A Tale of Two Floods  
Reconstruction and Improvements to the CRANDIC Iowa River Crossing

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ABSTRACT
The Cedar Rapids and Iowa City Railway (The CRANDIC) mainline near Amana, Iowa suffered severe damage from flooding in 1993 and 2008 at its crossing of the Iowa River. The Iowa River crossing is approximately 1.5 miles long and has three bridges, two of which needed replacement for structural deficiencies. Rather than replace these bridges in kind, the CRANDIC, together with HDR, implemented a comprehensive study to evaluate the feasibility of rebuilding the entire river crossing to withstand future flood events.

The resulting efforts of the project included replacement of a 234 ft bridge with a 458 ft bridge, replacement of a 112 ft bridge with a 336 ft bridge, and a grade raise throughout the project of 2 to 4 ft.

Before the project was complete, another major flood struck, this one greater than the 1993 flood which damaged the line. However, because of construction of the 458 ft structure and grade raise for that portion, the line was able to withstand the flooding and maintain service.

INTRODUCTION
The Cedar Rapids and Iowa City Railway (The CRANDIC) connects with four railroads in eastern Iowa. These include Union Pacific, Canadian National, Iowa Northern and Iowa Interstate Railroad. Of these four railroads, more than half the traffic shipped and received comes via Iowa Interstate Railroad over the CRANDIC’s Amana Line, which handles around 12 MGT annually.

A notable feature of the Amana Line is where it crosses the Iowa River at Amana, Iowa (see Figure 1). At this point, the rail line passes over 1.5 miles of river bottom ground, and includes three significant bridges; one bridge over the main channel, and two bridges that serve as overflow relief bridges during high water. For reference these are referred to as the North Overflow Bridge, the Main Channel Bridge and the South Overflow Bridge.
The challenge of operating the railroad across the Iowa River Crossing has been its limited hydraulic capacity to handle flooding. The drainage area for this portion of the Iowa River basin includes 2,794 square miles. Originally constructed by the Milwaukee Line in the late 1800s, the bridges and track embankment across the river bottom were damaged in multiple floods throughout its life. At times, the Milwaukee had modified bridges in effort to add more hydraulic capacity.

The CRANDIC bought the line from the Milwaukee Road in 1980. In 1993, flooding damaged the line significantly for the first time under CRANDIC ownership, and the line was out of service for nearly six weeks. Historic flooding occurred again in 2008, causing significant damage to the Iowa River Crossing (see Figure 2).

For reference, the 1993 event peaked at 35,240 cfs (approximately a 35-year event). The 2008 event peaked at 51,500 cfs (approximately a 300-year event).
Figure 2 - View of 2008 Flood Looking North
Also in 2008, the CRANDIC was in the early stages of a five-year plan to upgrade the Amana line with new rail, ties, and turnouts to handle increases in traffic. In addition, plans were being made to replace all of the timber structures on the Amana line, including the North and South Overflow Bridges at the Iowa River Crossing.

But rather than replace the North and South Overflow Bridges in kind (similar size, height) an evaluation was deemed necessary to assess the overall hydraulic parameters of the Iowa River Crossing. Specifically, what was the hydraulic capacity of the existing bridges and embankment? And in replacement of the overflow bridges, could and should other work be performed to increase the overall hydraulic capacity of the river crossing?

FLOOD STUDY
Overview
Preliminary engineering conducted by CRANDIC indicated the river crossing was incapable of withstanding a 50-year flood event. Considering such, it was determined that a detailed study should be pursued to model the hydraulic parameters of the river crossing and determine if reasonable measures could be taken to sustain a minimum 100-year event without damage to the railroad.

In order to determine how the CRANDIC Railway could most effectively replace its aging North and South Overflow Bridges while also reducing future flood impacts to the Iowa River crossing, HDR was retained to perform a hydraulic study of the area. Extension and/or replacement of the Main Channel Bridge was also considered as a potential project component. The study’s purpose was to analyze the existing crossing hydraulics and evaluate proposed alternatives that would improve hydraulic conditions. Proposed alternative results would be compared with the existing condition and against hydraulic design criteria including the railroad’s hydraulic requirements and State of Iowa regulations. Estimated construction costs of the alternatives would be compared.

Approach
To analyze the complex hydraulic condition present at the crossing, a 2D hydraulic model known as SRH-2D was employed. It was developed by the United States Bureau of Reclamation (USBR) to analyze rivers in which a two-dimensional description of the velocity field is important, such as a skewed bridge crossing with multiple relief structures and very wide flood plains compared to the channel width. SRH-2D simulates wetting and drying of elements, providing applicability for flood inundation modeling. A more complete description of model equations and assumptions are provided in the user’s manual (1). This method was chosen over the more common one dimensional hydraulic modeling for this project due to the increased accuracy of upstream and downstream backwater and flexibility to review different bridge and track geometries after the initial model was created.

The setup for the existing-conditions hydraulic model and subsequent proposed bridge alternative models included determination of an appropriate model area, incorporation of channel bathymetry and digital terrain model, computational mesh development, incorporation of Manning’s roughness coefficients, and boundary condition definition.

Model Area
The model area was determined to incorporate the dominant terrain features in the vicinity of the project, eliminate error from the project area’s vicinity to the upstream or downstream boundary, and allow for the model to be validated using measurements taken during the 2008 and 1993 flood events taken at the US Highway 151 and Iowa Highway 220 bridges. The upstream boundary condition of the model is approximately 2.6 miles west (upstream) of the Iowa Highway 220 Bridge. The downstream boundary is approximately 0.6 miles east (downstream) of the US Highway 151 Bridge. Laterally, the left (northern) extent of the model area is Iowa Highway 220 (220th Trail) and the right (southern) extent is the Iowa Interstate Railroad upstream of the CRANDIC Iowa River Crossing, and the natural high-terrain feature downstream of the crossing. The total model measured approximately 12 miles long by 2 miles wide.

Digital Elevation Model
The digital elevation model (DEM) required by the 2D model was largely based on state-wide light detection and ranging (LiDAR) survey data from the Iowa LiDAR Mapping Project (Iowa DNR). LiDAR survey data was utilized to provide floodplain, embankment, roadway, and railroad elevations. Elevation data are reported to be accurate within plus or minus 0.3 ft. Typically there is a data point every 2 to 3 ft horizontally.

In its original form, the LiDAR data sets were too large to create a DEM for the entire study area. Data thinning algorithms were utilized to reduce the data in areas where a data point every 3-ft was excessive. In areas with
embankments, such as the CRANDIC railroad, highway crossings, and the Amana Mill Race canal, data was not thinned to assure highest-fidelity elevation data.

LiDAR data does not include elevations below water surfaces. To supplement LiDAR data, IIHR- Hydroscience and Engineering, a research group at the University of Iowa, provided a single-beam sonar bathymetric survey of the Iowa River channel in the modeled reach. Figure 3 shows the combined LiDAR points and channel survey points and the resulting DEM.

3a – Example of LiDAR Points and Channel Survey Points Shown as Red Dots
A 3D computational mesh of triangular and quadrilateral elements was created using the DEM. Adjustments to the mesh were made at the bridges to reflect existing and proposed bridge geometry.

In order to calibrate the model, data from the 1993 and 2008 flood events recorded at the nearby highway bridges and the downstream Coralville Reservoir Flood Pool was utilized. High water surface elevations recorded by the USCG and USACE were coordinated with peak reservoir discharge. Model calibration was achieved by adjusting Manning’s roughness coefficients to produce modeled water levels that closely resembled the historic water surface elevations.

**Bridge and Track Options Considered**
Seven proposed bridge and track alternatives were considered in order to compare hydraulic effectiveness and construction costs of varying degrees of track and structure improvement. The options included some or all of the following elements:
- Replace the South Overflow Bridge with a bridge two to three times the existing bridge length (234 ft).
- Replace the North Overflow Bridge with a bridge two to five times the existing bridge length (112 ft).
- Replace and/or extend the existing Main Channel Iowa River Bridge. Extensions two to three times the existing bridge length of 314 ft were considered.
- Raise the existing track to maintain train service during flood events. Existing track tie elevations ranged from 716.5 to 719.5 along the 1.4 mile stretch of track being considered for a raise. A proposed top of tie elevation of 719.00 was initially analyzed. This constituted a track raise of 2.5 ft for much of the length of the project.

**Consideration of Stream Barbs at Main River Crossing**
The existing Iowa River alignment at the main bridge crossing had migrated and was impacting the rail embankment 300 ft upstream from the bridge opening (to the south) (see Figure 3a). Construction of stream barbs of riprap (also referred to as jetties, spurs or spur dikes) along the impacted riverbank was investigated. The impact to channel hydraulics was analyzed by observing changes in velocity distribution and water surfaces.

**Study Results**
Results for the 50-year, 100-year and the 2008 event were compared. The 2D model produced water surface elevations and velocities. Representative results for one of the considered options are shown in Figure 4.
Figure 4 – Example of Stream Velocity Results

100 Year Event - North Overflow x 3, Main and South Overflow x 2
Minimum Rail Elevation: 719 ft

Water Surface Elevation (ft)

Distance Across Channel (ft)

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**Selected Option**

The Railroad ultimately decided to pursue the following improvements to the Iowa River Crossing:

- Replace South Overflow Bridge with a bridge two times as long as the existing bridge. Bridge length increased from 234 ft to 458 ft. Bridge raised about 3-ft.
- Replace North Overflow Bridge with a bridge three times as long as the existing bridge. Bridge length increased from 112 ft to 340 ft. Bridge raised about 2-ft.
  - It should be noted that utilizing the 2D hydraulic model facilitated the observation that adding length to the North Bridge was more effective than adding length to the Main Channel Bridge.
- Raise the track to a new top of tie elevation of 719.0.
- Construct five stream bars upstream of the Main Channel Bridge.

The proposed river crossing geometry would provide a hydraulic capacity of greater than 43,100 cfs (or the 100-year event) before overtopping the track, and the increased hydraulic opening at the bridges would maintain the upstream water surface elevation at approximately the same elevation as the current condition during the 100-year event.

**DESIGN**

**Bridge Design Challenges**

A main goal of bridge design was to reduce the track outage time required for bridge construction. Bridge design for this project followed the basic design that has been used on several other CRANDIC bridges: prestressed concrete beams on precast concrete pile caps supported on driven steel piles. The steel piles are welded to embedded plates on the bottom of the pile caps. This design allows for piles to be driven around and through the existing bridge without taking the track out of service. Pile caps can also be installed at the interior bents within the limits of the existing bridge under the existing low chord. The only time train service is disrupted is when the existing bridge is removed, pile caps outside the limits of the existing bridge are installed and ballast and track are installed on the new bridge. Depending on the length of the bridge, this can be done in a window as small as several hours.

Since the tracks were being raised, the new top of pile cap elevations were above the existing low chord elevation, which meant the typical pile caps that had previously been used would not work. On shorter bridges, the caps can be installed during the track outage after the existing bridge spans have been removed. However, since the new bridges would be significantly longer than the existing structures, several pile caps would already need to be installed outside the limits of the existing bridges during the track outage. The Railroad determined that there was not enough time to install all pile caps during the track outage, so HDR was directed to create a new pile cap design to use within the existing bridge limits that would reduce the installation time.

A two-piece pile cap was developed for this purpose (see Figure 5). It allowed for installation of the bottom cap unit under the existing bridge low chord. After the existing bridge was removed, the top cap piece was set on the bottom piece. The interlocking concrete sections were designed to be structurally adequate without a positive dowel connection so train traffic could resume quickly. After the bridge was back in service, dowels connecting the top and bottom cap pieces were installed and gaps between the two pieces were injected with grout.
Figure 5 – Two-piece Pile Cap Detail
CONSTRUCTION

The project was divided into two construction phases for budgetary and construction planning purposes. These included:

- **Phase 1:**
  - Replacement of the South Overflow Bridge with larger structure (234 ft to 458 ft.)
  - 3,750 ft of track raise (up to 4 ft) and embankment construction
  - Construction of the five river jetties

- **Phase 2:**
  - Replacement of the North Overflow Bridge with larger structure (112 ft to 340 ft)
  - 3,575 ft of track raise (up to 2 ft) and embankment construction

Phase 1 was constructed in the late summer of 2012, and Phase 2 was constructed in the late summer of 2013. The total cost of the project was $3,805,000.

**CONSTRUCTION OF PHASE 1 - 2012**

The existing South Overflow Bridge was a 234'-6" timber open deck structure. This bridge had been previously modified by the Milwaukee Road, as half of the bridge was supported by timber bents, and the other half supported by concrete piers – many of differing sizes (see Figure 6).

Figure 6 – Existing North Overflow Bridge

The final design of the new structure consisted of a 458'-2" precast box-girder structure on 14x89 steel H-piles. The new structure was nearly twice as long as the existing structure, with most of the additional length to the south. In addition, the proposed top of rail elevation for the new structure also included a 4 ft grade raise.

Construction of the new structure was planned to maintain traffic throughout construction with the exception of one 20-hour outage for completion of the superstructure for the new bridge and subsequent grade raise off the ends of the bridge.
Before bridge construction began, track was raised off the ends of the bridge as much as possible to minimize grade raise during the bridge outage, while maintaining adequate track geometry. Meanwhile, piles were driven through the existing structure and caps were placed beneath it. It was at this location where the two-piece cap system was used, as a standard cap configuration could not be placed on account of the grade raise considering a standard cap height was in conflict with the stringers on the existing structure, and could not be placed while maintaining service (see Figure 7).

Figure 7 – Unloading South Overflow Bridge Material – note substructure (and the lower portion of the two-piece caps) for new bridge built beneath existing bridge.

With additional planning and the allocation of resources, the final superstructure of the new bridge was constructed with only one 17-hour service outage (see Figures 8 and 9).
Figure 8 – South Overflow Bridge during single 17-hour track outage Oct 2, 2012
THE SECOND FLOOD - 2013

As stated previously, the phasing plan for the project included building Phase 1 (the South bridge) in 2012, and Phase 2 (the North bridge) in late summer 2013. However, before Phase 2 could be implemented, the Iowa River Crossing was again hit with major flooding, this time in May 2013. It was at this time that the River Crossing was going to undergo a major test regarding the hydraulic capabilities of the new South Overflow Bridge and subsequent grade raise for that portion.

When the CRANDIC purchased the Amana Line from the Milwaukee, it was determined that the Iowa River Crossing could only withstand about a 25-year flood event (about 32,300 cfs) before washing out. In 1993 the line was out of service for over a month after flows reached 35,240 cfs (about a 35-year event) and washed out the railroad. In 2008 flows reached 51,500 cfs (about a 300-year event).

With the river forecast to get to 38,000 cfs on May 30, 2013 – with only half of the improvements constructed – it appeared that the CRANDIC may be in danger, as this was significantly higher than the event in 1993 that washed out the line. Photos comparing the performance of the crossing in 2013 versus 2008 are shown in Figure 10.
Figure 10a – South Overflow - 2008 Event at 35,000 cfs

Figure 10b – South Overflow - 2013 Event at 35,000 cfs

Figure 10 – Comparison of 2008 and 2013 Events at South Overflow Bridge
A summary of the flood events is as follows:

**TABLE – Comparison of Historic Flood Events to 2013 Event**

<table>
<thead>
<tr>
<th>Year</th>
<th>Peak Flow(cfs)</th>
<th>Flood Event</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>35240</td>
<td>35-year</td>
<td>Severe - 6 Week Outage</td>
</tr>
<tr>
<td>2008</td>
<td>51500</td>
<td>300-year</td>
<td>Severe - 3 Week Outage</td>
</tr>
<tr>
<td>2013</td>
<td>39000</td>
<td>45-year</td>
<td>None - No Service Disruptions</td>
</tr>
</tbody>
</table>

As shown in the above photos and table, CRANDIC was able to sustain service through the 2013 event, even though the peak flow was considerably higher than that which occurred in 1993. While the project as a whole was not yet complete, the replacement of the South Bridge and grade raise was key in sustaining service during the 2013 event. Had it not been replaced and improved, that portion of the line would have been lost.

**CONSTRUCTION OF PHASE 2 – 2013**

After the flooding of 2013 subsided, preparation was made for work on the North portion of the project. This included replacement of the North Overflow Bridge with a new structure three times longer (112 ft to 340 ft), and about 2 ft higher. Figure 11 shows the existing North Overflow Bridge during the 2008 flood.

During construction of the North Bridge challenges were encountered when pile driving began (14x89 Steel H-piles). At this location, records indicate there have existed three previous bridges. This included a previous structure which had 6 ft wide foundations beneath old concrete piers. However, the piers had been removed in the 1950s, leaving behind 6 ft wide foundations every 26 ft. These foundations were well buried and were not encountered by any soil borings.

The thickness of the old foundations did not allow for piling to be driven through them. To account for them, the bridge was reconfigured during construction by shifting much of the structure south 1 ft, replacing a 34 ft span with a 30 ft span, and shifting the remainder of the bridge south 5 ft. With the reconfiguration, piling was able to be driven without fault.

As with the South Overflow Bridge, the two-piece cap system was used to account for the construction of as much substructure as possible while still accounting for the raise in track elevation. Similarly, construction phasing was planned to allow only one service disruption not to exceed 20 hours.

The work was completed in October 2013 with only one service disruption of approximately 17 hours (see Figures 12 and 13).
Figure 11 – North Overflow Bridge Before Peak of 2008 Flood
Figure 12 – North Overflow Bridge During 17-hour Outage
CONCLUSION
Performing a detailed 2D hydraulic analysis of the Iowa River Crossing provided the CRANDIC with the information needed to plan an effective replacement of the existing overflow bridges and incorporate a track grade raise into the project in order to avoid future washouts during flood events. Proof of this is the fact that even though only half of the project had been completed in early 2013, the line was able to remain in service during a flood similar in magnitude to the event that washed out the line in 1993. Now that the full project is complete, the crossing should be able to remain in service during flood events with 100-year magnitudes and greater.

ACKNOWLEDGEMENTS
Some of the information presented in the Hydraulic Model section of this document was taken directly or paraphrased from the report *Iowa River Crossing – Amana Line, Final Hydraulic Technical Memorandum* dated August 2011. The report was prepared by HDR for the CRANDIC and was authored by Andrew McCoy, PhD, PE (HDR).

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A Tale of Two Floods

Reconstruction of the CRANDIC Crossing of the Iowa River Valley Utilizing Hydraulic Modeling

Chad Lambi, P.E.        Adam McCune, P.E.
Tale of Two Floods – Project Overview

• Two Engineering Problems
  – Structural Deficiencies in 2 of the 3 Railroad Bridges Crossing the Iowa River
  – Hydraulic Deficiencies in the entire River Crossing

Tale of Two Floods

Structural Deficiencies – South Overflow

Hydraulic Deficiencies – South Overflow

Tale of Two Floods

Structural Deficiencies – North Overflow

Hydraulic Deficiencies – North Overflow

Tale of Two Floods

Main Channel Bridge – Structurally Sound

Hydraulic Deficiencies – Entire River Crossing

Tale of Two Floods

Project Overview

Hydraulic Deficiencies – Entire River Crossing
Tale of Two Floods – Hydraulic Deficiencies

• Engineering Solutions
  – Evaluate Hydraulic Capacity of Iowa River Crossing
  – Evaluate Proposed Bridge Improvements to Replace Structurally Deficient Bridges While Also Improving the Hydraulics of the Iowa River Crossing

2D Hydraulic Model

• SRH-2D
• Developed by U.S. Bureau of Reclamation
• Usefulness when two-dimensional velocity description is important
  – Flood plains wide compared with channel width
• Increased accuracy of upstream and downstream backwater

Model Area

Survey Data for Hydraulic Model

Digital Elevation Model (DEM)
3D Computational Mesh

3D Computational Mesh at Channel

3D Computational Mesh at Bridge

Model Calibration

- Data used from 1993 and 2008 flood events
  - Upstream Iowa Highway 220 bridge
  - Downstream US Highway 220 bridge
  - Downstream Coralville Reservoir Flood Pool
- Historic flows used, Manning’s roughness coefficients adjusted to match historic water levels

Bridge and Track Improvement Options

- Replace 112’ North Overflow Bridge w/ structure 2x to 5x longer
- Replace 314’ Main Crossing Bridge w/ structure 2x to 3x longer
- Replace 234’ South Overflow Bridge w/ structure 2x to 3x longer
- Raise 1.4 miles of track to min. Elev. 719.0 (from 716.5 to 719.5)

Hydraulic Results

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Hydraulic Results

Selected Option

- Replace North Overflow Bridge & increase length from 112’ to 340’ (3x)
- 314’ Main Crossing – remain in place
- Replace South Overflow Bridge & increase length from 234’ to 458’ (2x)
- Raise 1.4 miles of track to Elev. 719.0
- Raise = 2’ at North Bridge
- Raise = 3’ at South Bridge

Design Challenge – Track Outage Time

Solution: Interlocking Riser Blocks

Additional Improvement Consideration

Additional Improvement – Stream Barbs
Construction of South Overflow Bridge
Double the Length (230’ to 458’) and Raise 4-ft

Challenges
• Active River Bottom
• Access
  – Material Delivery and Staging
• Train Traffic - 70% of CIC

Construction – South Overflow

Material Staging
Cap Design for Grade Raise

Construction – South Overflow Material Staging

South Overflow Bridge Outage 0730

South Overflow Bridge Outage

Riser Block Caps for Grade Raise 1000
Welding Caps Bridge Lengthening 1000

Setting Spans 1500
Setting Track 1830
South Overflow – Bridge Outage

2200 Dumping Ballast – Note Caps
Next Day – Second Train

The Second Flood
1993 – Washed Out at 32,000 cfs
2008 – Washed Out at 32,000 cfs
2012 – South Overflow Constructed
May 2013 – River Peaked at 35,000 cfs, service sustained, but with challenges
Oct 2013 – North Overflow Constructed
June 2014 – River Peaked at 35,000 cfs, service sustained without challenges

Construction of North Overflow Bridge
Triple the Length (110’ to 240’) and Raise 2-ft

Cap Design
Bridge Outage – 17 hours

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Tale of Three Floods!

- In June 2014 Hit with 3rd Highest Flood
  - 2008 – Record Event
  - 2013 – 2nd Highest
  - 2014 – 3rd Highest

Tale of Three Floods

2013: South Bridge at 35,000 cfs
2014: South Bridge at 35,000 cfs

Tale of Three Floods

- Total Project Cost
  - South Overflow Bridge and Grade Raise: $2,350,000
  - North Overflow Bridge and Grade Raise: $1,455,000
  - Total Project Cost: $3,805,000

Questions?