REVIEW OF HYDRAULIC MODELING

MISSOURI RIVER BNSF BRIDGE – BISMARCK / MANDAN, ND

September 18, 2020

ACKERMAN ESTVOLD

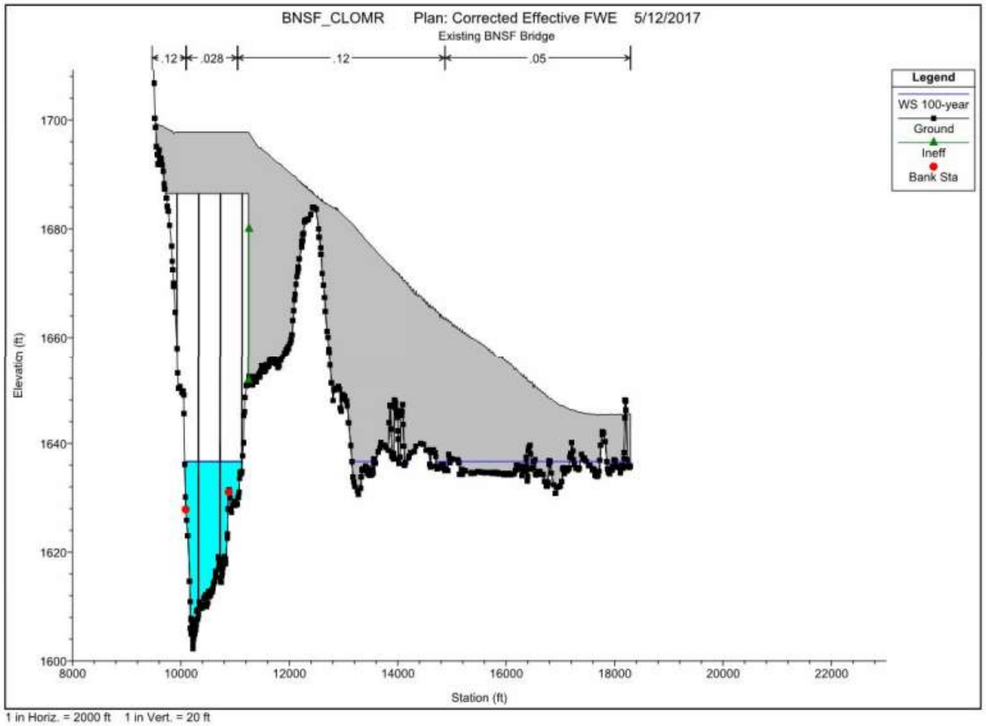
OUTLINE OF OBSERVATIONS

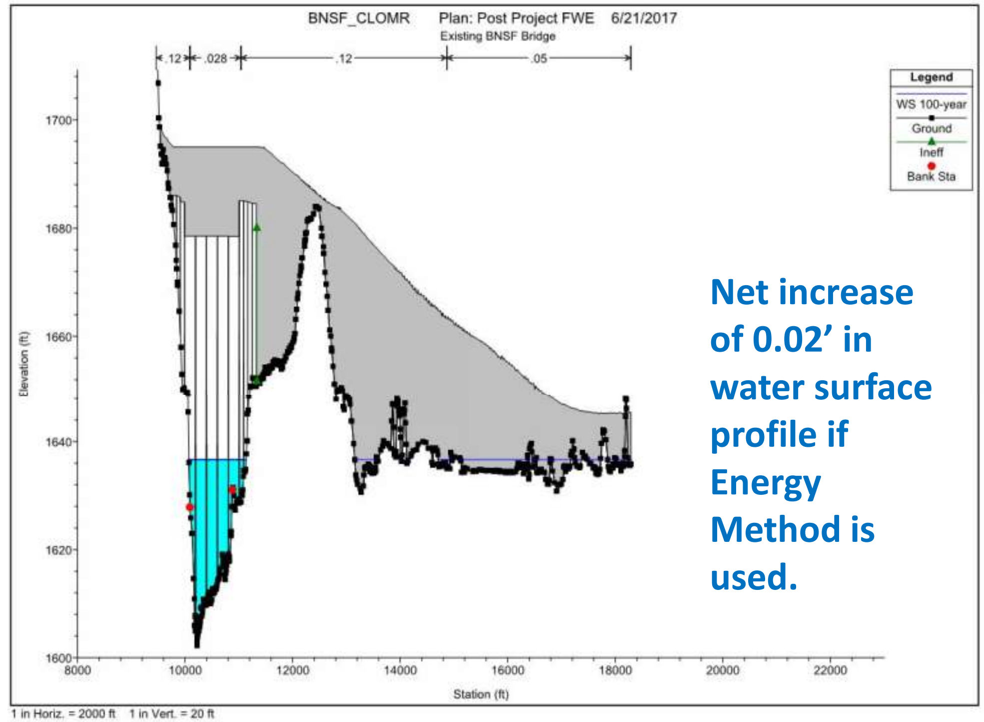
- Review of Conditional Letter of Map Revision (CLOMR) Submittal to FEMA
- Review of BNSF Concept 3 – Existing Bridge Remains / New Bridge 42.5 Feet Upstream
- BNSF Concept 3 Impact Mitigation
- Alternative Hydraulic Modeling Approach (2-Dimensional Modeling)

Review of Conditional Letter of Map Revision (CLOMR) to FEMA

- CLOMR computations based on HEC-RAS model used by FEMA for Flood Insurance Study
- Appears to be two submittals:
    - Submittal 1 - indicated 0.02-foot rise with 64 structures impacted
    - Submittal 2 - compares BNSF preferred option to existing conditions to indicate ‘no rise’
- Notable difference is in how bridge losses are computed (1 – Energy Equation; 2 – Yarnell Equation)
- Submittal 2 uses **Yarnell K=1.15 for Existing Bridge** and K=1.05 for BNSF Preferred Option
    - This means that the model treats the preferred option as a more hydraulically efficient option than the existing option (lower K values indicate lower friction losses)

Review of Conditional Letter of Map Revision (CLOMR) to FEMA





- Existing Conditions
  - Gross width of piers is 40 feet in water
- Proposed Conditions
  - Gross width of piers is 60 feet in water after existing bridge is removed

Review of Conditional Letter of Map Revision (CLOMR) to FEMA

Because the BNSF Preferred Option has more blockage, the only way the Yarnell method will show “no rise” is to choose Yarnell coefficients where with the coefficient for the existing bridge is higher (less efficient) than the Preferred Option.

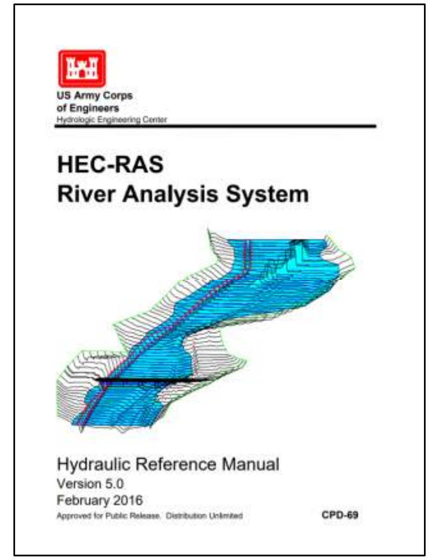


Table 5-4

Yarnell's pier coefficient, K, for various pier shapes

Chapter 5– Modeling Bridges

Pier Shape	Yarnell K Coefficient
Semi-circular nose and tail	0.90
Twin-cylinder piers with connecting diaphragm	0.95
Twin-cylinder piers without diaphragm	1.05
90 degree triangular nose and tail	1.05
Square nose and tail	1.25
Ten pile trestle bent	2.50

Review of Conditional Letter of Map Revision (CLOMR) to FEMA

The CLOMR states that the existing piers have a semi-circular tail and that "while the nose incorporates a sharp ice nose form, it is relatively wide with potential to act as a square nose, and is not vertical to the surface of the water." This is used in the CLOMR to justify a less efficient K coefficient of 1.15.

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The Yarnell equation is as follows (Yarnell, 1934):

$$H_{3-2} = 2K(K + 10\omega - 0.6)(\alpha + 15\alpha^4)\frac{V_2^2}{2g} \qquad (5\text{-}4)$$

Where: H_{3-2} = Drop in water surface elevation from section 3 to 2

K = Yarnell's pier shape coefficients

ω = Ratio of velocity head to depth at section 2

Term that includes pier width → α = Obstructed area of the piers divided by the total unobstructed area at section 2

V_2 = Velocity downstream at section 2

- **An argument can be made that the existing pier configuration is more hydraulically efficient than what is proposed**

Review of Conditional Letter of Map Revision (CLOMR) to FEMA

Preferred Option piers could be less efficient than existing piers.

If K=1.00 for existing bridge, K=1.05 for Preferred Option, Preferred Option will cause a 0.01-ft rise

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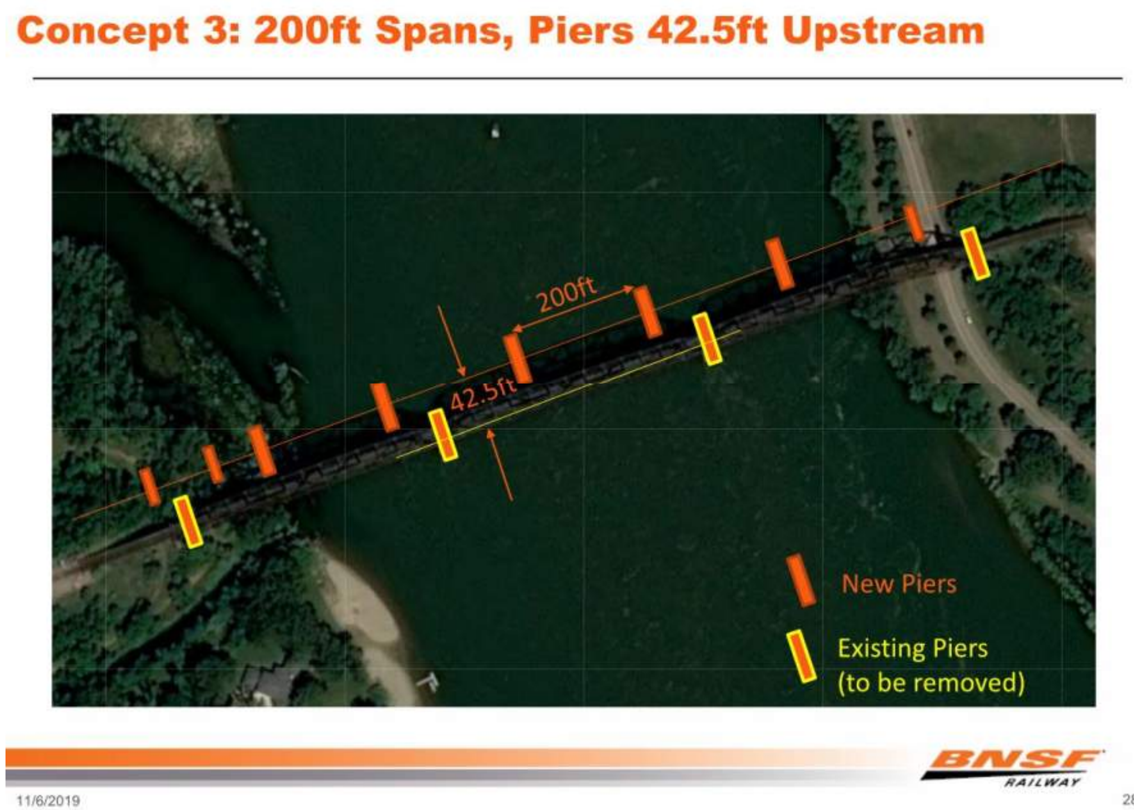
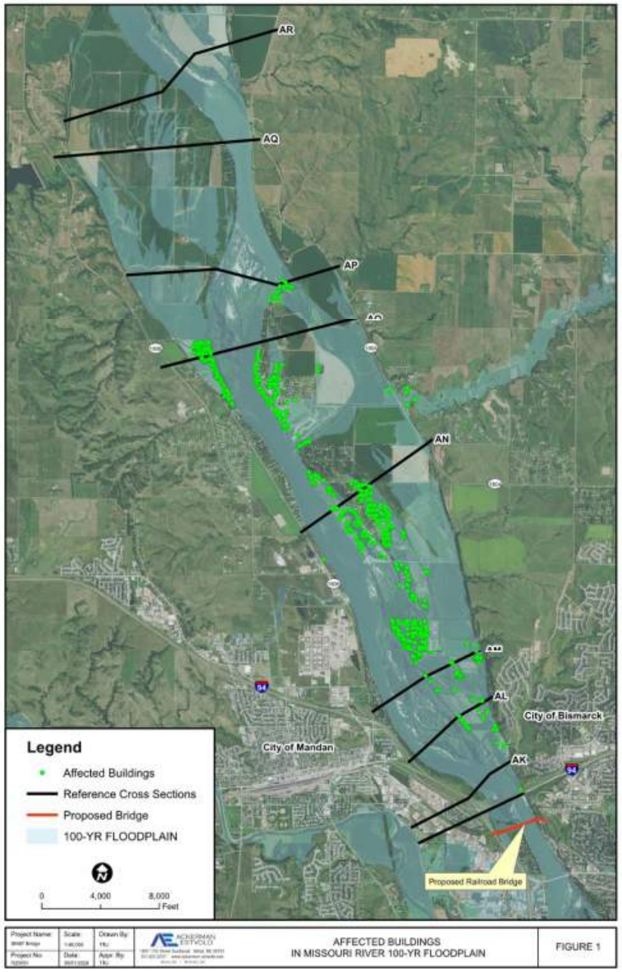
Review of BNSF Concept 3 – Existing Bridge Remains / New Bridge 42.5 Feet Upstream

- Possible compromise solution
- Able to accept two new tracks
- Results in 0.03-ft upstream rise based on One-Dimensional HEC-RAS model
- Increased construction cost and schedule



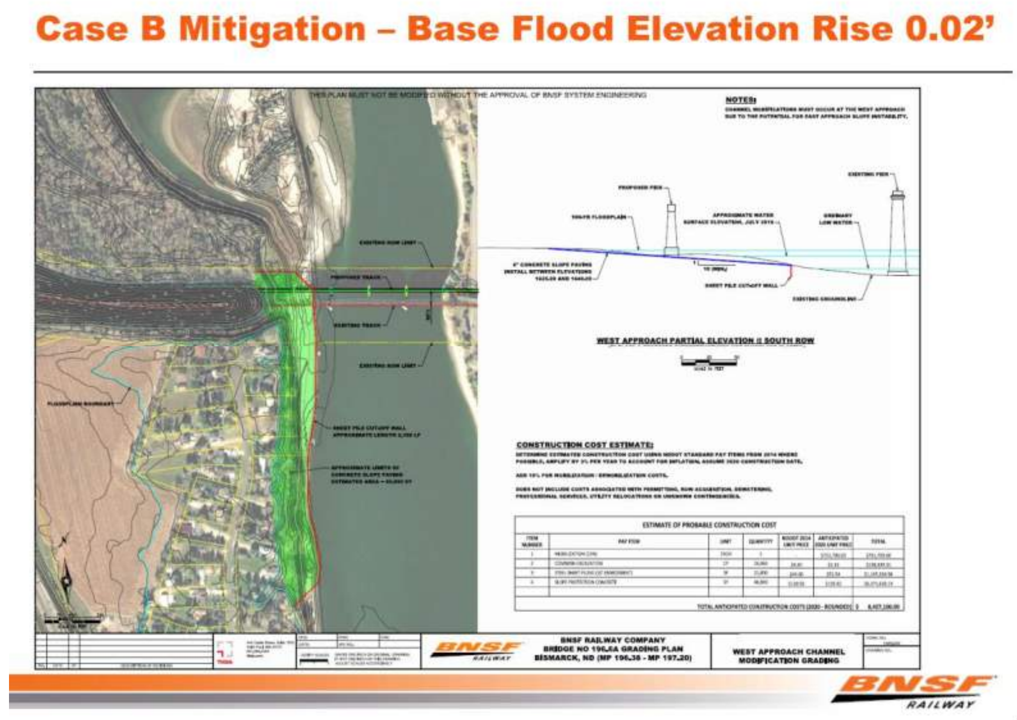
Review of BNSF Concept 3 – Existing Bridge Remains / New Bridge 42.5 Feet Upstream

- Results of One-Dimensional HEC-RAS Modeling & Mapping
    - 0.03-ft upstream rise upstream of bridge
    - 552 structures potentially affected
    - All 552 structures are currently in the 100-year floodplain
    - 317 structures the rise is less than 3/8 inch
    - 235 structures the rise is less than 1/4 inch



BNSF Concept 3 Impact Mitigation – BNSF Mitigation Concept

- Reduce water surface profile to eliminate modeled rise
- BNSF evaluated solution to pave ¼ to ½ mile of beach to mitigate 0.02′ rise
- ~$8.4 M Cost
- More expensive to mitigate 0.03′ rise
- Likely socially and environmentally unacceptable



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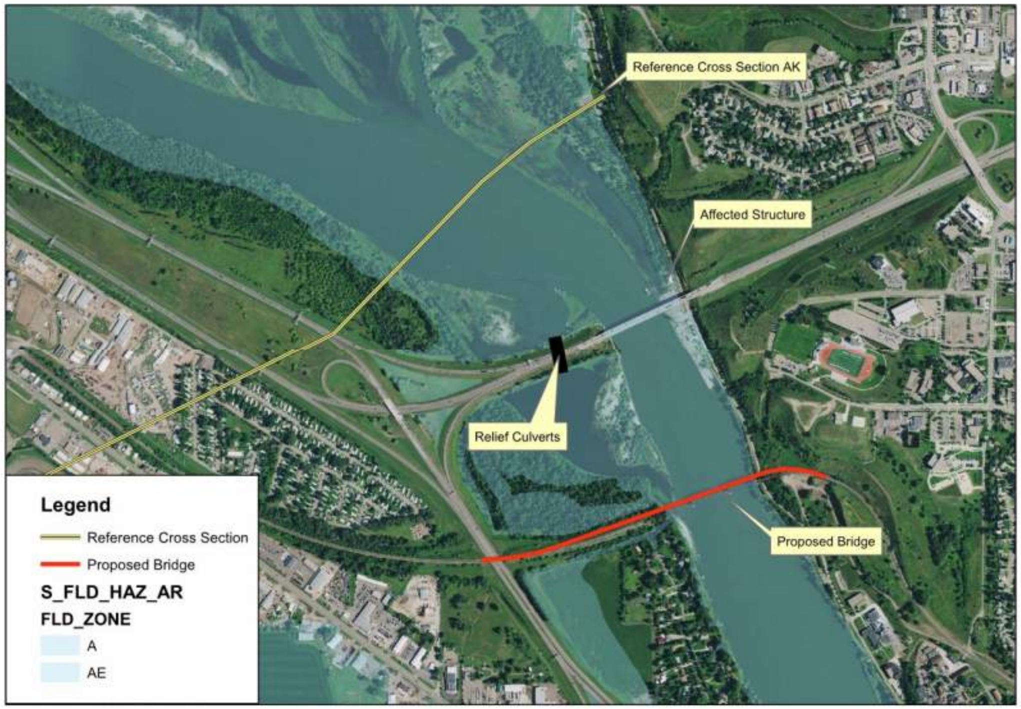
BNSF Concept 3 Impact Mitigation – Alternative Mitigation Concept

- Results Based on One-Dimensional HEC-RAS Model
  - Reduce water surface profile to eliminate modeled rise
  - Provide three 12-ft relief culverts through Interstate 94 embankment
  - Cost $5M to $10M
  - Enhance floodplain hydraulics
  - Provide wildlife passage across I-94 corridor
  - Possibly affect 1 structure – increase BFE less than 1/2-inch on posts of deck/boat dock



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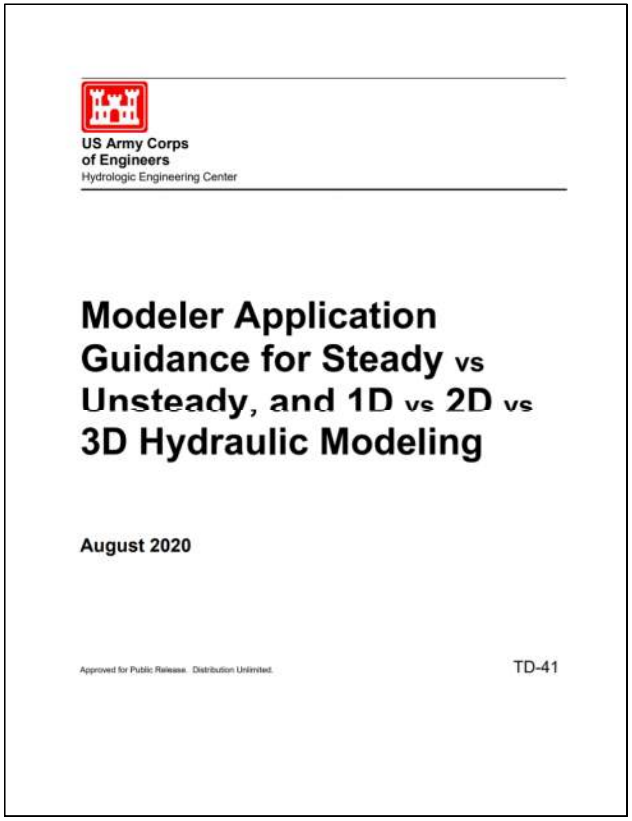
Alternative Hydraulic Modeling Approach (2-Dimensional Modeling)

2D Modeling Advantages:

- The flow path of the water, for all events, does not have to be known to develop the model. However, the extent of the flooding does need to be correctly defined.
- The direction of the flow can change during the event. Water can move in any direction, based on energy and momentum of the flow.
- Velocity, momentum, and the direction of the flow are more accurately accounted for with 2D modeling. This accountability is especially true for flow going over roads, levees, barriers, structures, around bends, and at flow junctions/splits. Additionally, 2D models can be used to analyze eddy zones within the flow field. Around bends, 2D models produce accurate water surface elevations, but velocity distributions might be erroneous due to the existence of helical flow.
- Energy and force losses due to contractions and expansions, etc. are directly accounted for, and do not require empirical coefficients, increased roughness, or user defined ineffective flow areas.
- The mapping of the inundated area, as well as velocities, and flood hazards (depth x velocity) is more accurate.
- Detailed modeling of hydraulic structures, in a full 2D modeling approach, can provide more insight into the flow distribution approaching, going through, and coming out of a structure.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Modeler Application Guidance for Steady vs Unsteady, and 1D vs 2D vs 3D Hydraulic Modeling

August 2020

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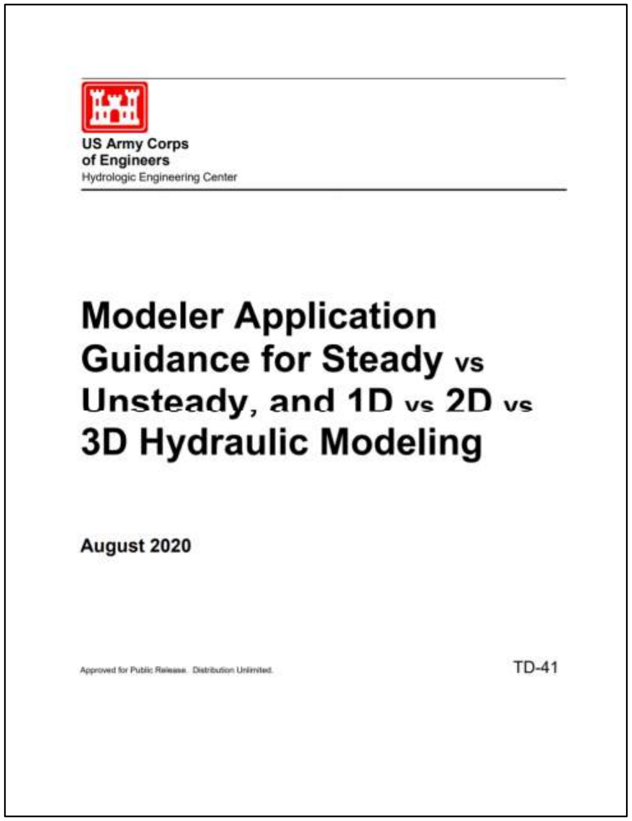
Alternative Hydraulic Modeling Approach (2-Dimensional Modeling)

2D Model Disadvantages:

- More accurate and detailed terrain models are required in order to develop an accurate 2D model. The terrain must include the details of the channels at all locations within the model as well as correctly capturing features such as roads, berms and levees. Overly filtered LiDAR data sets or data sets that have been processed at too large of a grid size may not properly resolve these key terrain features that influence flow behaviors and patterns.
- Defining and modifying roughness values requires more spatial definition, and can be more difficult and time consuming during the calibration process.
- Requires significantly more computational time and/or computational resources. May require the purchase of a very high level computer (many cores, fast CPU's, lots of RAM, and fast hard disk), or utilizing HPC and cloud computing solutions.
- May require using larger grid sizes than desirable for the problem, in order to reduce the run times to a manageable amount of time.
- May not really produce better results, if the data used to perform the modeling (terrain, channel data, and roughness) do not support the level required for accurate 2D modeling.



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Alternative Hydraulic Modeling Approach (2-Dimensional Modeling)

Existing Bridge and New Bridge 42.5-feet Upstream - Two-Dimensional Modeling

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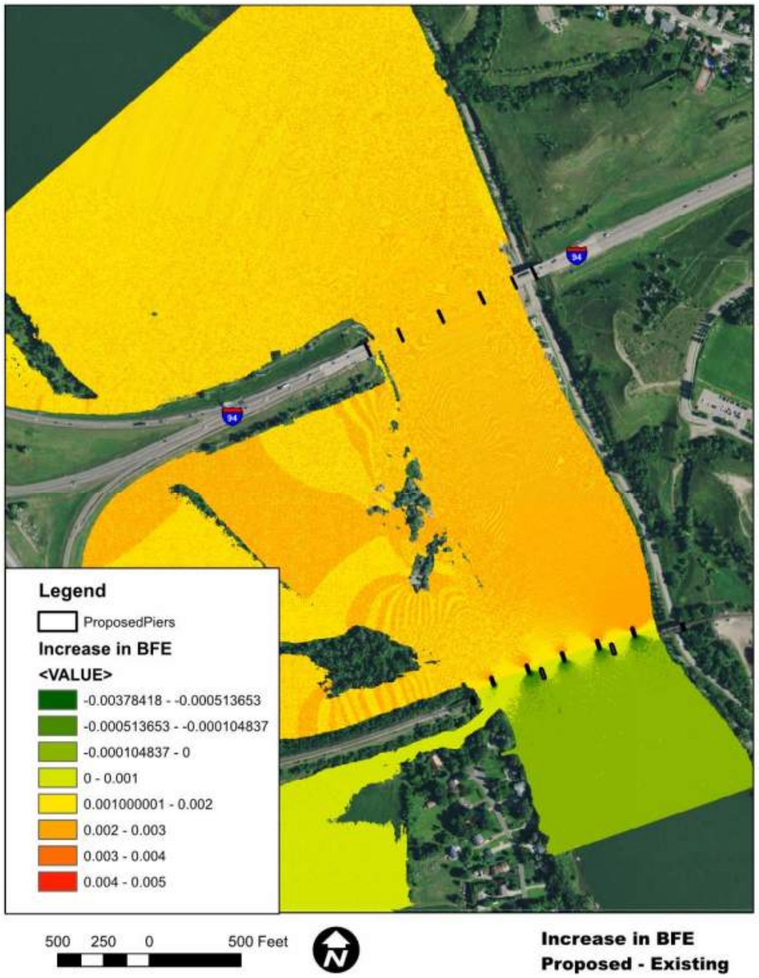
Alternative Hydraulic Modeling Approach (2-Dimensional Modeling)

- Shows less than 0.003-ft upstream rise (1/32 of an inch)



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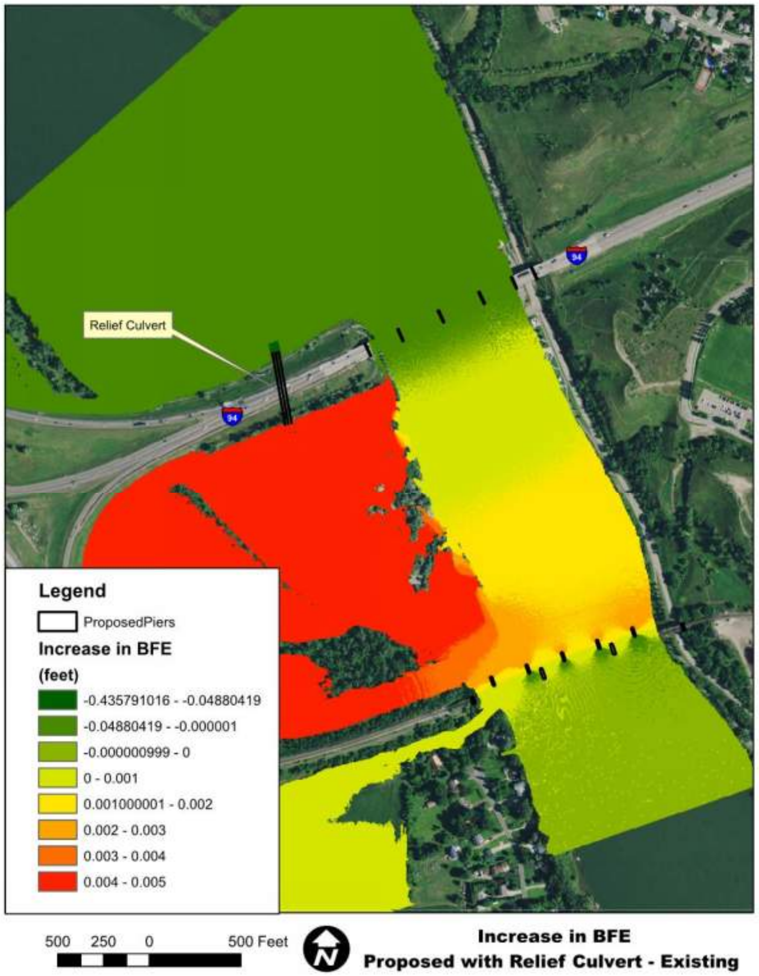
Alternative Hydraulic Modeling Approach (2-Dimensional Modeling)

- Relief culverts allow flow on the west floodplain and mitigates rise upstream of Interstate 94

Alternative Hydraulic Modeling Approach (2-Dimensional Modeling)

- Single relief culvert mitigates rise upstream of Interstate 94



CONCLUSIONS

- The BNSF proposed option, when using the one-dimensional HEC-RAS model, seems to mitigate rise through increasing the K-factor for the existing bridge above published values
- The FORB preferred option, when using the one-dimensional HEC-RAS model, indicates a rise of 0.03 feet, potentially affecting 552 structures already located within the 100-year floodplain
- Relief culverts through the Interstate 94 embankment can mitigate the rise
- Two-dimensional modeling indicates a modest rise of 0.003 feet (1/32 of an inch) for the FORB preferred option without any additional mitigation measures (relief culvert)
- FEMA has not yet indicated if a two-dimensional model would be accepted. They indicated that the local floodplain administrators (Bismarck and Mandan) should be consulted.