Iowa’s Bridge Sensor Rating Curve Demonstration Project

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Outline

- History/Motivation
- Project & Methodology
- Looking Ahead

NWS Des Moines, Iowa office
Flooding is Iowa’s #1 weather-related hazard.

- ~80% of all Presidential disaster declarations.
- Ranks #2 in U.S. for flood-related losses.

Flooding & related impacts occurring more frequently in Iowa.

Floods in Iowa can be devastating.

- 2008 – $11 billion/
  40,000 people.
- 1993 – $14 billion/
  300,000 people.
History/Motivation

Post-2008 Flood: Iowa Flood Center Created

2009 Iowa Legislation, House File 822. Purposes:

- Develop hydrologic models for physically based flood frequency estimation & real-time forecasting of floods, including hydraulic models of flood plain inundation mapping.
- Establish community-based programs to improve flood monitoring & prediction along Iowa's major waterways & to support ongoing flood research.
- Share resources & expertise of Iowa Flood Center.
- Assist in development of a workforce in the state, knowledgeable regarding flood research, prediction & mitigation strategies.
History/Motivation

Post-2008 Flood: Additional Activities

2013 Iowa Hazard Mitigation Plan: Objective 5.

Mitigation Measure – Establish procedures, installation, networks, response teams & equipment necessary to issue warnings, alert officials, emergency personnel & inform the public & ensure they are in place & operational.

Iowa Governor's 2014 Long Term Recovery Task Force.

Significant state investment in flood risk communication & planning tools.

Subsequent Need for Dense Network of Stage + Discharge Streamgages.

Cedar River at Cedar Rapids, Iowa (June 2008) – Courtesy Iowa Civil Air Patrol
Iowa Bridge Sensor Rating Curve Flood Risk Management Demonstration Project
This Study Documents:

- Field survey data collection methods.
- Procedures, hydrology & hydraulic analyses.
- Development of bridge sensor rating curve methodology.
- Product strengths & limitations.
- Peer review.
- Evaluation of rating curve products.
- Implementation costs.
- Anticipated use of bridge sensor rating curve methodology.
IFC bridge sensor data supplements established streamgages. It does not replace high-quality established streamgage data from USGS or other partners.
Project Partners Roles & Responsibilities

- USACE: Bi-monthly team meetings, site channel section data collection & processing, project documentation & reporting.
- IFC: Web support, rating curve development methodology & analysis.
- USGS: Technical methodology oversight.
- Iowa DNR, HSEMD & NWS: Workgroup oversight.
- All project partners: Project product & independent peer review members.
- Timeline: March 2015 – October 2016 (Phases I & II).
Iowa’s Real-Time Streamgaging Network

- U.S. Geological Survey (USGS)
  - 207 Streamgages
  - 153 Stage + Discharge

- U.S. Army Corps of Engineers (USACE)
  - 25 Streamgages
  - 21 Stage + Discharge

- Iowa Flood Center (IFC)
  - 222 Bridge Sensors
  - 0 Stage + Discharge
**IFC bridge sensor site selection criteria**

- Identification of collocated IFC bridge sensor / USGS streamgage sites.
- Drainage area, stream slope, period of record.
- Proximity to minimize survey crew travel time.
- Recent existing HEC-RAS model availability.
  - Iowa River at Marshalltown, Maquoketa River at Manchester, Fourmile Creek at Des Moines, Indian Creek at Marion.

**Additional sites added on ad-hoc basis based on desirability.**

*Great Flood of 1993 – Des Moines, Iowa (July 1993) – Courtesy Des Moines Water Works*
Project & Methodology—Phase I Locations

- Ames
- Marshalltown
- Marion
- Des Moines
- Kalona

Iowa Survey Sites
- Phase I
- Phase II
- HEC-RAS Model
- IFC 1D Model

Cross Sections (Phase I)
- English River
- Fourmile Creek
- Indian Creek
- Iowa River Marshalltown
- South Skunk River

Cross Sections (Phase II)
- Des Moines River
- Clear Creek
- Maquoketa River
- Raccoon River
Project & Methodology—Phase II Locations

**Iowa Survey Sites**
- Phase I
- Phase II
- HEC-RAS Model
- IFC 1D Model

**Cross Sections (Phase I)**
- English River
- Fourmile Creek
- Indian Creek
- Iowa River Marshalltown
- South Skunk River

**Cross Sections (Phase II)**
- Des Moines River
- Clear Creek
- Maquoketa River
- Raccoon River
- South Skunk River

Locations:
- Stratford
- Colfax
- Oxford
- Van Meter
- Manchester
- Iowa City
Phases I & II – based on one-time cross-sectional surveys at each site, combined with LiDAR data.

- Obtained via geodetic surveys conducted with total stations & GPS surveying equipment.
- Several channel cross sections measured in vicinity of bridge hosting IFC bridge sensor.
- Cross-section spacing 100 to 300 ft – provides stream channel geometry & allows determination of free surface slope.
- LiDAR for floodplain.
Phase I

- Uses slope-area method.
- Manning's Equation used at one cross section.

\[ Q(d) = \frac{1.49[H_r(d)]^{2/3} A(d)\sqrt{S}}{n} \]

**Manning's Equation**

- **Q** = discharge (ft³/s)
- **Hr** = hydraulic radius (ft) of cross section
- **A** = area of cross section (ft²)
- **S** = slope of water surface
- **n** = Manning’s coefficient, a measure of channel roughness

Hr, A & Q depend on direct stage d

*2011 Missouri River flood*
Phase I (cont’d)

Slope & roughness values for rating curve based on values found during survey.

Slope values

- Water surface slopes along left & right banks measured during geodetic survey.
- Consistency of slope estimation along the reach analyzed by selecting various cross section combinations for slope calculations (i.e., cross section 1 & 2, 1 & 3, 1 & 4, etc.).
- Most cases: first & last cross sections used for slope due to good consistency among different cross section slope measurements.
Phase I (cont’d)

- Slope & roughness values for rating curve based on values found during survey.
  - Roughness values
    - Channel
      - Set between 0.03 & 0.045 – based on collective experience of project partners of Iowa stream characteristics.
    - Overbank
      - Fixed values for each bank based on survey photos & observations, combined with USGS (1989) classifications.

North Raccoon River near Perry, Iowa (August 2010) – NWS Des Moines
Phase I (cont’d)

Monte Carlo simulation of varying roughness & slope to determine range of possible discharges at each elevation.

Random sample of 100 value pairs used from population of 10,000 Monte Carlo simulations for each location.

Random Sample of 100 out of 10,000 values of Manning’s coefficient & slopes used for Monte Carlo simulation
Phase II

1-D HEC-RAS Steady Flow Model Used.

- Used ~5 cross sections with interpolation between.
- Momentum Equation for rapidly varied water surface profiles.
- 10 flow values used as inputs – ranging from minimum to maximum USGS rating curve discharges.
  - Assumed steady flow condition in subcritical flow regime.
- Boundary condition: Normal Depth.

Example interpolation between two cross sections in HEC-RAS model
Phase II (cont’d)

- **Slope values**
  - Similar to process used in Phase I.

- **Roughness values**
  - **Channel**
    - Similar to process used in Phase I – set between 0.03 & 0.045.
  - **Overbank**
    - Fixed values for each bank based on National Land Cover Database.
    - GIS reclassification used, based on Liu & De Smedt (2004).

*Ames/Iowa State University (August 2010) – Courtesy Des Moines Register*
Phase II (cont’d)

Roughness values

Manning’s coefficient derived from National Land Cover Database map

Setup of Manning’s coefficients over HEC-RAS cross-section.
Value for channel ranges between 0.03 & 0.045.
Overbank values obtained from National Land Cover Database & reclassification
Phase II (cont’d)

Monte Carlo simulation of varying roughness & slope to determine range of possible discharges at each elevation.

Similar to process used in Phase I – Random sample of 100 value pairs used from population of 10,000 Monte Carlo simulations for each location.

Iowa Hwy 92 – Muchakinock Creek near Oskaloosa, Iowa (August 2010) – NWS Des Moines
Example Results from Monte Carlo Simulation

Blue Line: USGS Rating Curve
Black Line: Median Experimental Rating Curve
Light Grey: 0 & 100th percentiles
Dark Grey: 25th & 75th percentiles
Comparison of Phase I & Phase II Results

Clear Creek at Oxford, Iowa
Comparison of Phase I & Phase II Results

South Skunk River at Colfax, Iowa
Comparison of Phase I & Phase II Results

Raccoon River at Van Meter, Iowa
Comparison of Phase I & Phase II Results

Des Moines River at Stratford, Iowa
Comparison of Phase I & Phase II Results

Maquoketa River at Manchester, Iowa
# Comparison of Phase I & Phase II Results

## RMSE Using Simplified Slope-Area Method (in feet).

<table>
<thead>
<tr>
<th>Bank Level</th>
<th>Clear Creek at Oxford</th>
<th>South Skunk River at Colfax</th>
<th>Raccoon River at Van Meter</th>
<th>Des Moines River at Stratford</th>
<th>Maquoketa River at Manchester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over</td>
<td>1.24</td>
<td>3.66</td>
<td>2.39</td>
<td>3.43</td>
<td>8.56</td>
</tr>
<tr>
<td>Below</td>
<td>0.90</td>
<td>2.35</td>
<td>3.81</td>
<td>1.02</td>
<td>2.43</td>
</tr>
<tr>
<td>Combined</td>
<td>1.03</td>
<td>3.45</td>
<td>3.21</td>
<td>2.64</td>
<td>6.16</td>
</tr>
</tbody>
</table>

## RMSE Using HEC-RAS Method (in feet).

<table>
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<tr>
<th>Bank Level</th>
<th>Clear Creek at Oxford</th>
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<th>Maquoketa River at Manchester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over</td>
<td>1.07</td>
<td>3.05</td>
<td>1.56</td>
<td>1.44</td>
<td>1.98</td>
</tr>
<tr>
<td>Below</td>
<td>0.69</td>
<td>0.53</td>
<td>0.72</td>
<td>1.71</td>
<td>0.59</td>
</tr>
<tr>
<td>Combined</td>
<td>0.83</td>
<td>2.77</td>
<td>1.19</td>
<td>1.57</td>
<td>1.43</td>
</tr>
</tbody>
</table>
Strengths

- Low cost of equipment installation & maintenance.
- Internet/Web access.
- Could complement existing stage/discharge data.

Weaknesses

- Static rating curve & cross-section information.
- Rating curves not as accurate as USGS rating curves.
- No model calibration data.
  - Direct streamflow measurements not planned.
- Bridges/Sensors may become submerged in higher-end floods.

Missouri River at Fort Calhoun, Nebraska (2011) – Courtesy U.S. Army Corps of Engineers
### Estimated Cost Per IFC Bridge Sensor

<table>
<thead>
<tr>
<th>Task</th>
<th>Responsible Agency</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFC Bridge Sensor Deployment</td>
<td>IFC</td>
<td>$2,500</td>
</tr>
<tr>
<td>Field Survey [4 or 5 channel cross-sections]</td>
<td>USACE</td>
<td>$2,500</td>
</tr>
<tr>
<td>HEC-RAS Model Development</td>
<td>USACE</td>
<td>$1,000</td>
</tr>
<tr>
<td>Application of Rating Curve Method / IFIS Posting</td>
<td>IFC</td>
<td>$1,500</td>
</tr>
<tr>
<td>COST PER BRIDGE SENSOR/RATING CURVE</td>
<td></td>
<td>$7,500</td>
</tr>
</tbody>
</table>
Conclusions & Recommendations

Bridge sensor rating curve methodology is a resource of flow data to supplement established streamgage data.

Methodology & products not intended to replace established streamgage data.

Products have potential to provide water level & flow information at locations currently not served by established streamgages.

Best applied to below bankfull stages.

U.S. Hwy 6 – Cedar River near Atalissa, Iowa (June 2008) – Courtesy Iowa DOT
Conclusions & Recommendations (cont’d)

- Counties & communities using IFC Iowa Flood Information System (IFIS) Website accept & understand limitations to accuracy of information provided by IFIS & bridge sensor rating curves.
- Streamflow measurements & channel cross-section geometry must be periodically verified.

Iowa River at Wapello, Iowa (July 1993) – Courtesy Des Moines Register
Conclusions & Recommendations (cont’d)

- Online availability of data, where no other data is available, allows flood response teams to use their limited time/resources more efficiently rather than repetitive, time-consuming field reconnaissance in anticipation of an impending high water flood event.

Cedar River at Waterloo, Iowa (June 2008) — Courtesy Waterloo-Cedar Falls Courier
Looking Ahead

➢ Raises Flood Risk Awareness

➢ Pending confirmation of rating curve methodology & peer review, public will also be able to view flow through IFIS Website (stage is already available).

➢ IFC Bridge Sensor data (measured stage & calculated flow) can enhance risk communication, evacuation planning & inform flood response personnel.

➢ Application of rating curve methodology at non-USGS collocated locations.

Cedar River at Cedar Rapids, Iowa (June 2008) – Courtesy Scott Olson/Getty Images
For More Information

Websites

Iowa Flood Center

http://iowafloodcenter.org/

Iowa Silver Jackets

http://silverjackets.nfrmp.us/State-Teams/Iowa

Iowa River at Columbus Junction, Iowa (June 2008)
References
