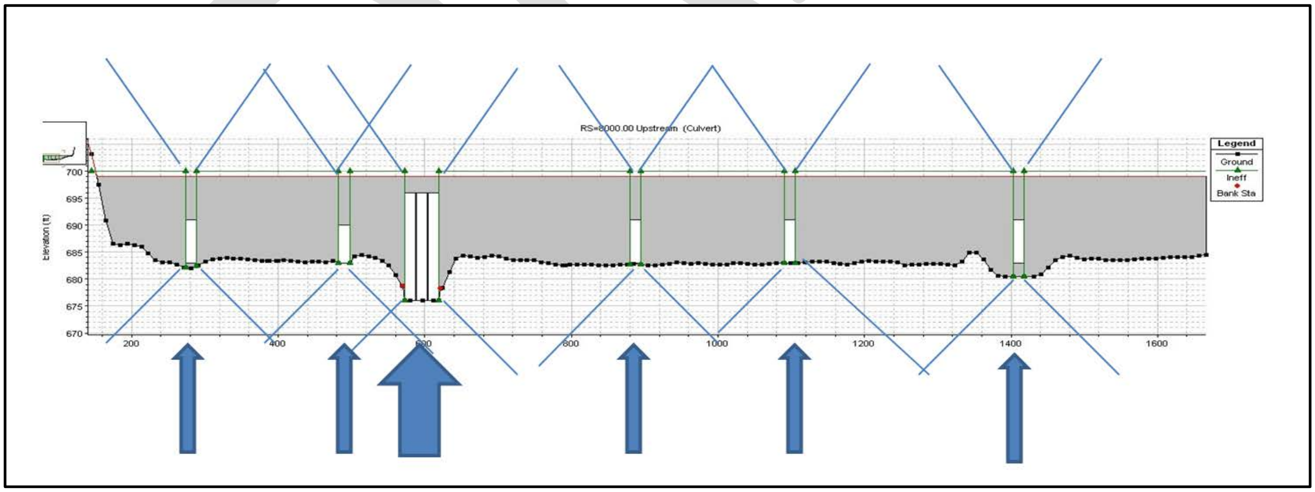


Figure IV-5: Ineffective flow limits for floodplain culverts

2-D models:

2-D models have the advantage of simulating surface water breakouts along a gridded surface without specifying ineffective flow limits. The flow already takes place in both the X and Y axes taking into account the expansion and contraction factors. As a result, the 2D simulation can better assess what is happening around the bridge area. 2-D models such as 2D-SRH allow the user to see specific velocity and shear stress incidences on any designated layer, unlike the 1-D models which usually averages the values across the overbanks.

However, building the model requires more work preparing the gridded surface and representing the channel within that surface, which varies from one model to another. For example, in HEC-RAS 5.0.3, steps are needed to connect the 2D surface to the 1D channel through connectors specified in the model. For the 2-D-SRH (SMS) model, the channel needs to be delineated and meshed separately within the same 2-D (DEM) surface, choosing between either 'paving' or 'patching' mesh types. Consult the models' manuals for more information.

Both the HEC-RAS 5.0.3 and 2D-SRH can simulate 2-D flow around bridges with some notable differences, summarized below:

Table Three: Comparison between HEC-RAS 5.0.3 and 2D-SRH (SMS)

Feature	HEC-RAS 5.0.3	2D-SRH
Bridges	Crossings can only be represented using 2D-connectors but not through the 'Bridge Culvert Data".	For multi-channel openings, can use the HY-8 program to enter bridge information
2-D Flow	Channel flow is 1-D only	Channel flow can be 2-D based on the node density and specified grid mesh
Type of Gridded Surface	Square grids specified within each polygon	TIN mesh generated according to nodal distribution
Type of Flow Condition	Unsteady state condition	Steady and Unsteady State conditions
Cost	Free! Downloadable from the USACE website	Purchased from Aquaveo

Figures IV-6 and IV-7 illustrate how distributed floodplain culverts are represented in the mesh using 2D-SRH (SMS) model, for two different projects. In both projects, the bridge and culverts are entered after drawing 'arcs' on the grid to represent the inlet and outlet, as shown in Figures 8 through 11. Then after selecting each arc and launching the HY-8 program, the bridge/culvert data can be specified. The HY-8 tool can be launched within the 2D-SRH 'boundary condition' coverage. The width of the on-channel opening can then be varied by changing the elevation of the individual grid elevations within the same model domain, in order to compare the two cases; the confined on-channel culvert condition versus the distributed flow. Another way is to use two different grid surfaces, one for each scenario.

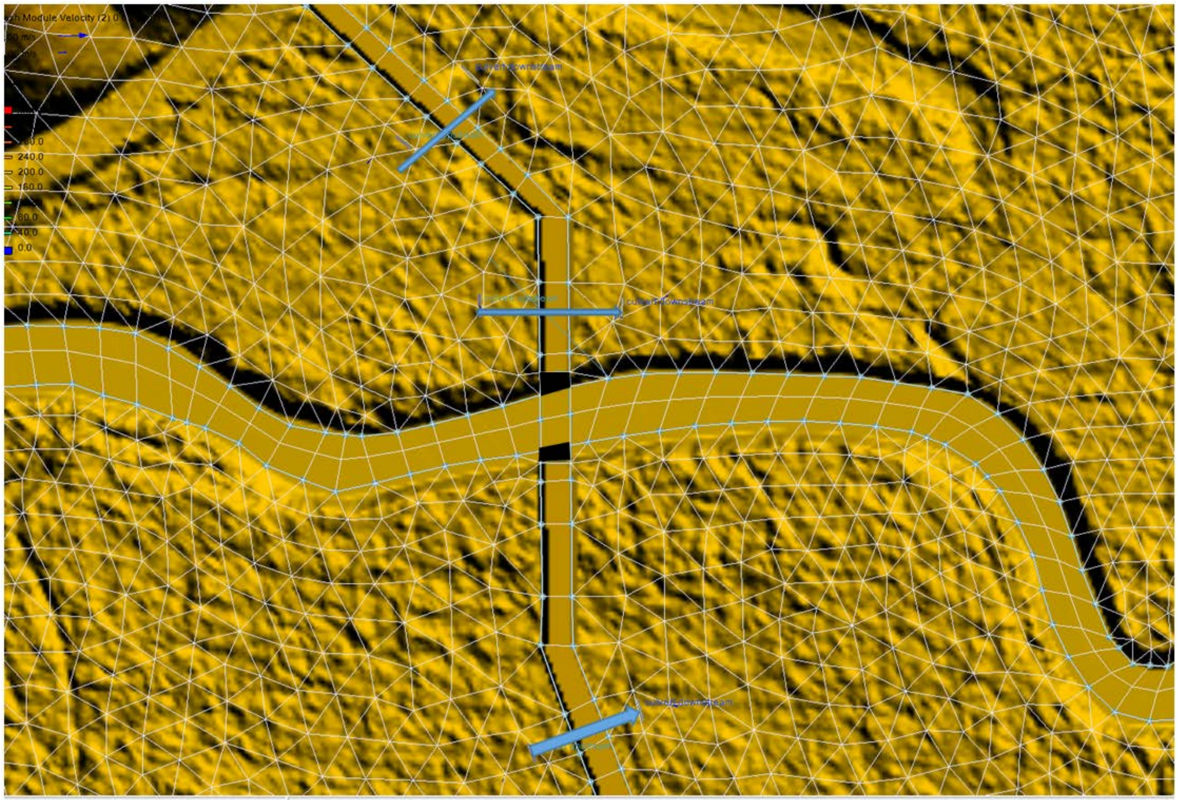


Figure IV-6: Floodplain culverts for the Lower Whitewater River, Winona County.

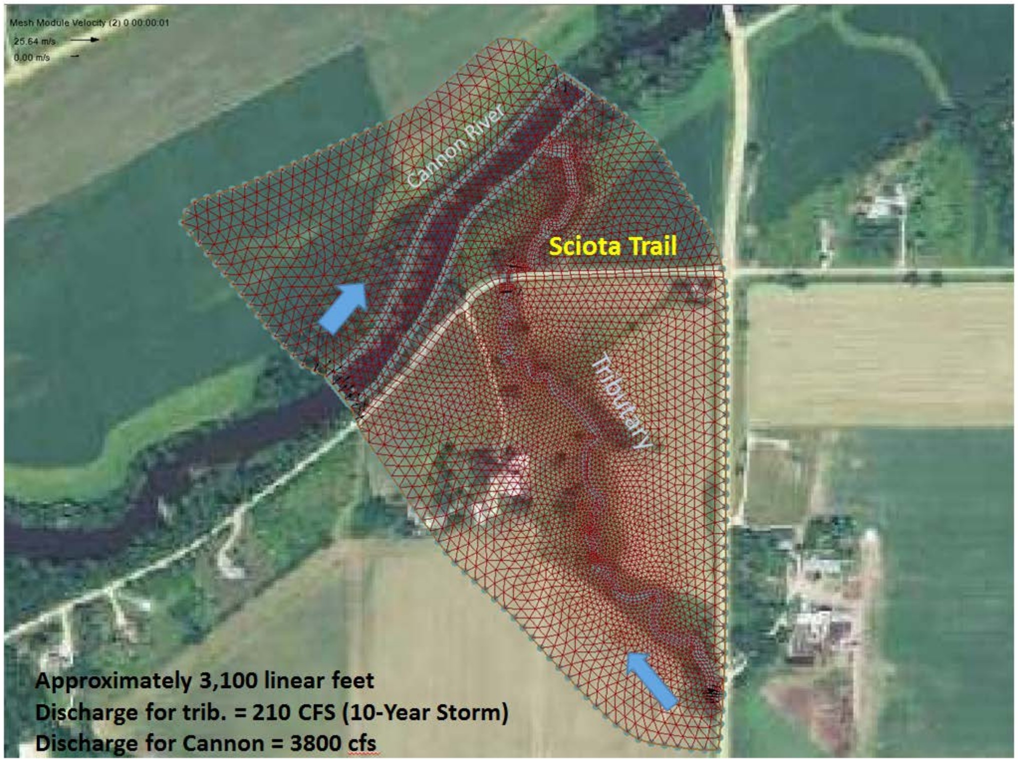


Figure IV-7: Floodplain Culverts for Sciota Trail, Sciota Township, Dakota County.

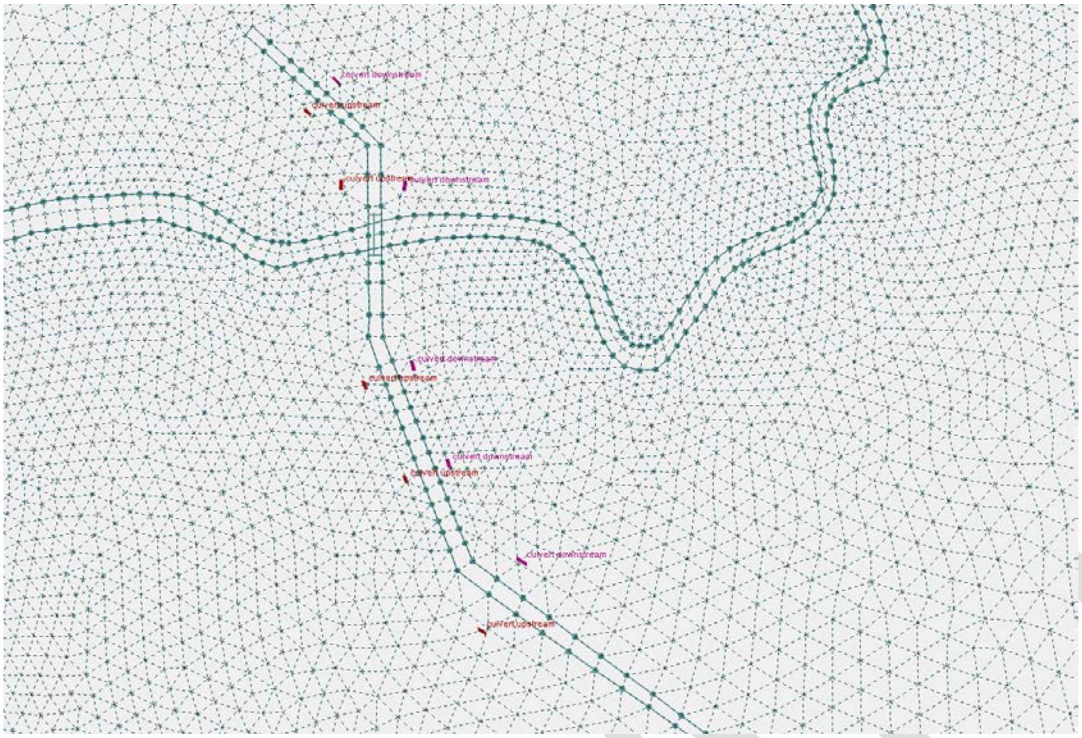


Figure IV-8: Grid showing arcs representing the on-channel and two floodplain culverts for the Whitewater lower reach model

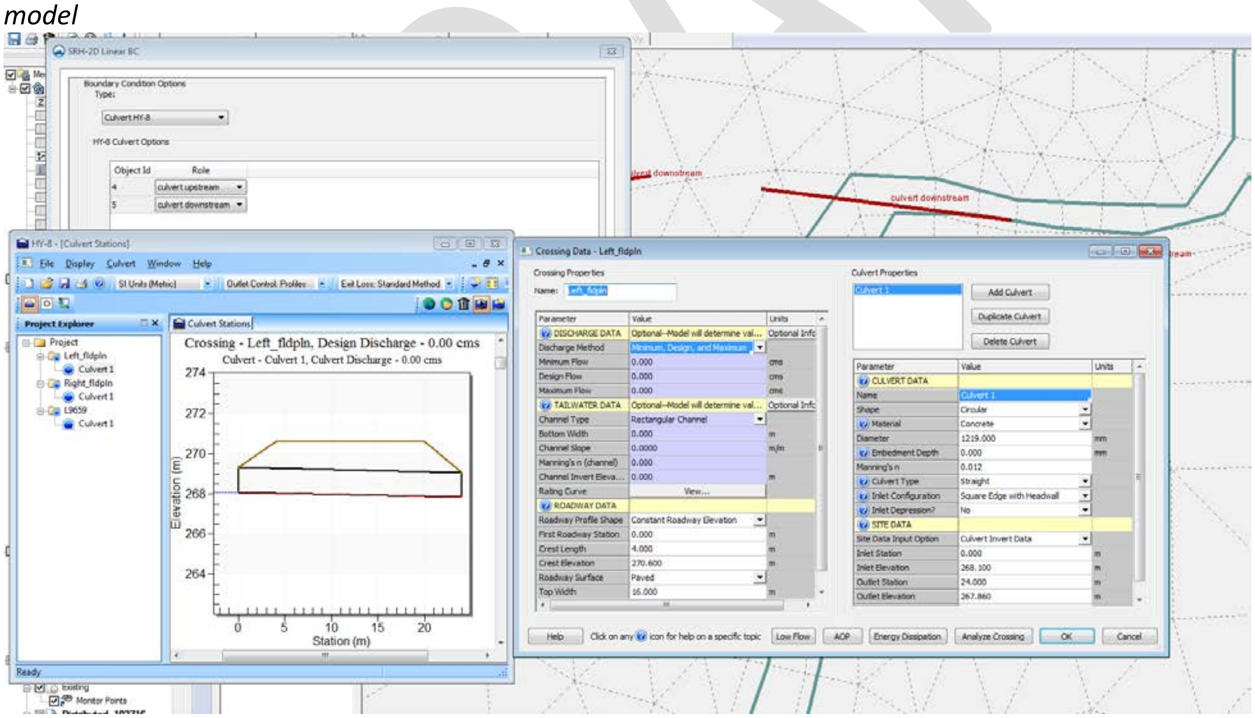


Figure IV-9: Using Hy-8 tool to enter bridge/culvert data in 2D-SRH (SMS) for the Whitewater lower reach model

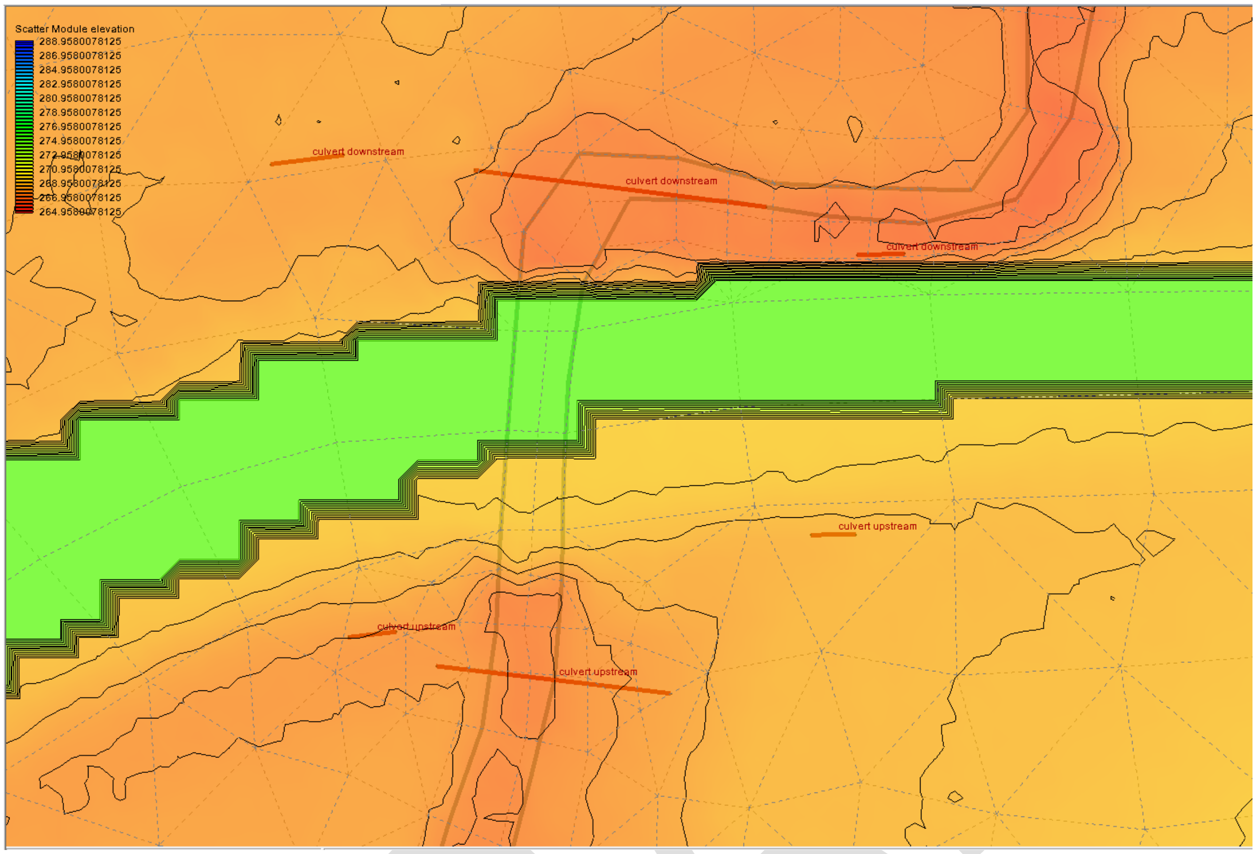


Figure IV-10: grid showing arcs representing the on-channel and two floodplain culverts for Sciota Trail

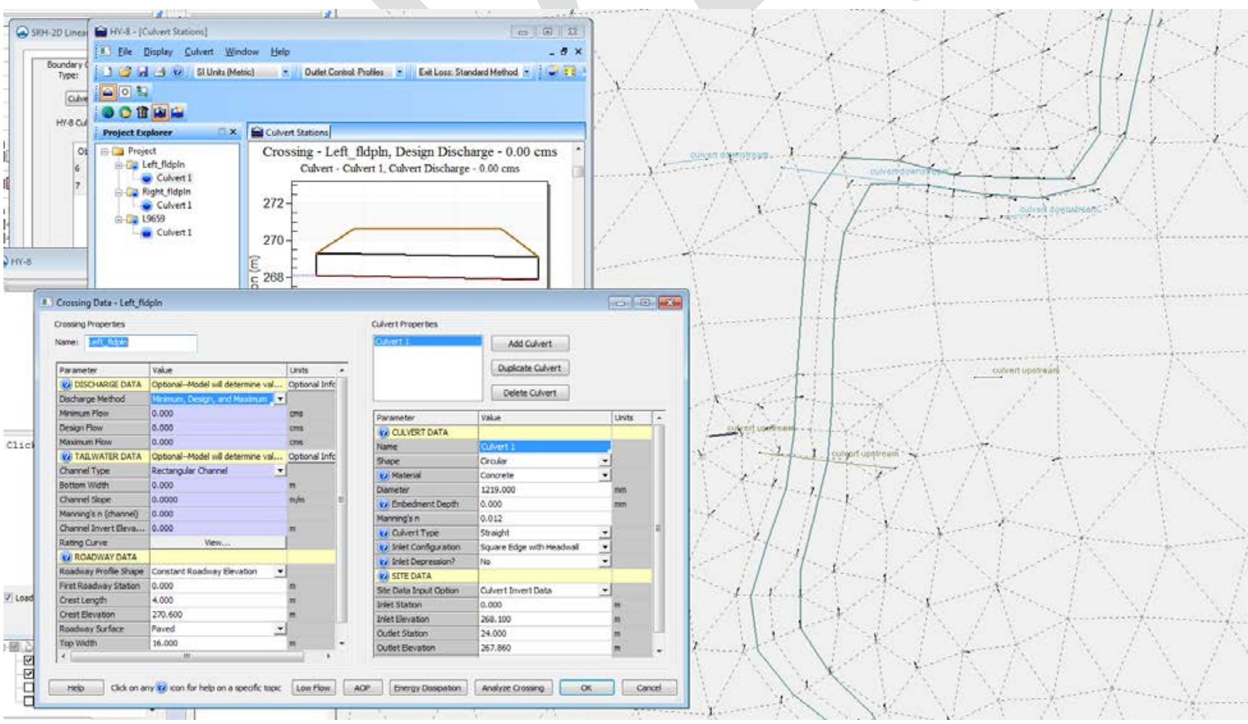


Figure IV-11: Using Hy-8 tool to enter bridge/culvert data in 2D-SRH (SMS)

HEC-RAS - Bank Stability and Toe Erosion Model (BSTEM):

BSTEM, which is part of the HEC-RAS 5.0.3 package can be used as an additional tool to simulate sediment transport. The program determines the risk of bank planar failure and toe scour, allowing for the vertical erosion or deposition to take place at specified cross-sections. BSTEM capabilities have been recently incorporated into HEC-RAS 5.0 to simulate the sediment processes taking place on river banks, in addition to the channel bed. The simulation can take place using 1-D and quasi-unsteady state flow conditions. For information about the algorithm used and applications, please consult the most recent HEC-RAS 5.0 Manual. Please note that HEC-RAS already runs sediment transport for channel beds only. So, the addition of BSTEM will allow for sediment transport interactions to take place between the channel bed and banks.

The following information is needed to run BSTEM:

- The limits of the toe and edge stations for the left and right banks.

- Sediment gradations for the left and right banks, in addition to the channel bed.

- Groundwater elevation (static elevation)

- Material properties such as the saturated unit weight, friction angle, cohesion, phi b, critical shear stress and erodibility.

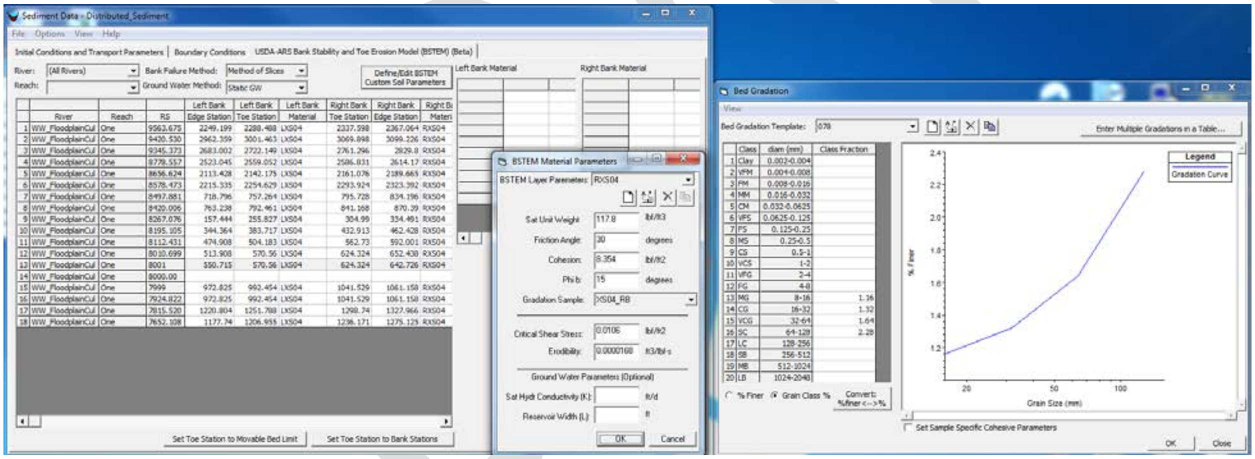


Figure IV-12: BSTEM sediment data in HEC-RAS

c. Hydraulic Analysis:

The following parameters were used in our analysis to quantify benefits of using floodplain culverts and to assess its relatively reduced impact when compared to no-road conditions. The modeling results analyzed are:

- Water surface elevation
- Channel velocity
- Channel shear stress
- Energy gradient of the channel

Note: The 1% annual chance elevation, also known as the Base Flood Elevation (BFE) is an important FEMA zone consideration. If the project site is located in a designated Special Flood Hazard Area (SFHA), it must comply with local, State and FEMA requirements. Velocity and shear stress parameters both contribute to the sediment transport processes. Energy gradient slope along the channel can assess changes in longitudinal connectivity, especially through the roadway.

This section provides examples of typical responses that confined versus distributed flows have on the above parameters using the following modeling conditions listed below. As a result of using different modeling methods, the response of each model will be assessed differently based on the model capabilities and the given site.

- Steady state
- Unsteady state
- 2-D un-steady state

The table below lists the project used:

Table Four: List of project sites in this report

Project Site	Simulation	Parameters
CSAH 7 and Redwood River, Lincoln County	Steady State Condition (HEC-RAS), 1% annual chance flow	WSEL, Velocity, Shear Stress and E.G. Slope
Whitewater lower reach, Winona	Unsteady State Condition (HEC-RAS), 9/2010 Hydrograph (10 Year)	WSEL, Velocity, Shear Stress and E.G. Slope
Whitewater lower reach, Winona	2-D Unsteady State (2D-SRH), 9/2010 Hydrograph (10 Year)	Water Depth, Velocity and Shear Stress

Water Surface Elevation (WSEL):

Figure IV-13 is a water surface output for a 1% annual chance discharge event on a proposed bridge replacement, in Lincoln County, using <u>1-D steady state flow conditions</u>. The three (3) lines represent:

- Existing, in place road conditions *(_Exist)*
- Applied land form conditions *(_Dist)*
- No Road Conditions *(_nobridge)*

The graph below indicates that by increasing the conveyance through the distributed floodplain culverts, the WSEL decreases upstream of the embankment but increases slightly just downstream, which is expected as the channel attempts to adjust to a more connected flow and a smoother transition through the bridge. The No Bridge scenario, shown in blue, represents the ideal case or the natural channel condition without any obstruction. By comparing to the natural channel condition, confining the flow to the channel would cause the channel to depart from its natural condition causing the roadway embankment to back-up flow upstream while increasing the velocity downstream, thus upsetting the equilibrium of the natural system. As a result, applying land form metrics increases conveyance through the installation of floodplain culverts.

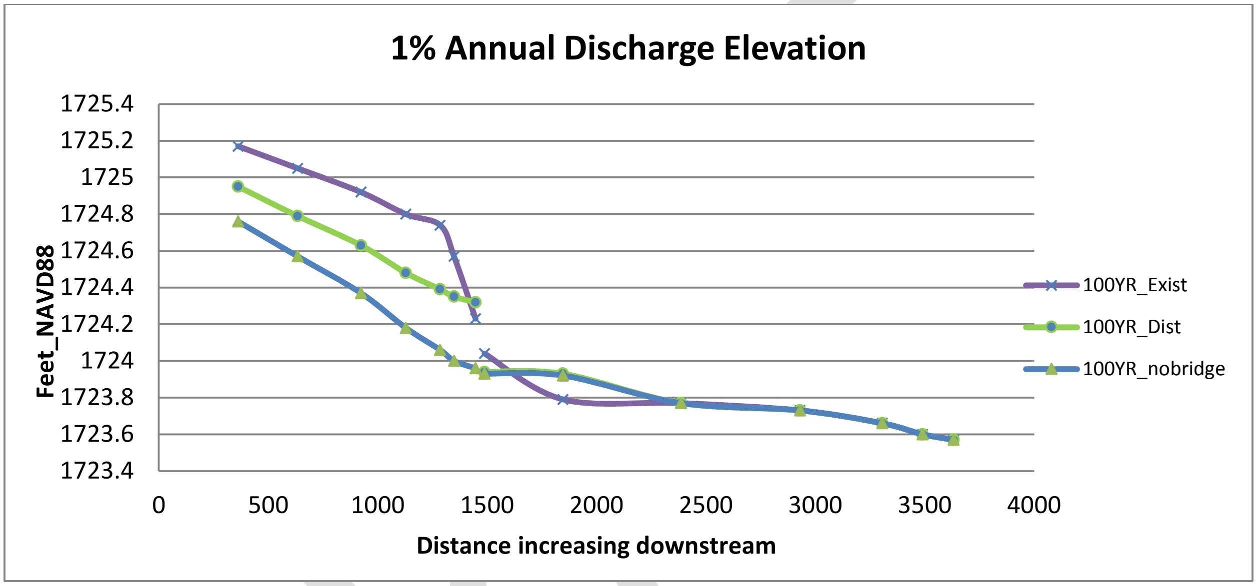


Figure IV-13: Effects of proposed floodplain culverts on the 1% annual chance flow elevation using steady state conditions for the CSAH 7 Redwood River replacement bridge, Lincoln County

Figure IV-14 shows the effects of proposing floodplain culverts on the water surface elevation for a hypothetical bridge replacement, using 1-D unsteady state flow conditions. This bridge was the subject of the study published in the following link:

http://www.dnr.state.mn.us/eco/streamhab/geomorphology/index.html

Based on the unsteady state hydrograph (10-Year peak flow), proposing floodplain culverts would decrease the WSEL upstream of the bridge by approximately 2-ft when compared to the confined flow conditions. By comparing both the confined and distributed flow to the natural conditions, proposing floodplain culverts would be considered an improvement. In this example, the improvement was based on the same amount of area of opening for both the confined and distributed flow. So the improvement is only expected to increase as the floodplain culvert openings become larger.

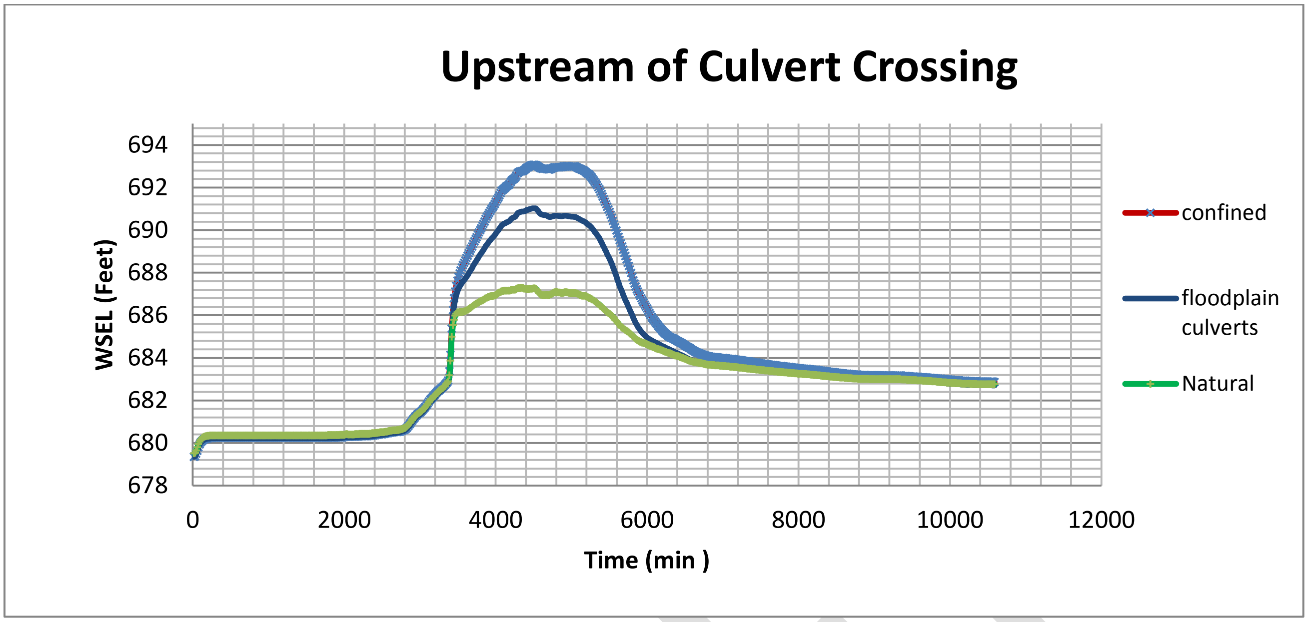


Figure IV-14: Effects of proposed floodplain culverts on the WSEL using unsteady state conditions for the Whitewater lower reach, Winona County

Figure IV-15 shows the effects of proposing floodplain culverts on the water surface elevation along the upstream 'observation' cross-section, shown in yellow in the upper left diagram, for a hypothetical bridge replacement, using 2-D unsteady state flow conditions. Consistent with Figure IV-14, the modeling results show that proposing floodplain culverts would be an improvement.

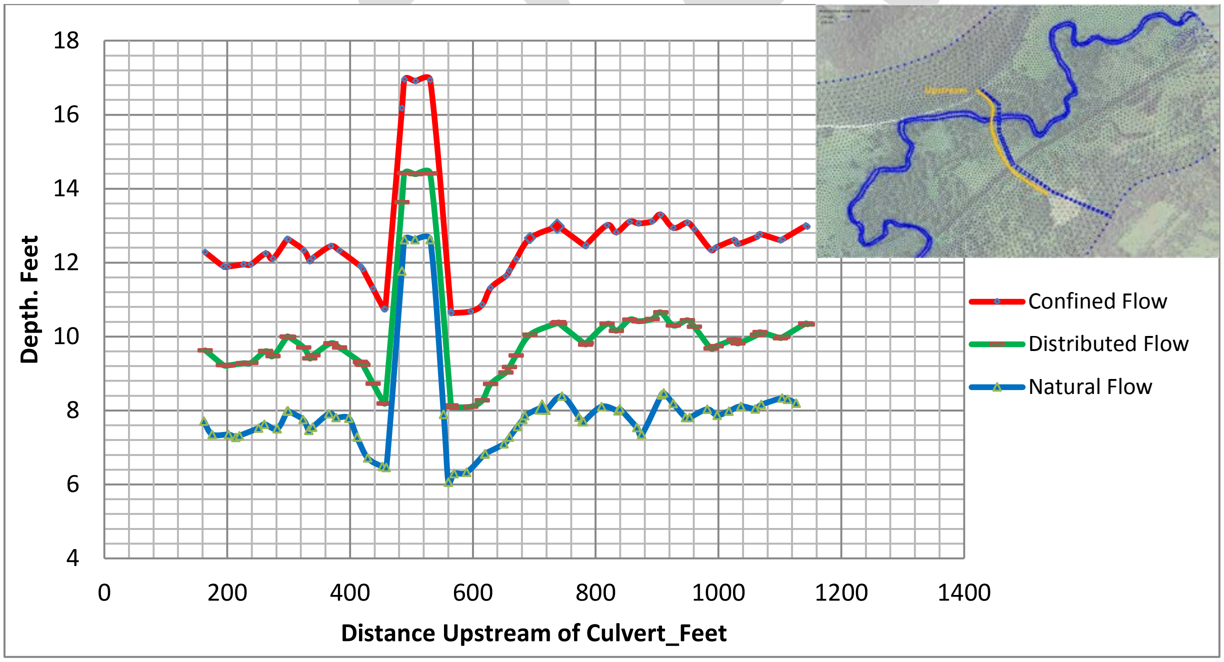


Figure IV-15: Effects of the proposed floodplain culverts on the water depth along the yellow-highlighted upstream cross-section using 2-D and unsteady state conditions for the Whitewater lower reach, Winona County

Velocity

Figure IV-16 shows the effects of proposing floodplain culverts on the velocity profile for the 1% annual chance flow for a proposed bridge replacement project in Lincoln County, using 1-D steady state flow conditions. The graph shows that by increasing the conveyance through the distributed floodplain culverts, the channel velocity adjusts upstream and downstream as the channel becomes more connected, mimicking the velocity profile of the natural condition. Notice that the improvements in velocity are more pronounced than the changes in water surface elevation.

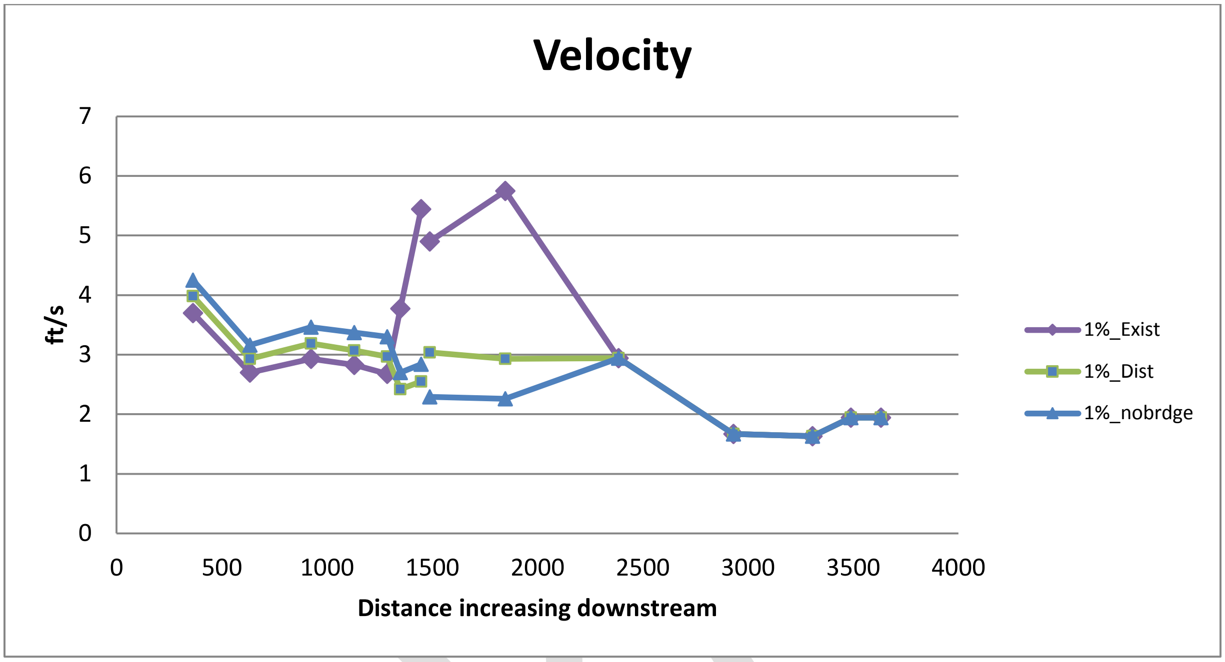


Figure IV-16: Effects of proposed floodplain culverts on channel velocity profile for the 1% annual chance flow under steady state conditions for the CSAH 7 Redwood River replacement bridge, Lincoln County

Figure IV-17 shows the effects of proposing floodplain culverts on the channel velocity profile for the Whitewater lower reach, using 1-D unsteady state flow conditions. Notice how the velocity adjusts rapidly just upstream and downstream of the culvert when compared with the confined flow conditions. The peak flow in the on-channel culvert is expected to further decrease as conveyance through the floodplain increases with increasing floodplain flow areas.

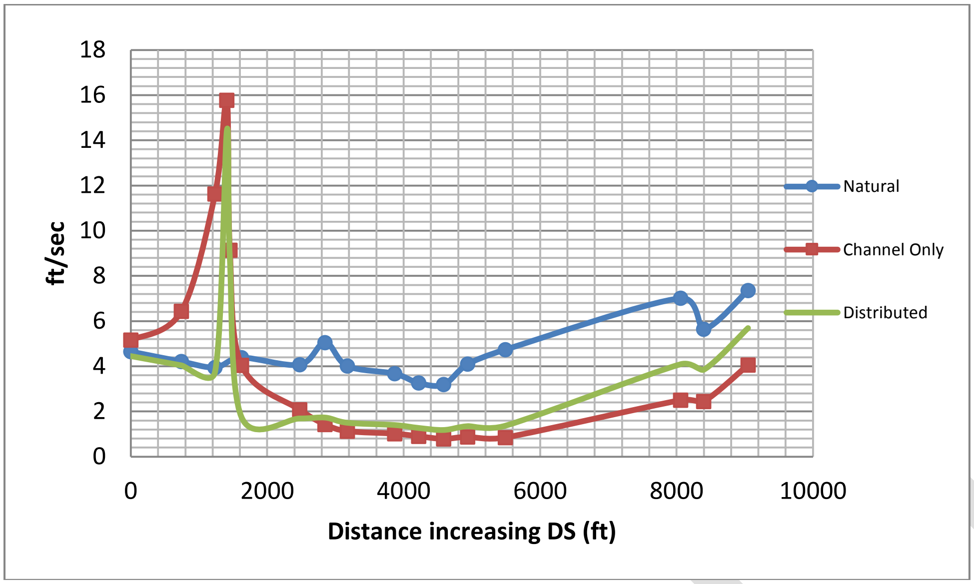


Figure IV-17: Effects of proposed floodplain culverts on the channel velocity profile under unsteady state conditions for the Whitewater lower reach, Winona County.

Figure IV-18 shows the effects of floodplain culverts on the upstream velocity profile represented by the 'observation' cross-section shown in yellow in the upper right diagram for a hypothetical bridge replacement, using 2-D unsteady state flow conditions. The results of the 2-D model allowed us to examine the changes in velocity in more detail across the upstream cross-section. From the graph, distributing the flow along the floodplain reduces the peak velocity in the channel and increases it on the floodplain. We would expect the channel peak velocity to further decrease as the size of the floodplain culverts increases until we reach natural floodplain conditions.

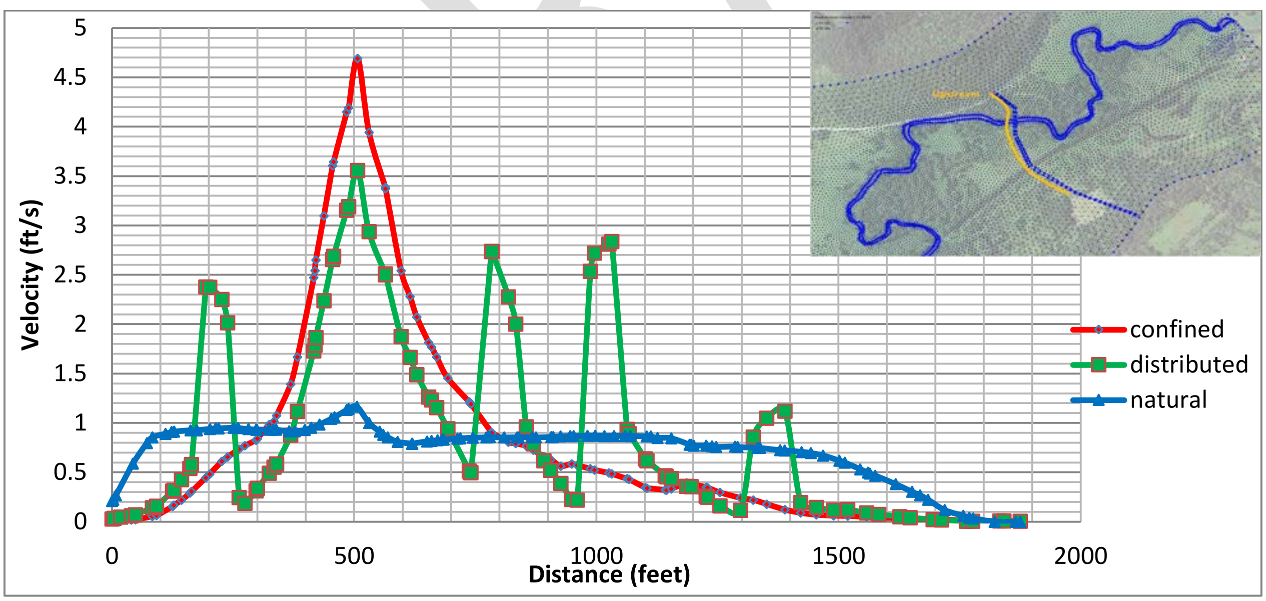


Figure IV-18: Effects of proposed floodplain culverts on the upstream velocity along the yellow-highlighted cross-section using 2-D and unsteady state conditions for the Whitewater lower reach, Winona County

Shear Stress

Figure IV-19 shows the effects of floodplain culverts on the shear stress profile for the 1% annual chance flow for the bridge replacement project in Lincoln County, using 1-D steady state flow conditions. The graph shows that by increasing the conveyance through the distributed floodplain culverts, the channel shear stress decreases significantly. Similar to the velocity profile in Figure IV-16, the improvements in shear stress are more pronounced than the changes in water surface elevation.

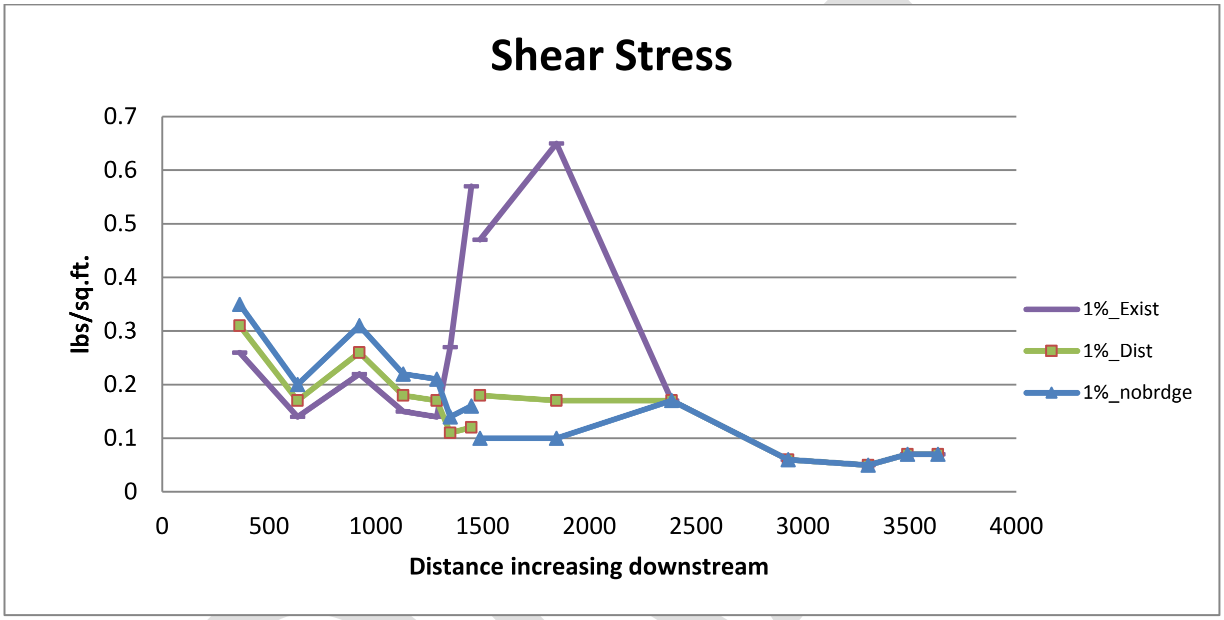


Figure IV-19: Effects of proposed floodplain culverts on channel shear stress profile for the 1% annual chance flow under steady state conditions for the CSAH 7 Redwood River replacement bridge, Lincoln County

Figure IV-20 shows the effects of floodplain culverts on the channel shear stress profile for the Whitewater lower reach, using 1-D unsteady state flow conditions. Increasing conveyance through using floodplain culverts reduces shear stress in the channel by approximately 24%. Furthermore, the response of the peak shear stress is consistent with the velocity profile.

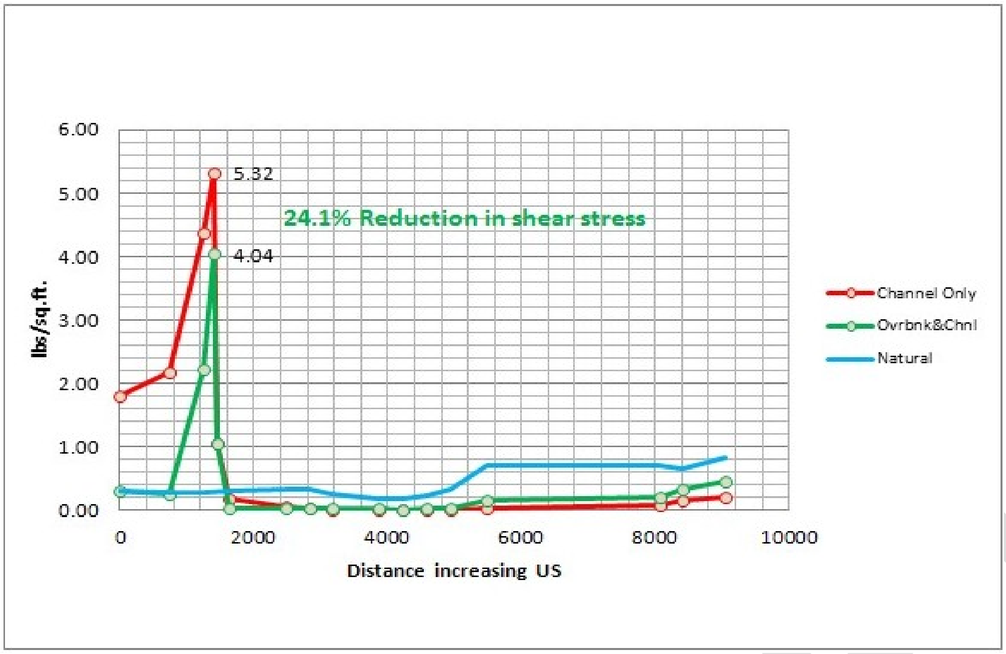


Figure IV-20: Effects of proposed floodplain culverts on the channel shear stress profile under unsteady state conditions for the Whitewater lower reach, Winona County.

Figure IV-21 shows the effects of floodplain culverts on the upstream shear stress profile represented by the 'observation' cross-section shown in yellow in the upper right diagram for a hypothetical bridge replacement, using 2-D unsteady state flow conditions. Similar to the velocity profile diagram shown in Figure IV-18, the results of the 2-D model allowed us to examine in more detail the changes in shear stress across the upstream cross-section. From the graph, distributing the flow along the floodplain reduces the peak shear stress in the channel and increases it on the floodplain.

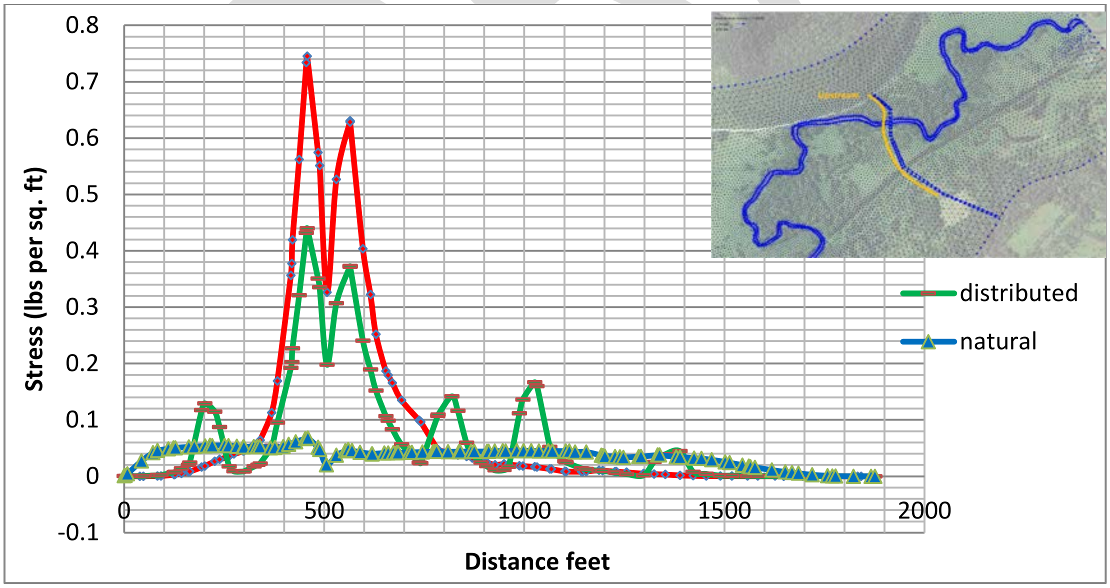


Figure IV-21: Effects of proposed floodplain culverts on the upstream shear stress along the yellow-highlighted cross-section using 2-D and unsteady state conditions for the Whitewater lower reach, Winona County

Energy Gradient

Figure IV-22 shows the effects of floodplain culverts on the energy gradient slope profile for the 1% annual chance flow for the bridge replacement project in Lincoln County, using 1-D steady state flow conditions. The graph shows that by increasing the conveyance through the distributed floodplain culverts, the changes in energy gradient slope become more gradual and smoother, mimicking the natural conditions of the stream.

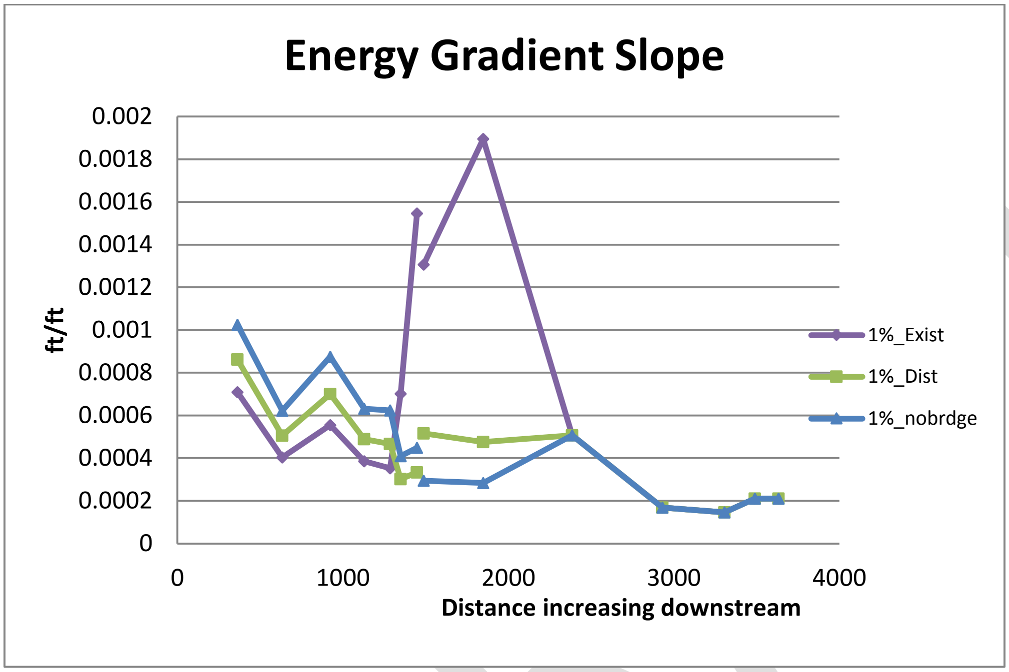


Figure IV-22: Effects of proposed floodplain culverts on the energy gradient profile for the 1% annual chance flow under steady state conditions for the CSAH 7 Redwood River replacement bridge, Lincoln County

d. Local, state and FEMA floodplain requirements

The floodplain related requirements are summarized in the *MNDNR LOMC Process* document. The document was developed by the Floodplain Program, Land Use Unit to address 'development' projects in Minnesota and FEMA regulated floodplains. Please refer to it for related compliance with the local, state and federal requirements. It can be accessed through the following link:

http://files.dnr.state.mn.us/waters/watermgmt_section/floodplain/LOMR%20Guidance_01122017.pdf

Basically, the floodplain requirements depend on the type of FEMA study conducted, FEMA flood zone, and the effects of the project on the established 1-percent annual chance flows and base flood elevations (BFE). Depending on the effects of the project, FEMA zone and hydraulic analysis, the modeling can be conducted as part of a LOMR, CLOMR or No-rise. For no-rise submittals, the hydraulic analysis must be reviewed by the local community having jurisdiction over the floodplain management of that district, such as the county or municipality. Please refer to that document for a list of hydraulic analysis approved by FEMA, certifications required and fees involved. For natural systems and ecological restoration projects, the FEMA fee is exempt. Current efforts are underway to extend that exemption to floodplain bridge/culvert projects as well.

IV. Example Site Reports

a. Sciota

See attached report

b. Redwood Falls

See attached report

c. Hawk Creek

See attached report

d. Jack

See attached report

Glossary:

Please include all potential definitions in your review response

One dimensional hydraulic model: simulate steady or gradually varied channel flow conditions along one direction only between specified cross-sections (HEC-RAS) or nodes (XPSWMM).

Two dimensional hydraulic model: simulates gradually varied (unsteady state) channel flow along two directions (x- and y- directions) using a gridded geometry.