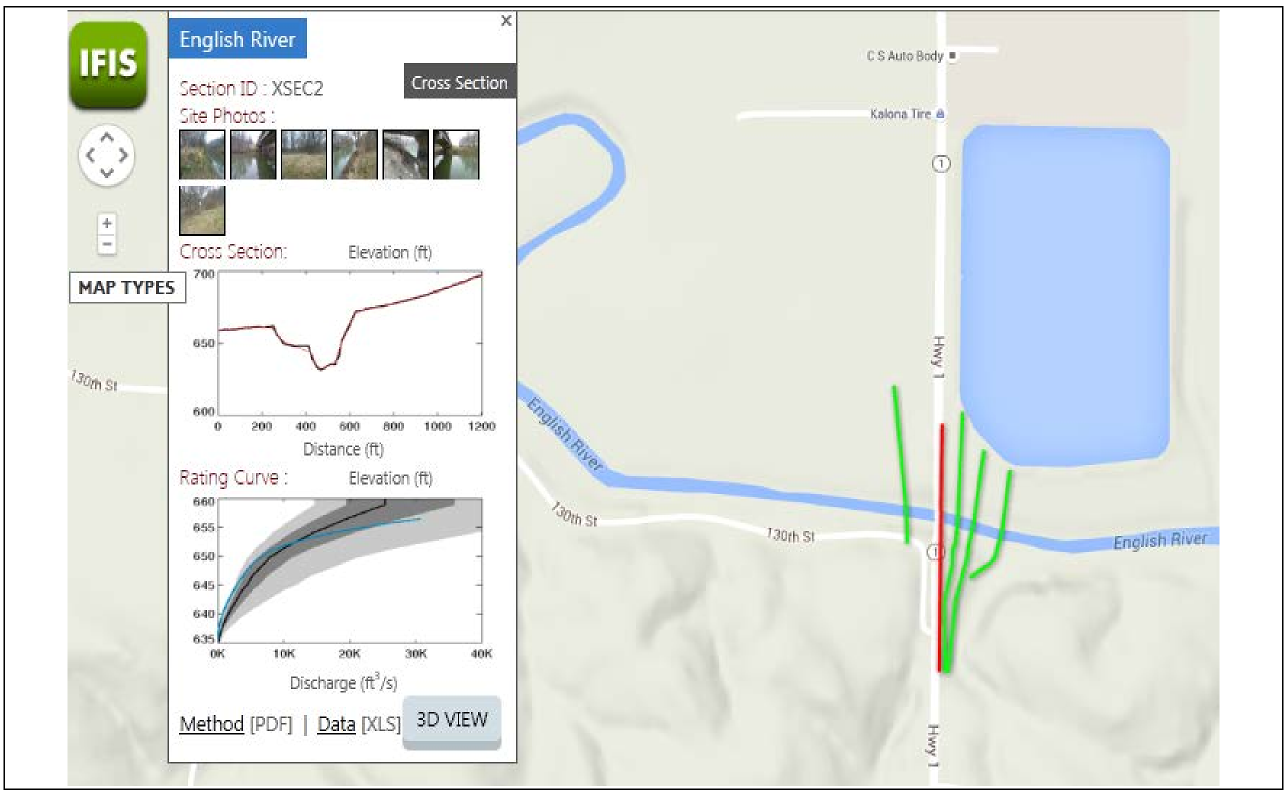
Iowa Bridge Sensor Demonstration Project
Phase I and Phase II Executive Summary Report

Floodplain Management Services
Silver Jackets Pilot Study



US Army Corps
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Rock Island District

Final Report

AUGUST 2016

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SILVER JACKETS PROGRAM

The Silver Jackets Program provides a formal and consistent strategy for an interagency approach to planning and implementing measures to reduce the risks associated with flooding and other natural hazards. State-led Silver Jackets teams bring together multiple state, federal, and local agencies to learn from one another, facilitate collaborative solutions, leverage resources, and reduce flood risk and other natural disasters. Within the U.S. Army Corps of Engineers (USACE), the Silver Jackets Program facilitates implementation of its Flood Risk Management Program at the state level. USACE established the Flood Risk Management Program to work across the agency to focus its policies, programs, and expertise and to align USACE activities with counterpart activities of other federal, state, regional and local agencies in order to manage and reduce flood risk.

PURPOSE OF REPORT

This study documents the survey methods, procedures, hydrology and hydraulic analyses, development of the bridge sensor rating curve methodologies, product strengths and limitations, peer review, evaluation of the rating curve products, and implementation costs. The bridge sensor data serves to supplement U.S. Geological Survey (USGS) gage sites and **not** replace the high quality of the USGS gage site data. Bridge sensor rating curves are intended for locations where no other means of hydraulic measurement are available as a means to provide some level of flood awareness for communities.

IOWA BRIDGE SENSOR DEMONSTRATION PROJECT PROPOSAL

Iowa's severe flooding in 2008 demonstrated the need for more extensive monitoring of the state's rivers and streams in real time. To address this, the Iowa Flood Center (IFC) developed and maintains a statewide network of stream stage sensors designed to measure stream height and transmit data automatically and frequently to the Iowa Flood Information System (IFIS), where a user can view the sensor locations and data in real-time. The IFC maintains a network of over 250 stream stage sensors across the state. Support for sensor deployment has come from the State of Iowa, Iowa Department of Natural Resources and the Iowa Department of Transportation.

The Iowa Bridge Sensor Demonstration Project leverages the existing IFC bridge sensor network data for stage-discharge rating curve development at IFC bridge sensor locations. Study partners (USACE, IFC, National Weather Service (NWS), USGS, Iowa Department of Natural Resources (IDNR), Homeland Security Emergency Management Department (HSEMD)) prioritized state-wide rating curve needs and developed a standard procedure for rating curve data collection by leveraging available data from Iowa state-wide LiDAR data, existing site specific HEC-RAS (HEC, 2010) models, and bridge plans.

The study was divided into two phases to evaluate different methodologies. Phase I and Phase II funding [$45,000 / Phase] provided to USACE was applied to bi-monthly team coordination web-meetings, project documentation and reporting, and selected site channel cross-section data collection and processing. Soundings were collected in the channels by USACE survey crews. Elevation data was collected for the water surface for each bank station at each cross-section, as well as overbank data points which were used to tie the survey data in with LiDAR data. State-wide available LiDAR elevation data was used for the overbank area to complete the cross-sections. The IFC provided project in-kind IFIS web support and rating curve development methodology and analysis. The USGS provided in-kind technical oversite. The IDNR, NWS, and HSEMD provided in-kind workgroup oversight and all project partners provided in-kind independent peer review members for project products.

During Phase I of the project, five bridge sensor locations were selected to evaluate a slope-conveyance method to produce rating curves. During Phase II, five additional bridge sensor rating curve sites were selected to expand the database for the slope-conveyance methodology assessment. Phase II provided an opportunity to refine the Phase I application and update the rating curve development for all ten sites using the step-backwater method to better quantify and minimize methodology uncertainties at stream locations where USGS gage stream flow data is not readily available. The pilot project sites are all near to a USGS gage for evaluation of the rating curves produced; however, the implementation is intended for locations without a USGS gage nearby.

When available, USACE utilized previously developed and calibrated HEC-RAS hydraulic models for cross-section geometry. Three of the five Phase I site rating curve plots and one of the five Phase II site rating curve plots show HEC-RAS model step-backwater method results computed for recent flood plain management studies independent of this pilot study. Locations having a recent HEC-RAS model calibrated to the local USGS gage rating curve are noted in Table 1. Due to the presence of the calibrated model, full cross-section data were not collected at these locations for the demonstration project.

IFC rating curves and USGS gage rating curves were compared at the ten selected locations to assess the accuracy of the bridge sensor rating curves. The locations selected for both Phase I and Phase II can be seen in the map included as Figure 1.

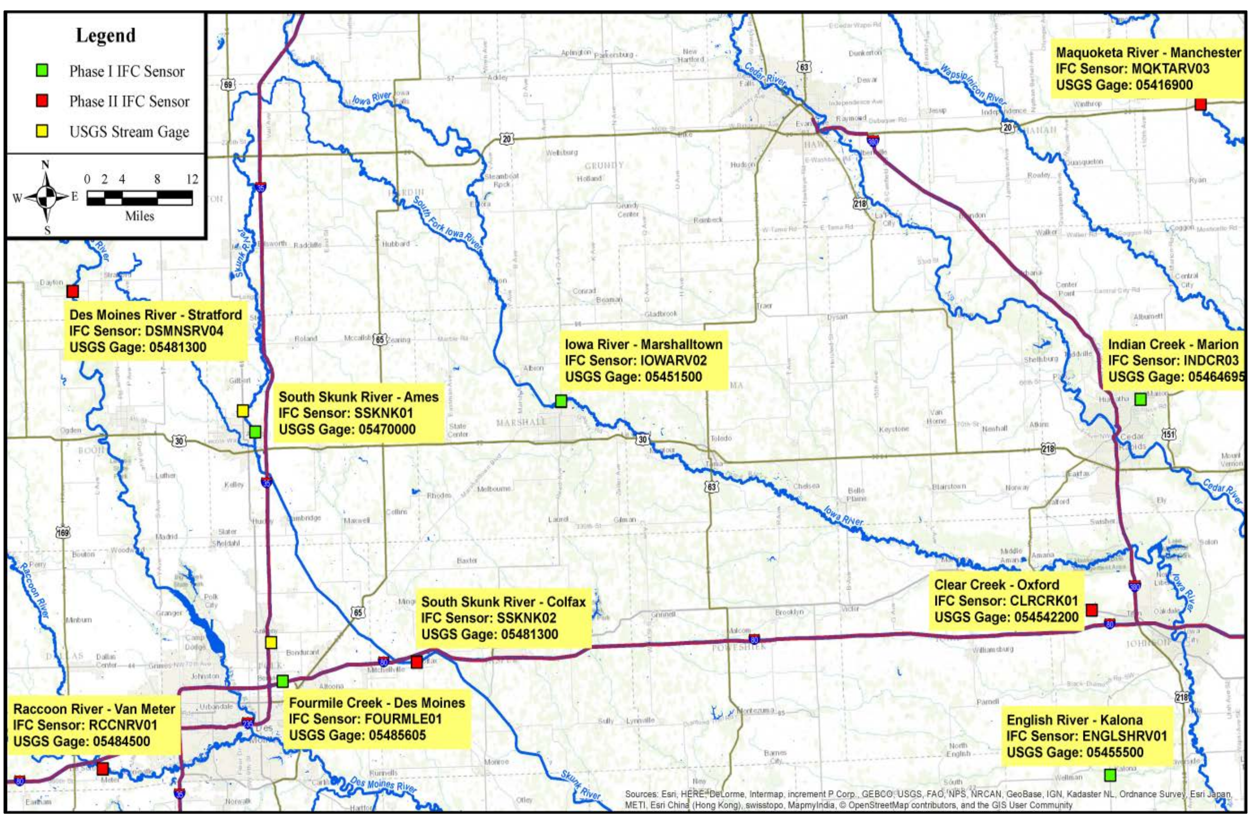

Figure 1: Iowa Bridge Sensor Rating Curve Phase I and Phase II Locations

Sites used in this assessment were selected by the interagency team members. Site selection was consistent with the requirements of the proposed methodologies to develop rating curves, and was based upon 1) the identification of collocated bridge sensor / USGS stream gage sites for rating curve comparison; 2) providing a range of drainage area, stream slope, and period of record; 3) proximity to Interstate 80 or USACE Rock Island District headquarters to minimize survey crew travel time; 4) recent existing HEC-RAS model availability to minimize the number of cross-sections collected; and 5) relatively straight reach of stream without a significant change in water slope in the study reach. If a specific site was found to be especially desirable, the IFC installed a bridge sensor at the site. The interagency team members specified and identified the number and location of cross-sections needed at each gage site for rating curve development based on the site specific channel geometry and standard hydraulic engineering practice.

Table 1: Bridge Sensor Rating Curve Sites Selected

PHASE I SELECTED SITES	**USGS Station Number**	**Drainage Area (sq. mi.)**	**Length of USGS Record (years)**	**Recent HEC-RAS Model**
ENGLISH RIVER AT KALONA	05455500	574	76	
INDIAN CREEK AT MARION	05464695	68	3	HEC-RAS
FOURMILE CREEK AT DES MOINES *	05485640	93	44	HEC-RAS
SOUTH SKUNK RIVER AT AMES *	05470000	315	96	
IOWA RIVER AT MARSHALLTOWN	05451500	1,532	84	HEC-RAS
PHASE II SITES SELECTED SITES				
CLEAR CREEK NEAR OXFORD	05454220	58	83	
DES MOINES RIVER NEAR STRATFORD	05481300	5,452	48	
RACCOON RIVER AT VAN METER	05484500	3,441	100	
SOUTH SKUNK RIVER AT COLFAX	05471050	803	30	
MAQUOKETA RIVER AT MANCHESTER	05416900	275	50	HEC-RAS

(*) Indicates sites where IFC and USGS sensors are not collocated.

RATING CURVE METHODOLOGY AND ASSUMPTIONS

The detailed description of the Iowa Flood Center Real-time Stage Sensors rating curve methodologies is provided in Appendix A ~ *Development of the Rating Curves for the Iowa Flood Center Real-time Stage Sensors, Iowa Flood Center, June 2016* ~ of this report. Briefly stated, two different methodologies were applied: 1) a slope-conveyance method, here called slope-conveyance method based on Rantz (1982), and 2) the step-backwater method computed using a one-dimensional hydraulic HEC-RAS model (HEC, 2010). It is worth noting that the first method is a very simplistic method, where a rating curve is obtained using the Manning's equation at a single cross-section without averaging conveyance across sections, and thus has limitations. The step-backwater method computed using HEC-RAS is well established in hydraulic engineering, and takes into account the changes in the geometry of the cross-section in the channel, among many other considerations.

In both cases, a general approach that handles the uncertainty of estimating the Manning's roughness was included. The approaches use Monte Carlo simulation to consider a range of feasible values of roughness in the channel derived from expert knowledge, and a range of slopes provided by surveyed data. The slope-conveyance approach is computationally inexpensive and does not require calibration. The derived rating curves consider implicitly the uncertainty of parameter estimation by providing an envelope of feasible realizations. A representative rating curve can be obtained as the median of the realizations.

Discharge ratings at USGS streamgages are generally empirically derived from periodic measurements of discharge and stage (Kennedy, 1984). The measurements of discharge are often made by direct means, such as mid-section measurement methods (Turnipseed and Sauer, 2010). At times, various types of indirect measurements are computed to define areas of the discharge rating where direct discharge measurements may not be available (Rantz and others, 1984). The rating curves obtained as part of the pilot project were compared with USGS rating curves active at the time of the survey. To quantify the difference between the USGS rating curves and the computed IFC rating curves, the root mean square error (RMSE) was calculated.

RATING CURVE RESULTS

The summary of the Phase I and Phase II site rating curve results are shown in Figures 2 through 11 of the full report. Three of the five Phase I site rating curve plots and one of the five Phase II site rating curve plots show HEC-RAS model step-backwater method results computed for recent flood plain management studies independent of this pilot study. Due to the natural shifting present in the rating curves, the USGS rating curve shown for each site is the curve that was current at the time the cross-section bathymetry data was collected. Table 1 lists the sites as well as the USGS gage number and length of record. Dates of the field survey and the USGS rating curve number and date can be found in Table 10 of the full report.

PHASE I METHOD RESULTS

The rating curves obtained using the slope-conveyance method for the full cross-section produced RMSE values, as shown in Table 2 and Table 3. Despite its simplicity and readiness for implementation without extensive maintenance, the results presented in this study show that the slope-conveyance method, as proposed here, has limitations. The main weakness of the slope-conveyance method is associated with the reliance on the geometrical characteristics of only one cross-section at a time, hence not being able to consider the effect of the transition between the cross-sections along the reach.

PHASE II METHOD RESULTS

The rating curves obtained using the HEC-RAS step-backwater modeling approach produced RMSE values, as shown in Table 2 and Table 3. The rating curves obtained using the HEC-RAS step-backwater method compare better to the curves developed by the USGS than the slope-conveyance method.

Table 2: RMSE (in feet) and Average % Error Using Slope-Conveyance and Step-Backwater Methods

Bridge Sensor Location Name	Drainage Area (sq. mi.)	Slope-Conveyance			Step-Backwater		
		Over Bank	Within Channel	Full Section	Over Bank	Within Channel	Full Section
English River at Kalona	574	5.8 (-0.6)	1.2 (-0.08)	3.4 (0.07)	5.2 (0.58)	1.3 (-0.06)	3.1 (-0.05)
Indian Creek at Marion	68	1.2 (0.31)	1.3 (0.27)	1.3 (0.31)	1.4 (0.14)	1.7 (0.21)	1.6 (0.16)
Iowa River at Marshalltown	1,532	3.2 (-0.31)	0.8 (0.07)	2.4 (-0.10)	0.9 (-0.1)	1.0 (-0.1)	0.9 (-0.08)
Clear Creek at Oxford	58	1.2 (-0.07)	0.9 (-0.02)	1.0 (-0.03)	1.1 (-0.13)	0.7 (-0.01)	0.8 (-0.06)
South Skunk River at Colfax	803	3.7 (-0.06)	2.4 (-0.33)	3.5 (0.13)	1.1 (0.01)	0.9 (0.11)	1.1 (0.01)
Raccoon River at Van Meter	3,441	2.4 (0.10)	3.8 (0.45)	3.2 (0.34)	1.6 (-0.19)	0.7 (-0.01)	1.2 (-0.07)
Des Moines River at Stratford	5,452	3.4 (-0.11)	1.0 (0.16)	2.6 (0.10)	1.4 (0.11)	1.7 (0.18)	1.6 (0.14)
Maquoketa River at Manchester	275	8.6 (-0.84)	2.4 (-0.09)	6.2 (-0.46)	2.0 (-0.21)	0.6 (-0.05)	1.4 (-0.10)

Table 3: RMSE (in cfs) and Average % Error Using Slope-Conveyance and Step-Backwater Methods

Bridge Sensor Location Name	Drainage Area (sq. mi.)	Slope-Conveyance			Step-Backwater		
		Over Bank	Within Channel	Full Section	Over Bank	Within Channel	Full Section
English River at Kalona	574	8,266 (-38)	366 (11)	4,646 (-6)	7,912 (-33)	188 (8)	4,439 (5)
Indian Creek at Marion	68	1,332 (-46)	395 (-56)	1,017 (-52)	844 (-32)	351 (-48)	665 (-43)
Iowa River at Marshalltown	1,532	56,356 (306)	644 (-48)	41,780 (92)	2,335 (15)	1,046 (61)	1,867 (41)
Clear Creek at Oxford	58	2,345 (41)	143 (3)	1,353 (5)	2,084 (55)	86 (6)	1,187 (15)
South Skunk River at Colfax	803	65,045 (47)	790 (-117)	58,735 (-38)	2,052 (0)	417 (-46)	1,861 (-1)
Raccoon River at Van Meter	3,441	11,813 (-27)	4,814 (-63)	8,860 (-51)	12,216 (28)	747 (-3)	8,442 (11)
Des Moines River at Stratford	5,452	22,201 (19)	2,838 (-32)	16,655 (-27)	4,270 (-11)	2,676 (-29)	3,648 (-20)
Maquoketa River at Manchester	275	73,631 (431)	8,886 (93)	51,227 (365)	5,957 (35)	618 (17)	4,136 (27)

CONCLUSIONS AND RECOMMENDATIONS

The step-backwater method computed using HEC-RAS requires more cross-section geometry information from the channel than the slope-conveyance method. The HEC-RAS–step-backwater method also necessitates surveying enough cross-sections downstream from the sensor of interest that the HEC-RAS model will produce accurate results at the location of the sensor. The distance between the most upstream and downstream section ranges between 3,000 and 6,000 feet. This condition is necessary to guarantee the stability of the flow along the channel reach within the hydraulic model and for the model to achieve a normal depth solution downstream of the sensor (Davidian, 1984). In a strict sense, the slope-conveyance approach requires only one cross-section that is representative of the channel's hydraulic conditions at the stream-stage sensor. The implementation of the slope-conveyance model used to calculate the rating curves only takes into account the geometry of one cross-section at a time, and does not consider the interpolation between the sections.

The most important limitation that applies to both methods is that the produced rating curves do not take into account changes over time to the stage-discharge relationship, in contrast with this capability in the USGS gaging approach. Both methods also require a good estimation of the water-surface slope, but the value that is used as input is based on the observed slope at the time of the survey. For the slope-conveyance method, the calculation of the rating curve uses the input range of values directly in Manning's equation. The HEC-RAS step-backwater method uses an initial slope value in the model set-up. However, the model performs several iterations to solve the one-dimensional equation of flow along the channel, producing a profile of the energy line that can change from section to section. The effort required to produce a rating curve using the step-backwater method is greater than what is needed for the slope-conveyance method. The most time- and money-consuming tasks are the cross-section surveys (including the post-processing with LiDAR information on the overbanks) and the set-up of multiple models in HEC-RAS to produce inputs for the Monte Carlo simulations.

Given the limitations of the slope-conveyance method, the applicability of the rating curves should be narrowed to the cross-section area below the bankfull level. Their multiple limitations lead to inaccurate results in the floodplain. For the purpose of the Iowa Flood Center, it is important to provide reliable information of stage and discharge on flooding events. Therefore, the rating curves obtained using the step-backwater method result in a more useful product.

ANTICIPATED USE OF BRIDGE SENSOR RATING CURVE METHODOLOGY

The implementation of the bridge sensor rating curve methodology utilizing the step-backwater method is a suitable resource of flow data to supplement established USGS stream gage data at locations that do not currently have a USGS stream gage. The methodology and products are not intended to replace established stream gage data. However, the products do provide water level and flow information at locations that are currently not served by the USGS gaging systems. Counties and communities using the IFIS web site and products accept the limitations to the accuracy of the information provided by IFIS. Counties and communities using the bridge sensor rating curve methodology would need to be aware that the channel cross-section geometry will need to be periodically verified. The on-line availability of this data, where no other data is available, allows flood response teams to use their limited time and resources in a more efficient and effective manner rather than engaging in repetitive, time-consuming field reconnaissance in anticipation of an impending high water flood event.

Upon completion of peer review of the demonstration project, the rating curves will be user-ready on-line, accessed by a password protected page on the Iowa Flood Center website for the ten gages studied. In addition to showcasing this technology through Silver Jacket State and National presentations, the Bridge Sensor Silver Jackets Team members will be sharing the information state-wide. Small community resiliency will be enhanced by the installation of the affordable bridge sensor technology flood response tool.

PROJECT COST PER BRIDGE SENSOR/RATING CURVE

Estimated costs for each bridge sensor are provided in Table 4.

Table 4: Estimated Cost Per Bridge Sensor

TASK	RESPONSIBLE AGENCY	COST
IFC Bridge Sensor Deployment	IFC	$3,500
Field Survey [4 channel cross-sections]	USACE	$2,500
HEC-RAS Model Development	USACE	$1,000
Application of Rating Curve Method / IFIS Posting	IFC	$1,500
COST PER BRIDGE SENSOR/RATING CURVE		$8,500

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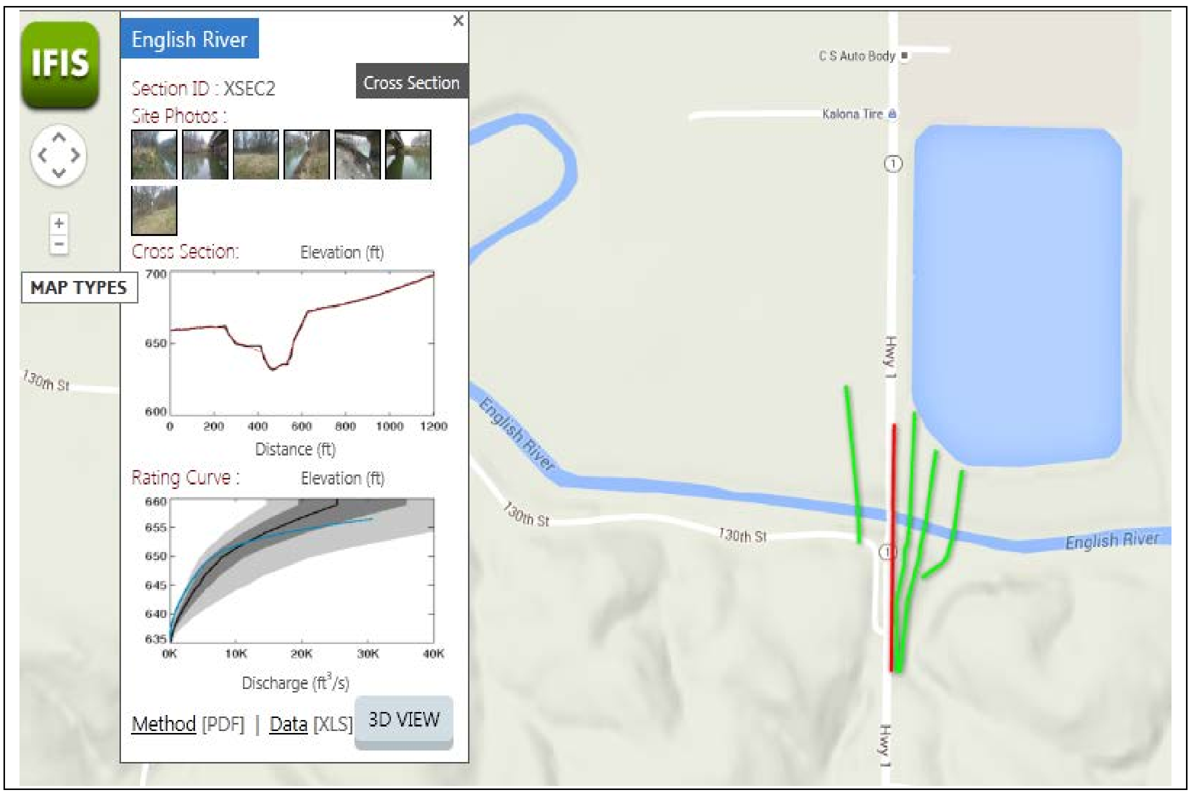

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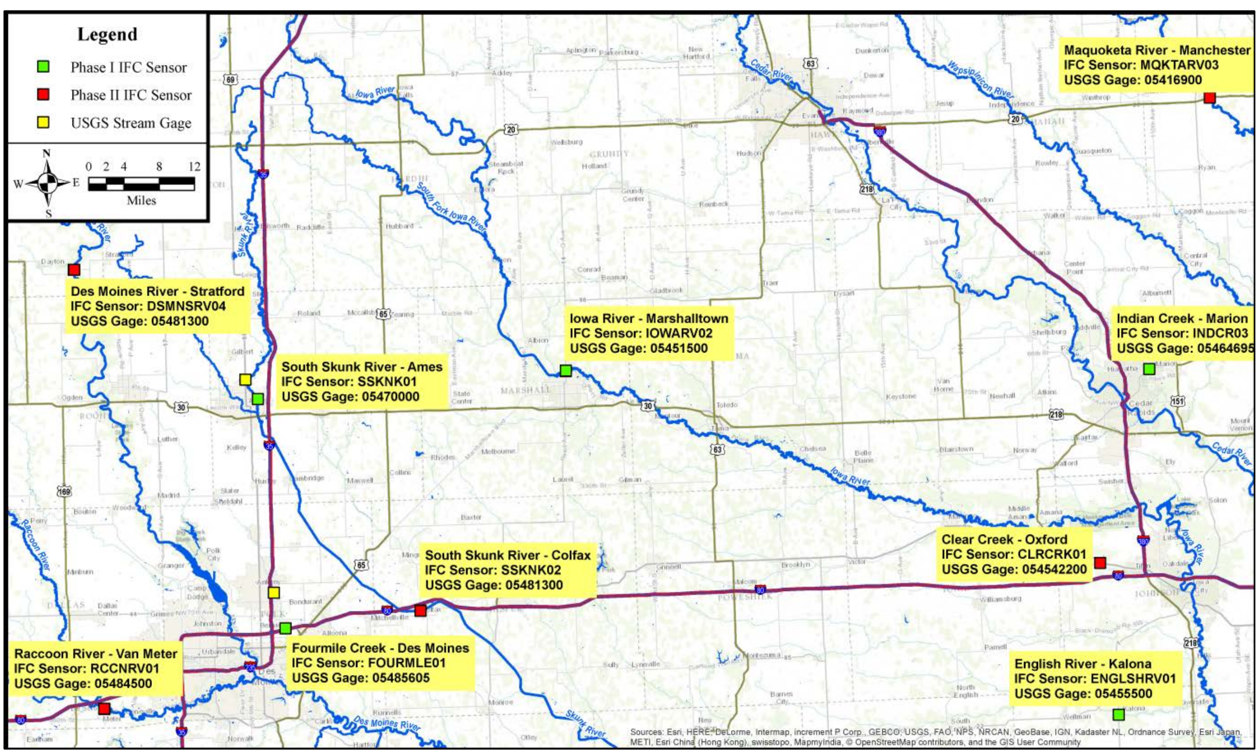

Figure 1: Iowa Bridge Sensor Rating Curve Phase I and Phase II Locations

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The rating curves obtained using the HEC-RAS step-backwater modeling approach produced RMSE values, as shown in Table 2 and Table 3. The rating curves obtained using the HEC-RAS step-backwater method compare better to the curves developed by the USGS than the slope-conveyance method.

Table 2: RMSE (in feet) and Average % Error Using Slope-Conveyance and Step-Backwater Methods

Bridge Sensor Location Name	Drainage Area (sq. mi.)	Slope-Conveyance			Step-Backwater		
		Over Bank	Within Channel	Full Section	Over Bank	Within Chann el	Full Section
English River at Kalona	574	5.8 (-0.6)	1.2 (-0.08)	3.4 (0.07)	5.2 (0.58)	1.3 (-0.06)	3.1 (-0.05)
Indian Creek at Marion	68	1.2 (0.31)	1.3 (0.27)	1.3 (0.31)	1.4 (0.14)	1.7 (0.21)	1.6 (0.16)
Iowa River at Marshalltown	1,532	3.2 (-0.31)	0.8 (0.07)	2.4 (-0.10)	0.9 (-0.1)	1.0 (-0.1)	0.9 (-0.08)
Clear Creek at Oxford	58	1.2 (-0.07)	0.9 (-0.02)	1.0 (-0.03)	1.1 (-0.13)	0.7 (-0.01)	0.8 (-0.06)
South Skunk River at Colfax	803	3.7 (-0.06)	2.4 (-0.33)	3.5 (0.13)	1.1 (0.01)	0.9 (0.11)	1.1 (0.01)
Raccoon River at Van Meter	3,441	2.4 (0.10)	3.8 (0.45)	3.2 (0.34)	1.6 (-0.19)	0.7 (-0.01)	1.2 (-0.07)
Des Moines River at Stratford	5,452	3.4 (-0.11)	1.0 (0.16)	2.6 (0.10)	1.4 (0.11)	1.7 (0.18)	1.6 (0.14)
Maquoketa River at Manchester	275	8.6 (-0.84)	2.4 (-0.09)	6.2 (-0.46)	2.0 (-0.21)	0.6 (-0.05)	1.4 (-0.10)

Table 3: RMSE (in cfs) and Average % Error Using Slope-Conveyance and Step-Backwater Methods

Bridge Sensor Location Name	Drainage Area (sq. mi.)	Slope-Conveyance			Step-Backwater		
		Over Bank	Within Channel	Full Section	Over Bank	Within Chann el	Full Section
English River at Kalona	574	8,266 (-38)	366 (11)	4,646 (-6)	7,912 (-33)	188 (8)	4,439 (5)
Indian Creek at Marion	68	1,332 (-46)	395 (-56)	1,017 (-52)	844 (-32)	351 (-48)	665 (-43)
Iowa River at Marshalltown	1,532	56,356 (306)	644 (-48)	41,780 (92)	2,335 (15)	1,046 (61)	1,867 (41)
Clear Creek at Oxford	58	2,345 (41)	143 (3)	1,353 (5)	2,084 (55)	86 (6)	1,187 (15)
South Skunk River at Colfax	803	65,045 (47)	790 (-117)	58,735 (-38)	2,052 (0)	417 (-46)	1,861 (-1)
Raccoon River at Van Meter	3,441	11,813 (-27)	4,814 (-63)	8,860 (-51)	12,216 (28)	747 (-3)	8,442 (11)
Des Moines River at Stratford	5,452	22,201 (19)	2,838 (-32)	16,655 (-27)	4,270 (-11)	2,676 (-29)	3,648 (-20)
Maquoketa River at Manchester	275	73,631 (431)	8,886 (93)	51,227 (365)	5,957 (35)	618 (17)	4,136 (27)

CONCLUSIONS AND RECOMMENDATIONS

The step-backwater method computed using HEC-RAS requires more cross-section geometry information from the channel than the slope-conveyance method. The HEC-RAS–step-backwater method also necessitates surveying enough cross-sections downstream from the sensor of interest that the HEC-RAS model will produce accurate results at the location of the sensor. The distance between the most upstream and downstream section ranges between 3,000 and 6,000 feet. This condition is necessary to guarantee the stability of the flow along the channel reach within the hydraulic model and for the model to achieve a normal depth solution downstream of the sensor (Davidian, 1984). In a strict sense, the slope-conveyance approach requires only one cross-section that is representative of the channel's hydraulic conditions at the stream-stage sensor. The implementation of the slope-conveyance model used to calculate the rating curves only takes into account the geometry of one cross-section at a time, and does not consider the interpolation between the sections.

The most important limitation that applies to both methods is that the produced rating curves do not take into account changes over time to the stage-discharge relationship, in contrast with this capability in the USGS gaging approach. Both methods also require a good estimation of the water-surface slope, but the value that is used as input is based on the observed slope at the time of the survey. For the slope-conveyance method, the calculation of the rating curve uses the input range of values directly in Manning's equation. The HEC-RAS step-backwater method uses an initial slope value in the model set-up. However, the model performs several iterations to solve the one-dimensional equation of flow along the channel, producing a profile of the energy line that can change from section to section. The effort required to produce a rating curve using the step-backwater method is greater than what is needed for the slope-conveyance method. The most time- and money-consuming tasks are the cross-section surveys (including the post-processing with LiDAR information on the overbanks) and the set-up of multiple models in HEC-RAS to produce inputs for the Monte Carlo simulations.

Given the limitations of the slope-conveyance method, the applicability of the rating curves should be narrowed to the cross-section area below the bankfull level. Their multiple limitations lead to inaccurate results in the floodplain. For the purpose of the Iowa Flood Center, it is important to provide reliable information of stage and discharge on flooding events. Therefore, the rating curves obtained using the step-backwater method result in a more useful product.

ANTICIPATED USE OF BRIDGE SENSOR RATING CURVE METHODOLOGY

The implementation of the bridge sensor rating curve methodology utilizing the step-backwater method is a suitable resource of flow data to supplement established USGS stream gage data at locations that do not currently have a USGS stream gage. The methodology and products are not intended to replace established stream gage data. However, the products do provide water level and flow information at locations that are currently not served by the USGS gaging systems. Counties and communities using the IFIS web site and products accept the limitations to the accuracy of the information provided by IFIS. Counties and communities using the bridge sensor rating curve methodology would need to be aware that the channel cross-section geometry will need to be periodically verified. The on-line availability of this data, where no other data is available, allows flood response teams to use their limited time and resources in a more efficient and effective manner rather than engaging in repetitive, time-consuming field reconnaissance in anticipation of an impending high water flood event.

Upon completion of peer review of the demonstration project, the rating curves will be user-ready on-line, accessed by a password protected page on the Iowa Flood Center website for the ten gages studied. In addition to showcasing this technology through Silver Jacket State and National presentations, the Bridge Sensor Silver Jackets Team members will be sharing the information state-wide. Small community resiliency will be enhanced by the installation of the affordable bridge sensor technology flood response tool.

PROJECT COST PER BRIDGE SENSOR/RATING CURVE

Estimated costs for each bridge sensor are provided in Table 4.

Table 4: Estimated Cost Per Bridge Sensor

TASK	RESPONSIBLE AGENCY	COST
IFC Bridge Sensor Deployment	IFC	$3,500
Field Survey [4 channel cross-sections]	USACE	$2,500
HEC-RAS Model Development	USACE	$1,000
Application of Rating Curve Method / IFIS Posting	IFC	$1,500
COST PER BRIDGE SENSOR/RATING CURVE		$8,500

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PHASE I SITES RATING CURVE RESULTS

ENGLISH RIVER AT KALONA [PHASE I]

The rating curve for the IFC sensor located at cross-section 2 for the English River at Kalona site shows good concurrence with the USGS rating curve below bankfull level, as shown in Figure 2.

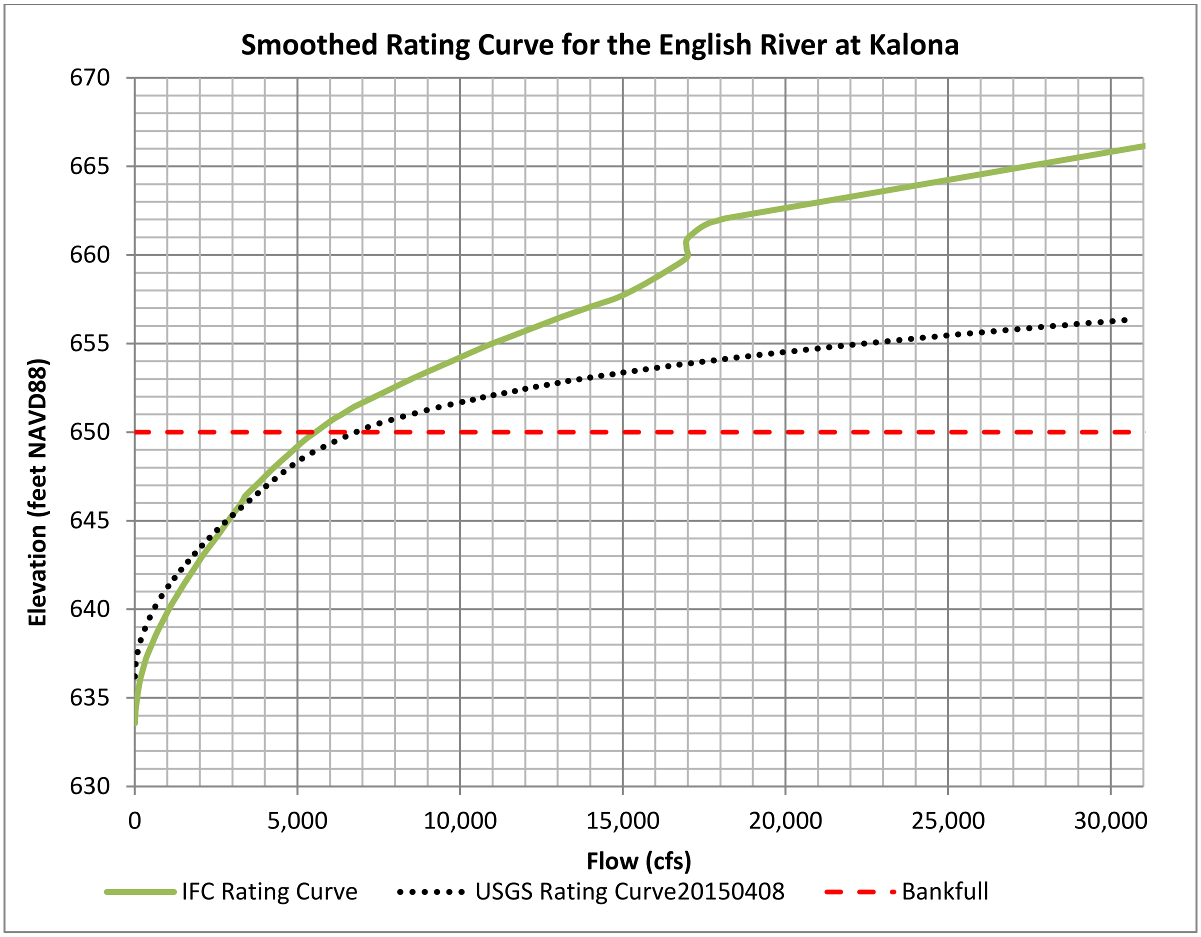

Figure 2: Rating Curve Results for the English River at Kalona, IA

INDIAN CREEK AT MARION [PHASE I]

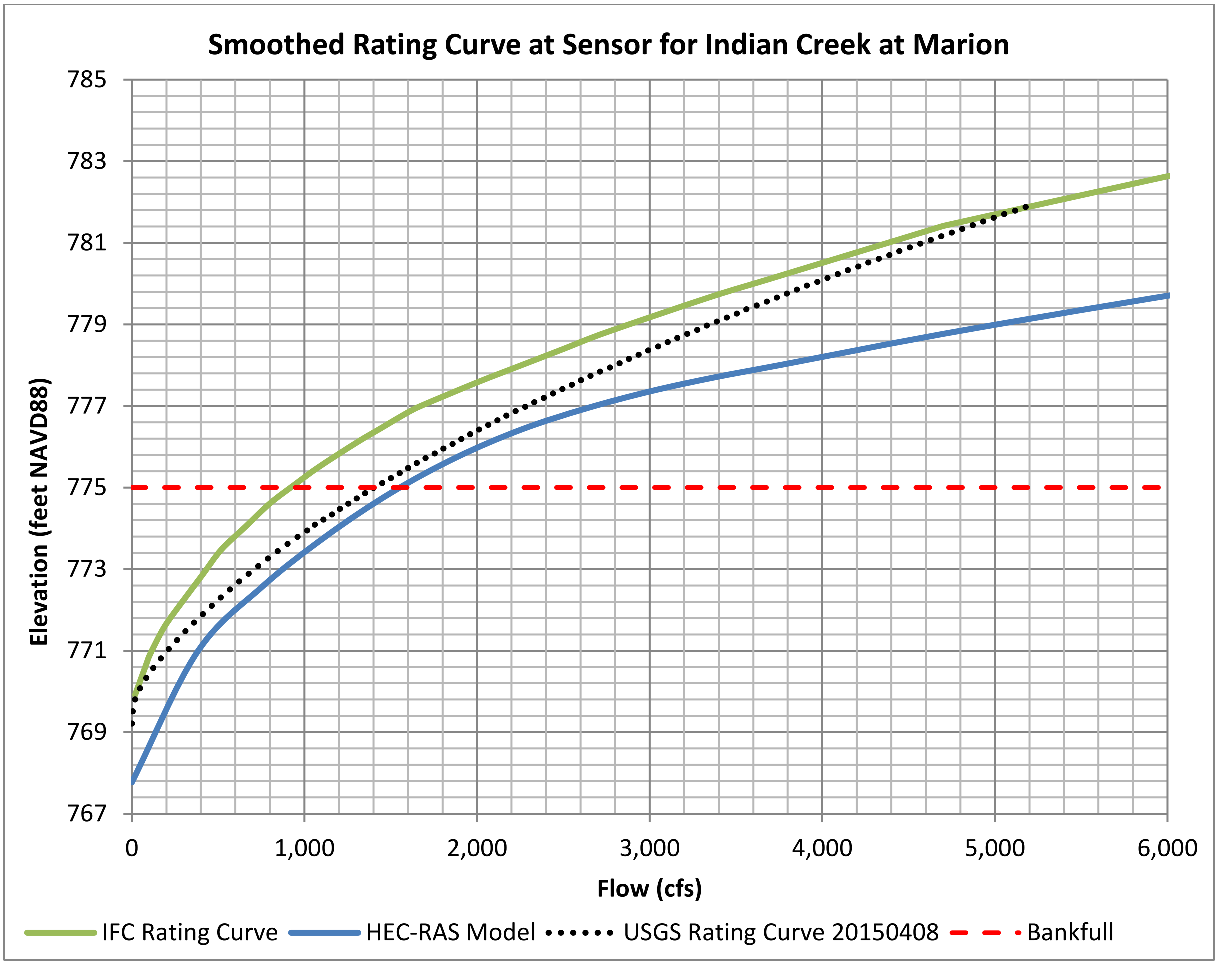

Figure 3: Rating Curve Results for Indian Creek at Marion, IA

FOURMILE CREEK AT DES MOINES [PHASE I]

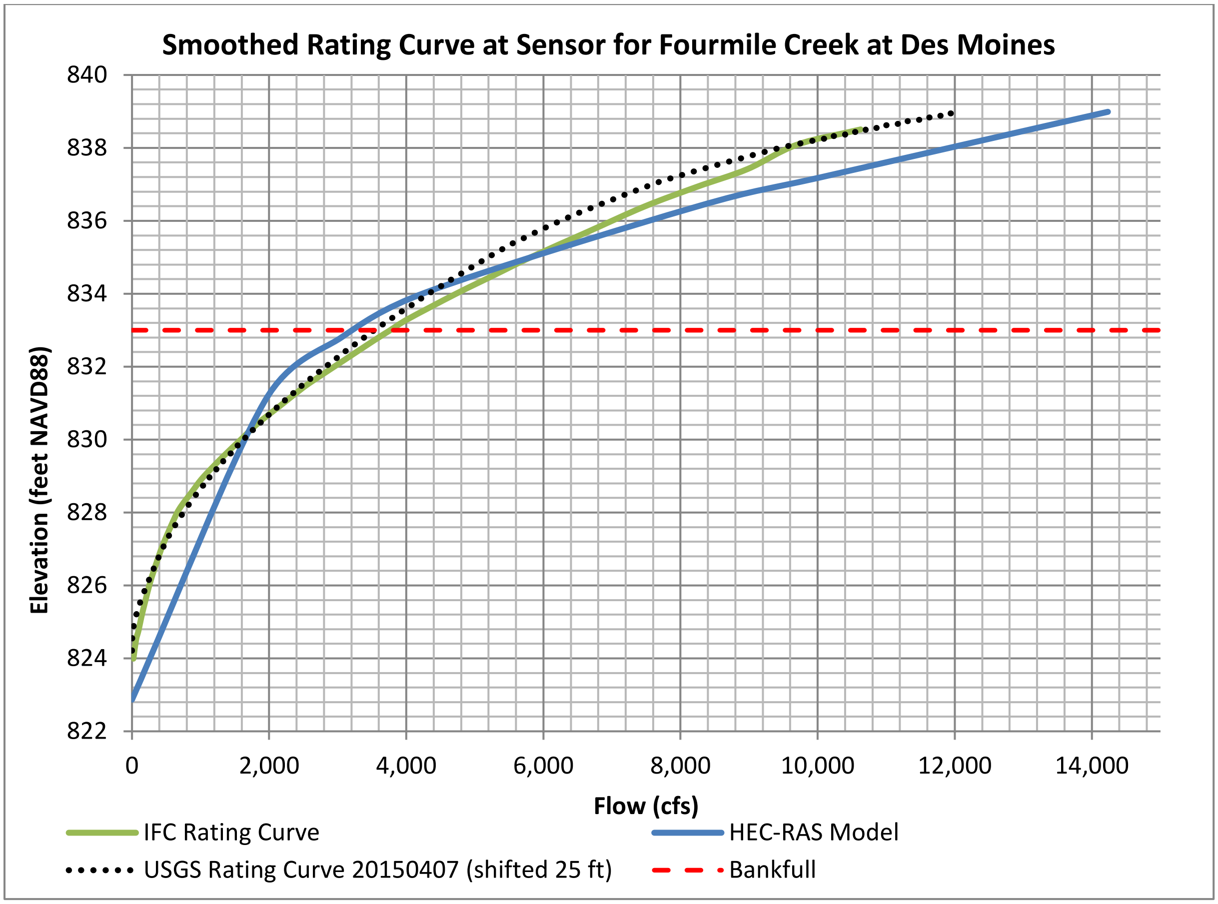

Figure 4: Rating Curve Results for Fourmile Creek at Des Moines, IA

SOUTH SKUNK RIVER AT AMES [PHASE I]

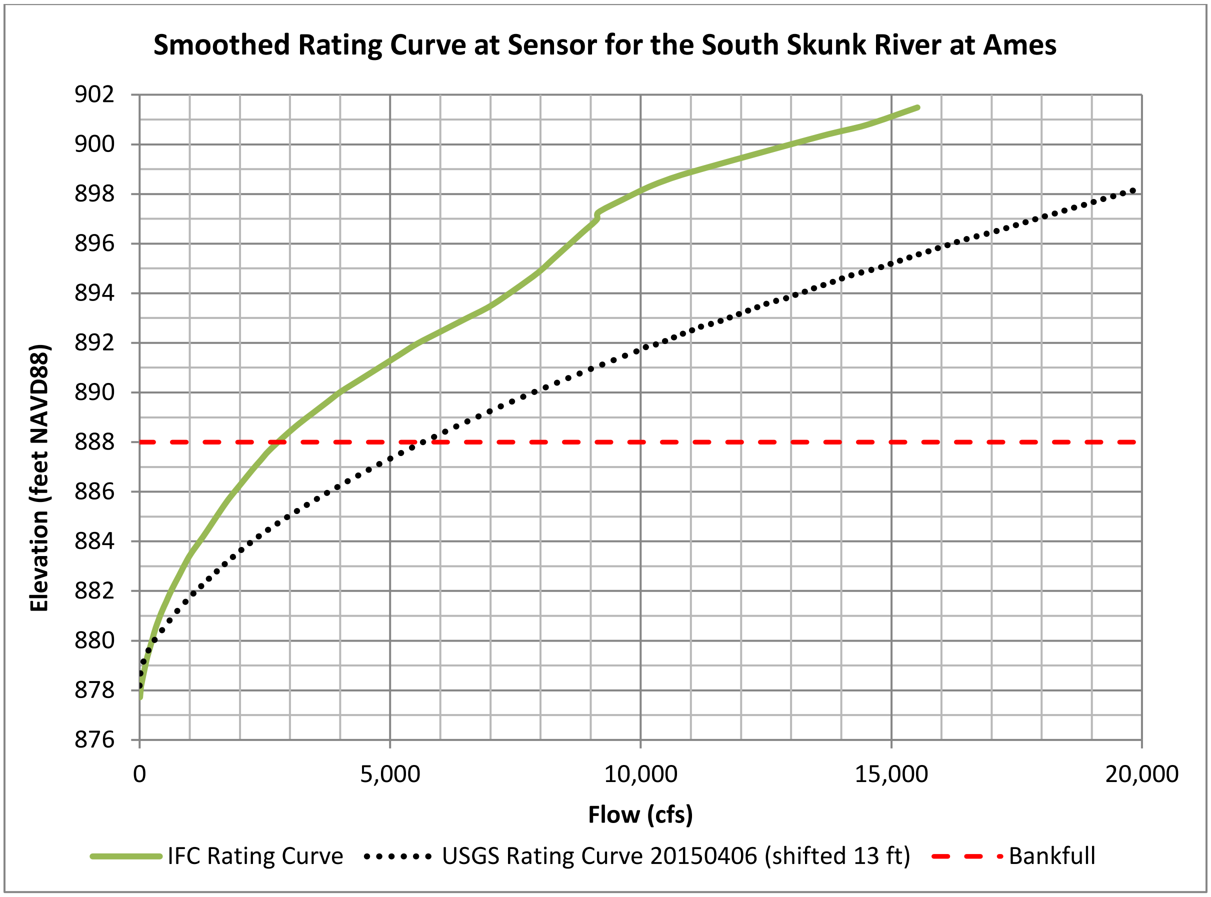

Figure 5: Rating Curve Results for the South Skunk River at Ames, IA

IOWA RIVER AT MARSHALLTOWN [PHASE I]

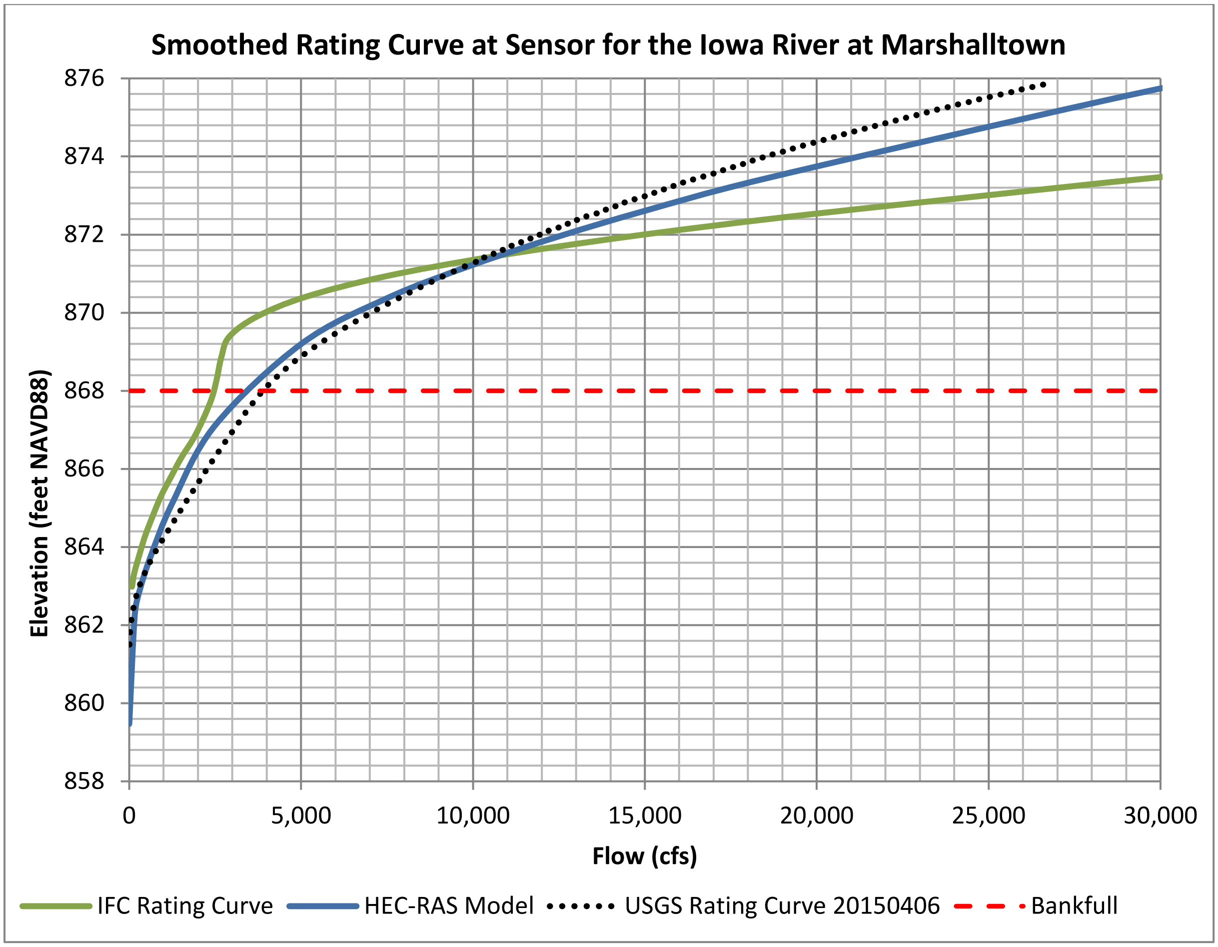

Figure 6: Rating Curve Results for the Iowa River at Marshalltown, IA

PHASE II SITES RATING CURVE RESULTS

CLEAR CREEK NEAR OXFORD [PHASE II]

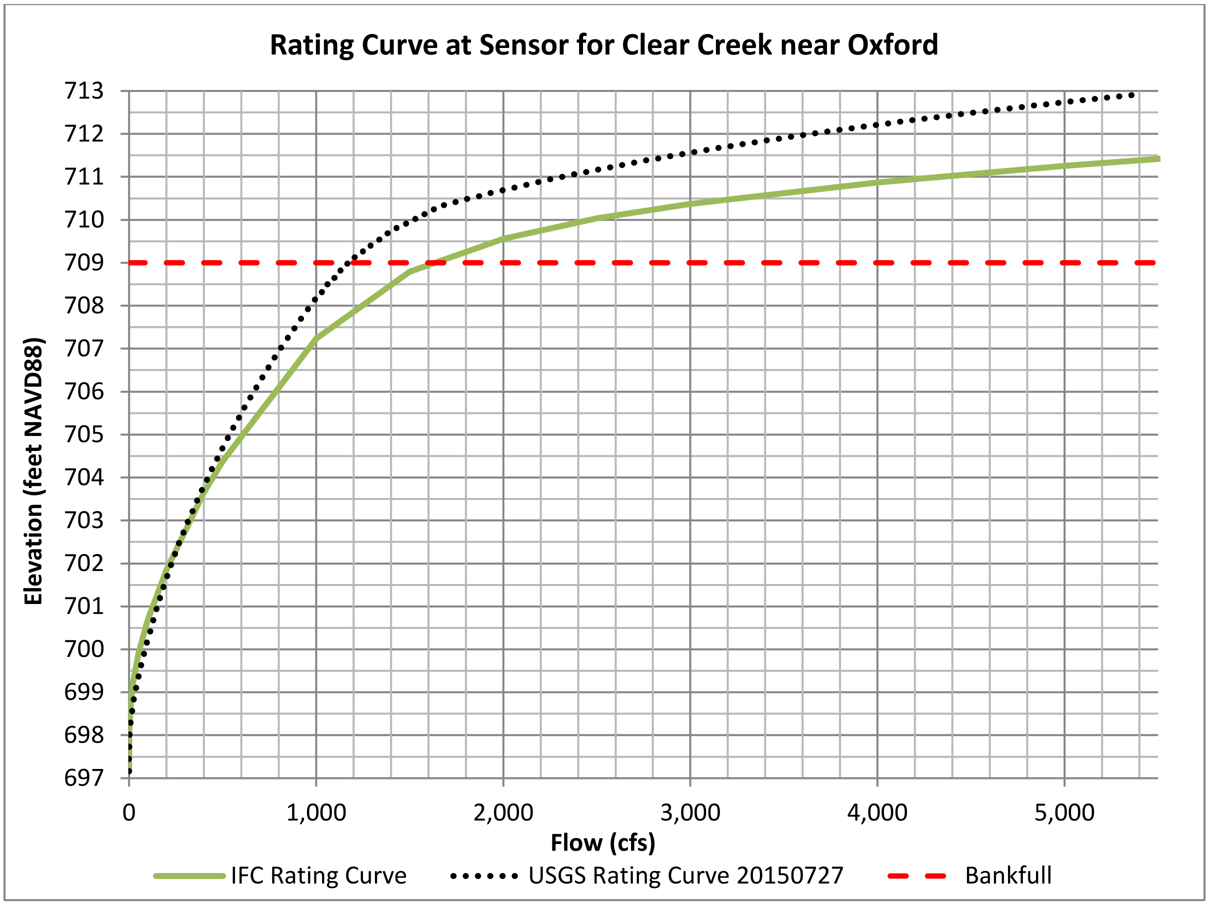

Figure 7: Rating Curve Results for Clear Creek near Oxford

Table 5: HEC-RAS RMSE Summary for Clear Creek near Oxford

RMSE	
Overbank (feet)	1.1
Belowbank (feet)	0.7
Combined (feet)	0.8
Overbank (cfs)	700
Belowbank (cfs)	100
Combined (cfs)	400

RACCOON RIVER AT VAN METER [PHASE II]

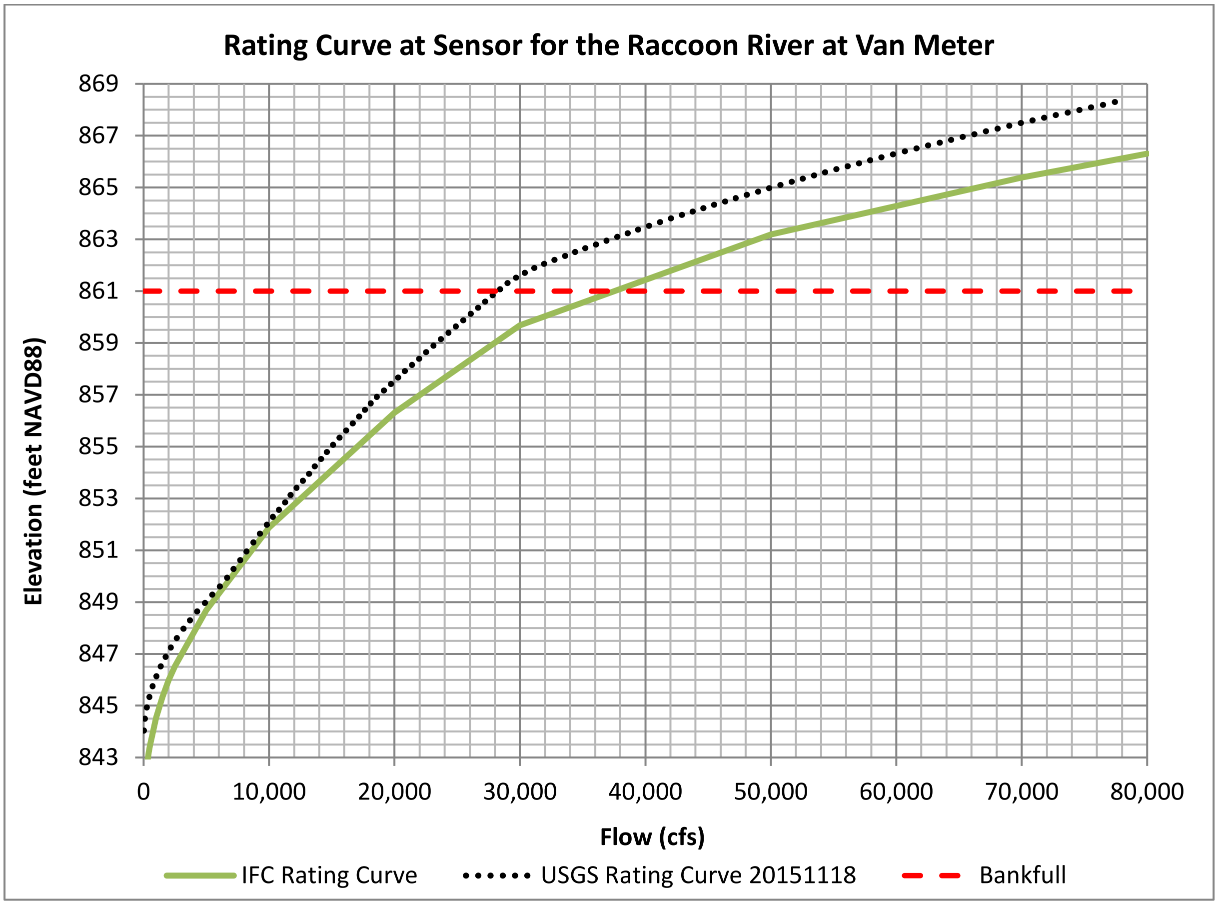

Figure 8: Rating Curve Results for the Raccoon River at Van Meter

Table 6: HEC-RAS RMSE Summary for the Raccoon River at Van Meter

RMSE	
Overbank (feet)	1.6
Belowbank (feet)	0.7
Combined (feet)	1.2
Overbank (cfs)	12,000
Belowbank (cfs)	1,000
Combined (cfs)	8,400

DES MOINES RIVER NEAR STRATFORD [PHASE II]

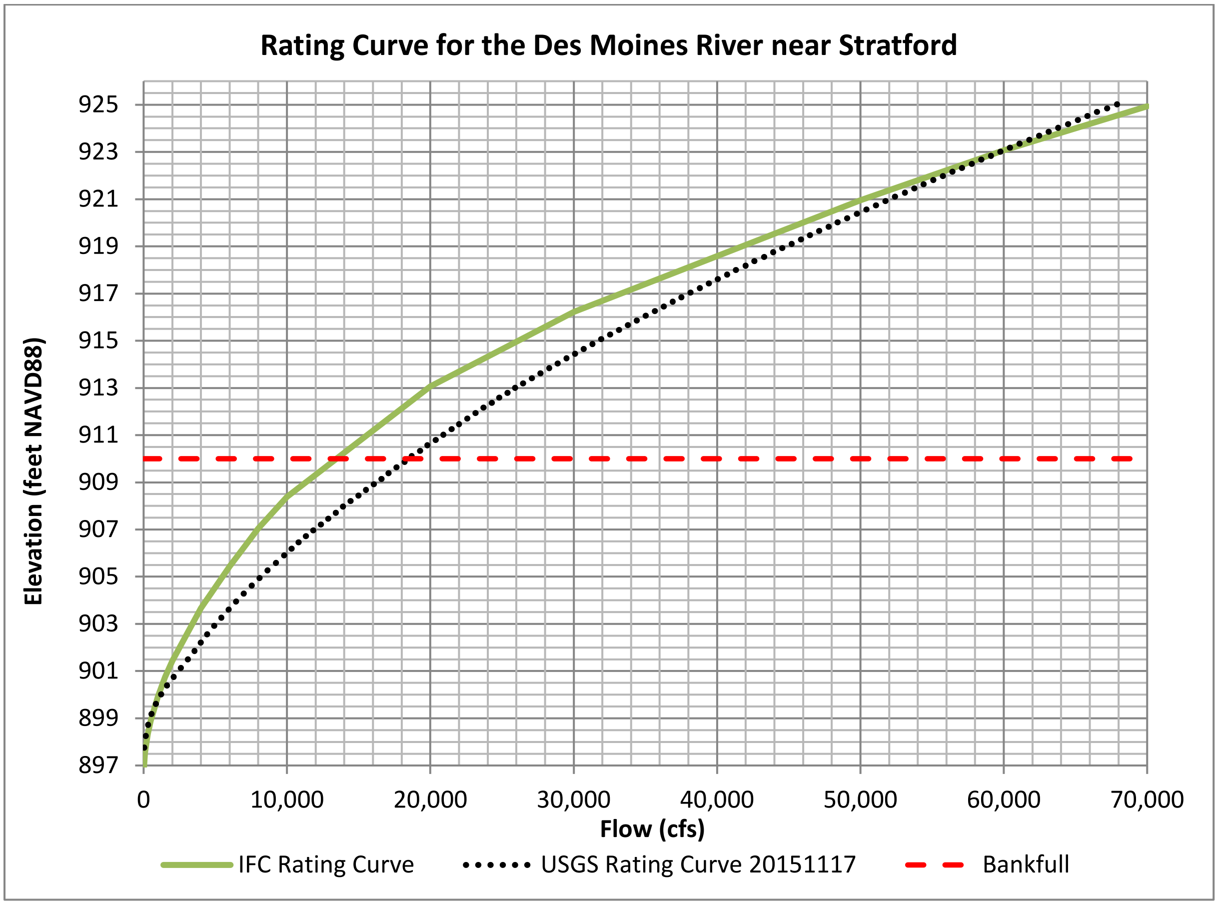

Figure 9: Rating Curve Results for the Des Moines River near Stratford

Table 7: HEC-RAS RMSE Summary for the Des Moines River near Stratford

RMSE	
Overbank (feet)	1.4
Belowbank (feet)	1.7
Combined (feet)	1.6
Overbank (cfs)	4,500
Belowbank (cfs)	2,800
Combined (cfs)	3,800

SOUTH SKUNK RIVER AT COLFAX [PHASE II]

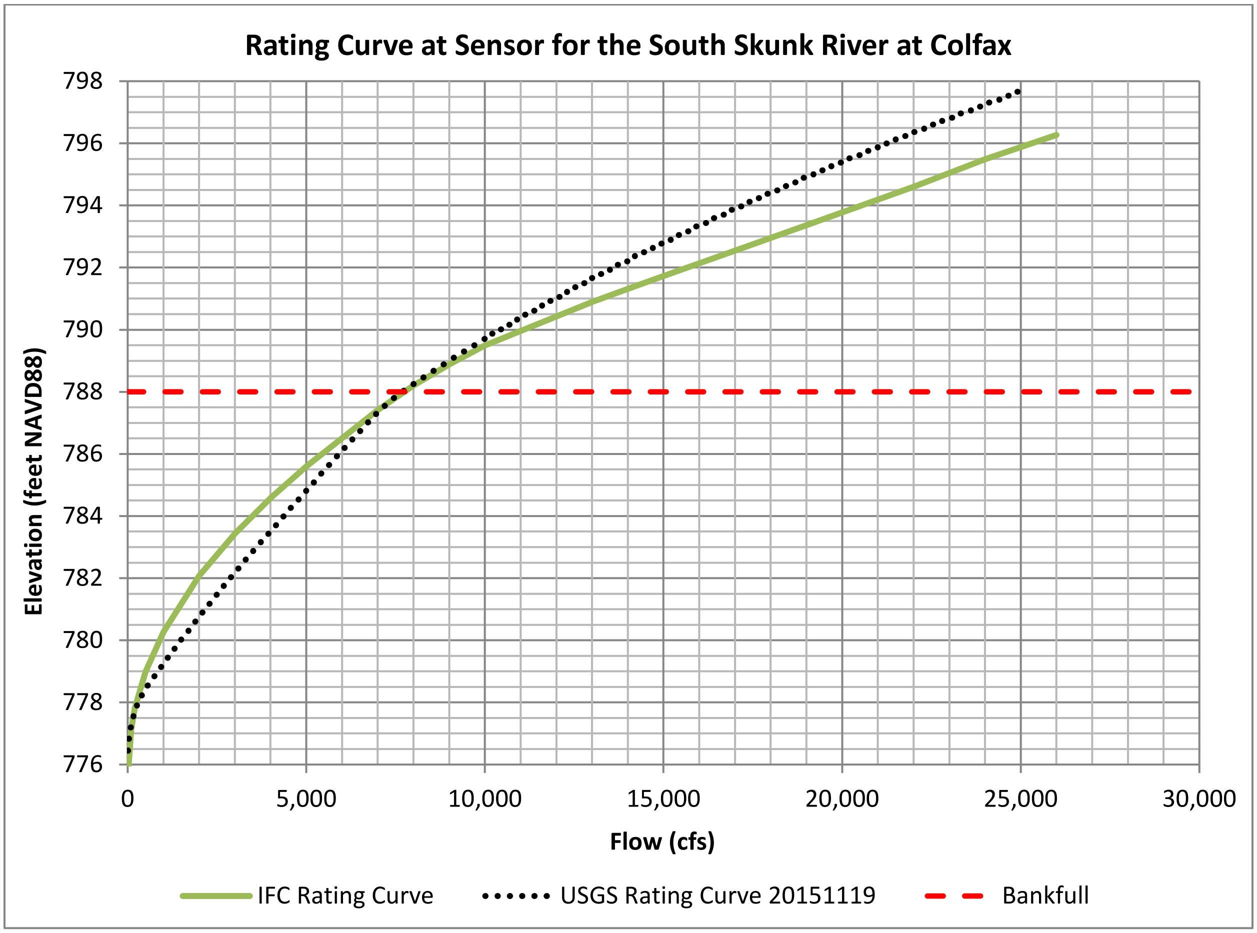

Figure 10: Rating Curve Results for the South Skunk River at Colfax

Table 8: HEC-RAS RMSE Summary for the South Skunk River at Colfax

RMSE	
Overbank (feet)	1.1
Belowbank (feet)	0.9
Combined (feet)	1.1
Overbank (cfs)	2,000
Belowbank (cfs)	350
Combined (cfs)	1,850

MAQUOKETA RIVER AT MANCHESTER [PHASE II]

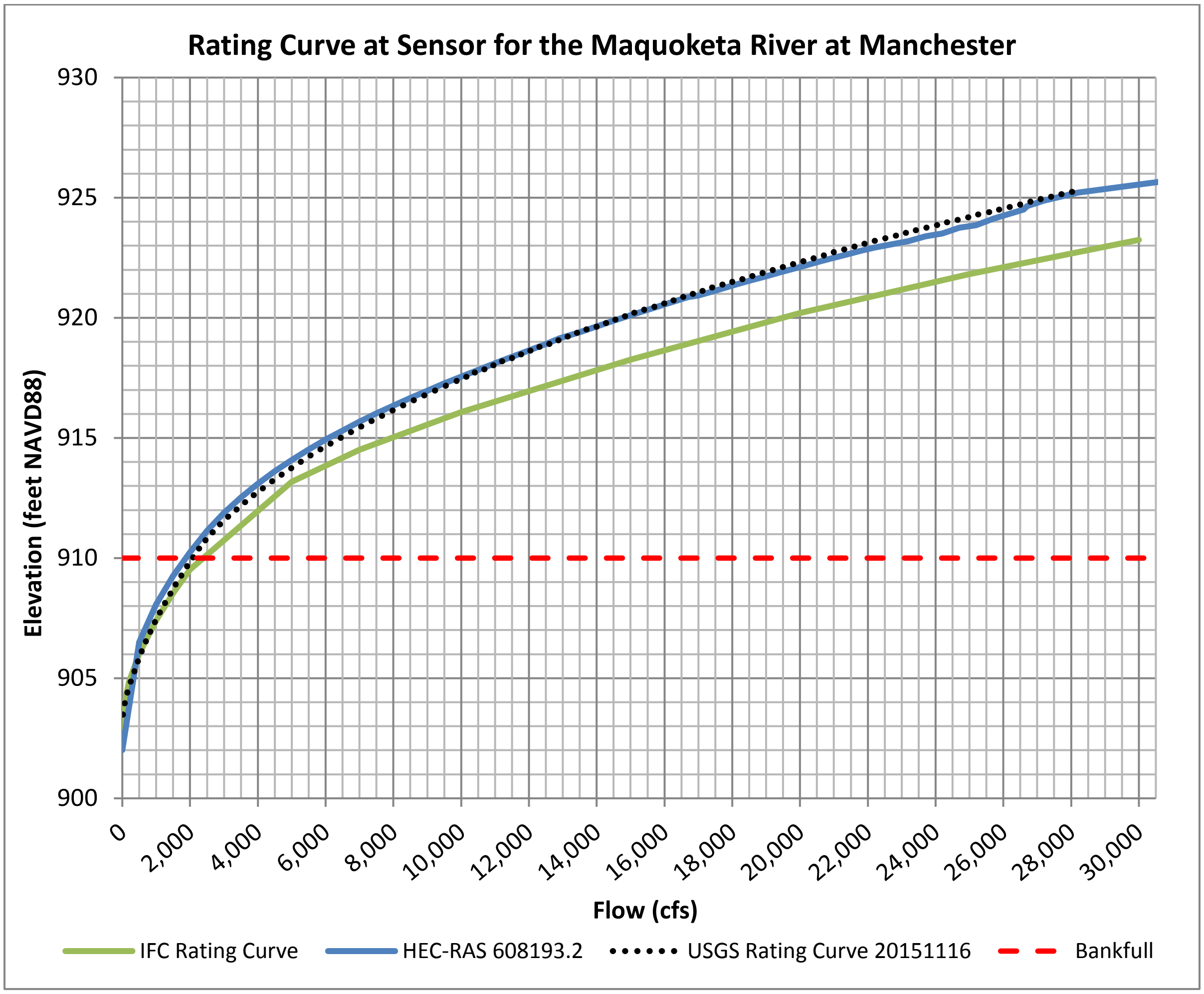

Figure 11: Rating Curve Results for the Maquoketa River at Manchester

Table 9: HEC-RAS RMSE Summary for the Maquoketa River at Manchester

RMSE	
Overbank (feet)	2.0
Belowbank (feet)	0.6
Combined (feet)	1.4
Overbank (cfs)	5,900
Belowbank (cfs)	600
Combined (cfs)	4,100

Table 10: USGS Rating Curve Details

Location	Field Survey Dates	USGS Rating Curve Number	USGS Rating Curve Shift Date
English River at Kalona	April 8, 2015	13.0	April 8, 2015
Indian Creek at Marion	April 8, 2015	1.1	April 8, 2015
Fourmile Creek at Des Moines	April 7, 2015	11.0	April 7, 2015
South Skunk River at Ames	April 6-7, 2015	9.1	April 6, 2015
Iowa River at Marshalltown	April 6, 2015 (at sensor) July 22, 2014 (all others)	27.1	April 6, 2015
Clear Creek near Oxford	July 27, 2015	9.0	July 27, 2015
Des Moines River near Stratford	November 17, 2015	8.0	November 17, 2015
Raccoon River at Van Meter	November 18-19, 2015	9.0	November 18, 2015
South Skunk River at Colfax	November 19, 2015	8.0	November 19, 2015
Maquoketa River at Manchester	November 16, 2015	5.0	November 16, 2015

SURVEY INFORMATION

The project mapping and water levels use the 1988 North American Vertical Datum (NAVD). USACE collected field survey data for the study sites used a combination of GPS and total station methods. Soundings were collected in the channels. Elevation data was collected for the water surface for each bank station at each cross-section, as well as overbank data points which were used to tie the survey data in with LiDAR data. State-wide available LiDAR elevation data was used for the overbank area to complete the cross-sections. Survey points are referenced by color, as shown in Table 11.

Table 11: Survey Point Descriptions

Survey Point Color	Survey Point Type
Blue	Soundings & Phase I Ground Data Points
Pink	Bridge and Roadway Data Points
Yellow	USGS and DOT Reference Marks
Teal	Water Surface Data Points
Brown	Phase II Ground Data Points
Orange	All other shots not included in the above categories

SELECTED SITE DESCRIPTIONS

PHASE I SELECTED SITES

ENGLISH RIVER AT KALONA (USGS Gage 05455500)

The English River at Kalona site is located in a rural watershed with a drainage area of 574 square miles within the Iowa River basin. This site has a USGS gage with a period of record from 1939 to the present. The IFC installed a new bridge sensor at this location for the pilot project. This site was selected due to the long period of record for the USGS gage, the moderately sized watershed, and the river characteristics through the study reach.

The study reach extends 140 feet upstream of the bridge at Highway 1, and 330 feet downstream of the bridge, for a total length of approximately 520 feet including the bridge width. Five cross-sections were selected for the English River site. The first cross-section (XSEC 1) is located upstream of the bridge, as shown in Figure 12. The remainder of the cross-sections are located downstream of the bridge.

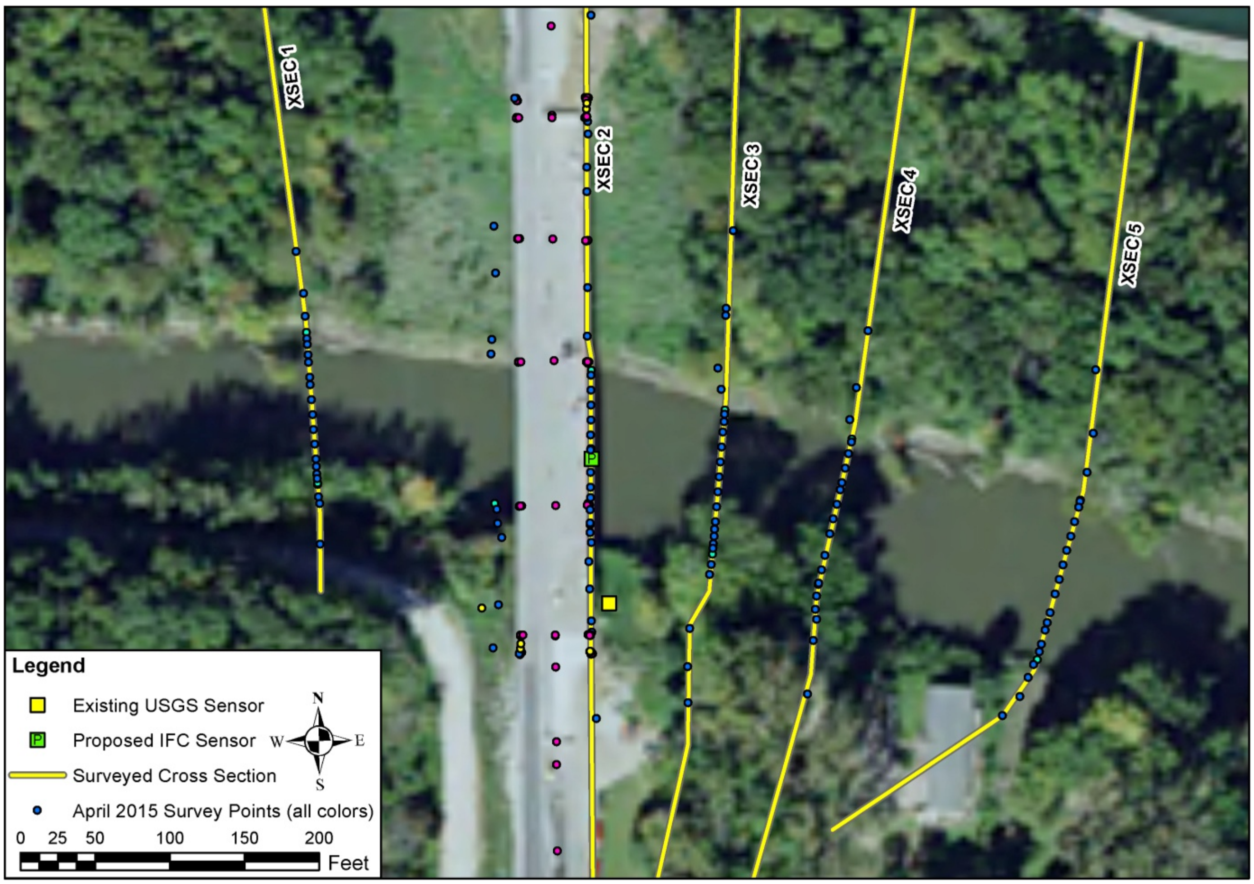

Figure 12: Cross-Section Layout for the English River at Kalona, IA

INDIAN CREEK AT MARION (USGS Gage 05464695)

The Indian Creek at Marion site is located in a mostly rural, partially urban watershed with a drainage area of 68 square miles within the Cedar River basin. This site has a USGS gage collocated with an IFC bridge sensor. The period of record for the USGS gage is from 2012 to the present. This site was selected due to the urban nature of the lower portion of the watershed, the straightness of the study reach, in addition to already having collocated gages and a recent HEC-RAS model.

The study reach extends 85 feet upstream of the bridge at Marion Blvd, and 200 feet downstream of the bridge, for a total length of approximately 385 feet including the bridge width. Four cross-sections were selected for the Indian Creek site. The first cross-section (XSEC 1) is located upstream from the bridge, as shown in Figure 13. The remainder of the cross-sections are located downstream of the bridge.

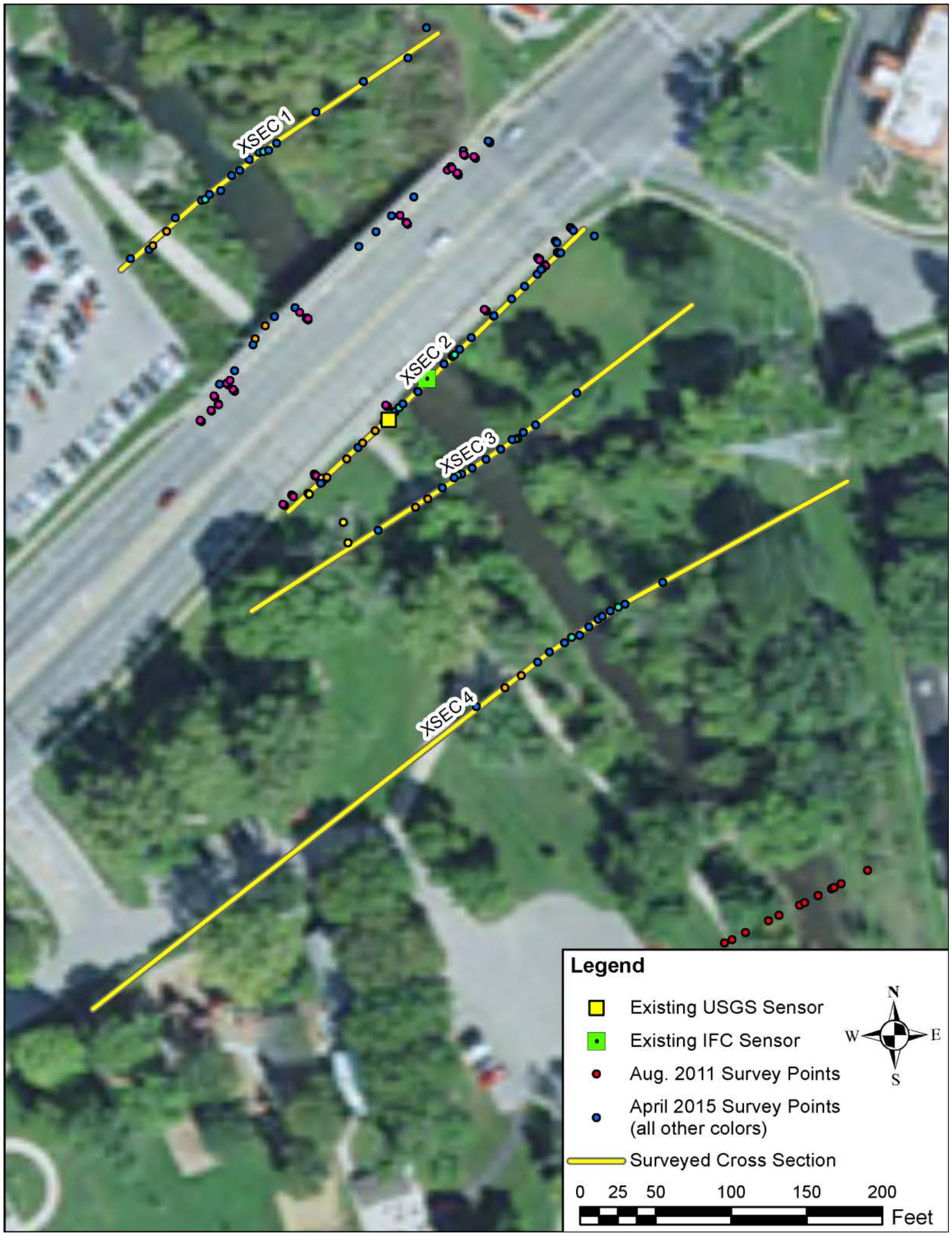

Figure 13: Cross-Section Layout for Indian Creek at Marion, IA

FOURMILE CREEK AT DES MOINES (USGS Gage 05485640)

The Fourmile Creek at Des Moines site is located in a mostly rural, partially urban watershed with a drainage area of 83 square miles within the Des Moines River basin. The study reach is located at the bridge at NE 54th Place, approximately 3.75 miles upstream from the USGS gage at Easton Blvd. The USGS gage has a drainage area of 93 square miles and a period of record from 1971 to the present. This site was selected due to the urban nature of the lower portion of the watershed, the straightness of the study reach, the proximity to a USGS gage with a long period of record, in addition to already having an IFC sensor installed and a recent HEC-RAS model.

The study reach extends 330 feet upstream of the bridge, and 100 feet downstream of the bridge, for a total length of approximately 470 feet including the bridge width. Four cross-sections were selected for the Fourmile Creek site. The first two cross-sections (XSEC 1 and XSEC 2) are located upstream from the bridge, as shown in Figure 14. The remainder of the cross-sections are located downstream of the bridge. Due to the Interstate 80 bridge located less than 700 feet downstream, the majority of the study reach was located on the upstream side of the NE 54th Place Bridge.

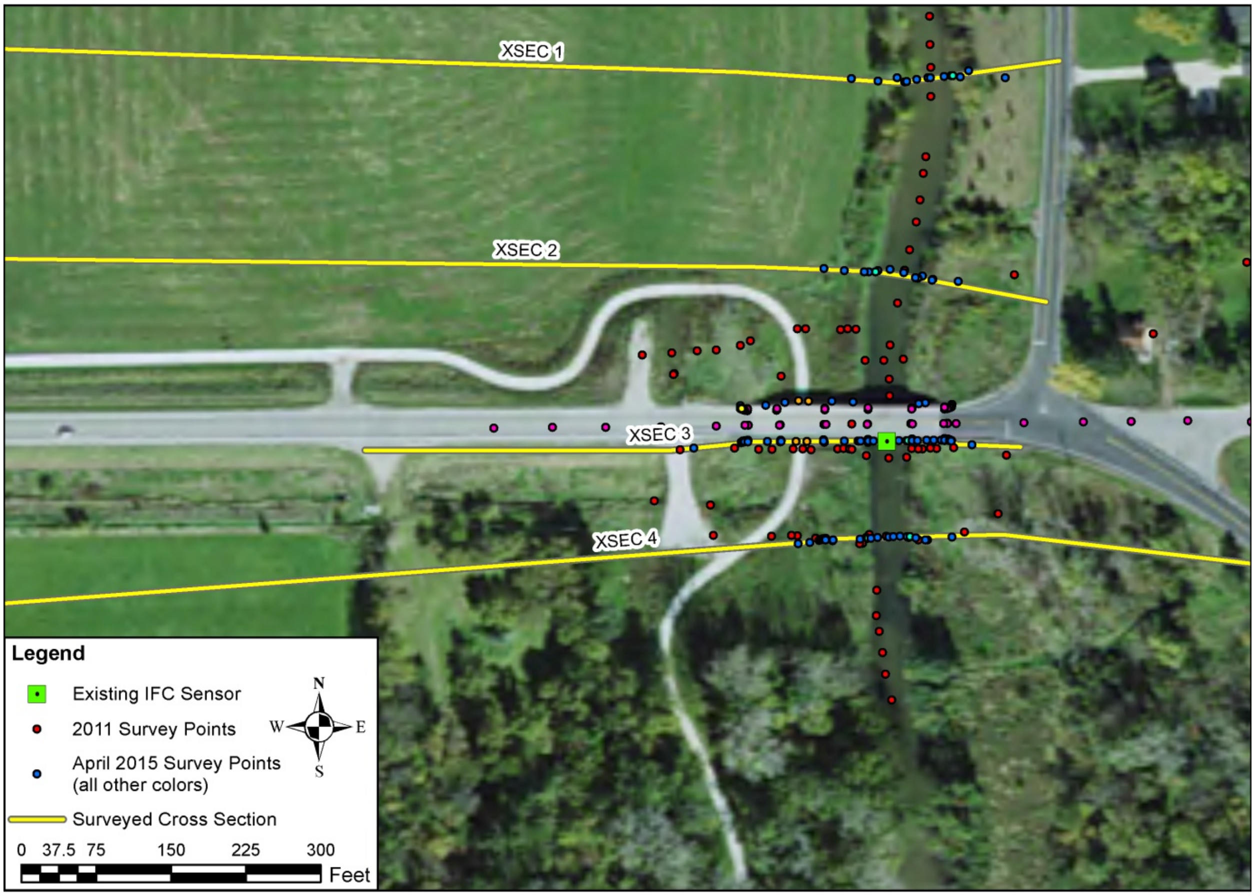

Figure 14: Cross-Section Layout for Fourmile Creek at Des Moines, IA

SOUTH SKUNK RIVER AT AMES (USGS Gage 05470000)

The South Skunk River at Ames site is located in a predominantly rural watershed with a drainage area of 326 square miles within the Skunk River basin. The study reach is located near the bridge at E. 13th Street, approximately 3.25 miles downstream from the USGS gage at W. Riverside Road. The USGS gage has a drainage area of 319 square miles and a period of record from 1920 to the present. This site was selected due to the urban nature of the lower portion of the watershed, the straightness of the study reach, and the proximity to a USGS gage with a long period of record, in addition to already having an IFC sensor installed.

The study reach extends 520 feet upstream of the bridge, and 75 feet downstream of the bridge, for a total length of approximately 680 feet including the bridge width. Four cross-sections were selected for the South Skunk River site. The first two cross-sections (XSEC 1 and XSEC 2) are located upstream from the bridge, as shown in Figure 15. The remainder of the cross-sections are located downstream of the bridge. The majority of the study reach is located on the upstream side of the E. 13th Street bridge due to several sandbars located downstream of XSEC 4.

Figure 15: Cross-Section Layout for the South Skunk River at Ames, IA

IOWA RIVER AT MARSHALLTOWN (USGS Gage 05451500)

The Iowa River at Marshalltown site is located in a predominantly rural watershed with a drainage area of 1,530 square miles within the Iowa River basin. This site has a USGS gage with a period of record from 1902 to the present. The IFC installed a new bridge sensor at this location for the pilot project. This site was selected due to the long period of record for the USGS gage, the large size of the watershed, the availability or recent survey data and a recently calibrated HEC-RAS model, and the river characteristics through the study reach.

The study reach extends 1,085 feet upstream of the bridge at Highway 14, and 2,020 feet downstream of the bridge, for a total length of approximately 3,200 feet including the bridge width. Five cross-sections were selected for the Iowa River site. The first two cross-sections (XSEC 1 and XSEC 2) are located upstream of the bridge, as shown in Figure 16. The remainder of the cross-sections are located downstream of the bridge. New survey data was collected for the cross-section at the bridge sensor (XSEC 3), in addition to bridge data and new water surface elevation points.

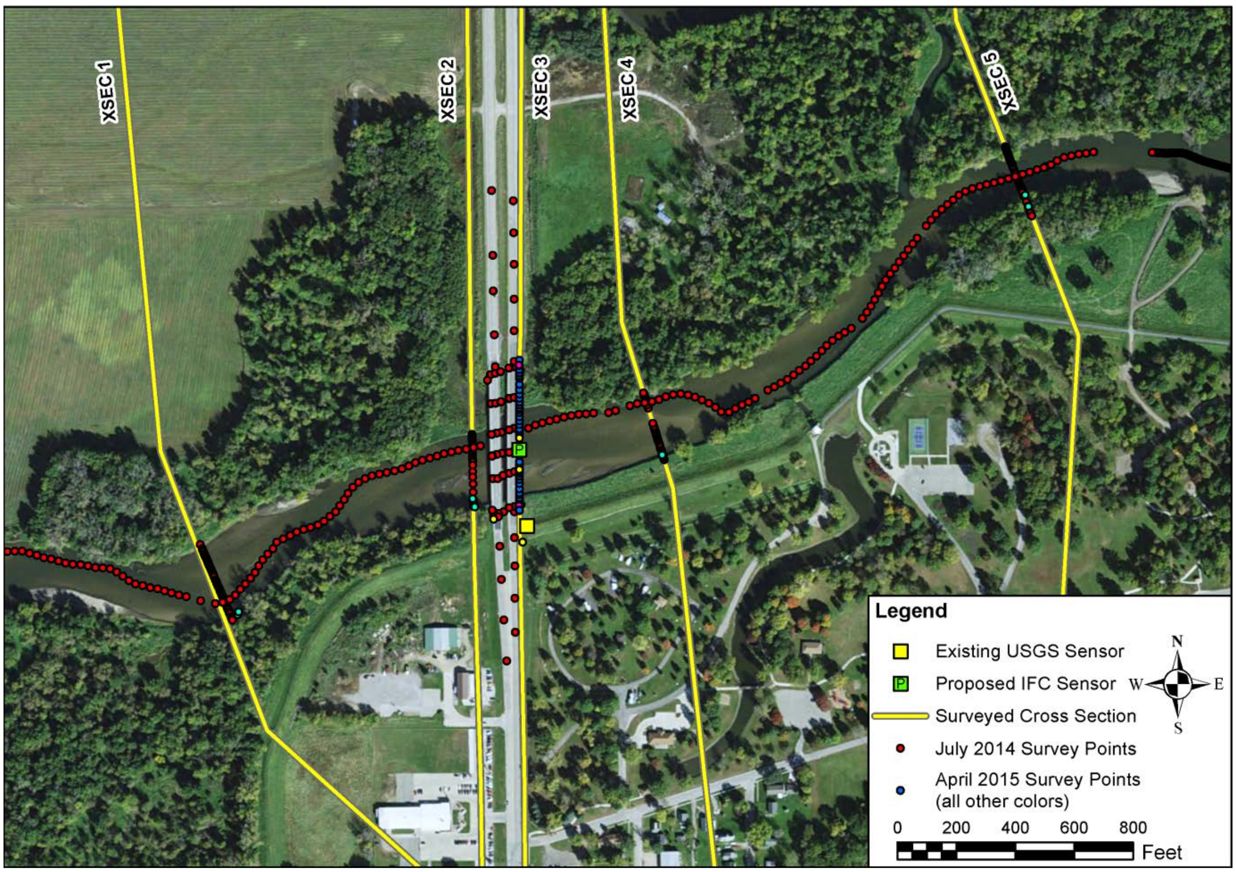

Figure 16: Cross-Section Layout for the Iowa River at Marshalltown, IA

PHASE II SELECTED SITES

CLEAR CREEK NEAR OXFORD (USGS Gage 05454220)

The Clear Creek near Oxford site is located in a rural watershed with a drainage area of 61 square miles within the Iowa River Basin. This site has a USGS gage collocated with an IFC bridge sensor. The period of record for the USGS gage is from 1993 to the present. This site was selected due to its proximity to the IFC, the amount of data gathered for this location by the IFC, and the river characteristics through the study reach, in addition to already having collocated gages.

The study reach extends 50 feet upstream of the bridge at Eagle Ave. NW, and 1,300 feet downstream of the bridge, for a total length of approximately 1,400 feet including the bridge width. Six cross-sections were selected for the Clear Creek site. The first cross-section (XSEC 1) is located upstream from the bridge, as shown in Figure 17. The remainder of the cross-sections are located downstream of the bridge, due to the straight nature of the downstream portion of the reach.

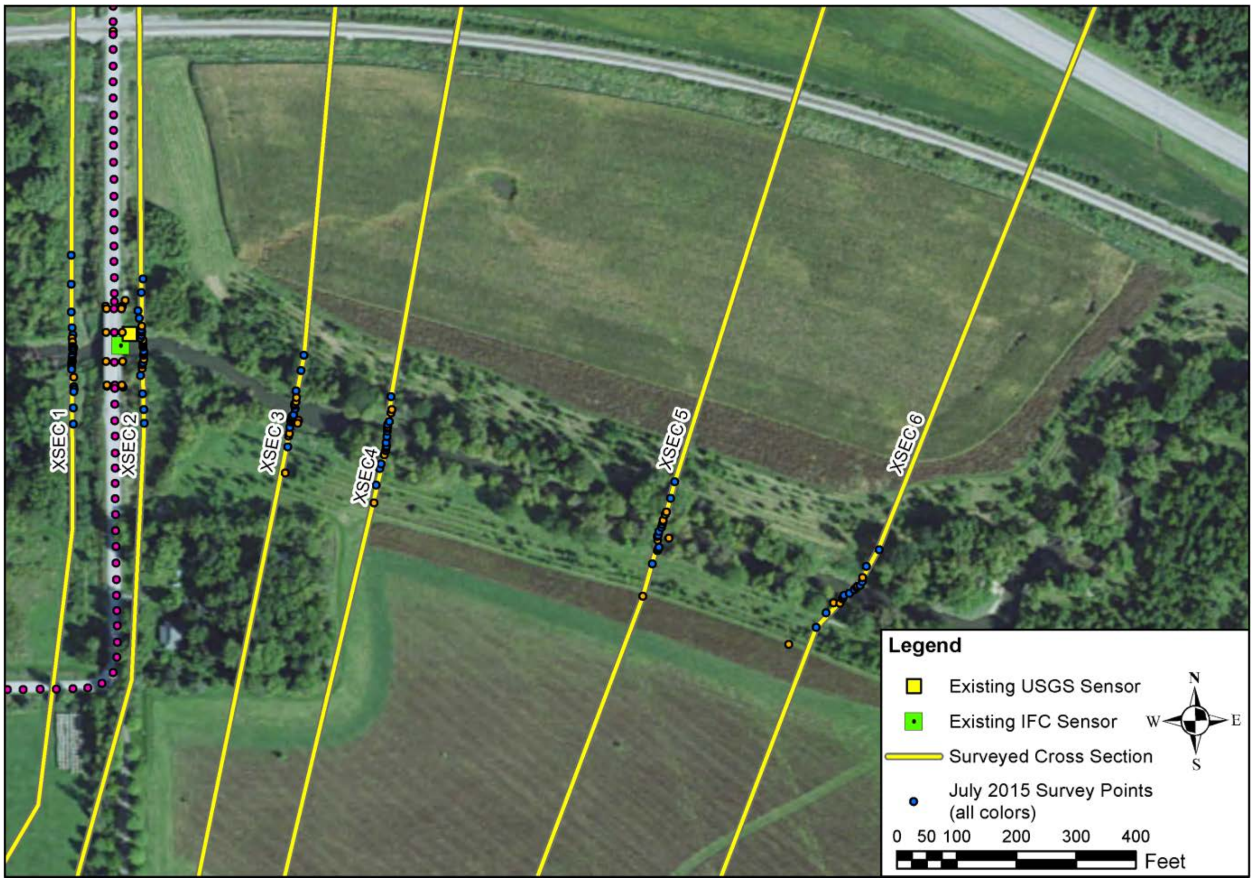

Figure 17: Cross-Section Layout for Clear Creek near Oxford, IA

DES MOINES RIVER NEAR STRATFORD (USGS Gage 05481300)

The Des Moines River near Stratford site is located in a rural watershed with a drainage area of 5,452 square miles within the Des Moines River basin. This site has a USGS gage with a period of record from 1967 to the present. The IFC installed a new bridge sensor at this location for the pilot project. This site was selected due to the long period of record for the USGS gage, the large sized watershed, and the river characteristics through the study reach.

The study reach extends 1,090 feet upstream of the bridge at State Highway 175, and 4,860 feet downstream of the bridge, for a total length of approximately 5,990 feet including the bridge width. Five cross-sections were selected for the Des Moines River site. The first cross-section (XSEC 1) is located upstream from the bridge, as shown in Figure 18. The remainder of the cross-sections are located downstream of the bridge.

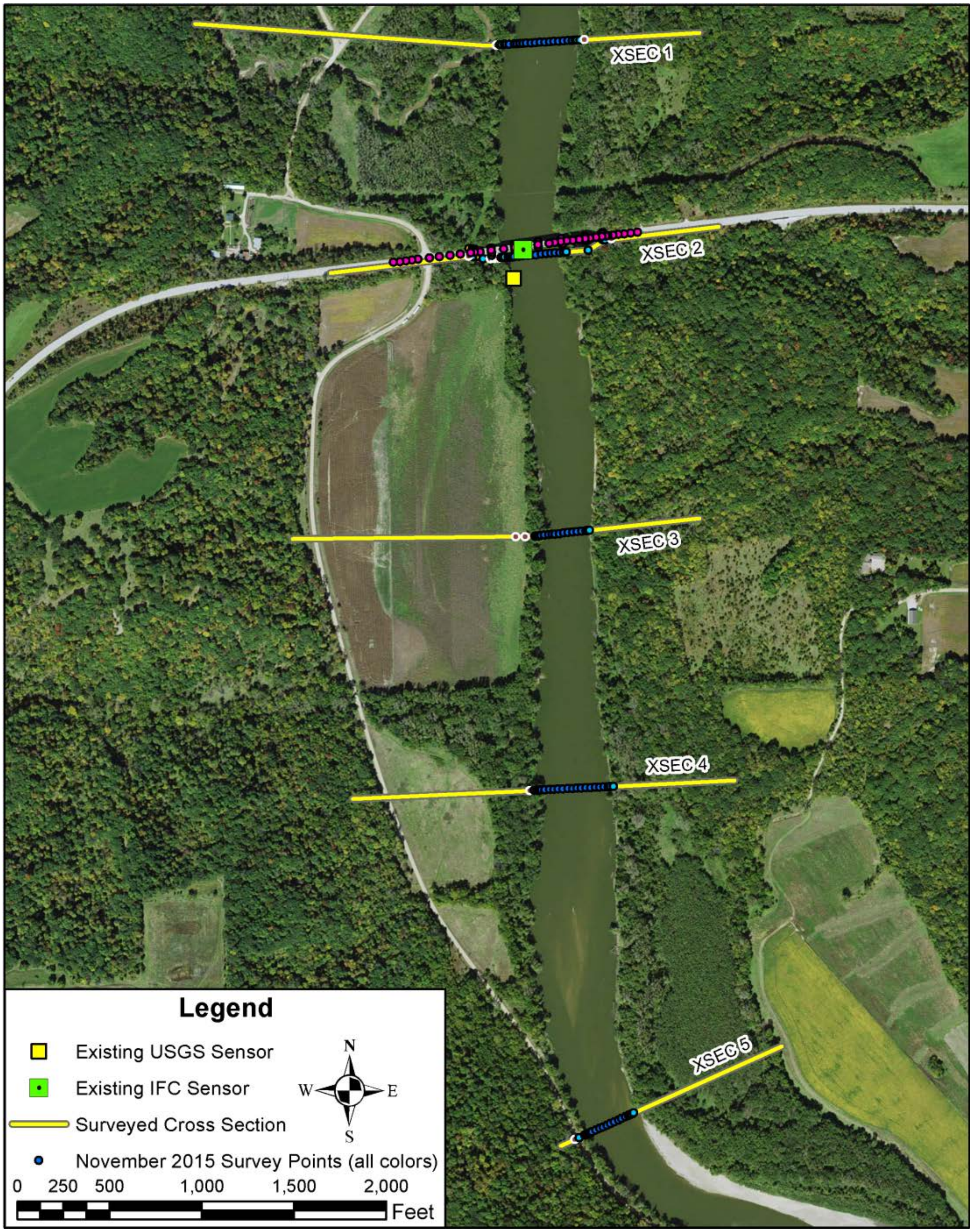

Figure 18: Cross-Section Layout for the Des Moines River near Stratford, IA

RACCOON RIVER AT VAN METER (USGS Gage 05484500)

The Raccoon River at Van Meter site is located in a predominantly rural watershed with a drainage area of 3,441 square miles within the Raccoon River basin. The site has a USGS gage collocated with an IFC bridge sensor. The period of record for the USGS gage is from 1915 to the present. This site was selected due to the large size of the watershed, the river characteristics through the study reach, and the long period of record for the USGS gage, in addition to already having collocated gages. The IFC bridge sensor for this location is installed on the upstream side of the bridge.

The study reach extends 5,450 feet upstream of the bridge at Mill Street, and 3,400 feet downstream of the bridge, for a total length of approximately 8,920 feet including the bridge width. Five cross-sections were selected for the Raccoon River site. The first three cross-sections (XSEC 1 – XSEC 3) are located upstream from the bridge, as shown in Figure 19. The remainder of the cross-sections are located downstream of the bridge.

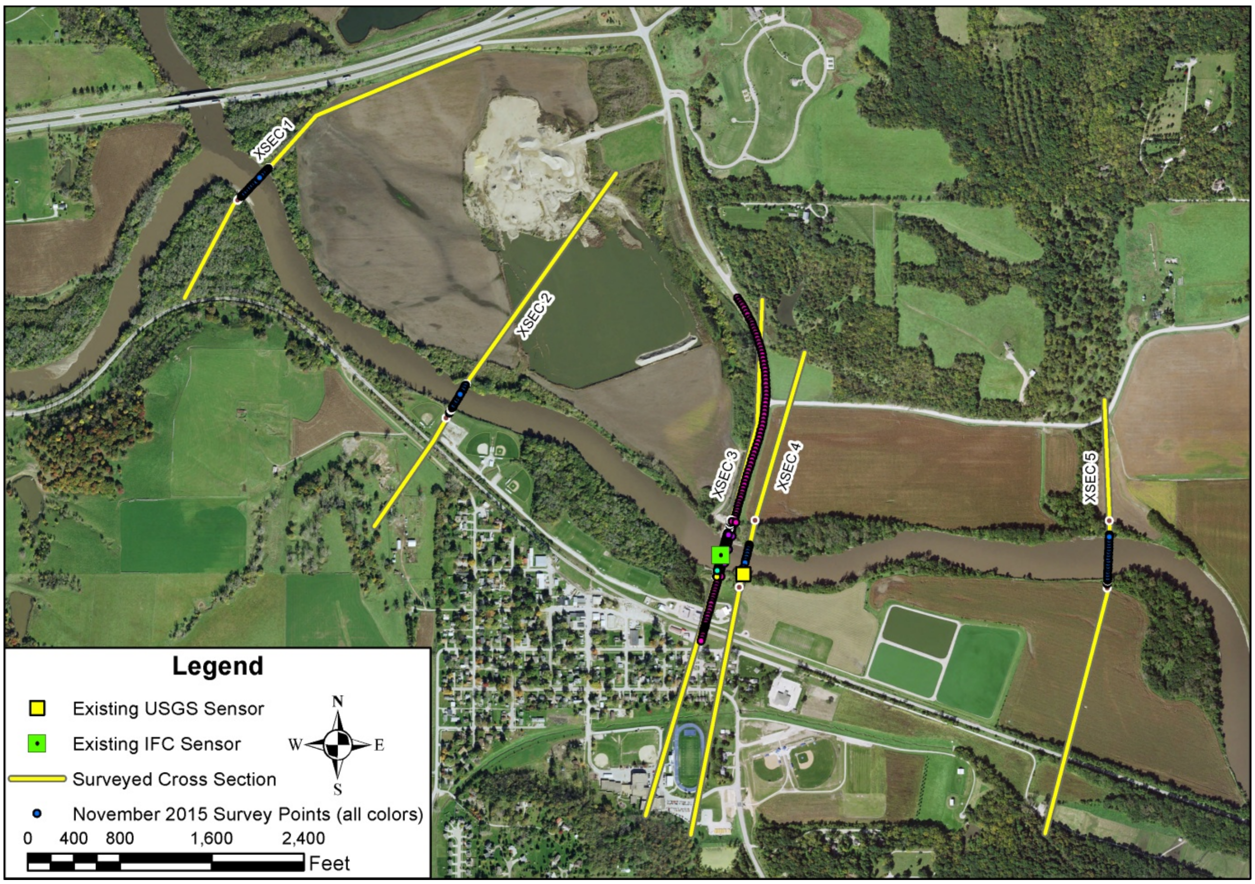

Figure 19: Cross-Section Layout for the Raccoon River at Van Meter, IA

SOUTH SKUNK RIVER AT COLFAX (USGS Gage 05471050)

The South Skunk River at Colfax site is located in a predominantly rural watershed with a drainage area of 803 square miles within the Skunk River basin. This site has a USGS gage with a period of record from 1985 to the present. The IFC installed a new bridge sensor at this location for the pilot project. This site was selected due to the relatively long period of record for the USGS gage, the medium sized watershed, in addition to the straight and stable nature of the river at this location.

The study reach extends 4,790 feet upstream of the bridge at State Highway 117, and 1,780 feet downstream of the bridge, for a total length of approximately 6,620 feet including the bridge width. Five cross-sections were selected for the South Skunk River site. The first three cross-sections (XSEC 1 – XSEC 3) are located upstream from the bridge as shown in Figure 20. The remainder of the cross-sections are located downstream of the bridge.

Figure 20: Cross-Section Layout for the South Skunk River at Colfax, IA

MAQUOKETA RIVER AT MANCHESTER (USGS Gage 05416900)

The Maquoketa River at Manchester site is located in a predominantly rural watershed with a drainage area of 275 square miles within the Maquoketa River basin. The site has a USGS gage with a relatively short period of record from 2000 to the present. The IFC installed a new bridge sensor at this location for the pilot project. This site was selected due to the urban nature of the lower portion of the watershed, the availability of recent survey data and a detailed HEC-RAS model calibrated to both the USGS gage rating curve and the 2010 high water event, in addition to the river characteristics through the study reach. The study reach represents the lower 0.75 mile portion of the three-mile HEC-RAS model.

The study reach extends 330 feet upstream of the bridge at Highway 20, and 3,025 feet downstream of the bridge, for a total length of approximately 3,495 feet including the bridge width. Eight cross-sections were selected from the HEC-RAS model for the Maquoketa River site. The first two cross-sections (608714.0 and 608446.5) are located upstream of the bridge, as shown in Figure 21. The remainder of the cross-sections are located downstream of the bridge. New water surface elevations were collected for each cross-section to determine the slope of the water surface through the reach, in addition to new bridge data.

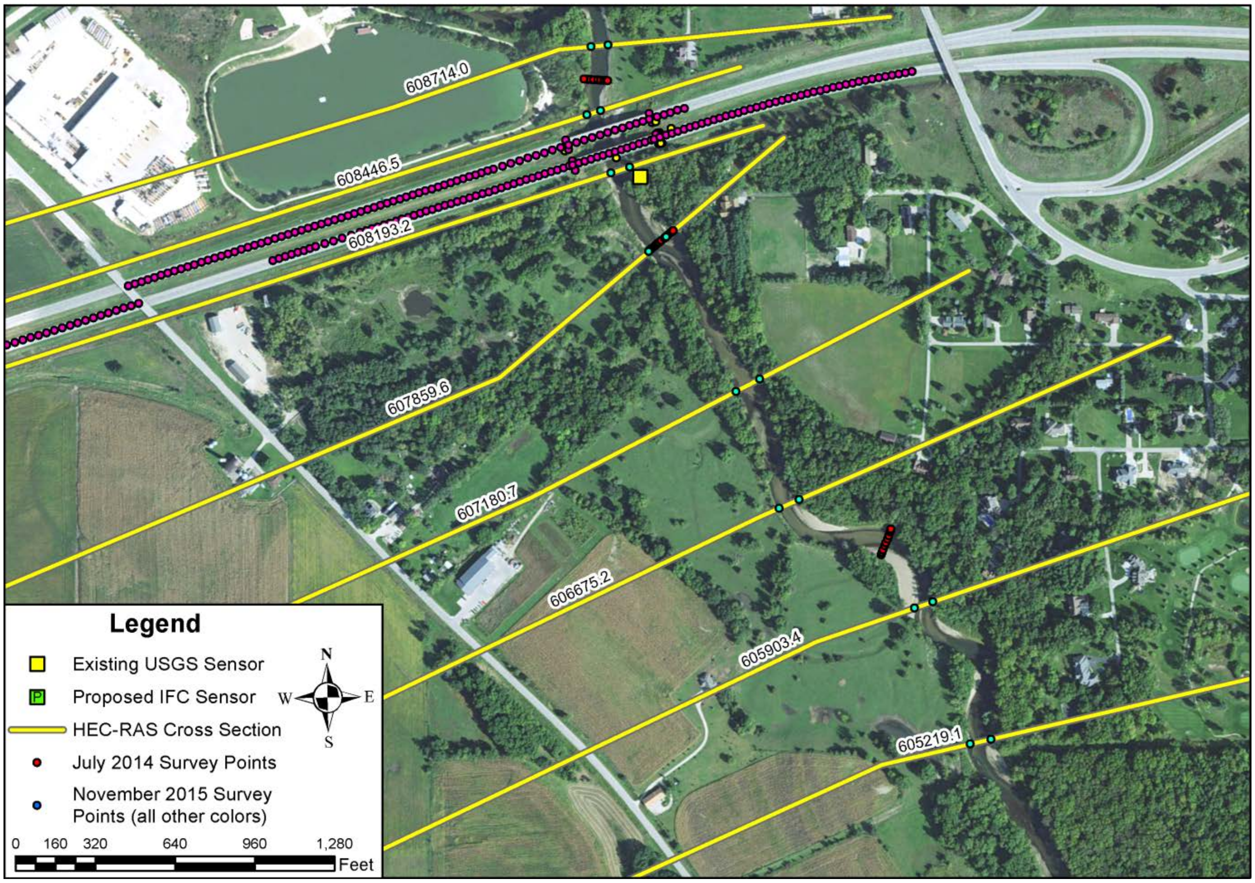

Figure 21: Cross-Section Layout for the Maquoketa River at Manchester, IA

APPENDIX A

Development of the Rating Curves for the Iowa Flood Center Real-time Stage Sensors

Development of the Rating Curves for the Iowa Flood Center Real-time Stage Sensors

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1. Introduction

Since its founding in 2009 by the State of Iowa legislature, the Iowa Flood Center (IFC) has worked to improve flood monitoring in the State. With funding from the Iowa Department of Natural Resources as well as other sources, the IFC has built about 250 stage sensors. To date, 226 have been deployed on Iowa's bridges that report stage readings every 15 minutes. The bridges provide a paid-for access to the river infrastructure. The sensors are autonomous, i.e. equipped with a battery recharged with a solar panel and a cell modem for relaying the data. Details of the design, construction and operation are given in Kruger et al. (2016). The network of the IFC bridge sensors complements similar number of stage sensors maintained by the United States Geological Survey (USGS) and National Weather Service. By a recent count, there are 223 real time river gauges in the State of Iowa.

While the IFC sensors provide stage values, i.e. the quantity most readily desirable and understandable by the general public, the data the sensors provide have much higher potential value. The Iowa Flood Center has established also a real-time hydrologic modeling system that is intended to produce discharge forecast simulations for all the communities in Iowa. A system of this kind would have a considerable potential for the improvement of the bridge sensor network capabilities, if their discharge simulations could be compared to discharge observations produced at all the locations where an IFC sensor is installed. However, for this purpose, it is necessary to establish a rating curve that translates the stage readings into discharge estimates, based on the local hydraulic characteristics of the channel where the sensor is installed.

The standard USGS approach for developing and maintaining the stage-discharge rating curve entails frequent visits at a gauging site for acquiring direct discharge measurements. This approach is prohibitively expensive for the Iowa Flood Center as the center is not manned for this kind of operations. However, the potential to add the discharge estimation to the large IFC network of bridge stage sensors has been recognized by federal and state agencies that operate in Iowa to benefit many stakeholders. This interest resulted in the formation of informal inter-institutional partnership in quest for an inexpensive yet robust methodology for producing rating curves at the IFC bridge sensor sites. If successful, the methodology could be extended for other federally or locally maintained gaging sites where only stage observations are being acquired. The partners fully recognize that the simpler methodology may not be able to produce rating curves of the degree of accuracy of the ones that employ the USGS approach. However, there is also recognition that less accurate rating curves could still be beneficial for many purposes in hydrological and water resources studies and investigations.

Given these considerations, the group developed a pilot project with the goal of exploring certain simple approaches to estimating rating curves. This document describes one of candidate techniques stemming from the slope-area method (Phase I of the pilot project). The conventional slope-area (SA) method (Dalrymple and Benson 1967) is typically used to extend the stage-discharge estimation method for high flows using high water marks produced by flood events (e.g. Dalrymple and Benson 1967; ISO 1070 1992; Herschy 2009). The SA procedure solves the energy equation for one-dimensional, gradually-varied, steady flow (Bernoulli), then uses a uniform-flow formula (Manning's equation) to solve for discharge. The single-most important step in successfully applying the SA method is the selection of suitable channel reaches for its implementation. Recommendations for site selection are numerous (e.g. Rantz et al. 1982; ISO 1070, 1992, Kennedy 1984) and quite difficult to fulfill in natural streams. Deviations from these recommendations combined with inaccurate measurement or parameter estimation lead to considerable uncertainties in discharge estimates. According to Benson and Dalrymple (1967) SA measurements can replicate discharge within 10% or less margin of error. Stewart et al. (2012) found that continuous SA measurements were affected by uncertainties ranging from 12.3% to 15.5% in the estimation of peak flows. In both cases, main sources of error arise the assumptions that channel geometry does not change during flows, variation of Manning's roughness coefficient and sensitivity to errors in the measurement of water-surface slope.

The method proposed herein takes advantage of the deployment by the Iowa Flood Center (IFC) of about 250 stage sensors throughout the Iowa streams and the availability of other associated data (e.g., in-situ survey of the stream cross sections at the bridge sensor location, lidar-based cross sections, and statewide roughness coefficient for Iowa floodplains). Given the large number of IFC sites and these additional resources, preliminary proof-of-concept investigations on using the simplified version of the SA method were prior tested for continuous estimation of discharges by Lee (2013).

The simplified SA method considered herein entails three steps: 1) geodetic survey of a cross section in a stream reach of known length; 2) survey of the free-surface slope (SGL), and 3) use of Manning's equation with a suitably selected roughness factor (Manning's n) and the slope obtained in step 2. This method is attractive for the available IFC infrastructure (stage sensors and cross-section profiles in their vicinity) as well as for other remote sensing technologies applied to rivers (Bjerklie et al. 2005). In particular, the ultrasonic sensors can provide stream stage, while LIDAR surveys can provide free-surface slope measurements and, for shallow flows, the geometry of the cross sections. To make the method economic and quickly applicable, some of the original SA protocol provisions were intentionally omitted in the simplified SA method. In particular, the method uses Manning equation for any flow condition and change in the stream geometry, one cross section for the construction of the rating curve, and a range of n-value and slope for all stages. Given these simplifications, the study documented herein has an exploratory nature and expected uncertainties. The role of these study is to quantifies these uncertainties for a variety of sites such that to infer a relevant conclusion on the entire IFC bridge sensor network If the uncertainties associated with the simplified SA method discharge estimates are deemed as acceptable for some practical uses (i.e., validation of large-scale simulations or providing flow estimates at ungauged sites within watersheds) the resultant economic benefits are considerable given that the IFC network of stream stage sensors is already in place.

This study assesses the feasibility of the rating curves produced by the simplified slope-area method by comparing them with well-established rating curves obtained by USGS observations of stage and discharge during flow events. Five gaging sites were selected where IFC and USGS sensors are either collocated or very close to each other. The Army Corps of Engineers conducted a geodetic survey of channel cross sections at all five locations. The surveyors have also collected information about free-surface elevations and provided detailed photographic records documenting the sites. This report summarizes the procedures for obtaining the rating curves associated with IFC bridge sensors, compares results of the IFC and USGS gage estimates and infer some insights resulted from the methodology implementation,

2. Methodology

The simplified slope-area method is essentially implementing the Manning's formula that is valid for steady, uniform open-channel flow

$$Q(d) \quad \frac{1.49[H_r(d)]^{2/3} A(d)\sqrt{S}}{n} \qquad (1)$$

where Q is the discharge (ft^3/s), H_r is the hydraulic radius (in feet) of the cross section, A is the area of the cross section (ft^2), S is the slope of the water surface, and n is the Manning's coefficient, a measure of the channel roughness. The terms H_r, A and thus Q in equation (1) depend on direct stage d. The IFC bridge sensors are providing the direct output the distance d (See Figure 1) that in conjunction with the geodetic survey of the cross section can be expressed as function of this variable, as described below.

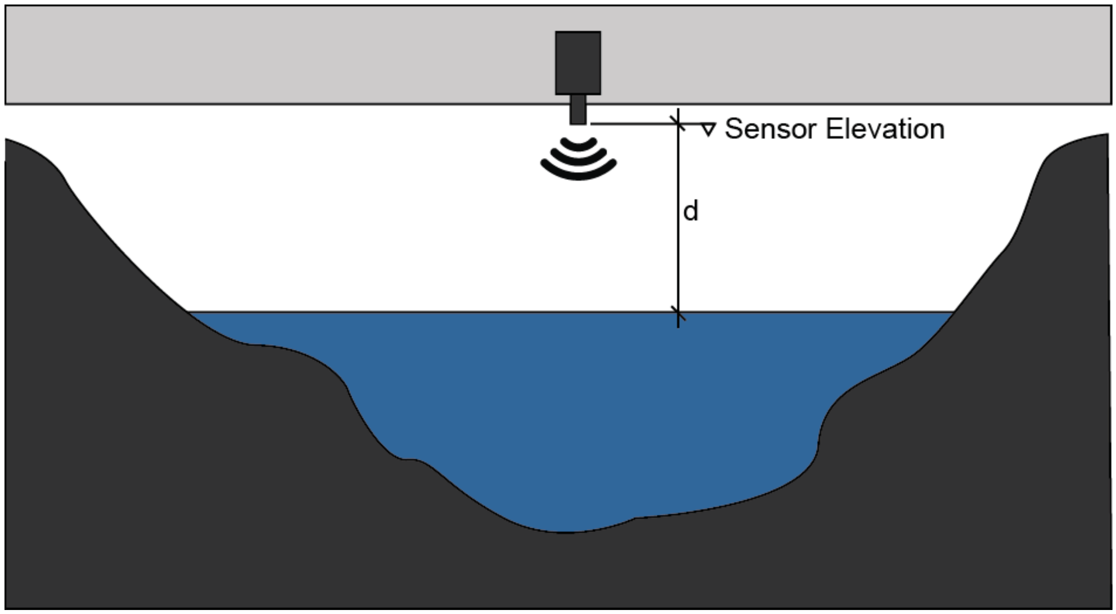

Figure 1. IFC bridge sensor measurement arrangement

2.1 Cross Section Geometry

Channel cross section for the study sites were obtained via geodetic surveys conducted complementary with total stations and GPS surveying equipment. When on site, the USACE surveying crew measured several channel cross-sections in the vicinity of the bridge with the IFC sensor. The cross-section spacing was 100 feet to 300 feet apart. This provides the stream channel geometry and allows determination of the free-surface slope, as shown in Figure 2. Figure 3 displays a cross section (labeled AB in Figure 2). The variation of the wetted perimeter and the area of the cross section used for the estimation of $H_r(d)$ in equation (1) is illustrated in Figure 4 for a range if stages (d). The stages are expressed as elevations represented NAVD88 coordinate system.

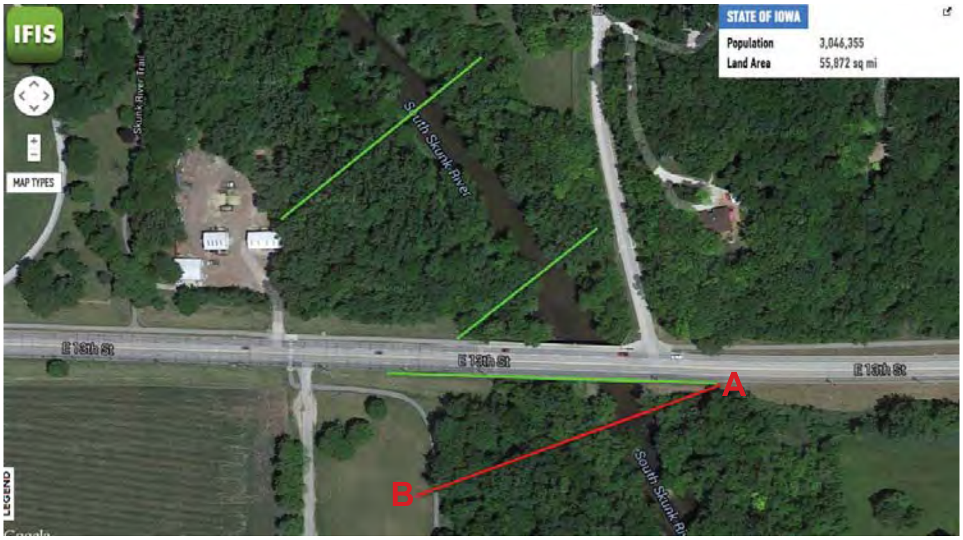

Figure 2. Sample cross sections (green and red lines) for one of the tested sites. Labeling on the red line are used to reference the downstream view of cross section in Figure 3

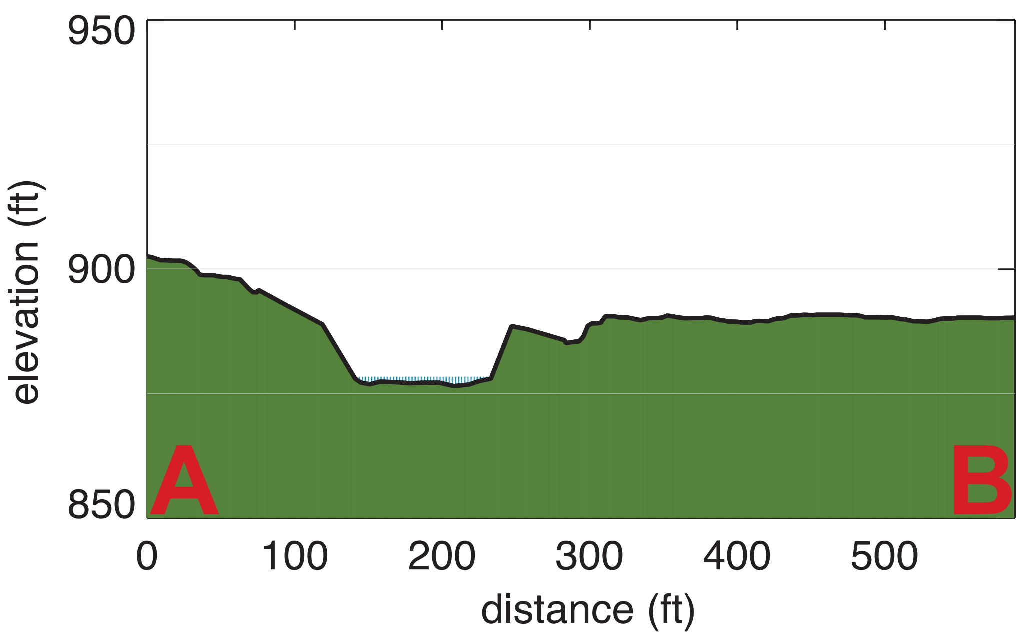

Figure 3. Downstream view of the cross section AB in Figure 2

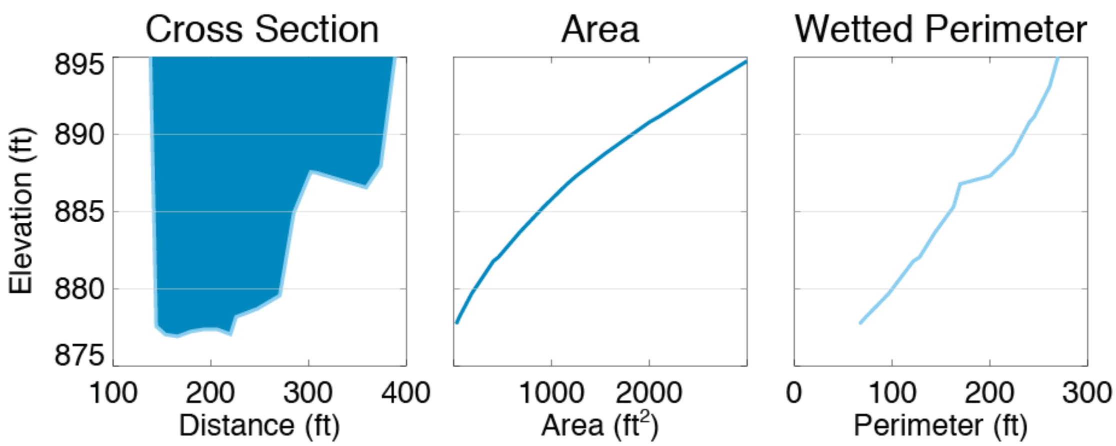

Figure 4. Variation of the stream wetted perimeter and cross-section area with stage

2.2 Slope Estimation

Using the approach for the free-surface slope estimation recommended in the slope-area method, the water surface slopes along the left and right banks of the stream were measured during the geodetic survey as illustrated in Figure 5. The consistency of the slope estimation along the reach was analyzed by selecting various combinations for the slope calculations (i.e., cross section 1 and 2, 1 and 3, 1 and 4 and). The consistency between the two slope measurements was overall good hence, for most of the cases only the first and last cross sections are used for slope estimation.

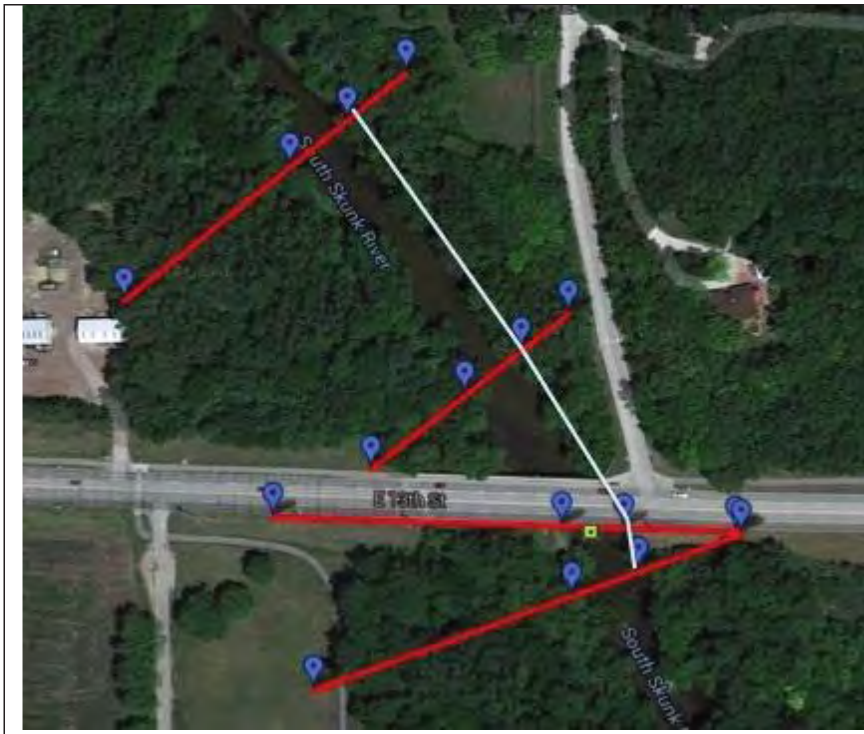

Figure 5. Bankline profiles used for the free-surface slope estimation

2.3 Estimation of Manning's Coefficient

The roughness coefficient is obtained through visual inspection of the photos taken during the surveys. There are several sources that support estimation of the roughness coefficient based on the geometry, geomorphology and vegetation at the site. For our study Table 1 (USGS, 1989) is used for assessing the roughness coefficient.

Table 1. Base values of Manning's n adopted from USGS (1989)

Bed Material	Base n value
Concrete	0.012-0.018
Firm soil	0.025-0.032
Coarse sand	0.026-0.035
Gravel	0.028-0.035
Cobble	0.030-0.040
Boulder	0.040-0.070

2.4 Uncertainty Considerations

The simple SA method is most sensitive to the values of the measured water surface slope and the channel roughness. Both parameters are typically small numerical values and prone to large errors, while their role in the functional relationship described by Equation (1) is critical. The accuracy of the channel and bank elevation measurements is limited by the equipment used but is on the order of a tenth of a foot. On the other hand, elevation of the water surface is difficult to measure accurately as it is a moving target subject to wind and other environmental effects. Therefore, estimates of the slope are subject to considerable uncertainty. Similarly, channel roughness is not a measurable quantity and has no local (cross section) meaning. In practice Manning's n is estimated through experience based on visual inspection of the channel characteristics. In contrast, the channel cross section can be measured rather accurately and it is only the spacing of the surveyed points that limits the accuracy.

Given the uncertainty considerations discussed above, it was decided to develop the rating curves as intervals rather than unique stage-discharge relationships through uncertainty analysis. Consequently, while the actual values for the free-surface slope and channel roughness are known, expected ranges for each of the variables around their known values are chosen. These ranges were assumed as uniform probability distribution as the probability to have any value in this range was the same. It was also assumed that our knowledge of one of the parameters is independent on the knowledge of the other one. Therefore, the two uniform distributions can be considered independent.

With these assumptions the problem of estimating $Q(d)$ in (1) comes down to determining probability distribution of Q. This is a derived distribution problem that can be solved analytically or numerically. A numerical solution is easy to implement and flexible to changes in assumptions and analysis of the output, therefore Monte Carlo simulation (e.g. Ang & Tang 2006) were used for building the rating curve estimates.

Randomly selected set of N feasible combinations for slope S and Manning's n values assuming a uniform distribution for both parameters was used. The slope range is defined by the minimum and maximum slopes obtained from the surveys along the stream banks. The range for Manning coefficient has been set between 0.03 and 0.045 given the variety of stream characteristics observed during the surveys (see Figure 6). This range is supported by the collective experience of the project partners, based mostly on numerical modeling studies.

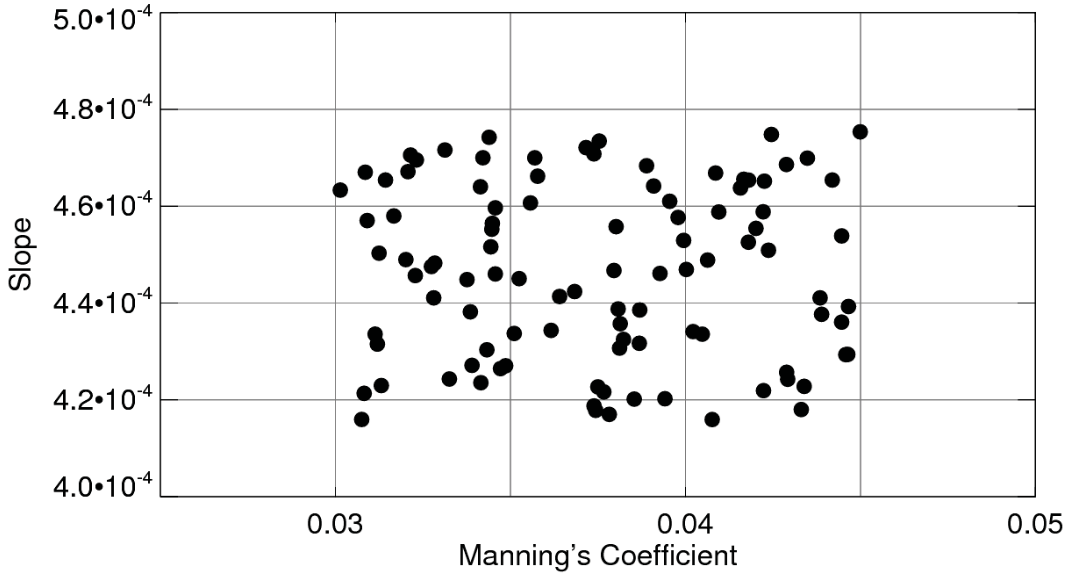

Figure 6. Sample of 100 out of 10,000 values of Manning's coefficient and slopes used for the Monte Carlo simulation

Conducting a large number of simulations is fast and convenient. It allows accurate derivation of the probability distribution of $Q(d)$. Another way of looking at this is that each combination of the S and n values results in a different rating curve. While the assumptions involved in the simulations are realistic and useful, the rating curves are provided as intervals over the entire range of variation of the stage. In other words, the rating curves provided by the method delivers intervals of equal probability for the discharge values within the specified range similarly to uncertainty limits. This type of output is accepted in analyses where the degree of uncertainty in the independent variables is high. But which one is the best? We obviously have no answer to this question. Users can decide for themselves. But to characterize the obtained distributions they are presented as a set of rating curves summarized by their quantiles: 50% (median), 25% and 75%.

2.5 Estimation of the Rating Curve

Each stream stage is associated with a range of possible values for discharge that takes into account the uncertainties in the measurement of water surface slope and estimation of Manning coefficient. The probable discharge values for a particular stage are given by the envelopes of the simulation illustrated in Figure 7 (light grey areas for the 0% and 100% percentiles, and dark grey area for the 25% and 75% percentiles). A representative rating curve can be assumed to be is obtained as the median of all possible realizations (solid black line). The blue line in the figure is the USGS rating curve for the gaging location (when the IFC and USGS sites are collocated). Bankfull line is shown as a dashed black line. The median rating curve can be directly compared with existing rating curves within or in the proximity of the surveyed site.

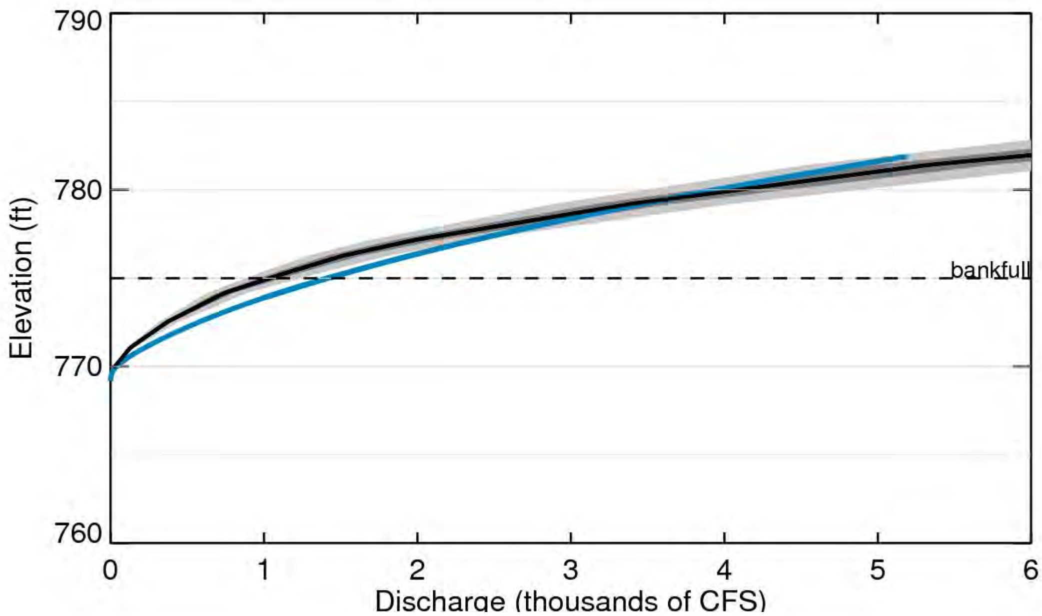

Figure 7. Example of rating curve estimation with consideration of uncertainty in the input variables

3. Study Area and Available Data

This study was conducted at five locations containing IFC bridge sensors and an USGS sensor collocated at the same bridge, or very close to it. These sites are described in Table 2. In the same table are presented the elevation of the bridge sensor and the drainage area of the basin. Table 3 presents the analogous characteristics from the corresponding USGS sensors, including the elevation of the USGS gage datum and the drainage area of their basins. The elevation of the USGS gage datum of the sensors that comes originally in NGVD29 system, was transformed to NAVD88 system. Of the investigated sites, only the Fourmile Creek and South Skunk river sites do not have the IFC and USGS sensors collocated. The distance between non-collocated sensors was obtained from a drainage network map derived from a 90 meter DEM.

Table 2. Characteristics of the IFC Sensors. Source: IFIS

Name / Code	Elevation of the tip of the Bridge Sensor (feet, NAVD88)	Upstream Area (mi^2)	Bankfull Level (feet)
English River at Kalona - ENGLSHRV01	668.43	574	650
Indian Creek at Marion - INDCR03	789.89	68	775
Iowa River at Marshalltown - IOWARV02	879.003	1,532	868
Fourmile Creek - FOURMLE01	838.22	81	833
South Skunk River at Ames - SSKNK01	897.59	327	888

Table 3. Characteristics of the USGS Sensors and Location With Respect to IFC Sensors. Source: USGS & IFIS

Name / Code	Gage Datum (feet,NAVD88)	Upstream Area (mi^2)	Location with Respect to IFC Sensor
English River at Kalona - 05455500	633.33	574	Collocated
Indian Creek at Marion - 05464695	766.89	68	Collocated
Iowa River at Marshalltown - 05451500	853.13	1,532	Collocated
Fourmile Creek at Des Moines - 05485640	795.95	93	Downstream 3.76 miles
South Skunk River at Ames - 05470000	888.69	315	Upstream 3.24 miles

The Iowa Flood Center created a website that contains and displays all the information collected in the survey and make it accessible in an interface similar to IFIS. The website can be accessed by visiting http://ifis.iowafloodcenter.org/ifis/sc/ratingcurve. When prompted for a password, type 'iowaratingcurves'.

4. Results

4.1 Cross Section Analysis

Figures 8a to 8e illustrate the cross sections located in the vicinity of the IFC bridges sensors analyzed in the present study. The vertical scale of the plots is intentionally distorted for substantiating the stream geometry. These are the cross sections for which the rating curves are constructed at each of the analysis site. For each of the investigated sites, up to 10 cross sections were surveyed at the time of the field trip. Appendix A contains all these cross sections. The cross sections in these figures combine the data garnered through the in-situ survey conducted by the USACE with LIDAR data for the floodplain portion of the cross sections. The water elevation in the cross section corresponds to the stream stage at the time of the survey.

The cross sections for the sites that are equipped with both IFC and USGS are illustrated in Figures 8a to 8c. For the analysis sites with sensors separated by some distance (but relatively close to each other and without tributaries within the connecting stream), each station has its own datum. The cross sections illustrated in Figures 8d and 8e are close to the IFC bridge sensors. The closest USGS reference sensor for the IFC sensor installed at Fourmile Creek bridge (Figure 8d) is located located about 3.1 miles downstream of the section shown in Figure 8d, in Des Moines. The drainage area of the USGS sensors is about 11 square miles larger than the catchment where the IFC bridge sensor is installed. The ther non collocated site of the study is on the South Skunk River near Ames. There the IFC bridge sensors (corresponding cross section shown in Figure 8e) is located upstream from the USGS station. The difference between the drainage areas of the two sensors is about 12 square miles (see Table 2, 3).

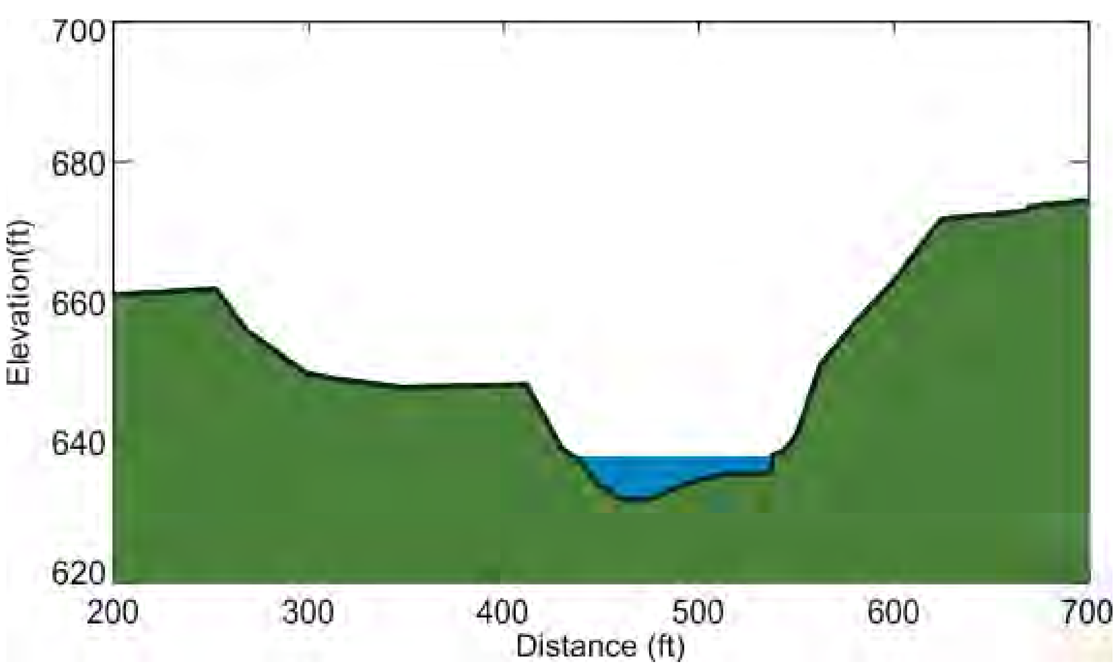

Figure 8a. Cross section located next to the IFC bridge sensor on English River at Kalona

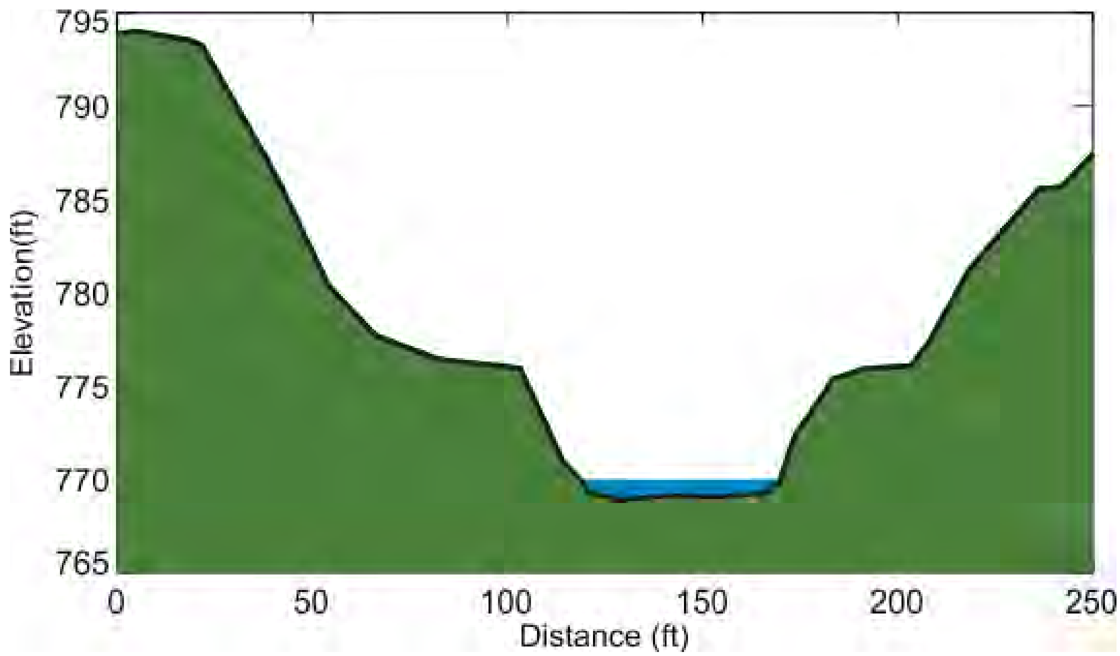

Figure 8b. Cross section located next to the IFC bridge sensor on Indian Creek at Marion

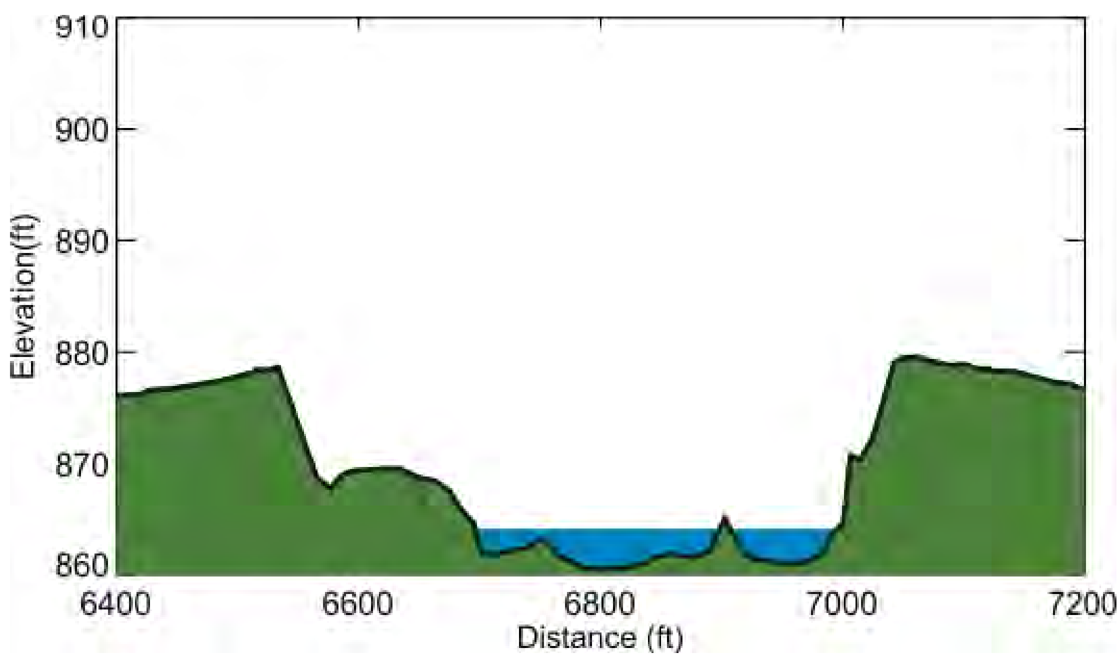

Figure 8c. Cross section located next to the IFC bridge sensor on Iowa River at Marshalltown

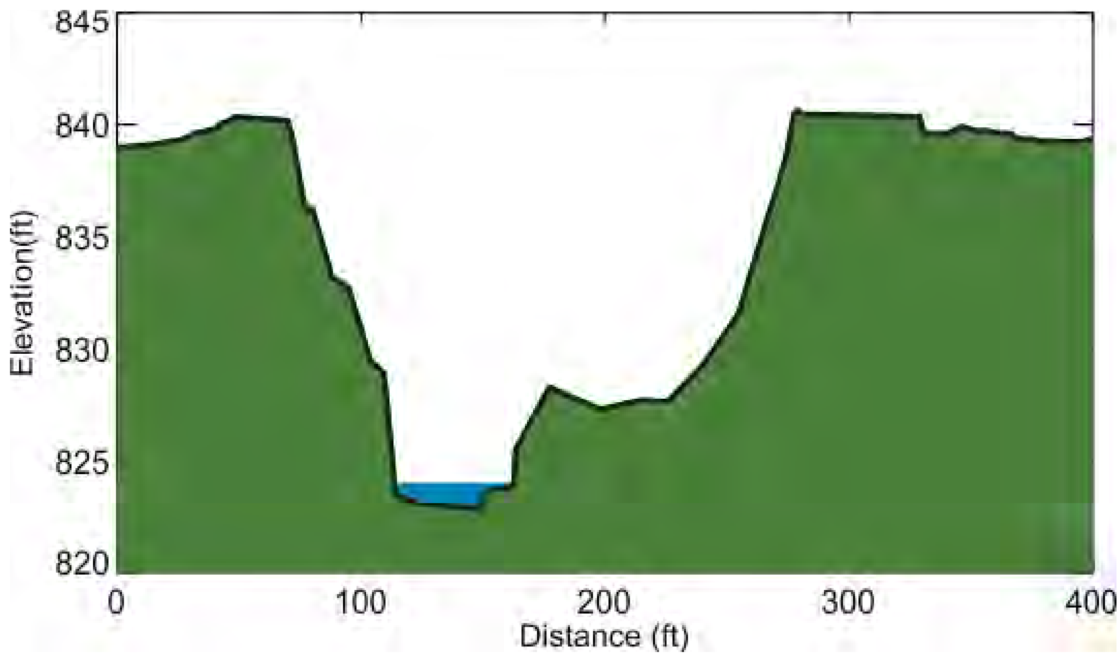

Figure 8d. Cross section located next to the IFC bridge sensor on Fourmile Creek

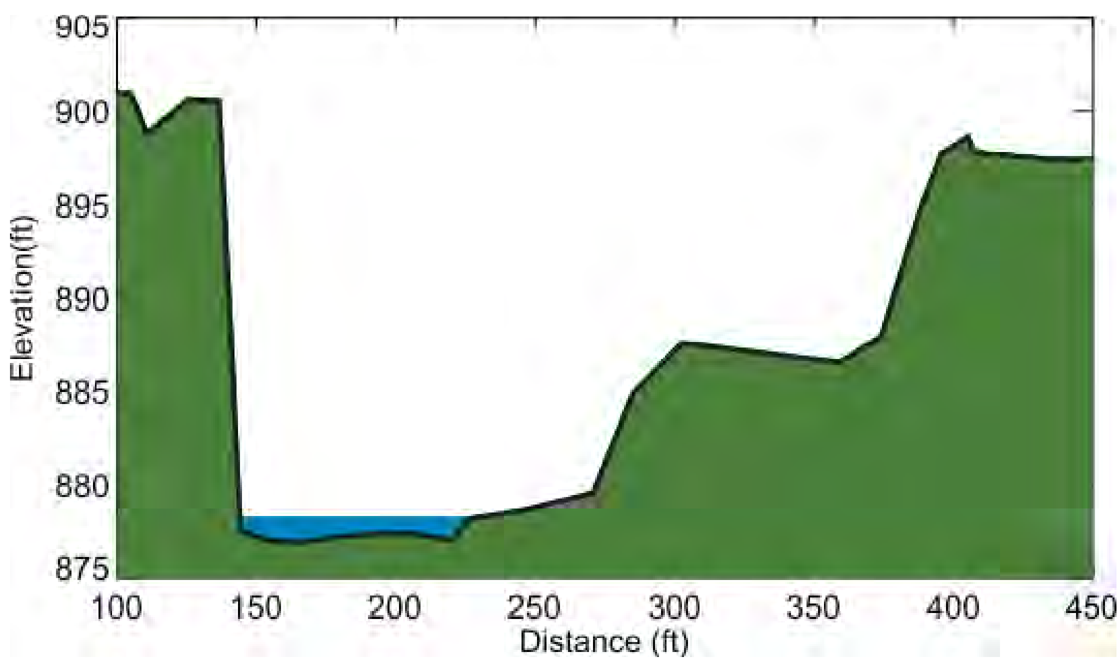

Figure 8e. Cross section located next to the IFC bridge sensor on South Skunk river near Ames

4.2 Measurements of Water Surface Elevation

As mentioned before, the IFC sensors measure the distance from the tip of the sensor to the water surface. Switching from relative distance to the sensor, to absolute value of the elevation in NAVD88 coordinate system is straightforward if the cross section and the sensors are surveyed in the same coordinate system. The USGS gaging station data is also expressed in the same coordinate system (using the gage datum provided in the station metadata) for analysis uniformity. This procedure is also useful in order to infer the free-surface gradients that can act as a checking during the analysis. Using the above considerations, Figures 9a to 9e illustrates the stage in the streams for the collocated and non-collocated gaging site pairs analyzed in the study. Black lines shows time series for the IFC sensors and blue lines shows the corresponding USGS records. The times series originate on April 1st to avoid erroneous data that can be measured by the IFC sensors due to ice jams forming in the winter season.

One can see that for the collocated sensors the overall agreement between the stage records obtained with the IFC and USGS sensors is good. Small fluctuations can be observed in the IFC sensor records caused by the impact of the diurnal cycle on the air temperature near the stream free surface that subsequently affect the reading of the IFC sensor (reference here….). In addition, when the distance from the sensor to the water surface is small (i.e. such as is the case of the stream responding to storm events), these fluctuations tend to be smaller because the air gap between the sensor and the free surface is shorter too. Thus, where it matters from the flood monitoring point of view, the IFC stage measurements display an improved accuracy.

At sites where the USGS and IFC sensors are not collocated (i.e. Fourmile Creek in Figure 9d and South Skunk river in Figure 9e), one can see that the difference in elevation of the locations is reflected in differences of elevation of the water surface. If the difference between the location of the gaging site pairs is accounted for (as reported in Table 3), the series of water free surface elevation display good agreement both in magnitude and similarity of the transitions in the flows. A difference between the peaks of the stage time series can be observed in Figures 9d and 9e that is due to the travel time that it takes for the peaks to move from a location to the other. Figures A11 to A15 in Appendix A provide an estimate of the travel time of peaks between non-collocated gauges using cross correlation statistical analysis.

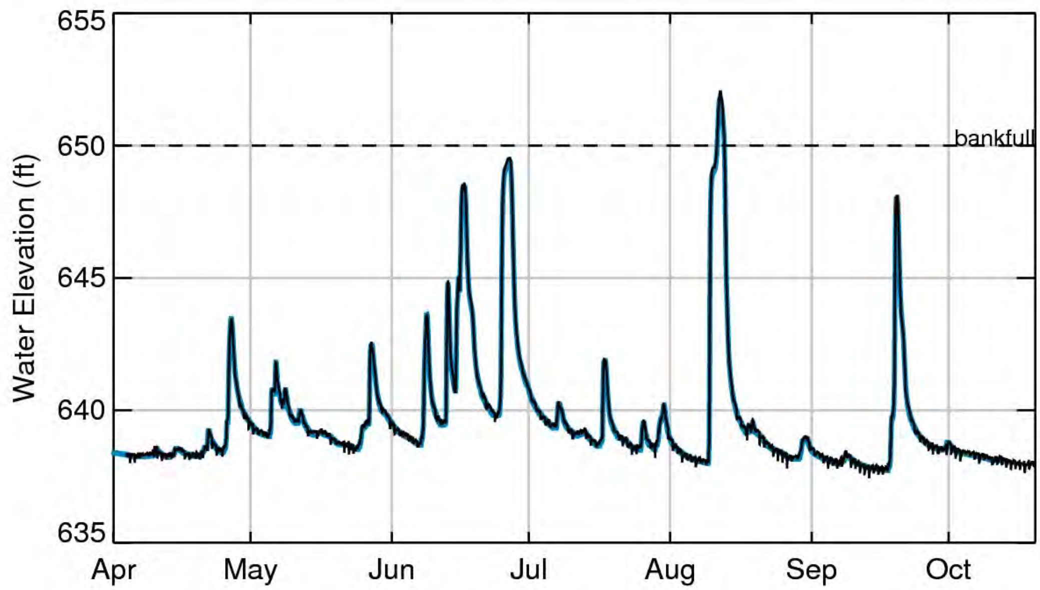

Figure 9a. Water elevation observed between April 1st 2015 and October 25th 2015 at the IFC bridge sensor on English River at Kalona

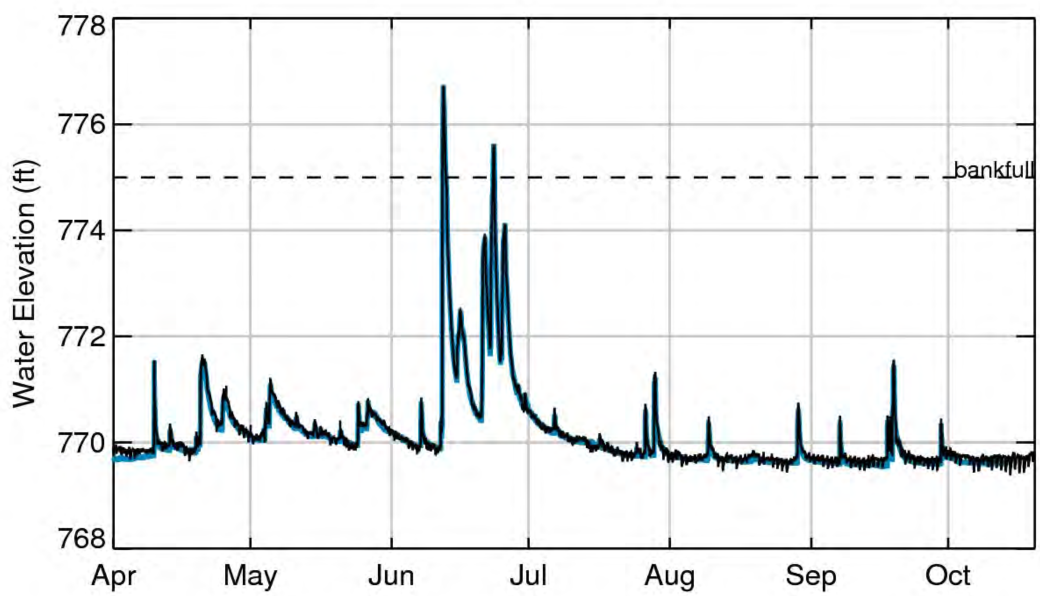

Figure 9b. Water elevation observed between April 1st 2015 and October 25th 2015 at the IFC bridge sensor on Indian Creek at Marion

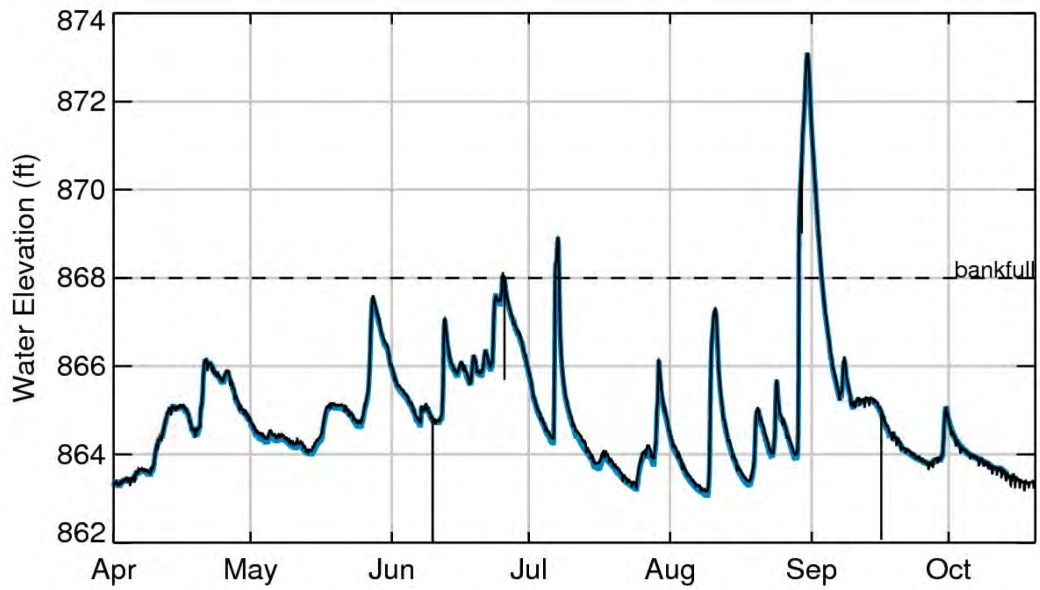

Figure 9c. Water elevation observed between April 1st 2015 and October 25th 2015 at the IFC bridge sensor on Iowa River at Marshalltown

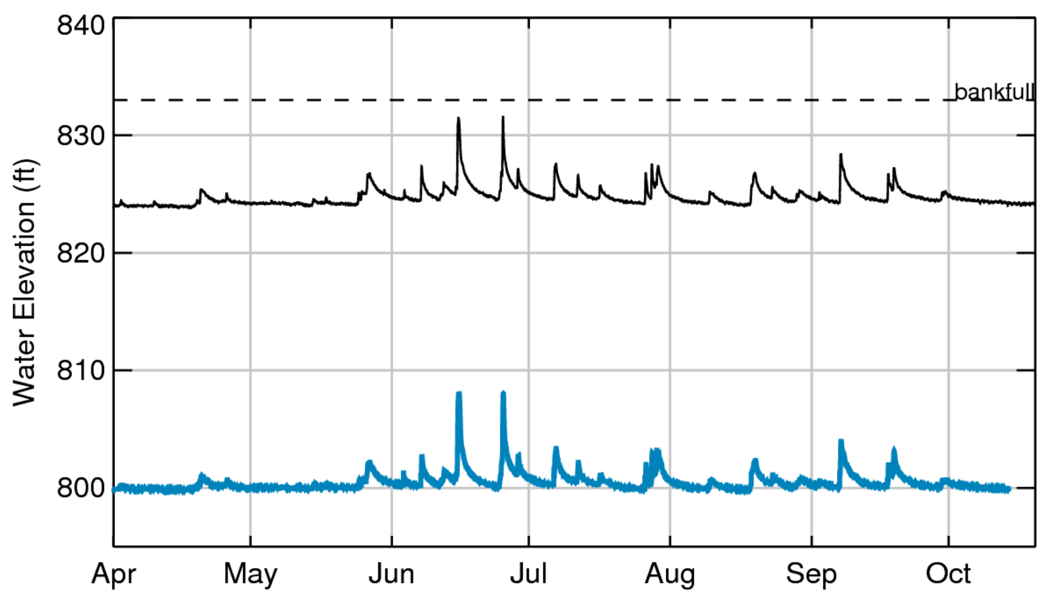

Figure 9d. Water elevation observed between April 1st 2015 and October 25th 2015 at the IFC bridge sensor on Fourmile Creek.

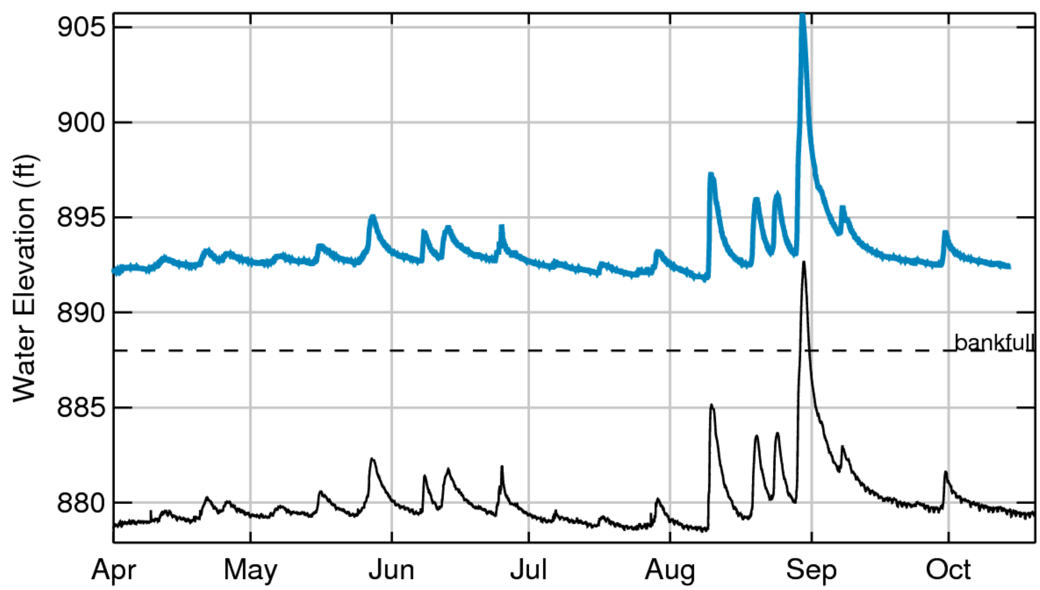

Figure 9e. Water elevation observed between April 1st 2015 and October 25th 2015 at the IFC bridge sensor on South Skunk River.

4.3 Results and Evaluation

4.3.1 Rating Curve Estimates

Figures 10a to 10e show the rating curves obtained after applying the methodology described in section 2 for all the sites analyzed in Phase I of the study. The preliminary steps leading to the rating curves, including the estimation of water surface slope and the geometrical properties of the sections, are shown in Appendix A. The discharge values corresponding a given water surface elevation are visualized as a probability of occurrence by the envelopes resulting from the Monte Carlo simulation: light grey areas correspond to 0% and 100% percentiles, and dark grey area to the 25% and 75% percentiles. The most probable rating curve is associated with the median of all possible realizations (solid black line). The blue line is the reference for the comparison as provided by the existing USGS rating curve at the collocated or the station in the immediate vicinity to the IFC bridge sensors. The bankfull line is shown as a dashed black line. The USGS rating curves in Figures 10d and 10e (non-collocated sites) have been shifted to account for the difference in datum between the IFC and USGS stations for making the comparison possible.

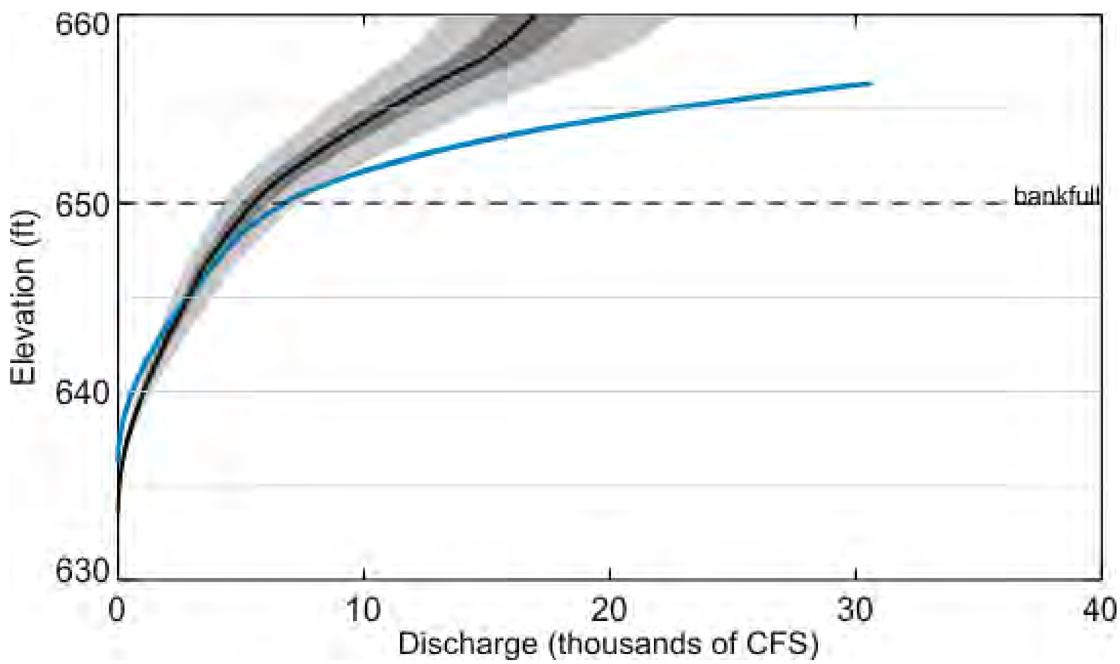

Figure 10a. Comparison of the rating curves for the IFC bridge sensor and USGS gaging station collocated on the English River at Kalona.

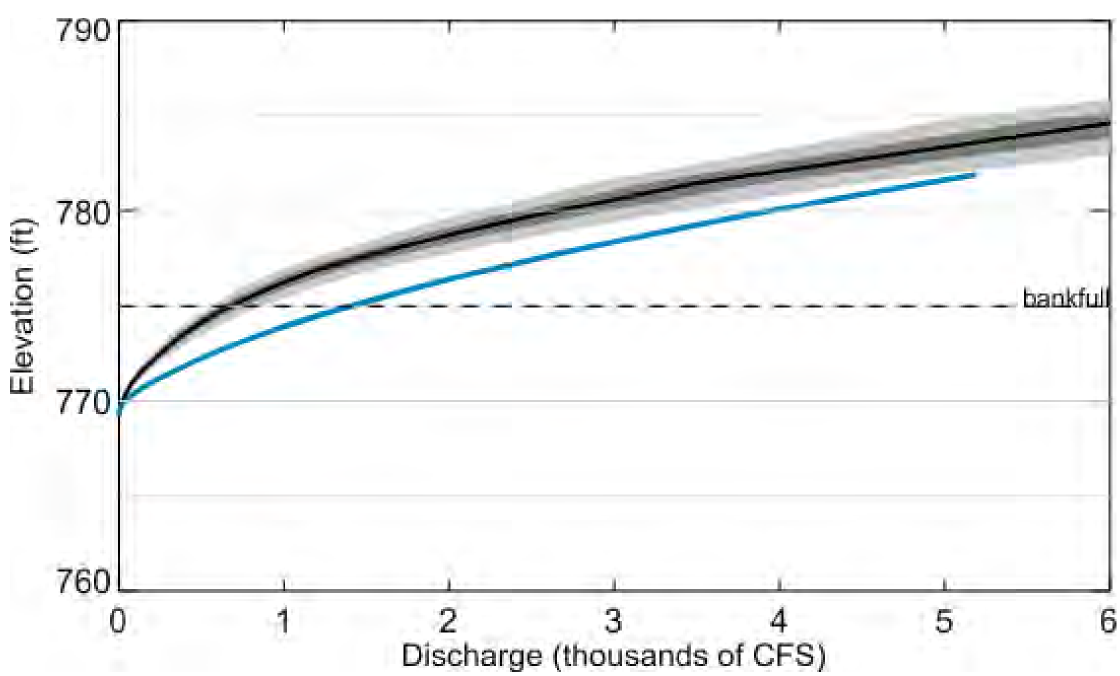

Figure 10b. Comparison of the rating curves for the IFC bridge sensor and USGS gaging station collocated on the Indian Creek at Marion.

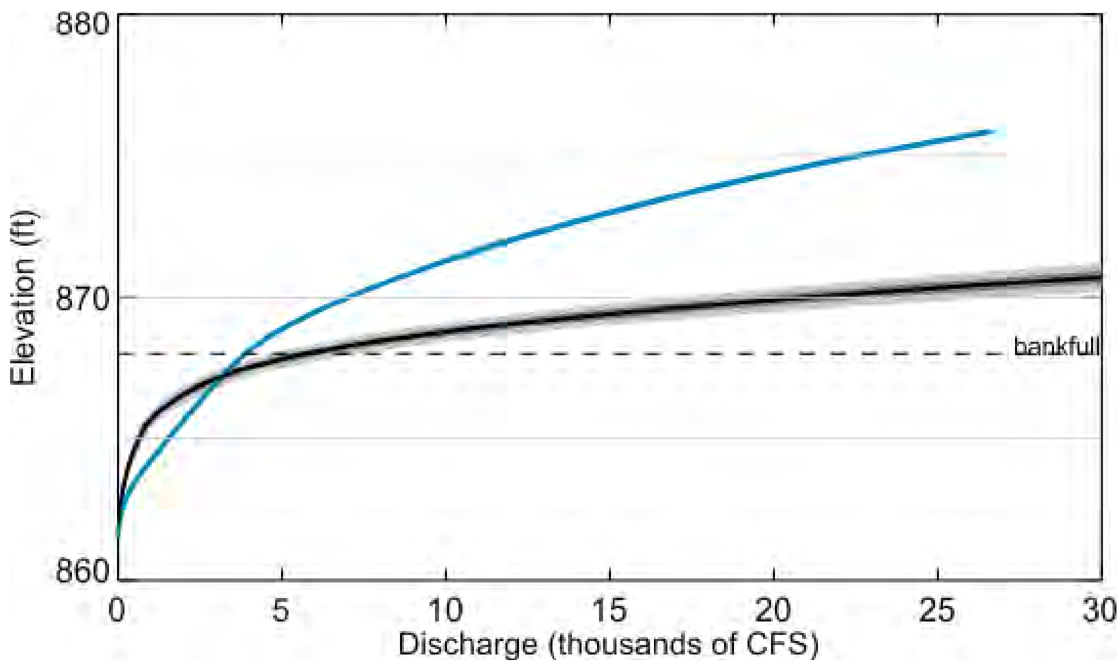

Figure 10c. Comparison of the rating curves for the IFC bridge sensor and USGS gaging station collocated on the Iowa River at Marshalltown.

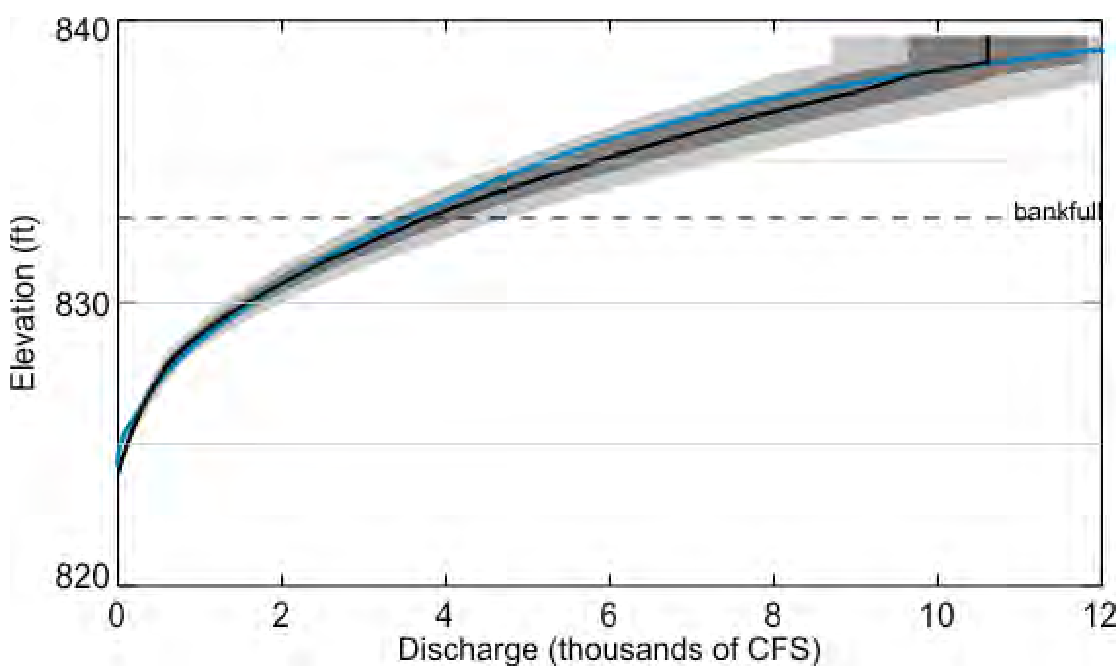

Figure 10d. Comparison of the rating curves for the IFC bridge sensor and USGS gaging station collocated on the Fourmile Creek.

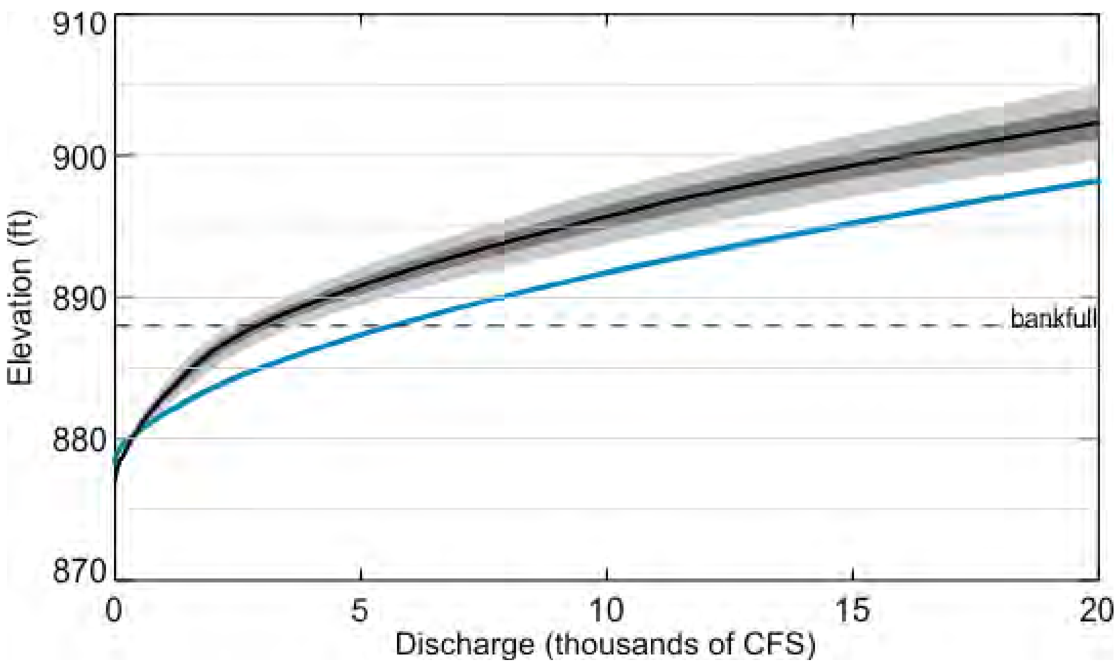

Figure 10e. Comparison of the rating curves for the IFC bridge sensor and USGS gaging station collocated on the South Skunk River near Ames

4.3.2 Comparison of the Discharge Hydrographs

Comparing rating curves at sites where the USGS and IFC stage sensors are not collocated needs additional evaluation, since rating curve are only valid for the site where they are constructed. A complementary assessment can be obtained from the comparison of the discharge hydrographs obtained with the IFC and USGS stage sensors readings and the associated rating curves. This comparison is more physically based and more illustrative for practical purposes as it visually substantiates the performance of the rating curves for various flow regimes. Concerns are associated with the comparison of non-collocated sites as tributaries or different amount of runoff may affect the comparison. However, visual inspection of satellite images of the area between the IFC and USGS site pairs analyzed in this study indicates absence of major tributaries that could significantly increase discharge at the downstream location. Given that the difference between the drainage areas of the IFC and USGS gaging station pairs was relatively small non-collocated sites, the comparison of the hydrographs is acceptable for the purpose of this study.

Figures 11a to 11e compare the discharge values obtained from mapping the water elevation obtained from IFC and USGS, through the corresponding rating curves. Figure 11a and 11b show a good agreement between the discharge series. However in Figure 11a there is a systematic, relatively small shift between the two hydrographs.

In most of the cases, the observed discharge is contained or very close to the envelopes provided by the 25% - 75% envelopes of the probabilistic hydrograph derived from the IFC rating curves.

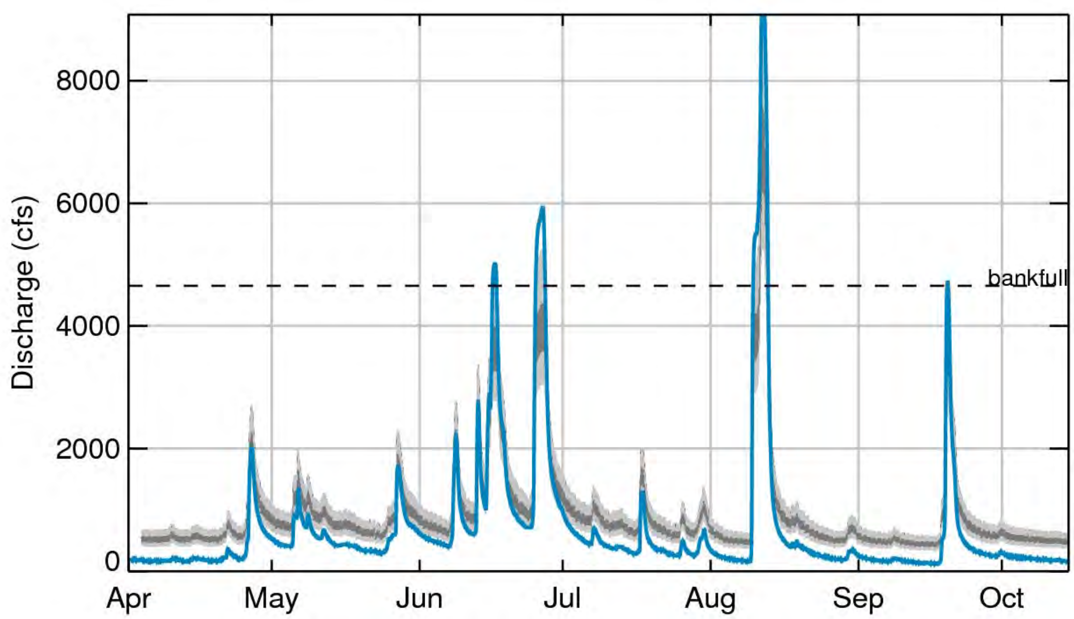

Figure 11a. Comparison of IFC and USGS discharge hydrographs at English River at Kalona.

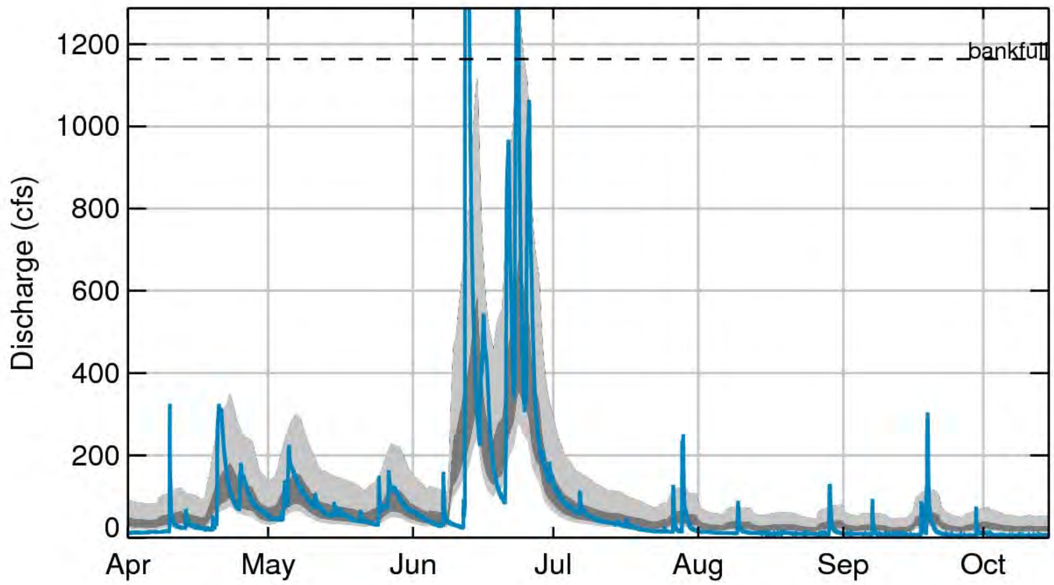

Figure 11b. Comparison of IFC and USGS discharge hydrographs at Indian Creek at Marion.

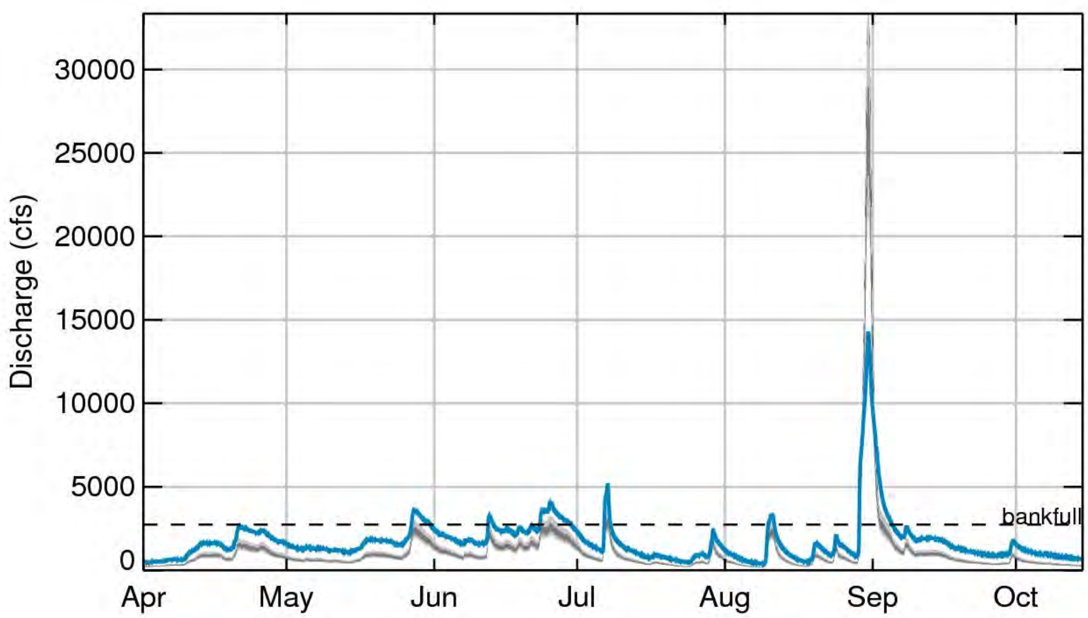

Figure 11c. Comparison of IFC and USGS discharge hydrographs at Iowa River at Marshalltown.

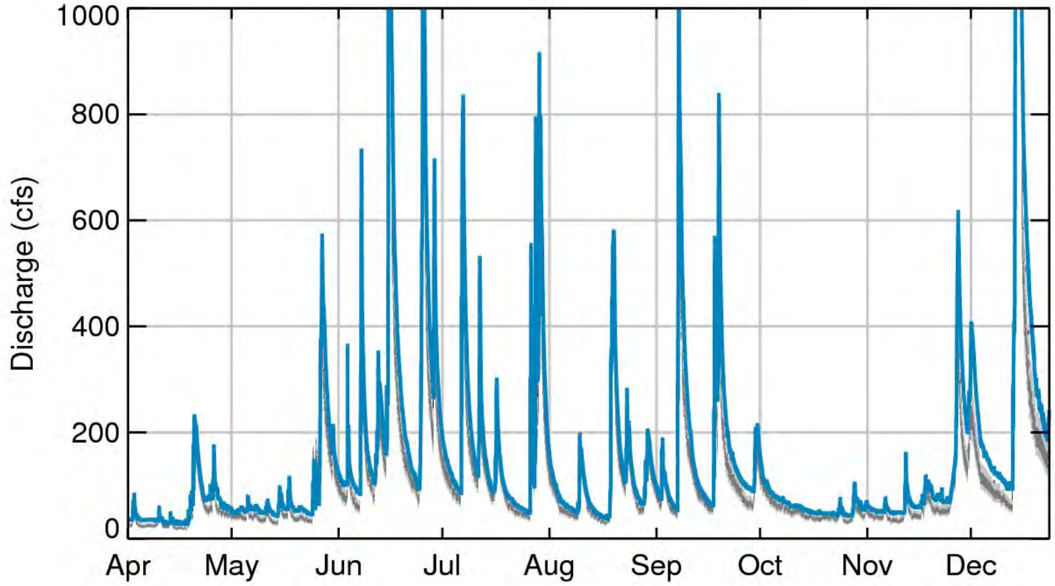

Figure 11d. Comparison of IFC and USGS discharge hydrographs at Fourmile Creek.

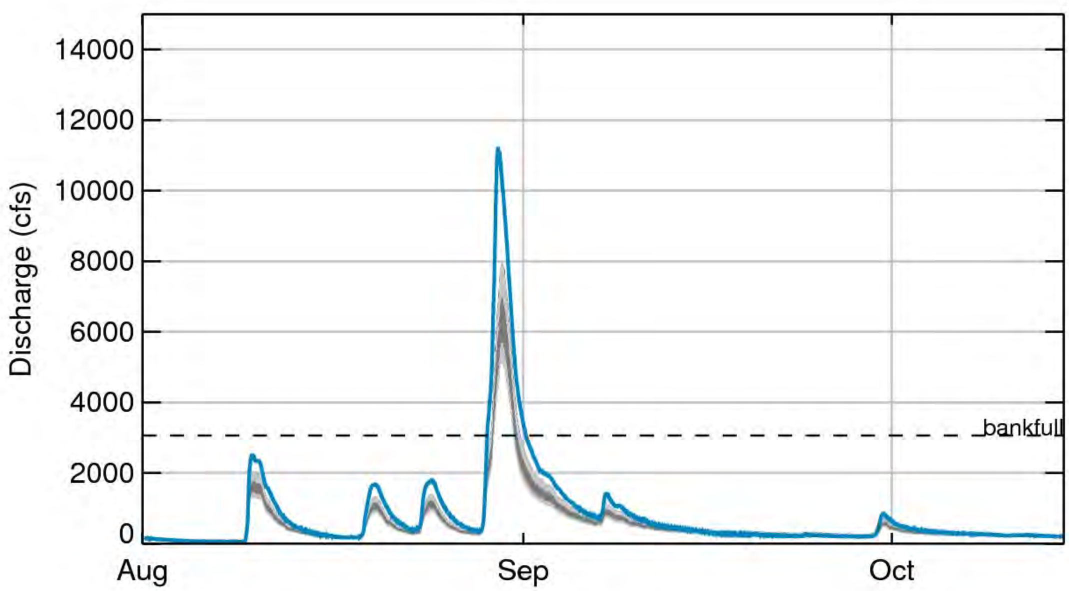

Figure 11e. Comparison of IFC and USGS discharge hydrographs at South Skunk River near Ames.

4.3.3 Evaluation tool

As a means for further evaluating the performance of the newly-obtained rating curves, estimation of the Root Mean Squared Error (RMSE) applied to the IFC rating curves using the USGS rating curves reference was carried out. The analytical formula for obtaining the RMSE is:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{k} (\hat{y}_i - y_i)^2}{k}} \quad (2)$$

where $\hat{y}_i$ is a vector of predictions (i.e. the rating curve values using slope-area method or hydraulic model method), y_i is a vector of observed values (i.e. the USGS rating curve) and k is the number of values evaluated for obtain the RMSE metric. The RMSE was carried out to illustrate errors in elevation and discharge. Figure 12 shows an example of the RMSE estimation for the elevation. In the figure, the red arrows correspond to the term $\hat{y}_i - y_i$ and k is the number of points in the USGS rating curve. The dashed horizontal line indicates the bankfull level. The errors were estimated for using values below the bankfull line, over the bankfull line, and a combination of both.

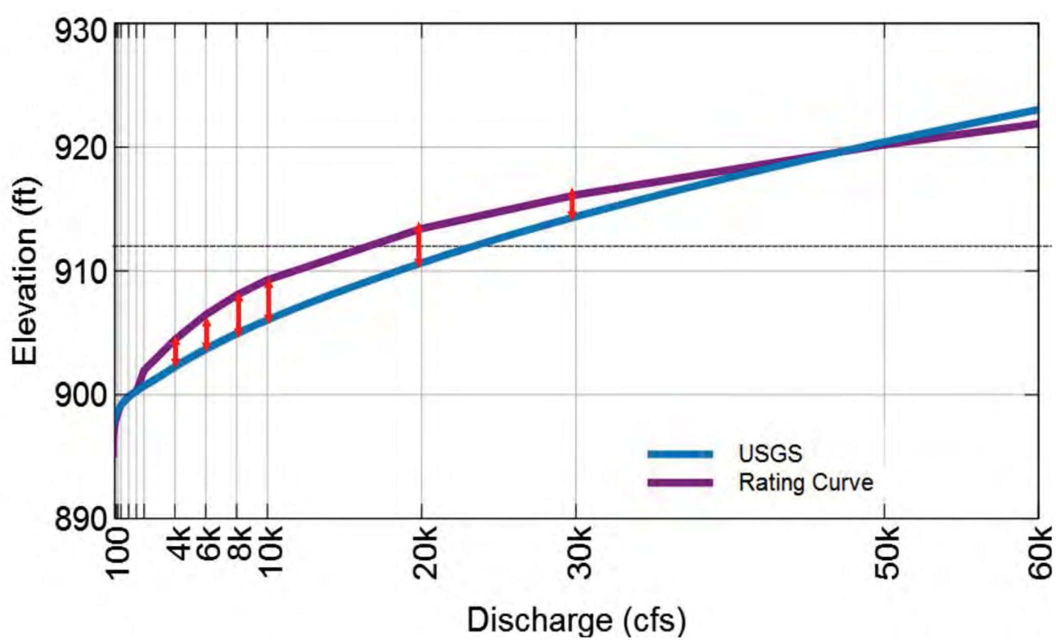

Figure 12. RMSE analysis results: the blue line is the USGS rating curve used as reference. The purple line is the IFC rating curve to be evaluated. Red arrows show the difference $\hat{y}_i$ - y_i in Equation (2). The dashed horizontal line indicates the bankfull level.

4.3.4 Performance evaluation

It is recognized that the simplified SA method used in conjunction with the IFC stage readings is strictly applicable for flows within the stream banks, as the Manning equation (i.e., the methodology used in our approach) was established on the grounds of canonical open-channel flows occurring in geometries with aspect ratios within certain ranges. Therefore the comparison of the IFC and USGS rating curve performance is most relevant for this type of flows. However, pressed by the relevance of this study for flood-related applications, it is imperative to test the performance of the rating curves outside the areas where they strictly apply. Consequently, the RMSE analysis described above was applied using various samples distinguished by their flow regimes.

An illustration of the relevance of the flow regimes is shown in Figure A16, whereby the sensitivity of the rating curves to the range of values of Manning's roughness coefficient n and slope s, is shown. It can be noted from that figure that the rating curves are most sensitive to the value n, as expected from its linear relation to discharge in Manning's formula. The discharge is sensitive to the square root of slope values, and thus less sensitive than n.

With the above considerations in mind, the RMSE analysis was differentiated through several computational approaches illustrated in Table 4, where the number of points of the rating curves that are over and below the bankfull line are displayed for all the analyzed sites. Analysis was also conducted using the total number of points of the IFC rating curves. These points were extracted from the IFC rating curve corresponding to the median (black line in figures 10a to 10e).

Using the number of points displayed in Table 4, the errors in elevations and discharges using the RMSE analysis are displayed in Tables 5 and 6, respectively. For stages over the bankfull level, the errors range between 0.74 and 7.07 feet, with an average of 3.94 feet. For stages below the bankfull level, errors range between 0.79 and 3.75 feet, with an average of 1.68 feet. When evaluating the discharge estimates, the errors range from 690 to 56,356 cfs over the bankfull level, and from 291 to 1944 cfs below the bankfull level.

Table 4 Number of rating curve discrete points used in the RMSE analyses

Bank level	**English River at Kalona**	**Indian Creek at Marion**	**Iowa River at Marshalltown**	**Fourmile Creek near Des Moines**	**South Skunk River near Ames**
Overbank (a)	646	688	804	488	912
Below bankfull (b)	1409	582	660	992	1099
(a) & (b) combined	2055	1270	1464	1480	2011

Table 5 RMSE using simplified slope-area method (in feet)

Bank level	**English River at Kalona**	**Indian Creek at Marion**	**Iowa River at Marshalltown**	**Fourmile Creek near Des Moines**	**South Skunk River near Ames**	**Weighted Average**
Overbank (a)	5.81	1.24	3.17	0.74	7.07	**3.94**
Below bankfull (b)	1.15	1.29	0.79	0.98	3.75	**1.68**
(a) & (b) combined	3.39	1.26	2.41	0.91	5.51	**2.96**

Table 6 RMSE using simplified slope-area method (in cfs)

Bank level	**English River at Kalona**	**Indian Creek at Marion**	**Iowa River at Marshalltown**	**Fourmile Creek near Des Moines**	**South Skunk River near Ames**	**Weighted Average**
Over	8,266	690	56,356	1021	7120	**16,426**
Below	366	291	644	489	1944	**786**
Combined	4,646	545	41,780	710	5006	**9,964**

5. Conclusions

This pilot study implemented and evaluated a methodology for obtaining rating curves at the IFC bridge sensors, using a simplified version of the slope-area method. The method allows establishing a relationship between the stages observed by the sensors and the estimated discharge. The proposed method requires a one-time measurement of the geometric characteristics of the channel, and a range of feasible water surface slopes and Manning's roughness coefficients. The methodology has several sources of error that includes the correct characterization of the geometry of the section, and the selection of representative water-surface slopes and Manning's coefficients used for establishing the relationship of discharge and stage.

The obtained IFC rating curves were compared with USGS rating curves derived from on-the-field observations of stage and discharge. For stages over the bankfull level, the errors ranged between 0.74 and 7.07 feet, with an average of 3.94 feet. For stages below the bankfull level, errors ranged between 0.79 and 3.75 feet, with an average of 1.68 feet. When evaluating the discharge estimates, the errors ranged between 690 and 56,356 cfs over the bankfull level, and between 291 and 1944 cfs below the bankfull level.

Despite its simplicity and readiness for implementation without extensive maintenance, the results presented in this study show that the simplified slope-area methodology proposed here limitations especially for sites that departs the flow conditions from the flow uniformity assumptions. These limitations were expected but not systematically assessed so far. The main weakness of the simplified method is associated with the reliance of the geometrical characteristics of only one cross sections at a time, hence not being able to consider the effect the transition of the cross section geometries along the reach when they are present at the gaging site. Phase II work will explore the sensitivity of the results to using a one-dimensional hydraulic modeling approach of the channel, which considers the energy losses due to friction and the changes in geometry along the channel.

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Appendix A

Figures A1 to A5 show all the cross sections obtained during the survey at the five locations. In the figures, the top panel shows a top view of the cross sections and the bottom panel contains a close up view of the elevations of the profile in the bank of the river surveyed on the field and the distance from the origin point of the survey. The elevations from the floodplains were obtained from LIDAR data. The blue color indicates the elevation of the water surface at the time when the survey was conducted. The dashed line on the top indicates the elevation of the tip of the bridge sensor. The dashed line on the bottom of the figures indicates the datum of the USGS sensor. For each cross section the area of the cross section and the wetted perimeter for different values of the water elevation was calculated, as presented in Figure 4. For the sake of simplicity these results have not been included as figures in this report, but all the computed values are available for download at the website of this project.

Figures A6 to A10 show the required elements to calculate the slopes of the water surface for different flow trajectories. Two slopes obtained surveying the free surface elevations along the left and right side of the stream were estimated for each location. The points surveyed on the left bank of the river are shown in black and the points surveyed on the right bank of the river are shown in grey. The x-axis corresponds to the distance of these points to the more upstream cross section following the river trajectory. At some bridges, the stretching of the section due to the bridge piles might produce an effect of breaking the monotonic decrease of water elevation, as observed in Figure A7 for Indian Creek and Figure A10 for South Skunk river. In order to mitigate the effects of these artifacts in the estimation of the river slope, the outermost sections were used, (i.e. the more upstream and the more downstream sections) to calculate the slope. The slope values obtained for each side of the bank are shown in the top right side of the figure.

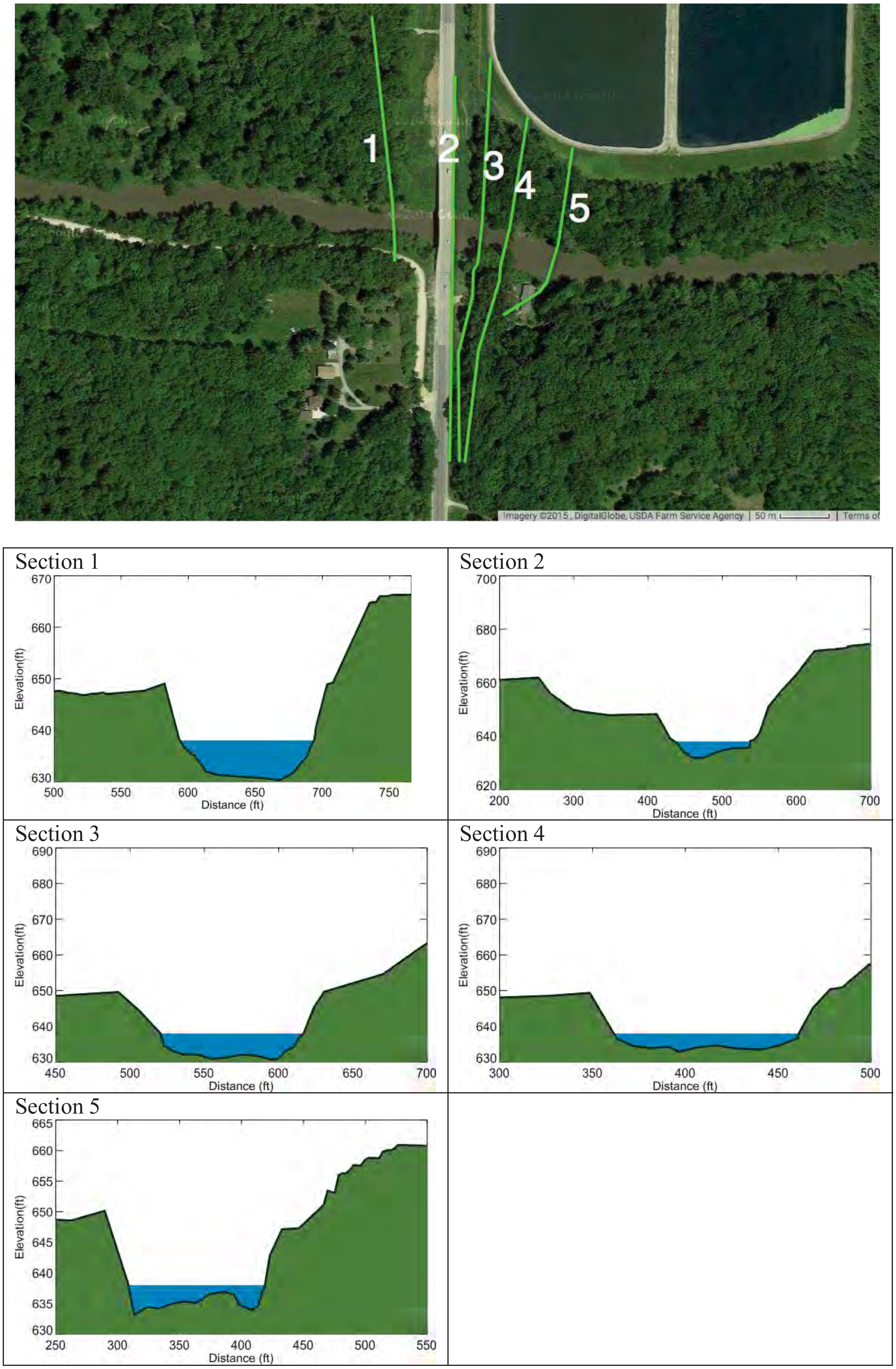


Figure A1 Cross sections of English River at Kalona

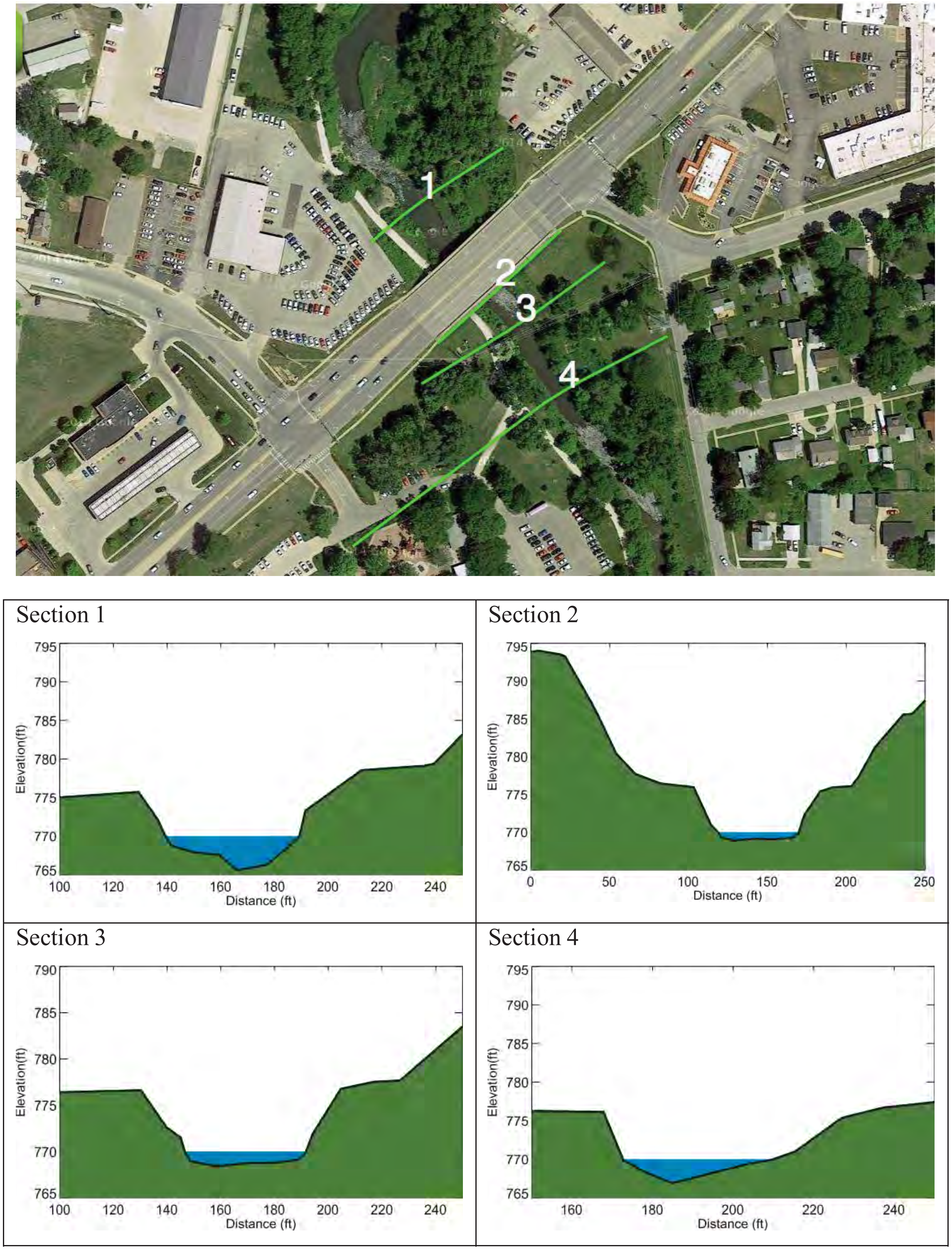
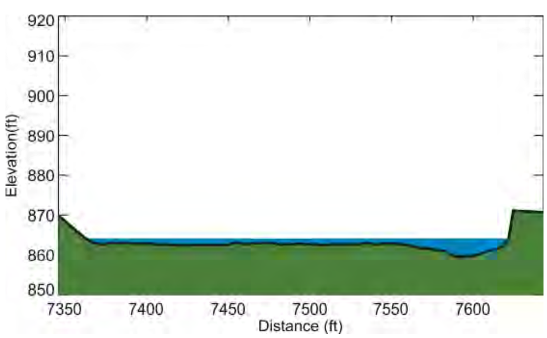
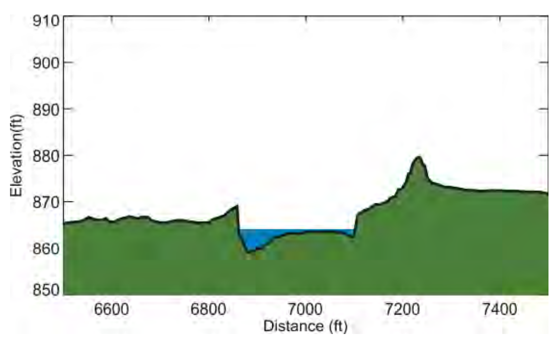
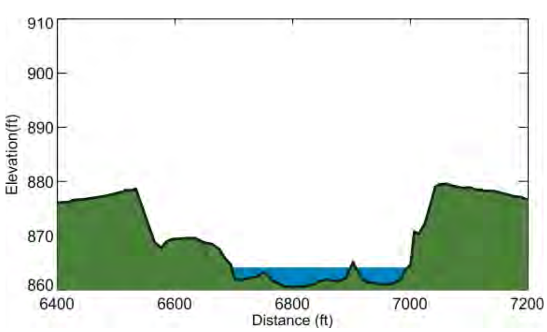
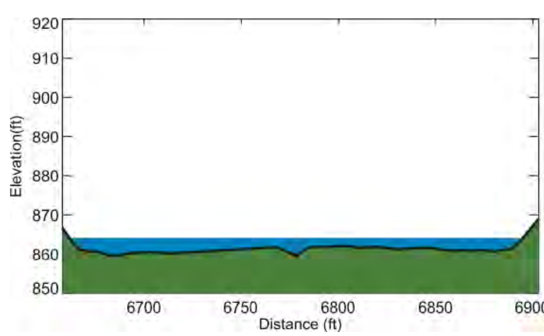


Figure A2 Cross sections of Indian Creek at Marion

Section 1	Section 2
	
Section 3	**Section 4**
	
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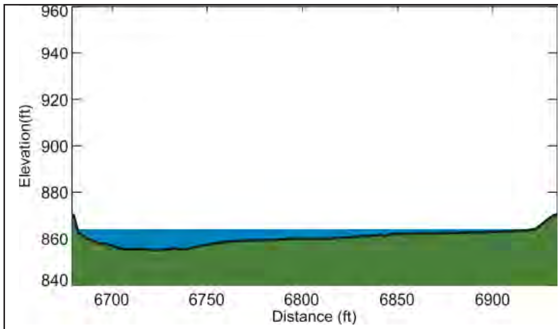


Figure A3. Cross sections of Iowa River at Marshalltown

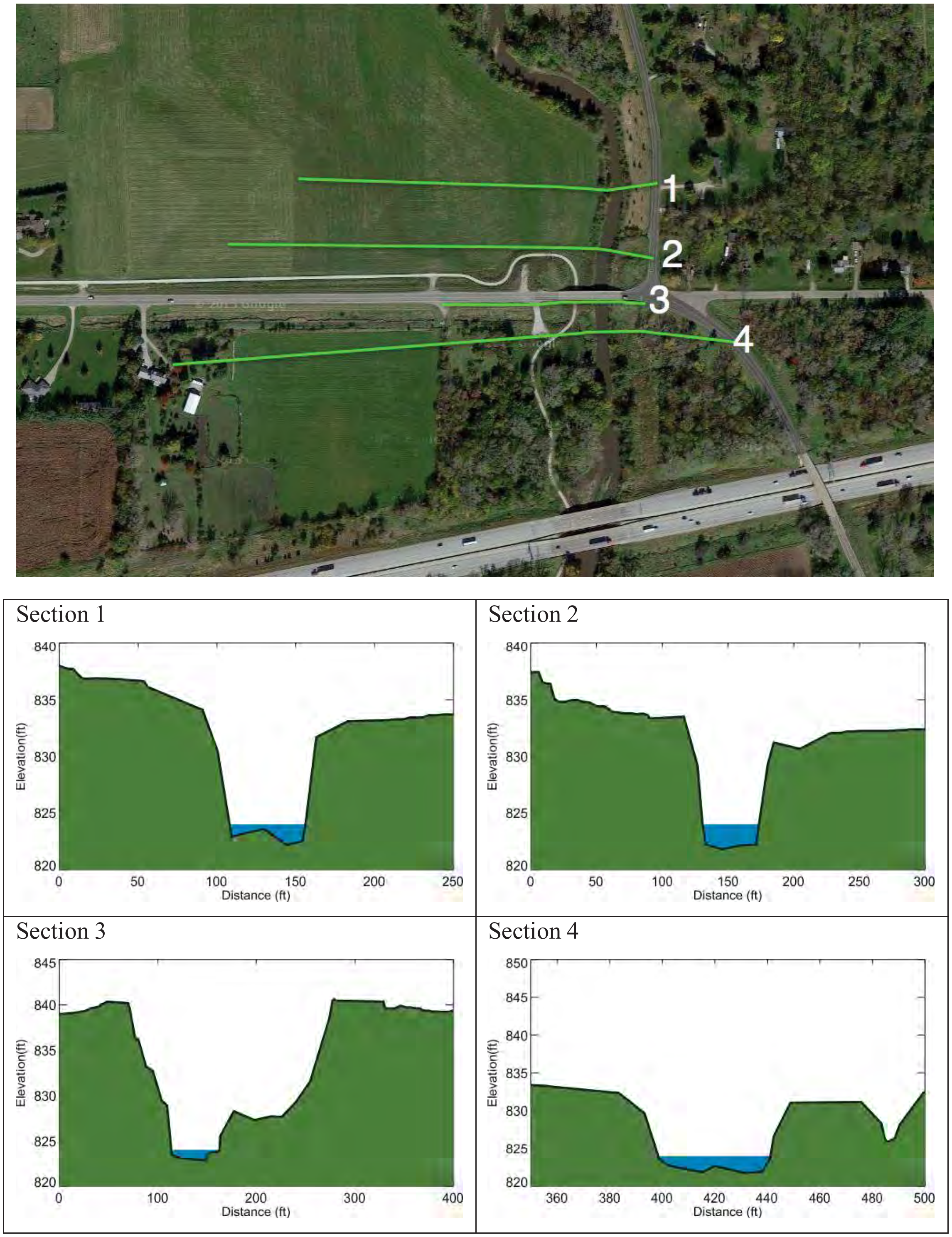
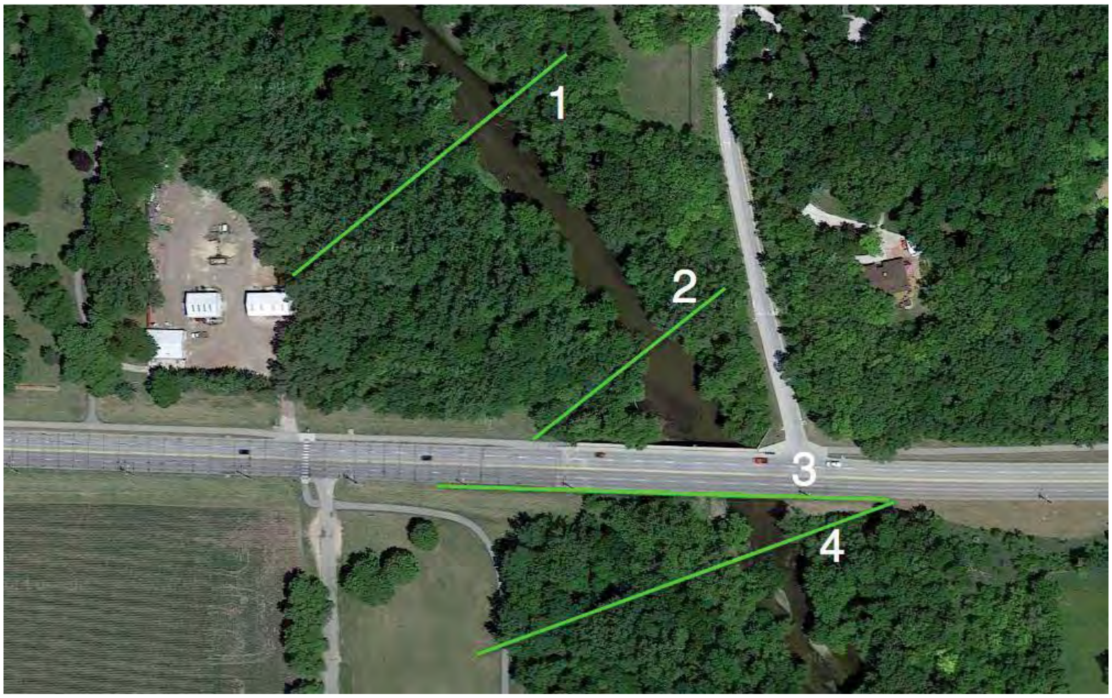


Figure A4. Cross sections of Fourmile Creek



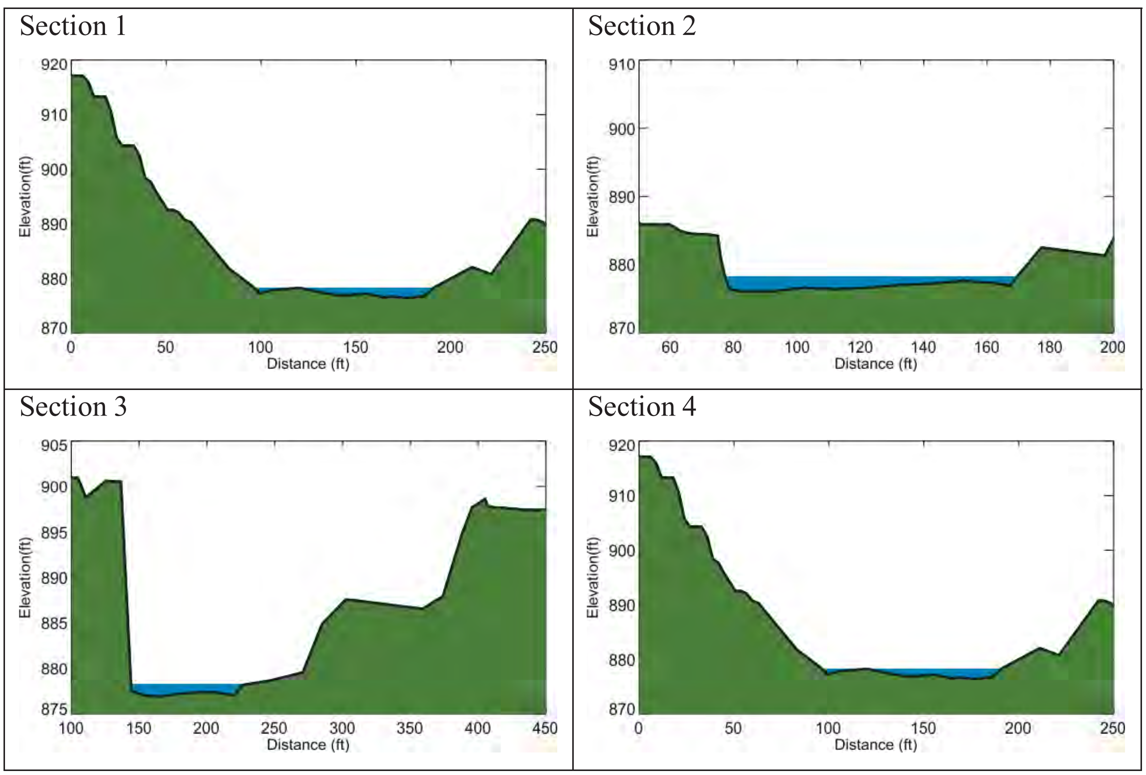


Figure A5. Cross sections of South Skunk river at Ames

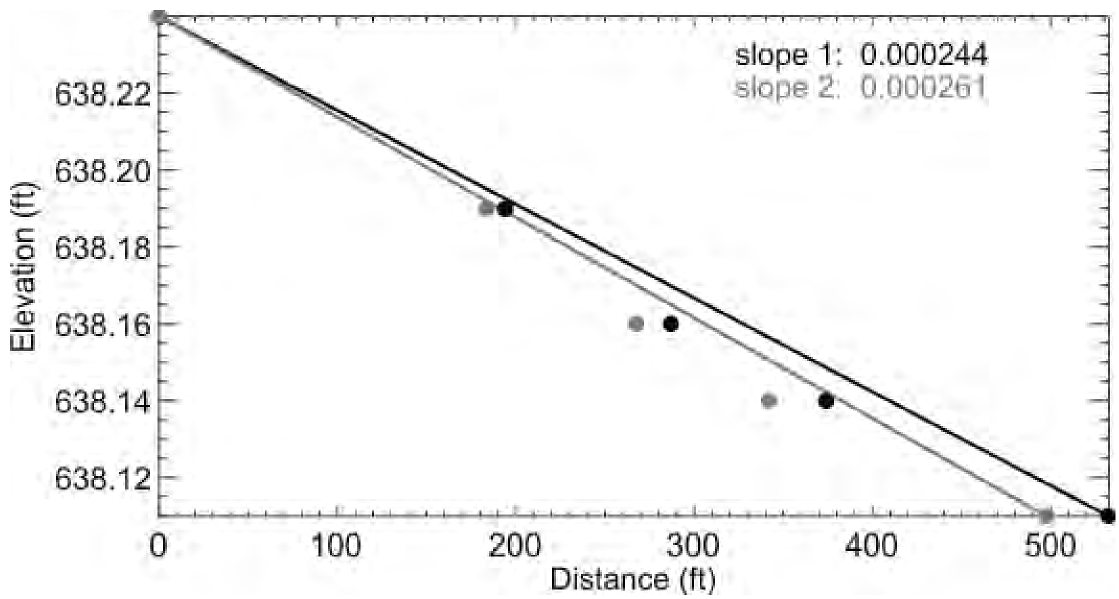


Figure A6. Observed water surface elevations and slope estimation at English River at Kalona. Black and grey points correspond to surveys of water surface in the left and right bank of the river (facing downstream) respectively. Black and grey lines show the estimated slope.

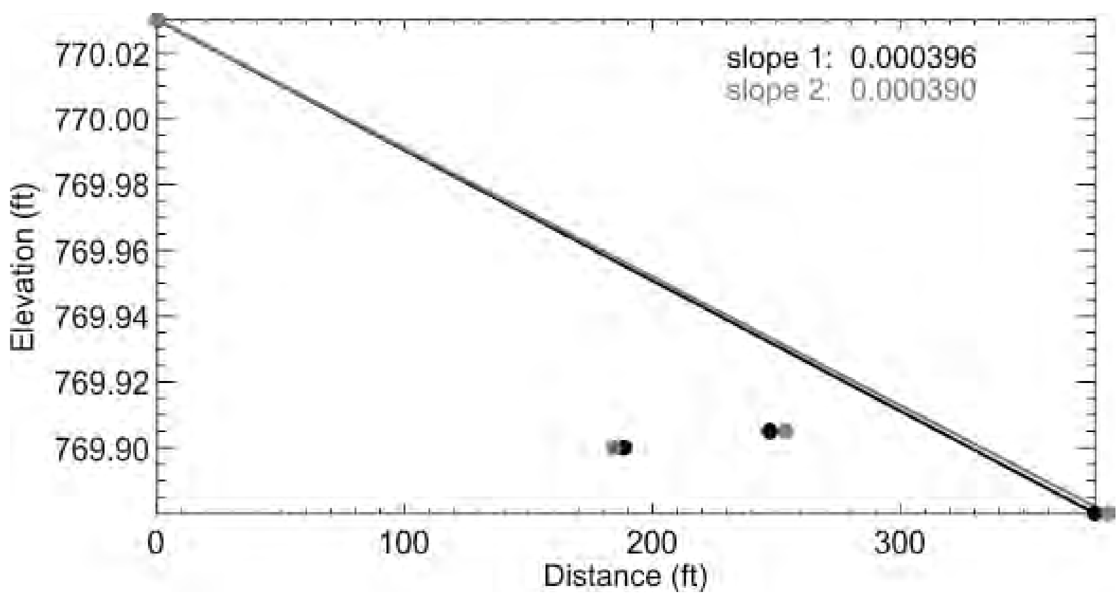


Figure A7. Observed water surface elevations and slope estimation at Indian Creek at Marion. Black and grey points correspond to surveys of water surface in the left and right bank of the river (facing downstream) respectively. Black and grey lines show the estimated slope.

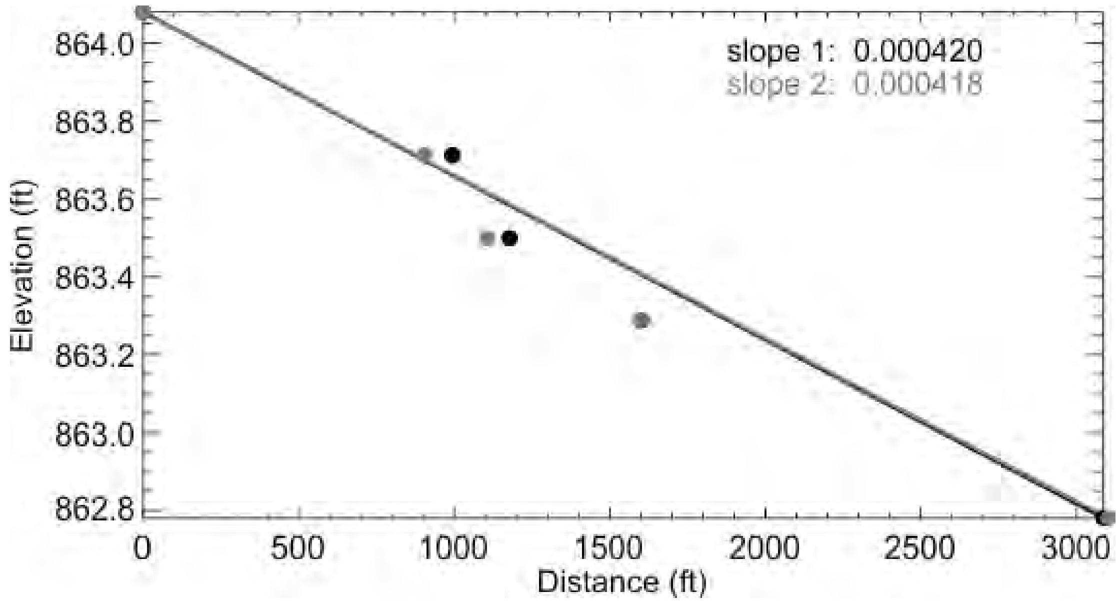


Figure A8. Observed water surface elevations and slope estimation at Iowa River at Marshalltown. Black and grey points correspond to surveys of water surface in the left and right bank of the river (facing downstream) respectively. Black and grey lines show the estimated slope.

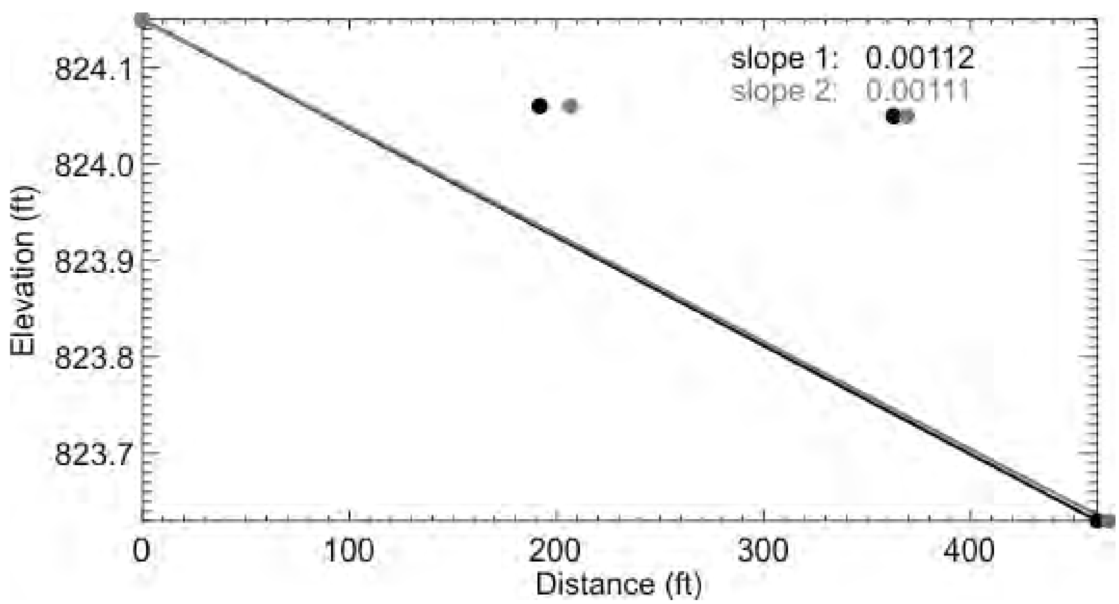


Figure A9. Observed water surface elevations and slope estimation at Fourmile Creek. Black and grey points correspond to surveys of water surface in the left and right bank of the river (facing downstream) respectively. Black and grey lines show the estimated slope.

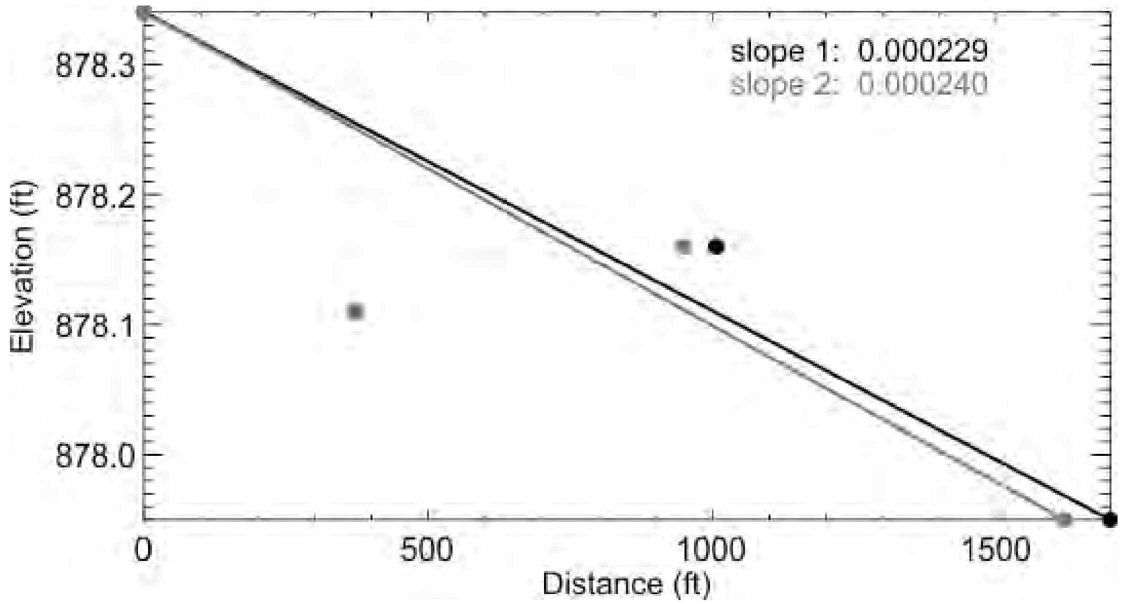


Figure A10. Observed water surface elevations and slope estimation at South Skunk River at Ames. Black and grey points correspond to surveys of water surface in the left and right bank of the river (facing downstream) respectively. Black and grey lines show the estimated slope.

The travel time of water between USGS and IFC sensors was calculated for both collocated and non-collocated sites investigated in the study. For the collocated sensors, one can see from Figures A11 to A13 that the maximum correlation coefficient r_{xy} (see Eqn. 2) of the stage time series occurs when the series are not shifted at all (t=0). For the non-collocated sensors (Figures A14 and A15), the maximum correlation of the series happens when the series are shifted an amount of time, that correspond with the travel time of water from one gauge to another. With the travel time and distance between non-collocated sensors reported in Table 3, the channel velocity at these two locations was estimated. For South Skunk river, channel velocity is 3.15ft/s and for Fourmile Creek is 4.43 ft/s.

$$r_{xy} = \frac{\sum_{i=1}^{n} (x_{i+t} - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_{i+t} - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}} \tag{2}$$

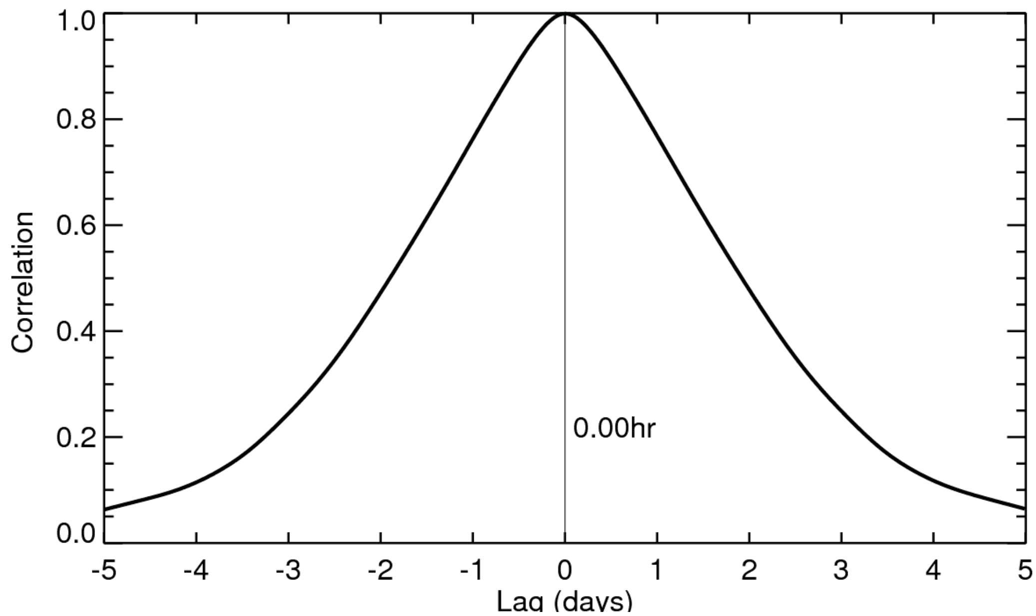


Figure A11. Cross correlation of the stage time series at English River at Kalona

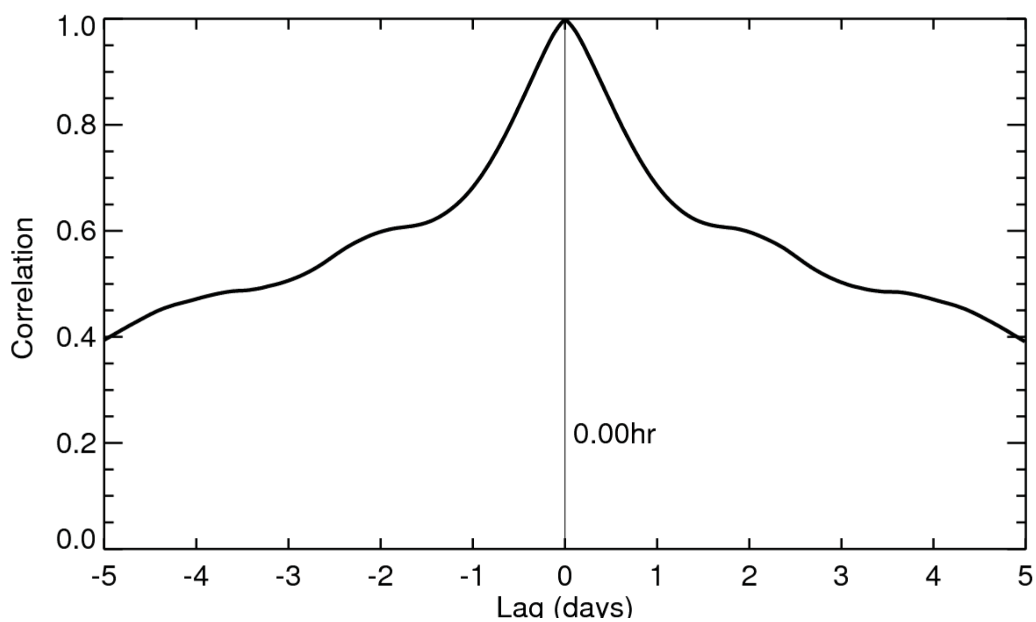


Figure A12. Cross correlation of the stage time series at Indian Creek at Marion

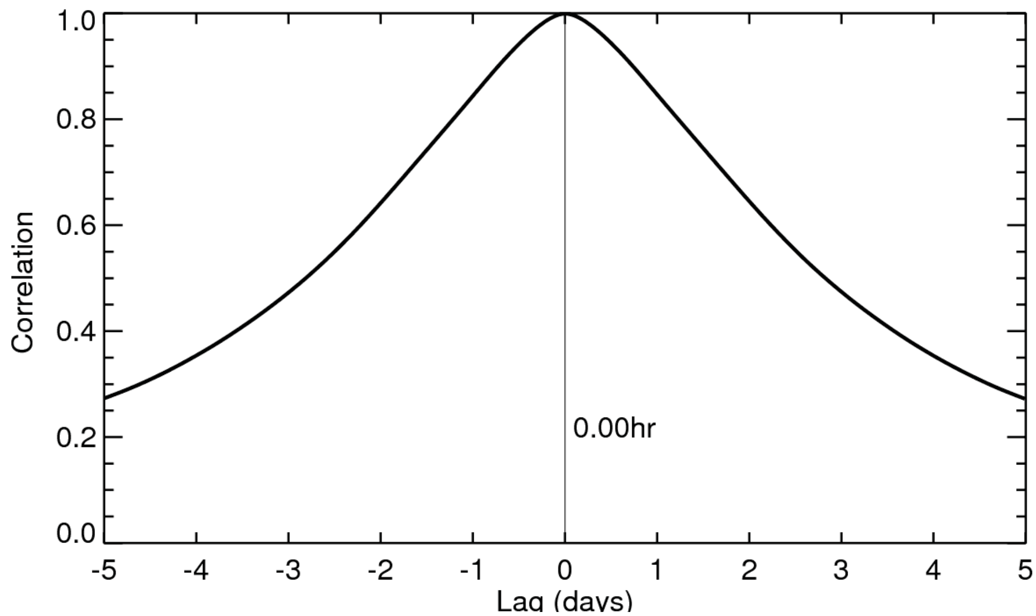


Figure A13. Cross correlation of the stage time series at Iowa River at Marshalltown

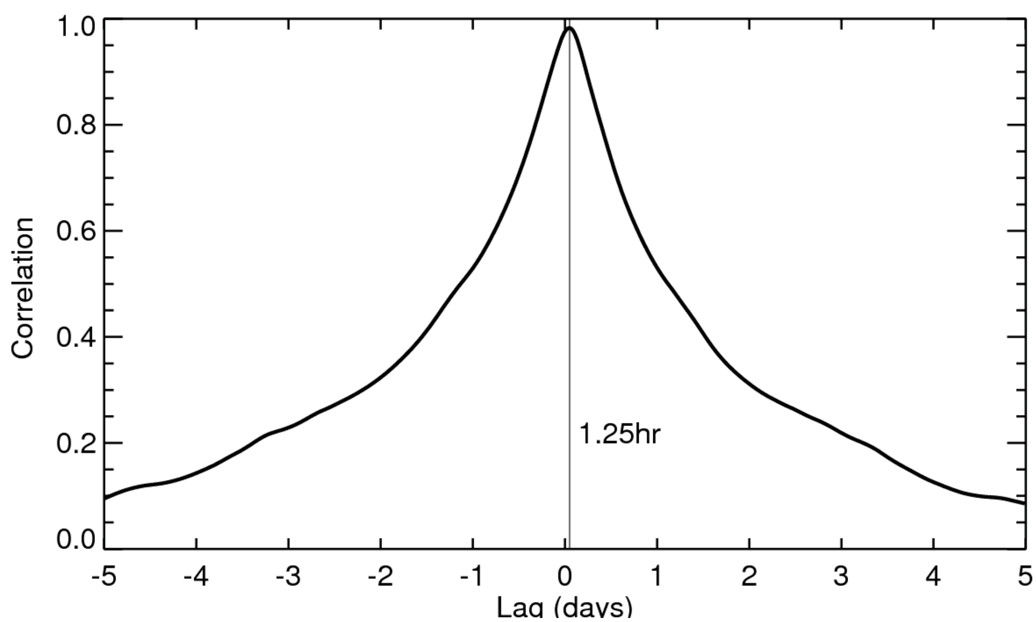


Figure A14. Cross correlation of the stage time series at Fourmile Creek

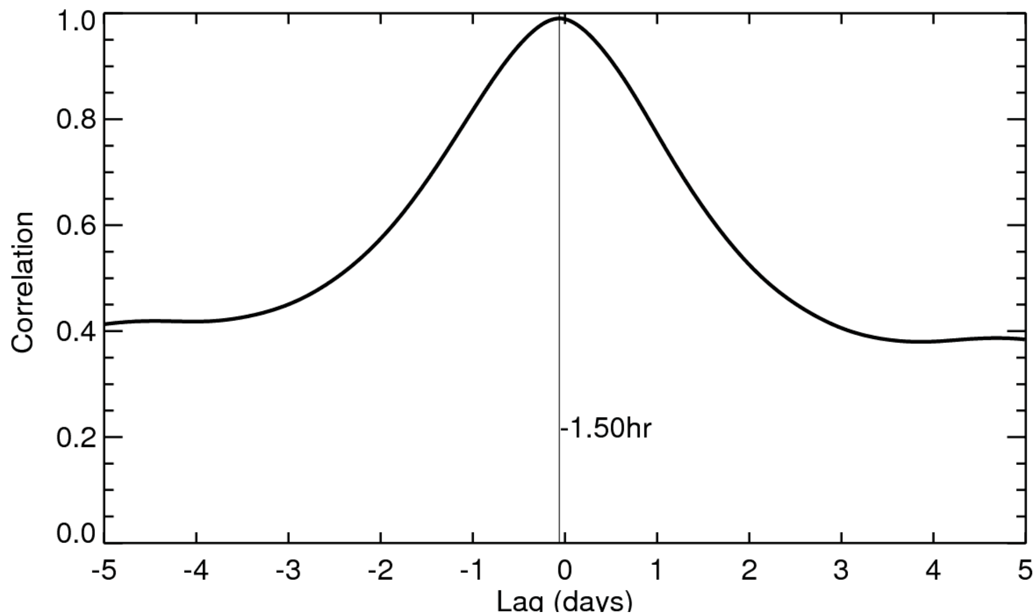


Figure A15 Cross correlation of the stage time series at South Skunk near Ames

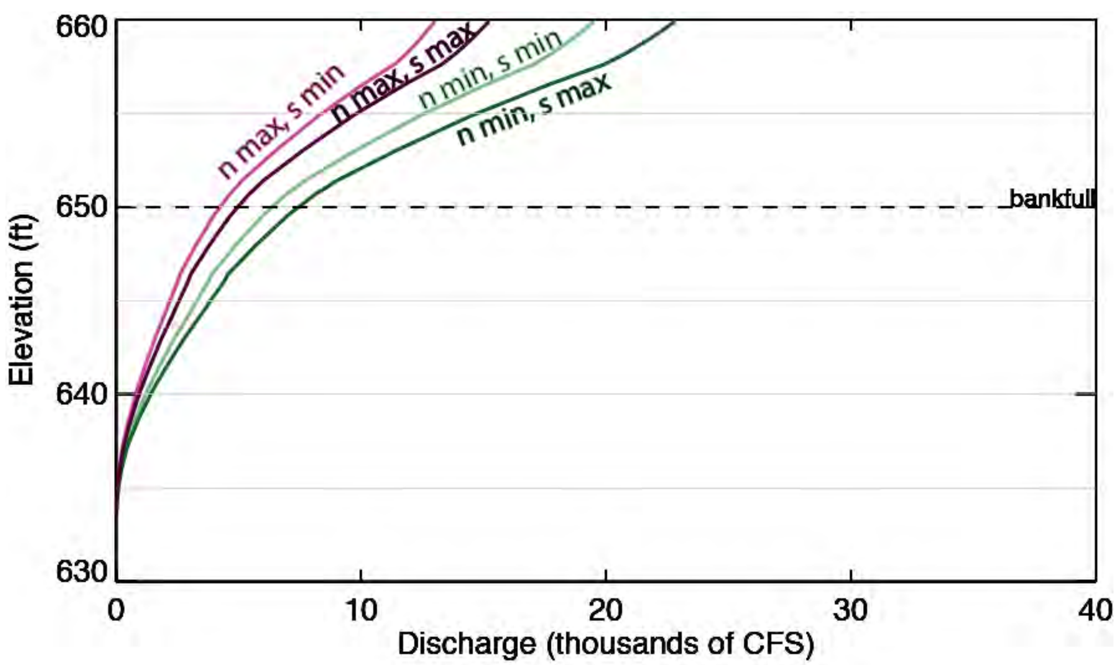


Figure A16. Sensitivity of rating curves to values of Manning's coefficient *n* and slope *s*

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PHASE II

1. Introduction

In phase I of the project, we used a simplification of the slope-area (SA) method to obtain rating curves at five locations in Iowa where an IFC stream-stage sensor and a USGS sensor are collocated or very close together. This proved to be a practical and useful method that allowed us to obtain rating curves where limited information was available. However, the simplicity of this method also brought some limitations that affected the quality of the obtained curves. One of the main problems with this method is that rating curve estimation is totally dependent on the local terrain characteristics of a particular cross-section, and the geometry information of upstream or downstream sections cannot be considered. This implies that the SA method cannot take into account geometry changes of the section along the channel.

In phase II, we used an approach based on hydraulic modeling to obtain rating curves at the locations of IFC stream-stage sensors. This approach allowed consideration of changes in the geometry of the sections within the channel reach. As a proof of concept, we applied the approach at five locations where IFC sensors are collocated with USGS sensors. We obtained results with the proposed approach and the simplified slope-area method used in phase I; we then compared the performance of the rating curves using the USGS curve as a reference.

2. Methodology

The approach described in this chapter is based on the use of a one-dimensional hydraulic model that computes a numerical solution of Saint-Venant equations in a channel reach. For this purpose, we used the well-established software HEC-RAS, which is widely used for rating curve estimation.

2.1 Hydraulic Model Based Method (HEC-RAS)

The Hydrologic Engineer Center´s River Analysis System (HEC-RAS) software allows users to perform one-dimensional hydraulic analysis components for steady flow water-surface profile computations. The system contains a component to estimate steady flow water-surface profiles, intended for calculation of water-surface profiles for steady gradually varied flow. The steady flow component is capable of modeling subcritical, supercritical, and mixed flow regime water-surface profiles. The basic computational procedure is based on the solution of the one-dimensional energy equation. We evaluated energy losses caused by friction (Manning´s equation) and contraction/expansion (coefficient multiplied by the change in velocity head). We used the momentum equation in situations where the water-surface profile is rapidly varied. These situations include mixed flow regime calculations, hydraulics of bridges, and evaluating profiles at river confluences.

2.2 Model Set-up

2.2.1 Cross-section Geometry

We included the cross-sections geometry data collected in the field survey in the set-up of the model. The geometry data include a combination of high-resolution data collected for the channel, and a DEM of 1 m resolution obtained from LiDAR data for the part of the section out of the channel. More details are included in the first part of this report. Cross-sections are interpolated to obtain a better description of terrain. The features in the overbank that could be important for the hydraulic model (e.g., railroads, roads, highways, etc.) are considered within the interpolation using master cords. Figure **1** shows an example of the cross-section information included in the model.

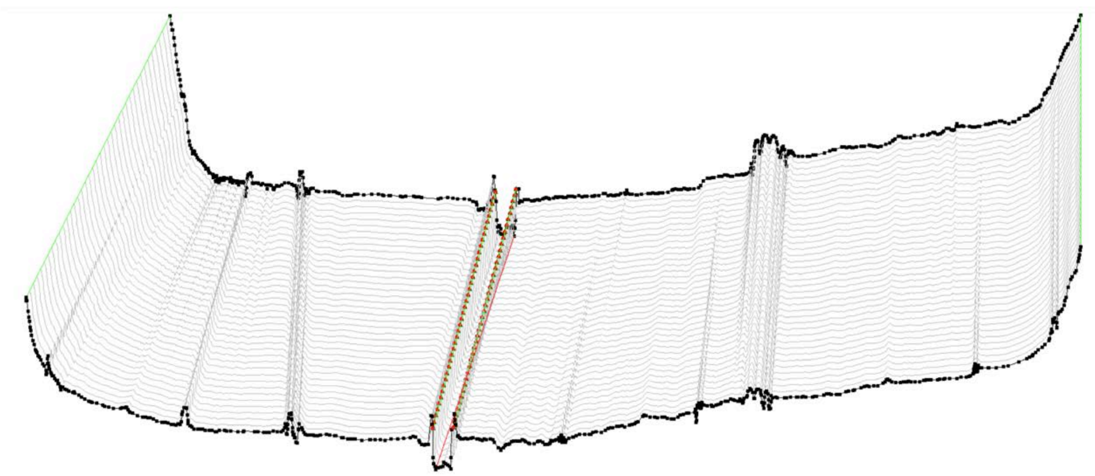

Figure 1. Example of the interpolation between two contiguous cross sections.

2.2.2 Estimation of Manning's Coefficient

Due to the availability of field information, we differentiated between the procedure for estimation of the Manning's coefficient for the part of the cross-section that belongs to the channel and the part that belongs to the overbank area.

Channel

We set the range for Manning's coefficient in the channel section between 0.03 and 0.045, given the variety of stream characteristics observed in the surveys. The collective experience of the project partners supports this range, based mostly on numerical modeling studies.

Overbank

For the overbank sections, we obtained the Manning´s coefficient from a map, based on the reclassification of the National Land Cover Database 2011. The reclassification is made using Table **1**. The land cover map used throughout the study was acquired from the National Land Cover Database.

Table 1. Correspondence between land uses and Manning's n roughness coefficient. Source: HEC-RAS Reference Manual Chapter 3, Table 3-1

Land Use	Manning
Pasture no brush	
Short grass	0.03
High grass	0.035
Cultivated Areas	
No crop	0.03
Mature row crops	0.035
Mature field crops	0.04
Brush	
Scattered brush heavy weeds	0.05
Light brush and trees in winter	0.05
Light brush and trees in summer	0.06
Medium to dense brush in winter	0.07
Medium to dense brush in summer	0.1
Trees	
Cleared land with tree stumps, no sprouts	0.04
Same as above, but heavy sprouts	0.06
Heavy stand of timber, few down trees, little undergrowth, flow below branches	0.1
Same as above but with flow into branches	0.12
Dense willows, summer, straight	0.15

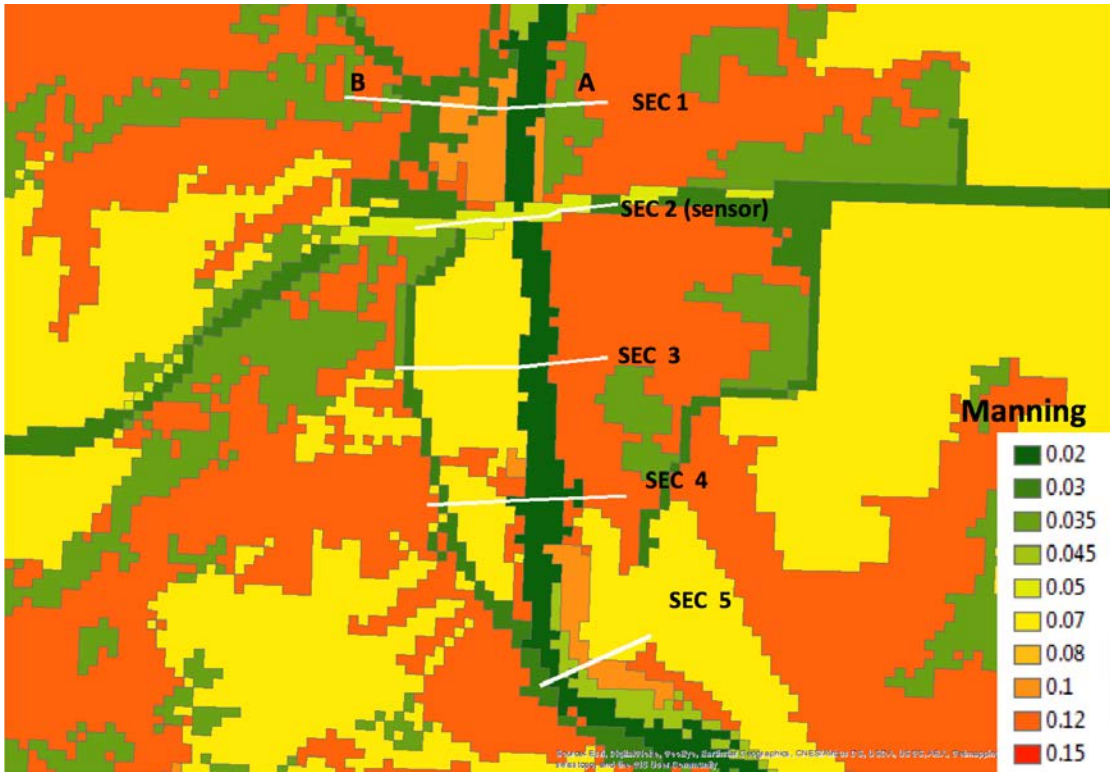

Figure 2. Manning's coefficient derived from the land cover map

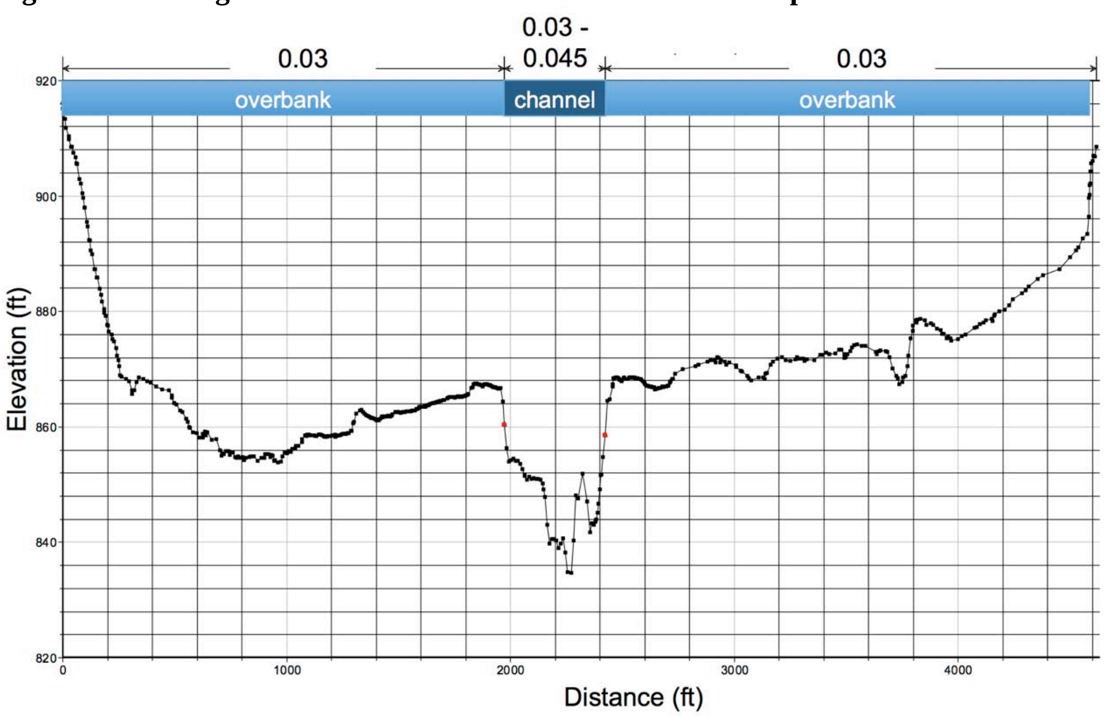

Figure 3. Set-up of Manning's coefficients over a HEC-RAS cross-section. The value for the channel ranges between 0.03 and 0.045. The value at the overbank is obtained from the Manning's map.

2.2.3 Slope Estimation

The procedure for estimating the free-surface slope is similar to the one used in the SA method. We estimated the free-surface slope along the left and right banks of the stream using the data collected during the cross-section surveys, as illustrated in Figure 5. We analyzed the consistency of the slope estimation along the reach by selecting various combinations for the slope calculations (i.e., cross-section 1 and 2, 1 and 3, 1 and 4). In most cases, we used the first and last cross sections for slope estimation.

2.2.4 Flow Data

One of the model inputs is a list of flow values used by the hydraulic model to calculate the corresponding stage at each section. We selected a set of 10 values ranging from the minimum to the maximum discharge observed in the USGS rating curves. In HEC-RAS, this is assumed as a steady flow condition in a subcritical flow regime, with boundary conditions at the downstream end of the river system. The selected boundary condition is normal depth. For this kind of condition, establishment of an energy slope is required for calculation of the normal depth (Manning's equation) at each location. Because the energy slope is unknown, we approximated it to the water-surface slope derived from the survey data.

2.3 Consideration of Uncertainty

We randomly selected a set of 100 feasible combinations for slope S and Manning's n values, assuming a uniform distribution for both parameters. The slope range is defined by the minimum and maximum slopes obtained from the surveys along the stream banks. We set the range for Manning's coefficient in the channel section between 0.03 and 0.045, given the variety of stream characteristics observed during the surveys. The Manning's coefficient at the overbank section is fixed at the values observed in the map as previously described. In HEC-RAS, this set-up resulted in 100 sets of geometry files, where each file represented a feasible combination of Manning's coefficient and initial water-surface slope.

2.4 Estimation of the Rating Curve

With the given set-up, the model results in a set of 100 rating curves that implicitly consider the uncertainty of the estimation of Manning's coefficient in the channel of the cross-section. To pick up a representative rating curve, we estimated a rating curve from the median of the results. We also obtained the envelope that contains all the realizations using the maximum and minimum stage values.

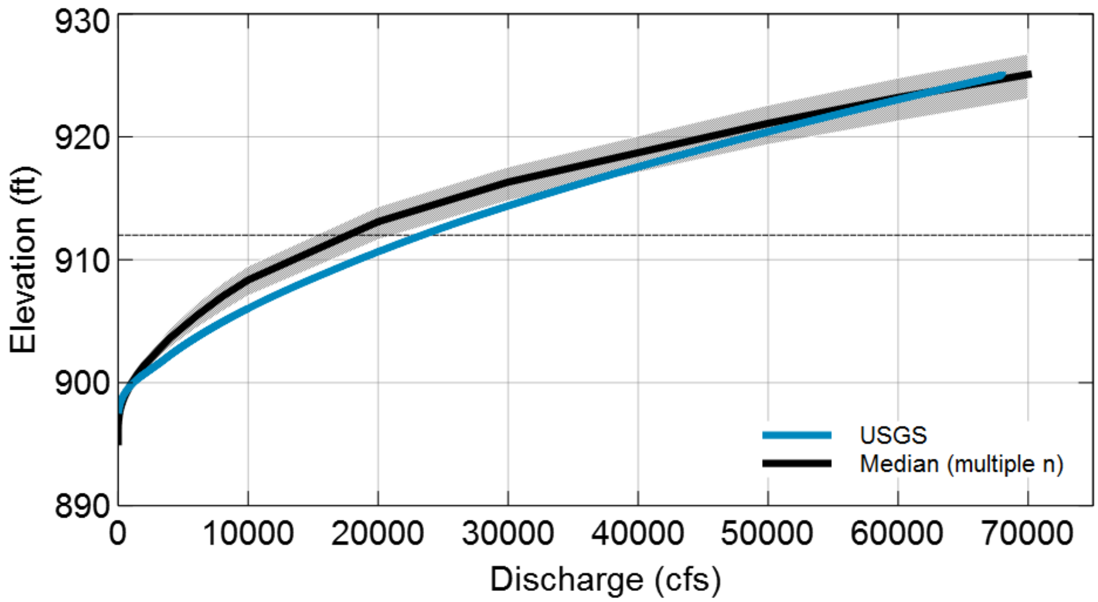

Figure 4. Example of the rating curves obtained using the hydraulic model and the proposed methodology. The black solid line represents the median of the rating curve realizations contained in the gray envelope. The blue line shows the USGS rating curve.

3. Study Area and Available Data

We conducted this study at five locations that had IFC stream-stage sensors and a USGS sensor collocated at the same bridge. These sites are described in Table 2. In the same table, we present the elevation of the stream-stage sensor and the basin's drainage area. Table 3 presents the analogous characteristics from the corresponding USGS sensors, including the elevation of the gauge datum and the drainage area of the basins. We transformed the gauge datum from the sensors, which originates in NGVD29 system, to NAVD88 system.

Table 2. Characteristics of the IFC Sensors. Source: IFIS

Name / Code	Elevation of the Tip of the Bridge Sensor (feet, NAVD88)	Upstream Area (mi^2)	Bankfull Level (feet)
Clear Creek at Oxford – CLRCRK01	718.96	58	709
South Skunk River at Colfax – SSKNK02	795.42	803	786
Raccoon River at Van Meter – RCCNRV01	869.69	3,441	860
Des Moines River at Stratford – DSMNSRV04	931.62	5,452	912
Maquoketa River at Manchester – MQKTARV03	931.47	275	911

Table 3. Characteristics of the USGS Sensors and Location with Respect to IFC Sensors. Source: USGS & IFIS

Name / Code	Gauge Datum (feet, NAVD88)	Upstream Area (mi^2)
Clear Creek at Oxford – 05454220	696.43	58
South Skunk River at Colfax – 05471050	770.11	803
Raccoon River at Van Meter – 05484500	841.35	3,441
Des Moines River at Stratford – 05481300	894.03	5,452
Maquoketa River at Manchester – 05416900	900.27	275

The U.S. Army Corps of Engineers (USACE) conducted field surveys at the five locations. They collected information about the geometry of the cross-sections and the elevation of the water surface at the moment of the survey. The survey also included detailed photographs showing the channels and its floodplains.

4. Results

4.1 Cross-section Analysis

Figures 5a to 5e show a top view of the surveyed cross-sections at the selected basins. The captions A and B with red letters in the figure indicate the direction of the survey, starting at point A and concluding in point B. The direction of the survey is constant for all the sections within a channel. The figures also indicate the section crossing below the stream-stage sensor. We produced rating curves for all the sections, but the results are shown for the section closer to the stream-stage sensor. Appendix B shows a transversal view of all the cross-sections obtained during the survey.

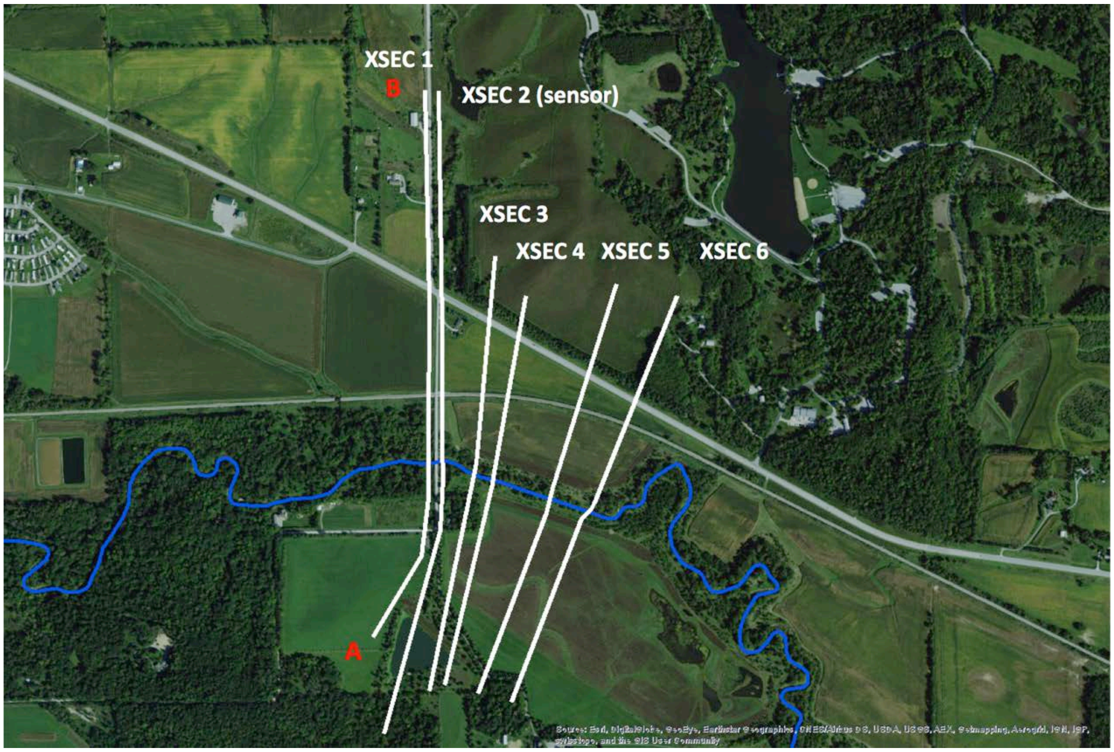

Figure 5a. Cross-sections surveyed next to the bridge over Clear Creek at Oxford.

Figure 5b. Cross-sections surveyed next to the South Skunk River bridge at Colfax.

Figure 5c. Cross-sections surveyed next to the Raccoon River bridge at Van Meter.

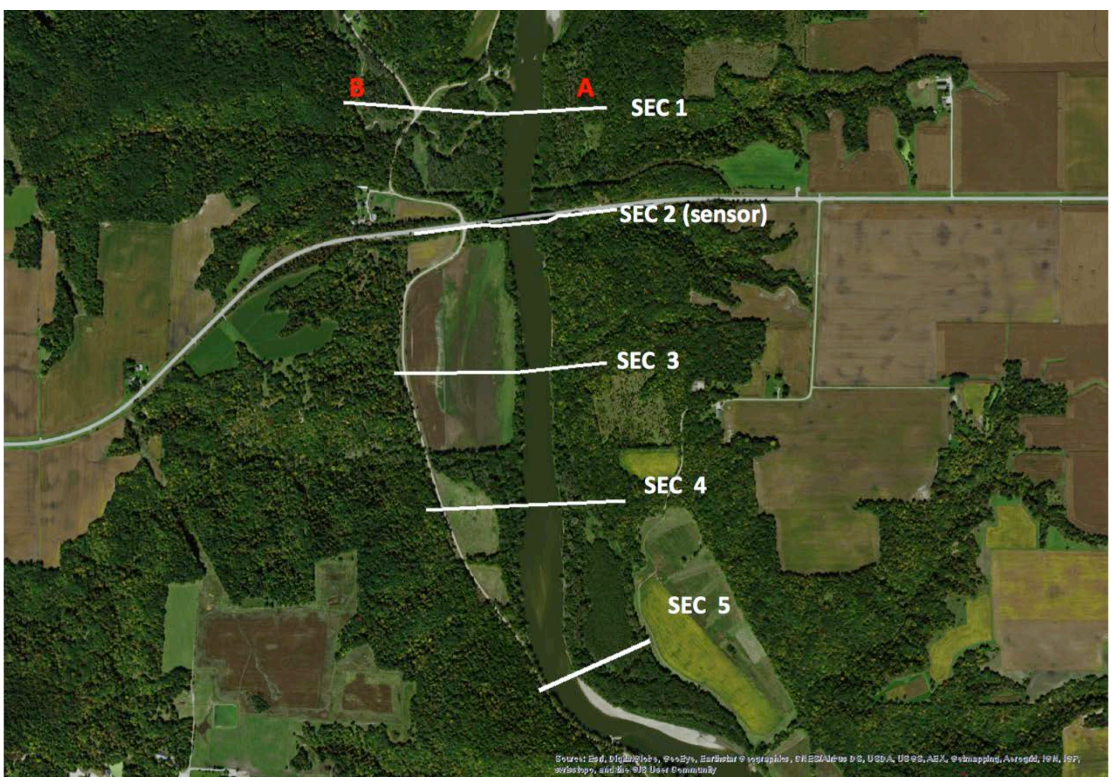

Figure 5d. Cross-sections surveyed next to the Des Moines River bridge at Stratford.

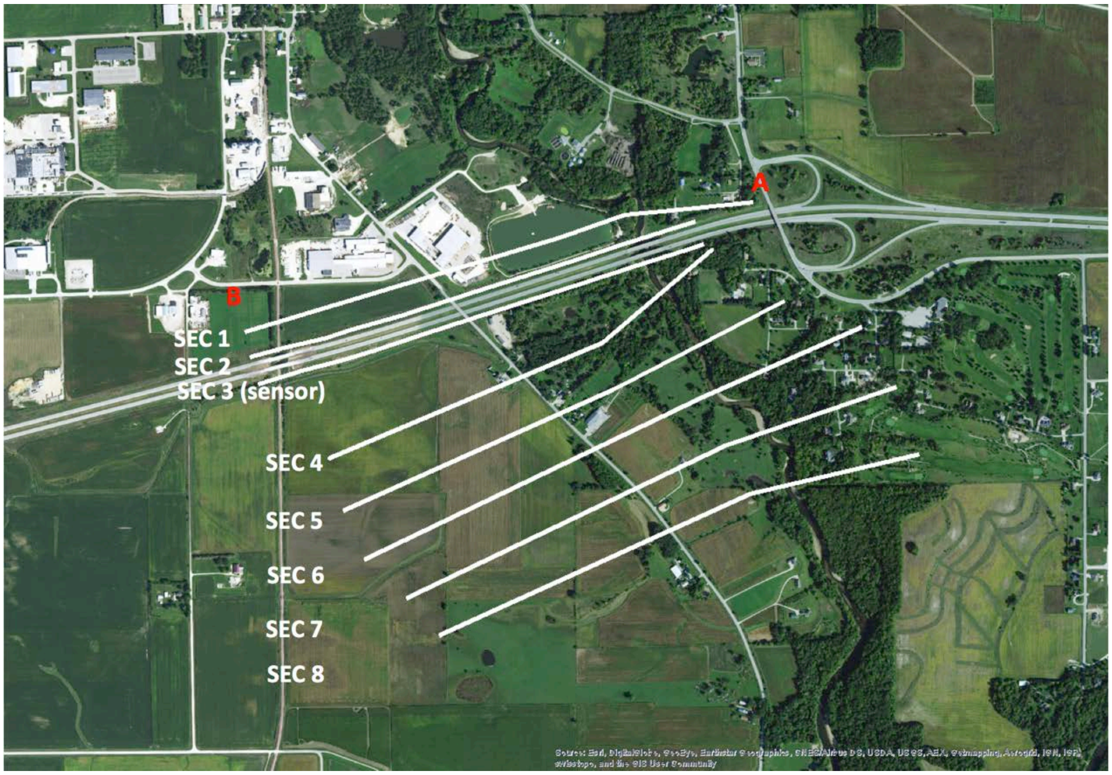

Figure 5e. Cross-sections surveyed next to the Maquoketa River bridge at Manchester.

4.2 Interpolation of Cross-sections

Figures 6a to 6e show a 3-D view of the interpolated cross-sections. The red lines in the figures denote the limit of the channel section. The interpolation of the features is manually controlled, and takes into account the location of features important for hydraulic modeling, such as railroads, levees, and others.

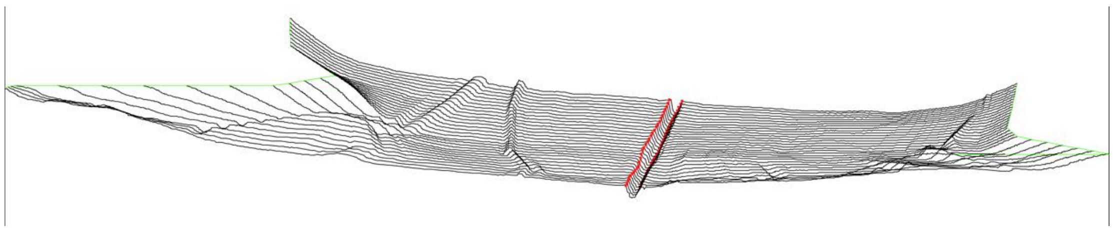

Figure 6a. View of the cross-section interpolation on Clear Creek at Oxford.

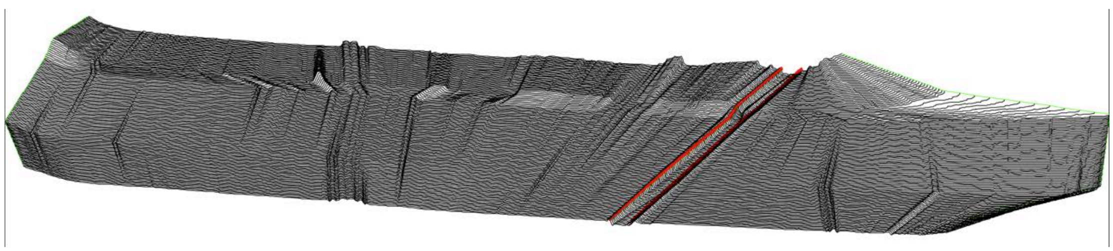

Figure 6b. View of the cross-section interpolation on South Skunk River at Colfax.

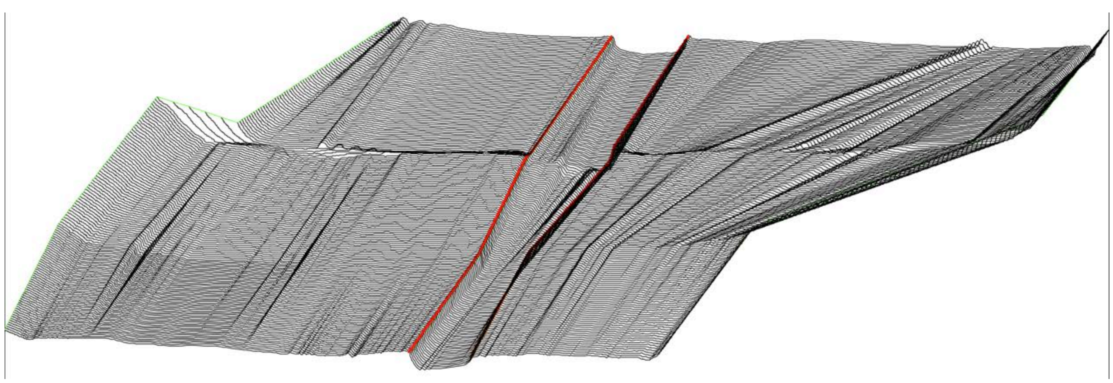

Figure 6c. View of the cross-section interpolation on Raccoon River at Van Meter.

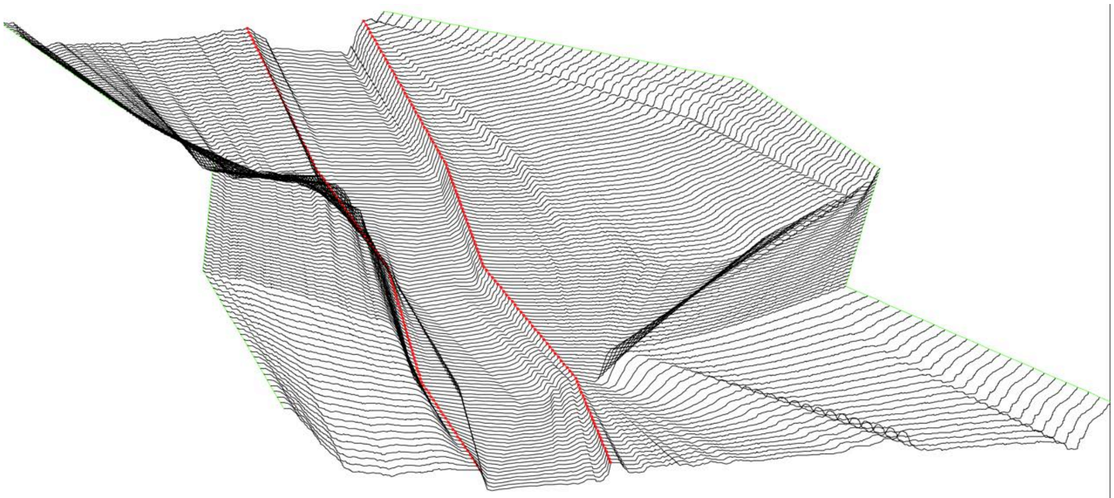

Figure 6d. View of the cross-section interpolation on Des Moines River at Stratford.

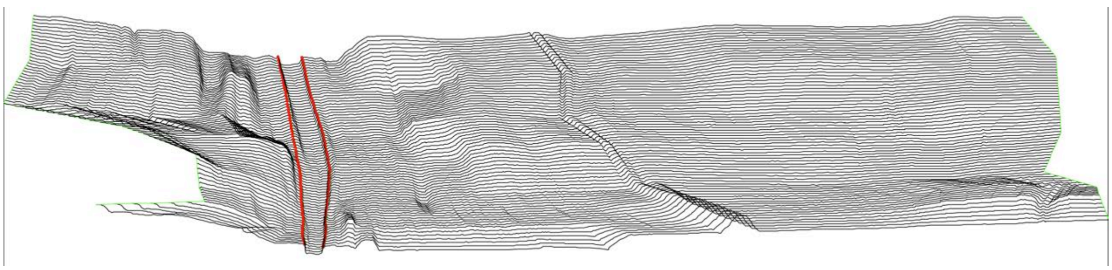

Figure 6e. View of the cross-section interpolation on Maquoketa River at Manchester.

4.3 Estimation of Manning's coefficient in channel and overbanks

Figures 7a to 7e show the maps of Manning's coefficients used in the set-up of the hydraulic model. The roughness values observed at each section were included into the set-up of the hydraulic model. Figures 8a to 8e show the set-up of these values in HEC-RAS. The light blue areas represent the overbank areas. The dark blue area represents the channel section. As previously explained, we produced 100 sets of geometries, varying the Manning's n from 0.03 to 0.045 in the channel section, and setting it to the value observed in the Manning's map in the overbanks.

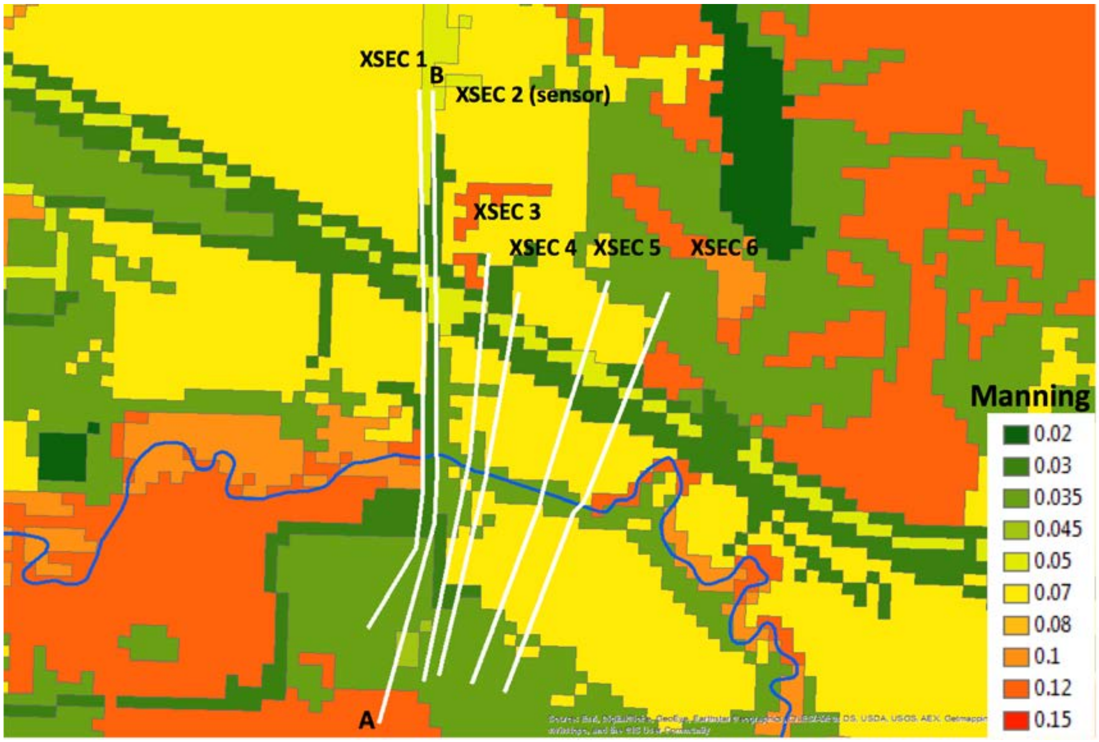

Figure 7a. Map of Manning's coefficient on Clear Creek at Oxford.

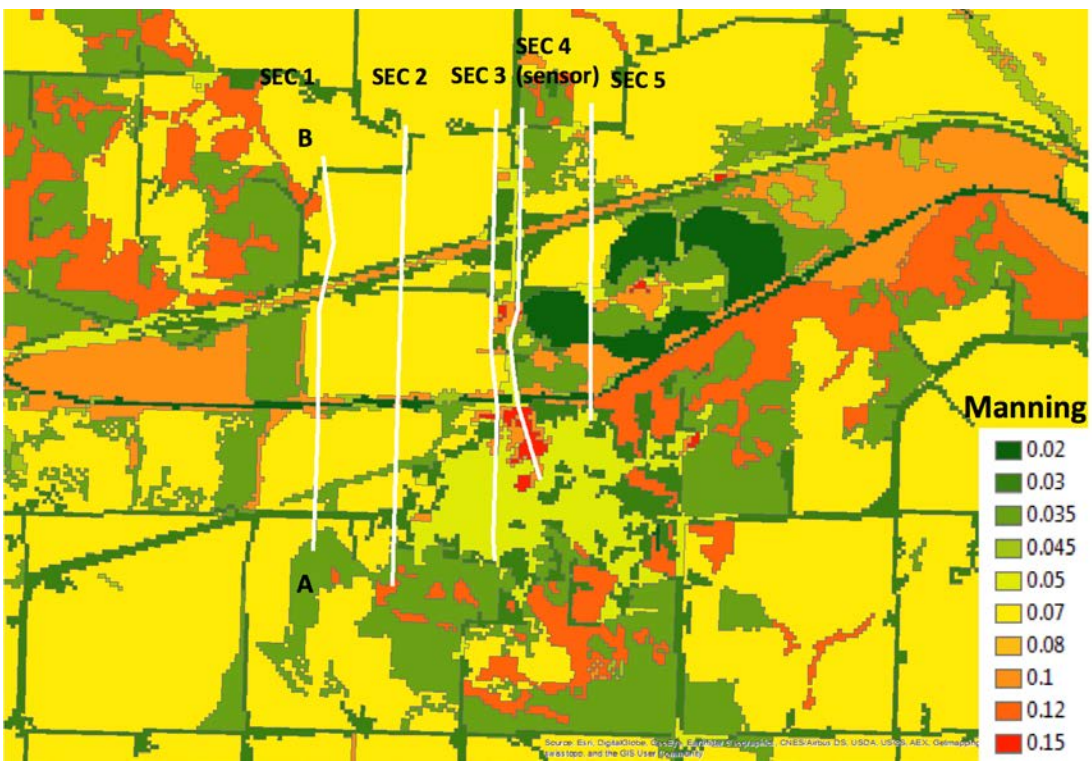

Figure 7b. Map of Manning's coefficient on South Skunk River at Colfax.

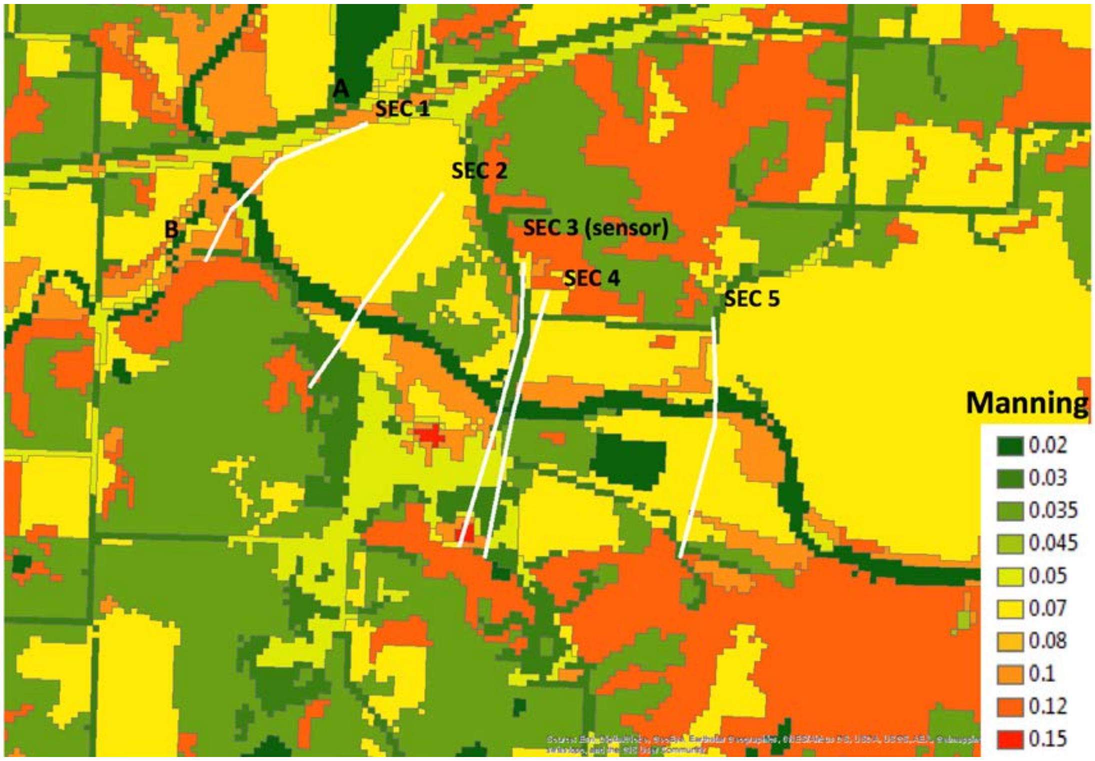

Figure 7c. Map of Manning's coefficient on Raccoon River at Van Meter.

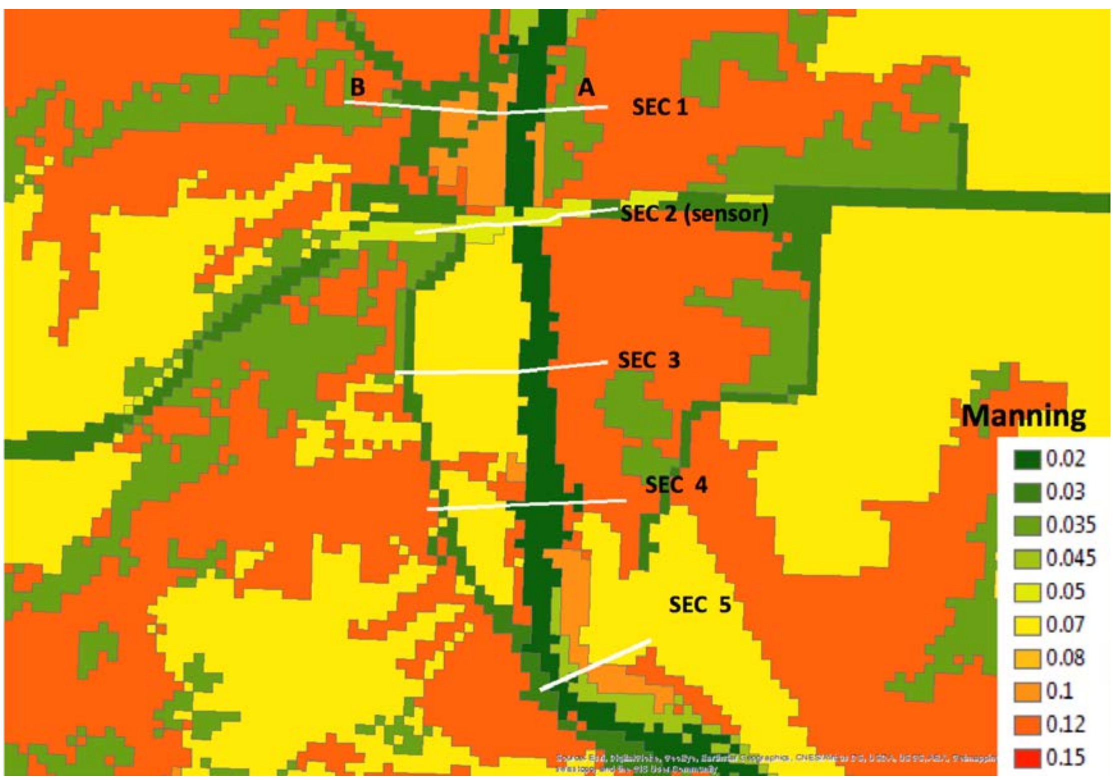

Figure 7d. Map of Manning's coefficient on Des Moines River at Stratford.

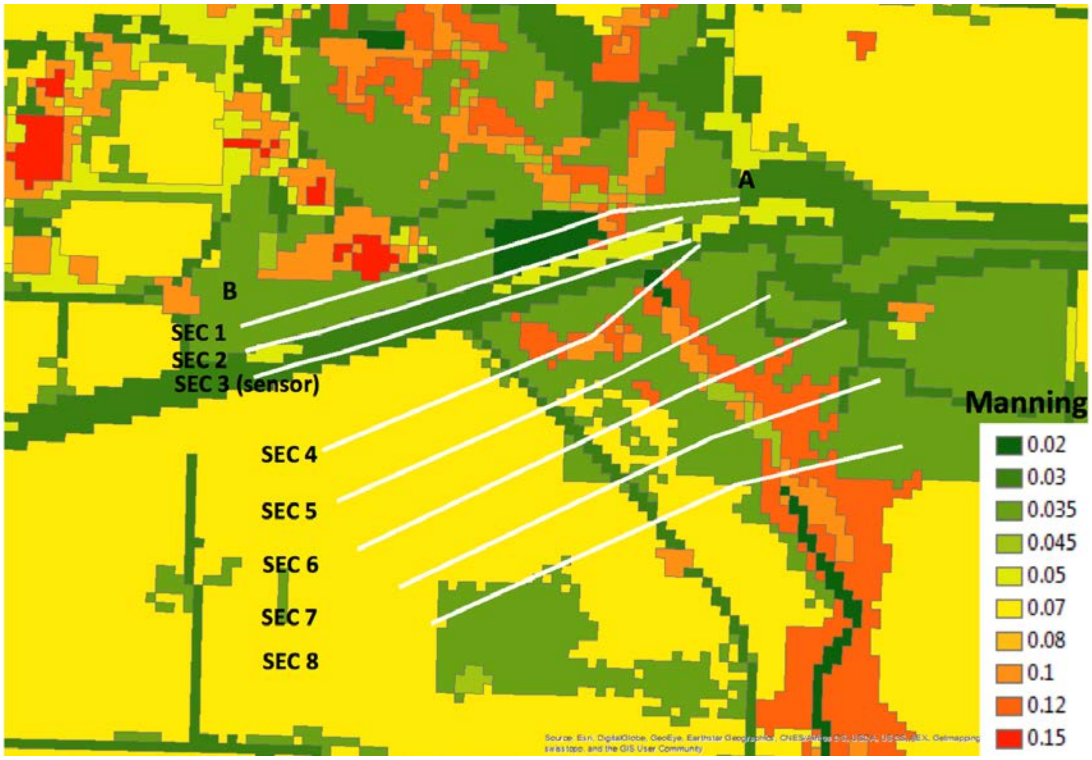

Figure 7e. Map of Manning's coefficient on Maquoketa River at Manchester.

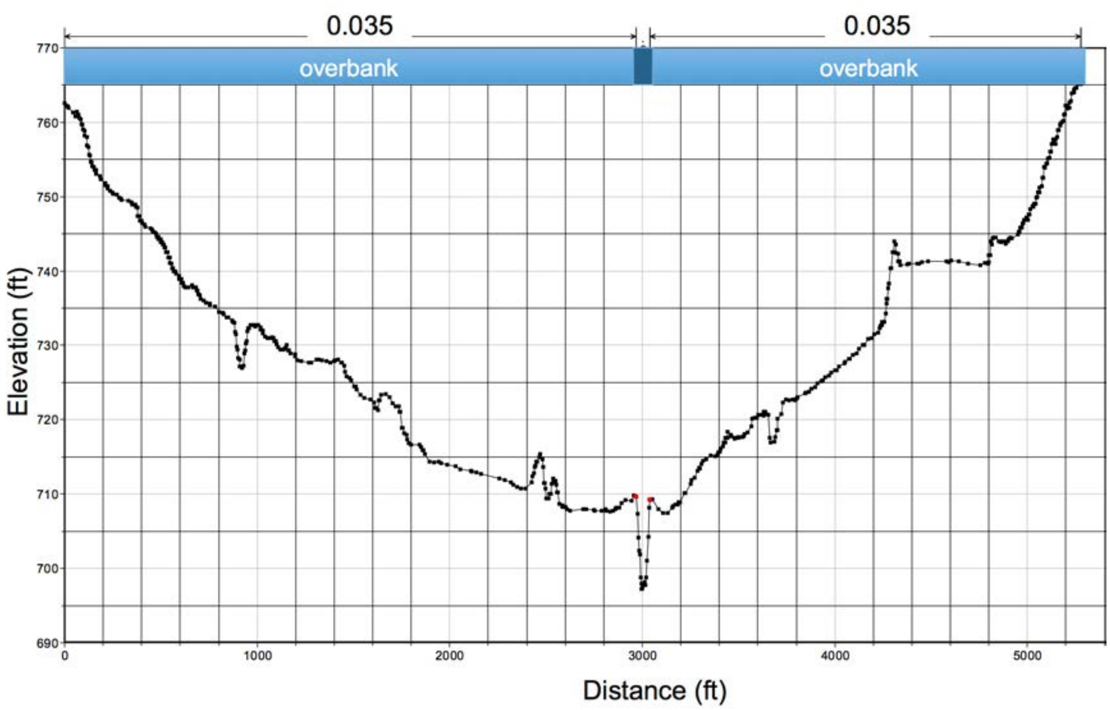

Figure 8a. Set-up of the Manning's roughness coefficient at the channel (dark blue) and overbank (light blue) sections on Clear Creek at Oxford

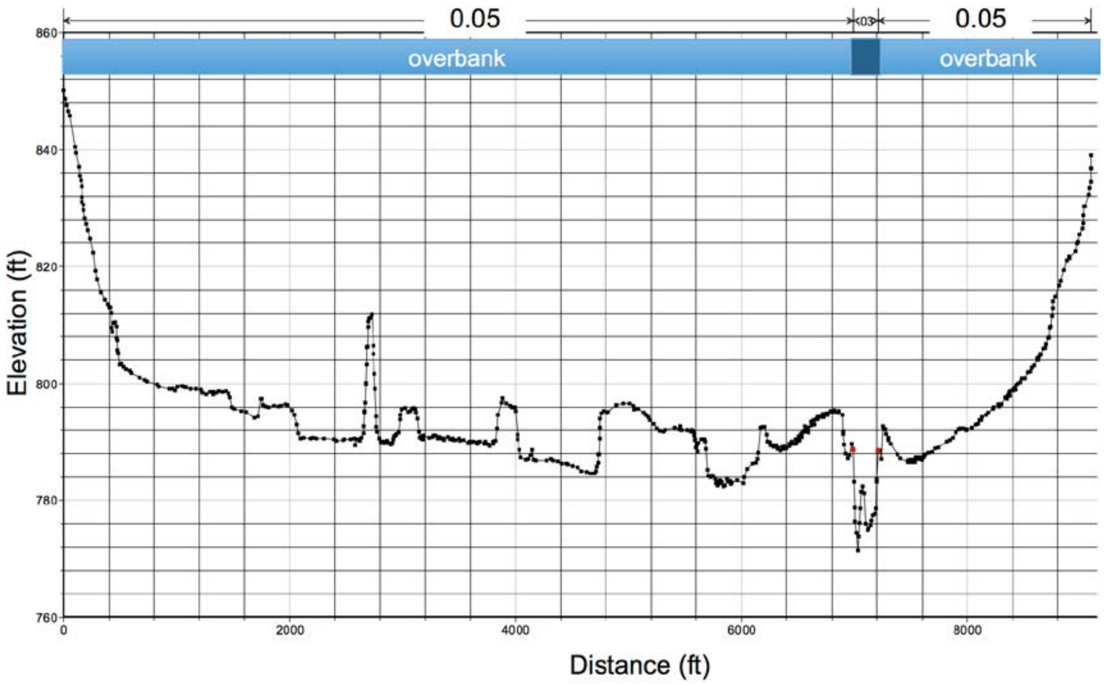

Figure 8b. Set-up of the Manning's roughness coefficient at the channel (dark blue) and overbank (light blue) sections on South Skunk River at Colfax.

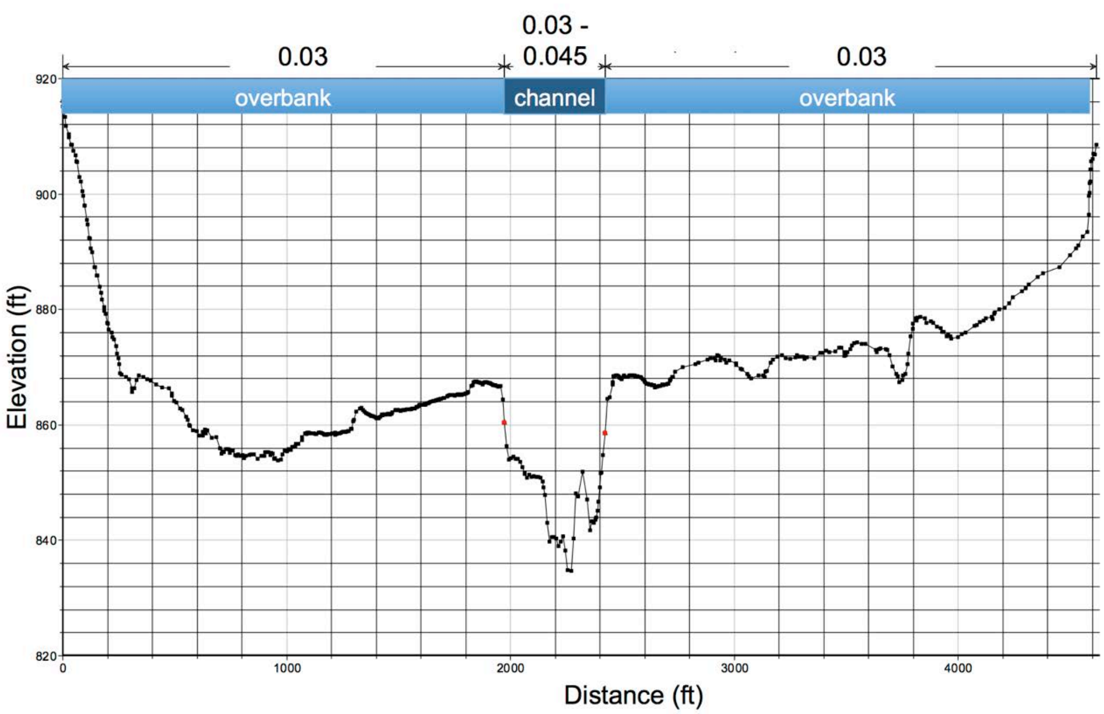

Figure 8c. Set-up of the Manning's roughness coefficient at the channel (dark blue) and overbank (light blue) sections on Raccoon River at Van Meter.

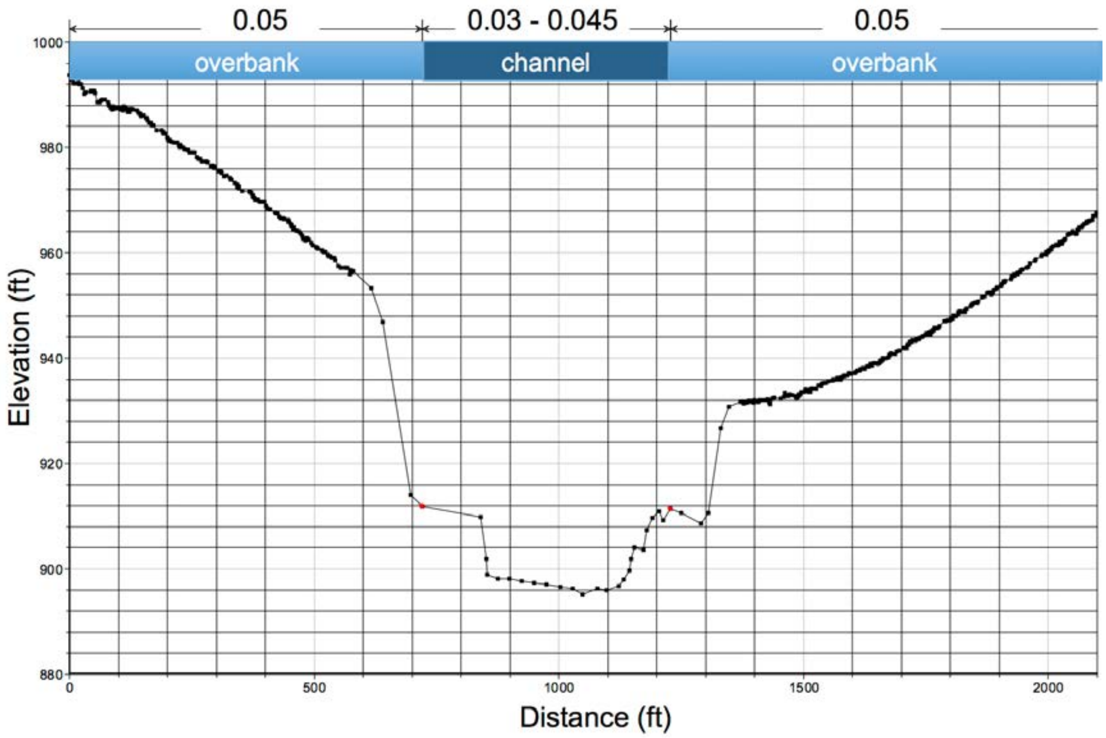

Figure 8d. Set-up of the Manning's roughness coefficient at the channel (dark blue) and overbank (light blue) sections on Des Moines River at Stratford.

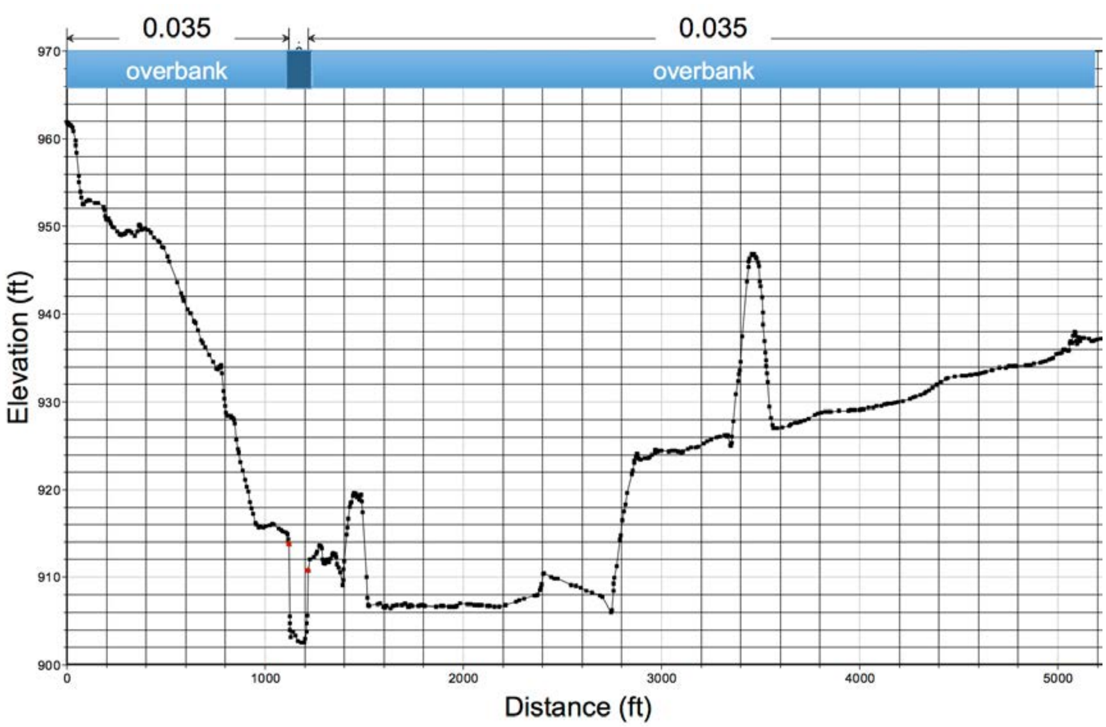

Figure 8e. Set-up of the Manning's roughness coefficient at the channel (dark blue) and overbank (light blue) sections on Maquoketa River at Manchester.

4.4 Rating Curves

Figures 9a to 9e show the rating curves obtained with the hydraulic model methodology. The probable discharge values for a given water surface elevation are given by the envelopes of the simulation (light grey areas for the 0% and 100% percentiles). A representative rating curve is obtained as the median of the possible realizations (solid black line). The blue line is the existing USGS rating curve located within the surveys stream. Bankfull line is shown as a dashed black line.

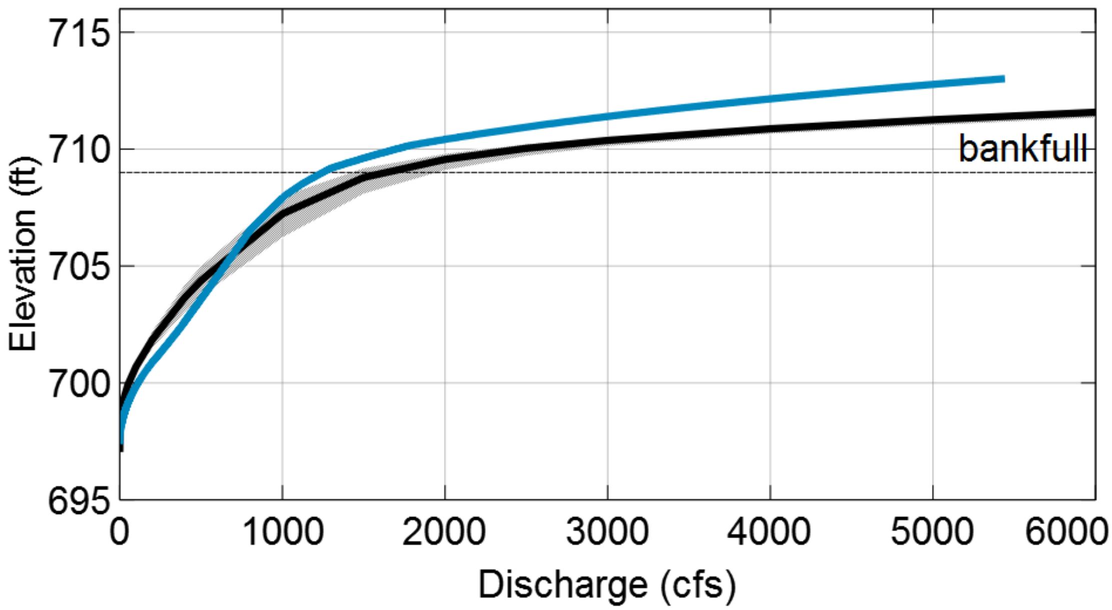

Figure 9a. Rating curve obtained for Clear Creek at Oxford. The blue line is the USGS rating curve. The black line and gray area are the median and the envelope of the rating curves obtained using a hydraulic model. Dashed line shows the elevation of the bankfull level.

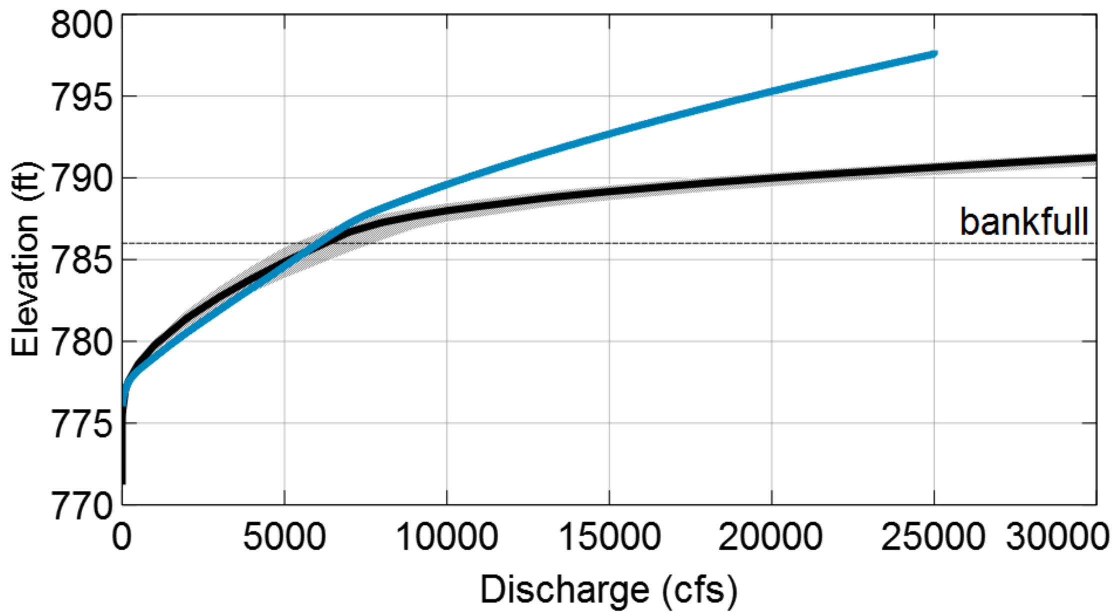

Figure 9b. Rating curve obtained for South Skunk River at Colfax. The blue line is the USGS rating curve. Black line and gray area are the median and the envelope of the rating curves obtained using a hydraulic model. Dashed line show the elevation of the bankfull level.

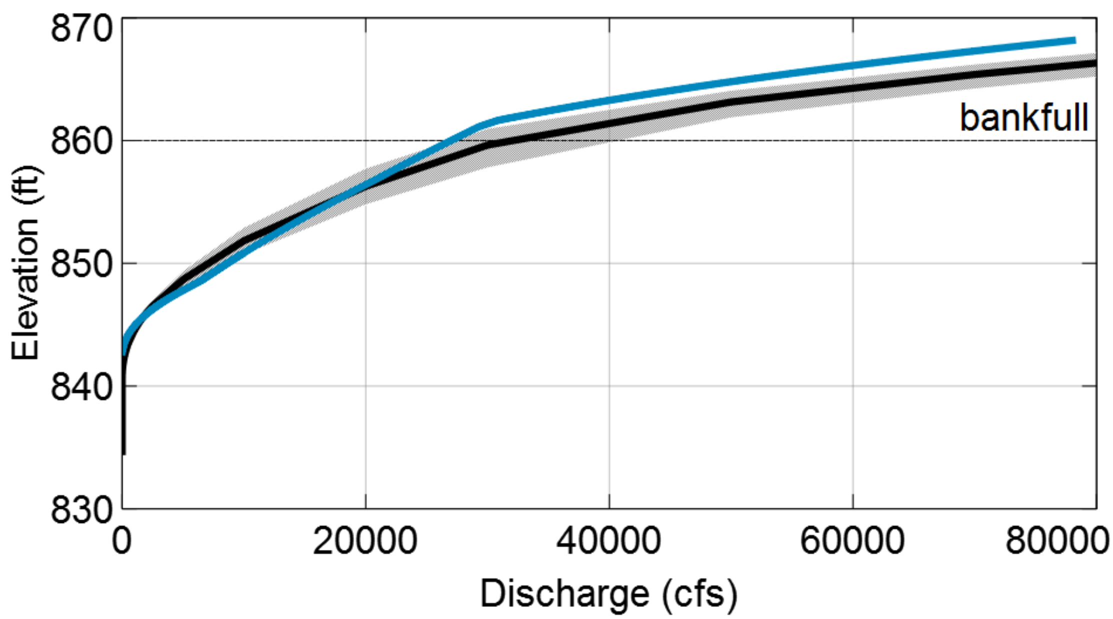

Figure 9c. Rating curve obtained for Raccoon River at Van Meter. The blue line is the USGS rating curve. Black line and grey area are the median and the envelope of the rating curves obtained using a hydraulic model. Dashed line show the elevation of the bankfull level.

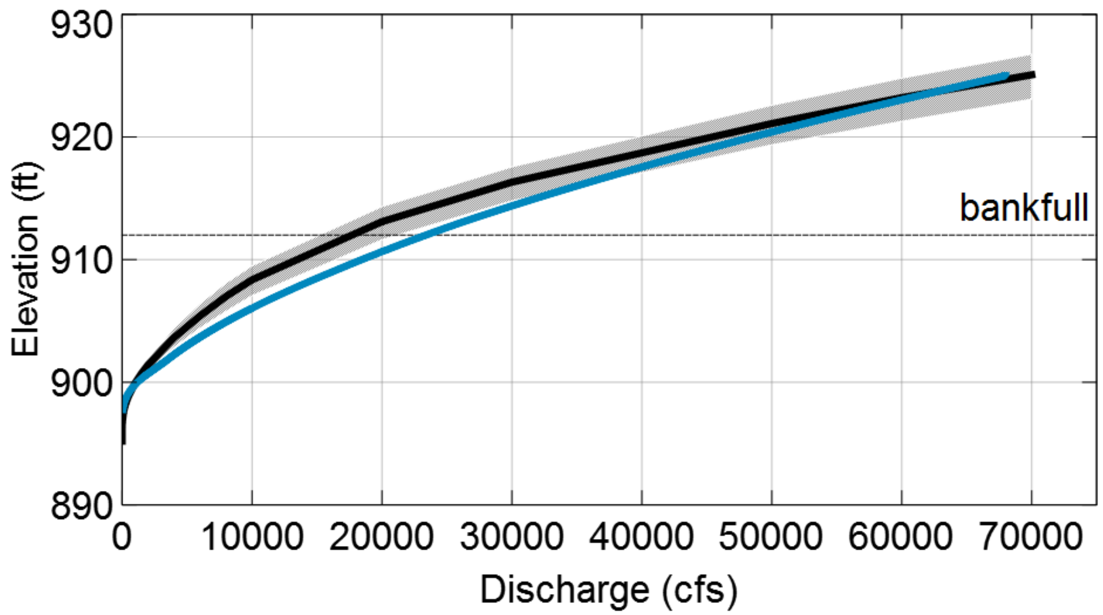

Figure 9d. Rating curve obtained for Des Moines River at Stratford. The blue line is the USGS rating curve. Black line and gray area are the median and the envelope of the rating curves obtained using a hydraulic model. Dashed line show the elevation of the bankfull level.

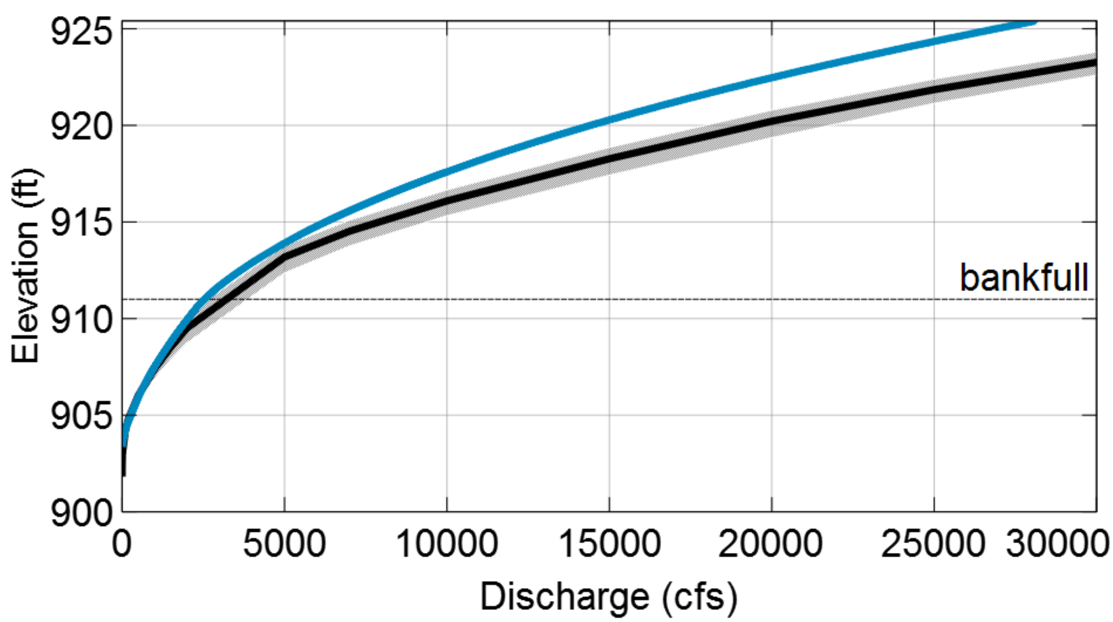

Figure 9e. Rating curve obtained for Maquoketa River at Manchester. The blue line is the USGS rating curve. Black line and gray area are the median and the envelope of the rating curves obtained using a hydraulic model. Dashed line show the elevation of the bankfull level.

4.5. Comparison with the Results Obtained using the Slope-Area Method

Figures 10a to 10e compare the results obtained using the HEC-RAS model with results acquired using the simplified slope-area approach. In these figures, the blue line is the USGS rating curve, the red line is the median of the rating curves produced by the simplified slope-area method, and the black line is the median of the rating curves obtained using the HEC-RAS model. The dashed horizontal line indicates the bankfull level. A visual inspection of the results reveals that the HEC-RAS model approach produces better results than the slope-area method does. In the next section, we provide a method to quantify the errors obtained in the rating curve estimation and to compare the performance of both approaches.

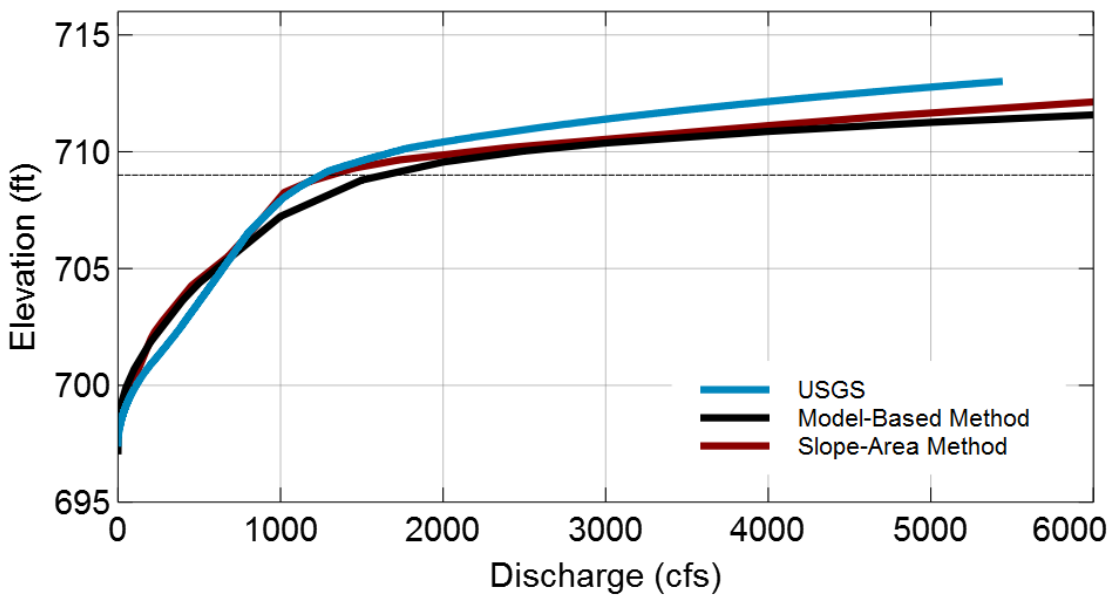

Figure 10a. Comparison of rating curves obtained with Slope-Area (red line) and HEC-RAS (black line) methods in Clear Creek at Oxford.

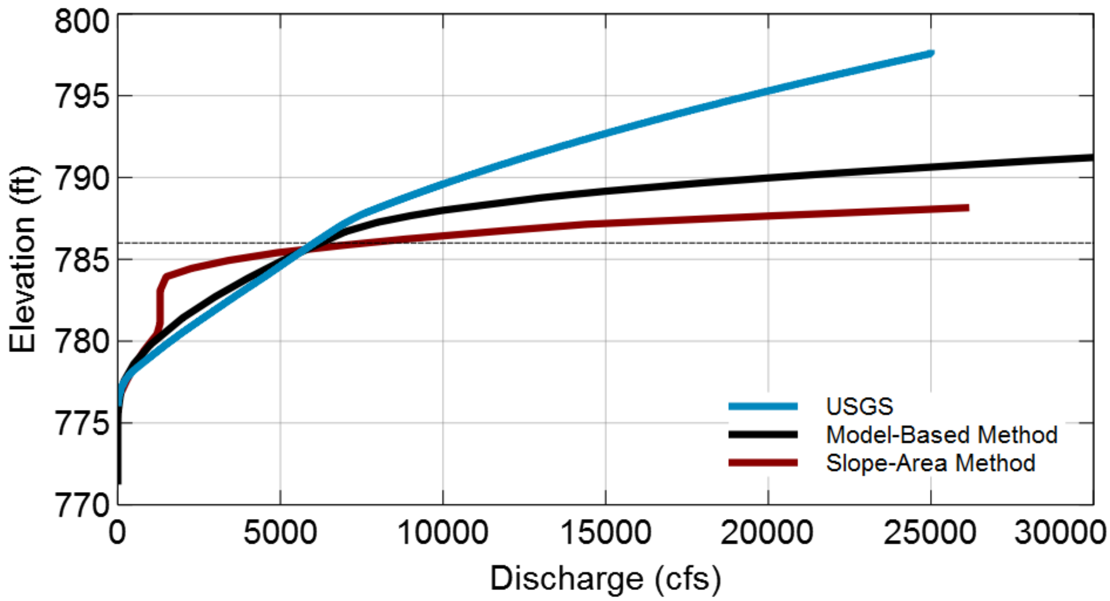

Figure 10b. Comparison of rating curves obtained with Slope-Area (red line) and HEC-RAS (black line) methods in South Skunk River at Colfax.

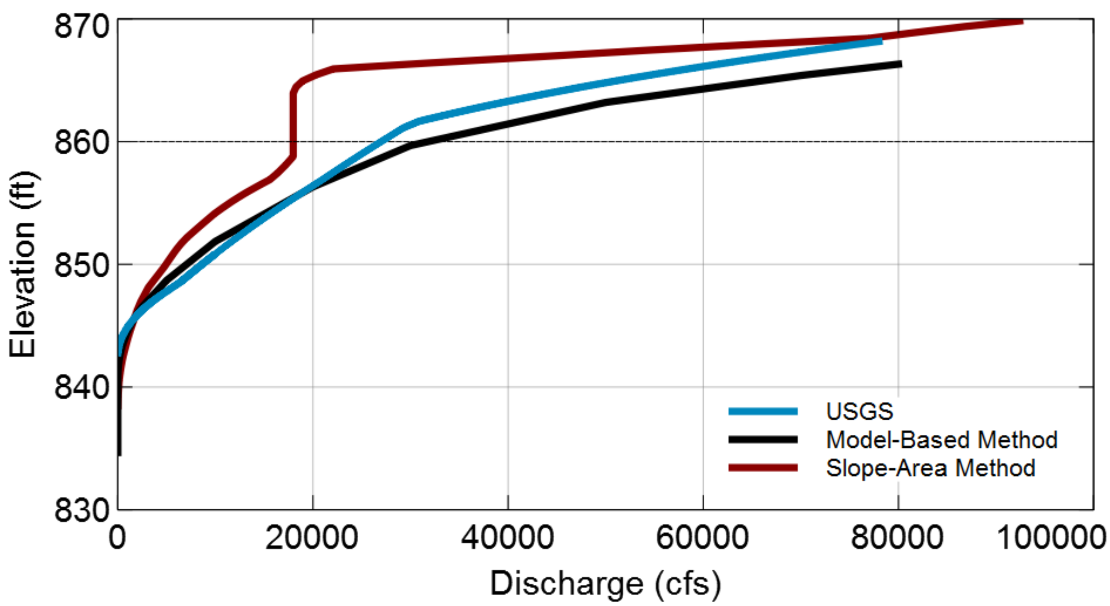

Figure 10c. Comparison of rating curves obtained with Slope-Area (red line) and HEC-RAS (black line) methods in Raccoon River at Van Meter.

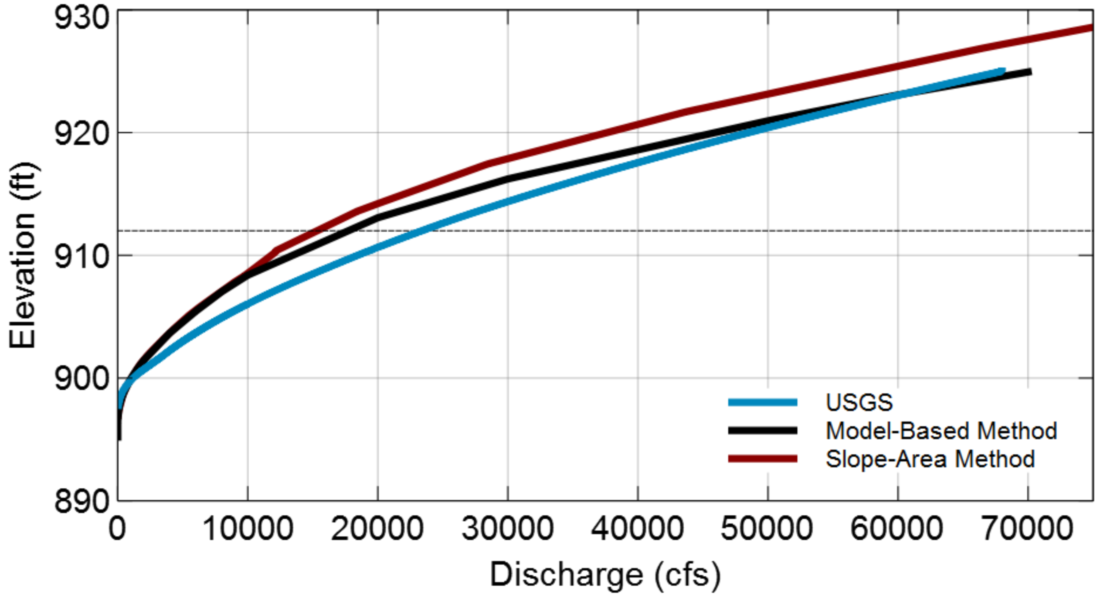

Figure 10d. Comparison of rating curves obtained with Slope-Area (red line) and HEC-RAS (black line) methods in Des Moines River at Stratford.

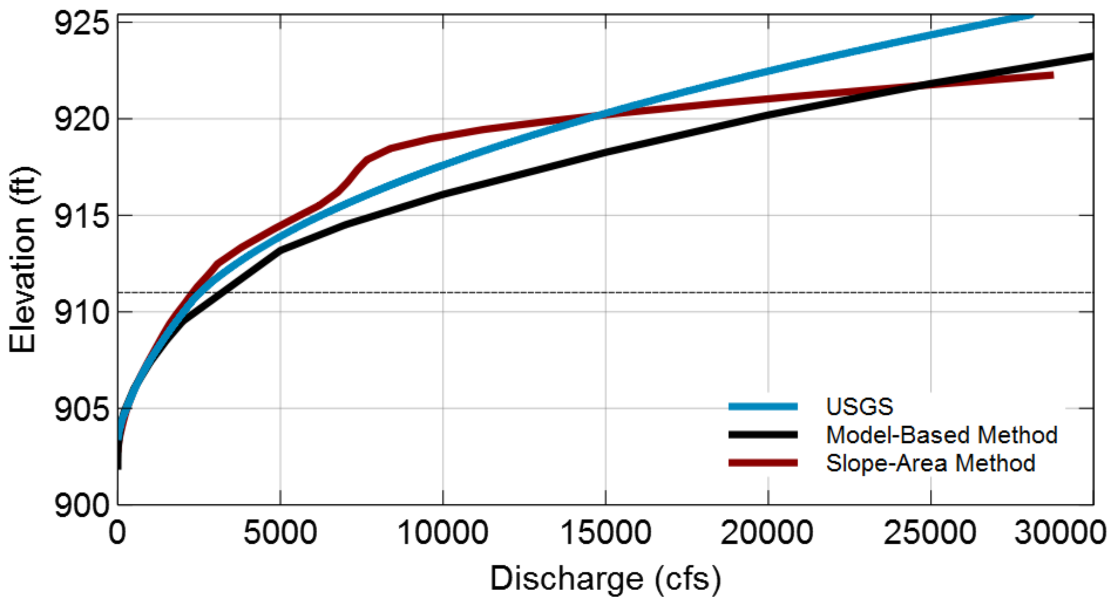

Figure 10e. Comparison of rating curves obtained with Slope-Area (red line) and HEC-RAS (black line) methods in Maquoketa River at Manchester.

4.6 Performance of the Rating Curve Estimation Methods

We measured the performance of the obtained rating curves by estimating the Root Mean Squared Error (RMSE). For this purpose, we used the values of the USGS rating curve as a reference and compared them to the values of our rating curves. We applied the RMSE for both methods: Slope-Area method and HEC-RAS model-based method. Equation 1 shows the formula used to obtain the RMSE.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{k}(\hat{y}_i - y_i)^2}{k}} \quad (1)$$

where $\hat{y}_i$ is a vector of predictions (i.e., the rating curve values using slope-area method or hydraulic model method), y_i is a vector of observed values (i.e., the USGS rating curve), and k is the number of values evaluated to obtain the RMSE metric. We calculated the RMSE for errors in elevation as well as errors in discharge. Figure **11** shows an example of the RMSE estimation procedure on the elevation errors. In the figure, the red arrows correspond to the term $\hat{y}_i - y_i$, and k is the number of points in the USGS rating curve. The dashed horizontal line indicates the bankfull level. We estimated the errors for values below the bankfull line, over the bankfull line, and a combination of both.

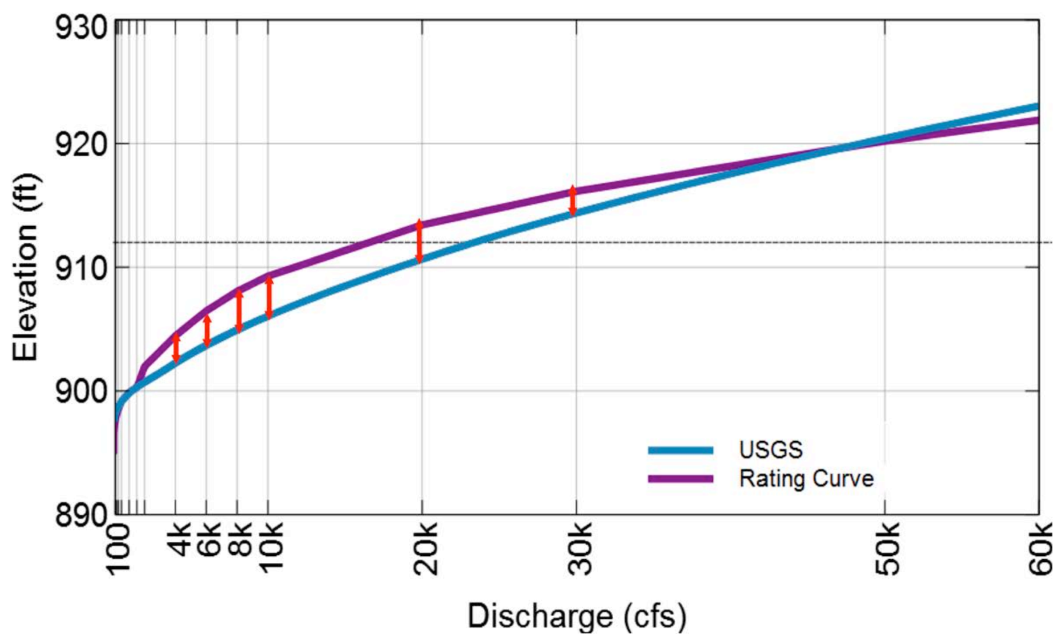

Figure 11. The blue line is the USGS rating curve used as reference. The purple line is a rating curve to be evaluated. The red arrow shows the difference $\hat{y}_i - y_i$. The dashed horizontal line indicates the bankfull level.

Table 4 shows the number of rating curve points over and below the bankfull level. These points are used as weights to compute the weighted average values shown in Tables 5 to 8. Tables 5 and 6 summarize errors that occurred using the HEC-RAS model approach in terms of elevation and discharge, respectively. Tables 7 and 8 show the errors obtained using the slope area approach in terms of elevation and discharge, respectively. Errors obtained using the HEC-RAS approach are in the order of 1.8 feet for the part of the section over the bankfull line, and in the order of 0.8 feet for the section below the bankfull line. In contrast, using the slope-area method, we got errors in the order of 4 feet for the section over the bankfull line and about 2.1 feet for the section below the bankfull line. The comparison of tables 5 and 7 shows that the HEC-RAS model approach produced better results than the slope-area method did. A similar result is found when comparing discharge errors from tables 6 and 8.

Table 4. Number of rating curve points over and below the bankfull line.

Bank level	**Clear Creek at Oxford**	**South Skunk River at Colfax**	**Raccoon River at Van Meter**	**Des Moines River at Stratford**	**Maquoketa River at Manchester**
Over	501	1,023	1,217	1,501	1,042
Below	1,048	982	1,321	1,223	1,146
Combined	1,548	2,005	2,537	2,723	2,187

Table 5. RMSE using HEC-RAS (in feet).

Bank level	**Clear Creek at Oxford**	**South Skunk River at Colfax**	**Raccoon River at Van Meter**	**Des Moines River at Stratford**	**Maquoketa River at Manchester**	**Weighted Average**
Over	1.06	1.10	1.56	1.44	1.98	**1.85**
Below	0.72	0.87	0.72	1.71	0.59	**0.87**
Combined	0.84	1.06	1.19	1.57	1.43	**1.57**

Table 6. RMSE using HEC-RAS (in cfs).

Bank level	**Clear Creek at Oxford**	**South Skunk River at Colfax**	**Raccoon River at Van Meter**	**Des Moines River at Stratford**	**Maquoketa River at Manchester**	**Weighted Average**
Over	2084	2033	12,034	4,484	5,904	**10,246**
Below	86	353	992	2,801	607	**1,008**
Combined	1187	1851	8,365	3,821	4,099	**7,995**

Table 7. RMSE using simplified slope-area (in feet).

Bank level	**Clear Creek at Oxford**	**South Skunk River at Colfax**	**Raccoon River at Van Meter**	**Des Moines River at Stratford**	**Maquoketa River at Manchester**	**Weighted Average**
Over	1.24	3.66	2,39	3.43	8.56	**4.00**
Below	0.90	2.35	3,81	1.02	2.43	**2.10**
Combined	1.03	3.45	3.21	2.64	6.16	**3.39**

Table 8. RMSE using Slope-Area (in cfs).

Bank level	**Clear Creek at Oxford**	**South Skunk River at Colfax**	**Raccoon River at Van Meter**	**Des Moines River at Stratford**	**Maquoketa River at Manchester**	**Weighted Average**
Over	2,345	83,923	18,794	37,609	97,066	**54,703**
Below	143	786	3,634	1,216	11,878	**3,997**
Combined	1353	75,781	13,226	28,045	67,546	**38,012**

5. Conclusions

This study presented a methodology for developing rating curves at the locations where IFC real-time stream-stage sensors are installed. We used two methods for this purpose: 1) a simplification of the slope-area method, and 2) the one-dimensional hydraulic model HEC-RAS. For both methods, we proposed a general methodology that handles the uncertainty of estimation of Manning's roughness coefficient and water-surface slope. This methodology uses Monte Carlo simulation to consider a range of feasible values of roughness in the channel derived from expert knowledge, and a range of slope provided by surveyed data. The methodology was used in both the simplified slope-area method and the HEC-RAS modeling. The methodology is computationally inexpensive and avoids the problem of calibration. Rating curves derived using this method consider implicitly the uncertainty of parameter estimation by providing an envelope of feasible realizations. A representative rating curve can be obtained as the median of the realizations. The rating curves obtained from the median were compared to the existing USGS rating curves in order to check the performance of the methodology.

We found that the rating curves obtained using the HEC-RAS modeling approach have errors ranging between 0.8 and 2.7 feet, with an average error of 1.5 feet. If the performance is characterized for values over and below the bankfull level, we obtain average errors of 0.8 feet and 1.8 feet respectively. The rating curves obtained using the simplified slope-area method have poorer performance compared to the HEC-RAS results. Their errors range between 1.03 and 6.1 feet. When characterizing errors over and below the bankfull line, these average 4 and 2.1 feet respectively.

The HEC-RAS model approach requires more cross-section geometry information from the channel than the simplified slope-area method does. The HEC-RAS model also necessitates surveying at least two cross-sections far upstream and two more downstream from the sensor of interest. This condition is necessary to guarantee the stability of the flow along the channel reach in the set-up of the model. In a strict sense, the simplified slope-area approach requires only one cross-section that is representative of the channel's hydraulic conditions near the stream-stage sensor. The program that calculates the rating curves with the simplified slope-area method only takes into account the geometry of one cross-section at a time, without considering the interpolation between the sections.

Both methods require a good estimation of the water-surface slope. For the simplified slope-area method, the calculation of the rating curve uses the input range of values directly in Manning's equation. The HEC-RAS model approach uses an initial slope value in the model set-up. However, the model performs several iterations to solve the one-dimensional equation of flow along the channel, producing a profile of the energy line that can change from section to section.

The effort required to produce a rating curve using the HEC-RAS model is greater than what is needed for the simplified slope-area method. The most time- and money-consuming tasks are the cross-section surveys (including the post-processing with LiDAR information on the overbanks) and the set-up of multiple models in HEC-RAS to produce inputs for the Monte Carlo simulations. Evaluation of the results is less energy-consuming, but not less important.

Given the limitations of the simplified slope-area method, the applicability of the rating curves should be narrowed to the cross-section area below the bankfull level. Its inability to take into account the changes in the geometry of the sections leads to inaccurate results in the floodplain. For the purposes of the Iowa Flood Center, it is important that rating curves for the stream-stage sensors provide an accurate estimate of the observed discharge in flood events. The HEC-RAS model-derived rating curves seem to provide sufficient information with an acceptable error.

Appendix B

Figures A1 to A5 show all the cross-sections produced during the survey at five Iowa locations. In the figures, the top panel shows a top view of the cross-sections; the bottom panel provides a close-up view of the elevations of the profile of the riverbank surveyed on the field as well as the distance from the origin point of the survey. We obtained the floodplain elevations from LiDAR data. The blue color indicates the elevation of the water surface at the time the survey was conducted.

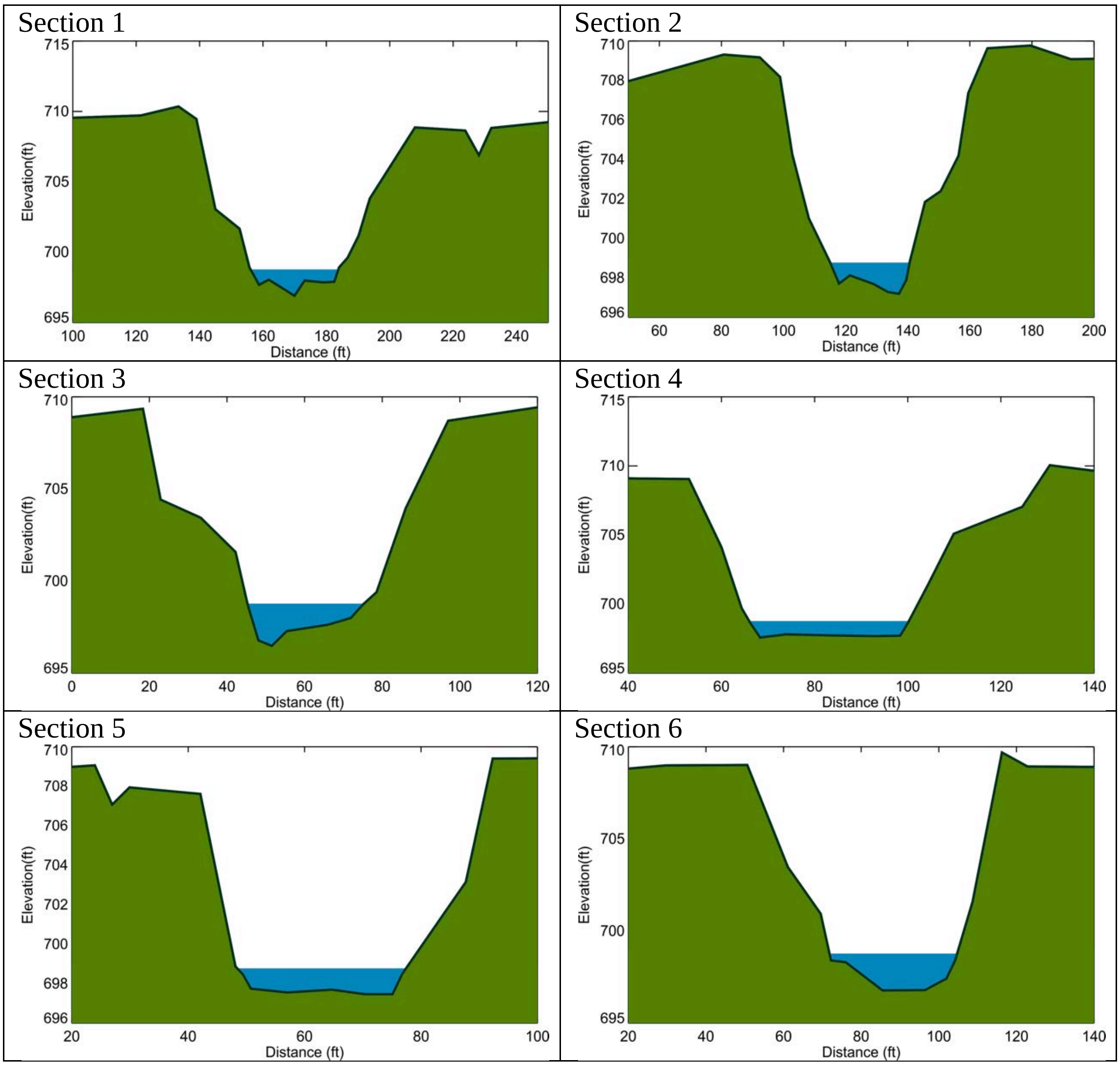

Figure B1 Cross-sections of Clear Creek at Oxford.

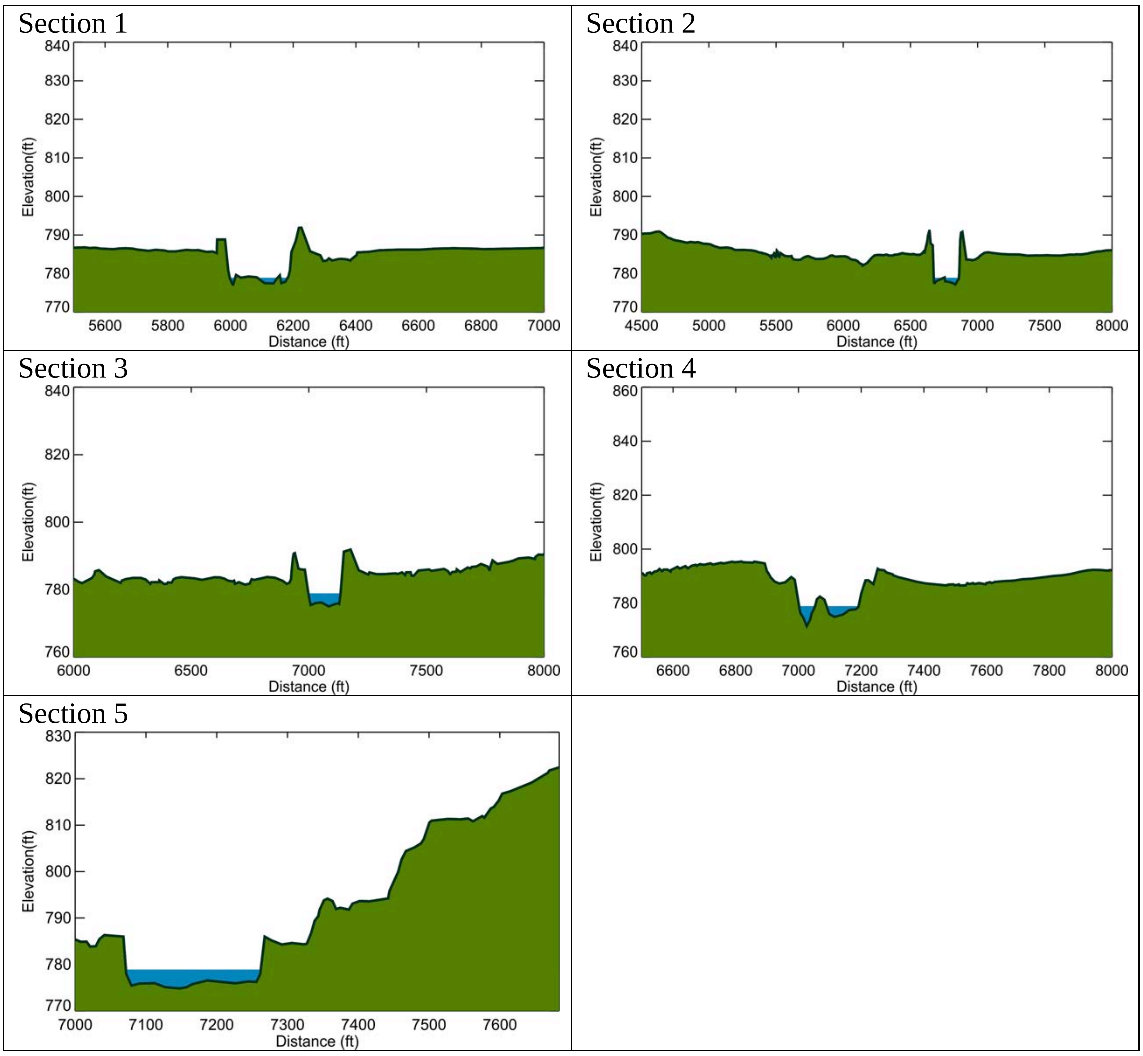

Figure B2 Cross-sections of South Skunk River at Colfax.

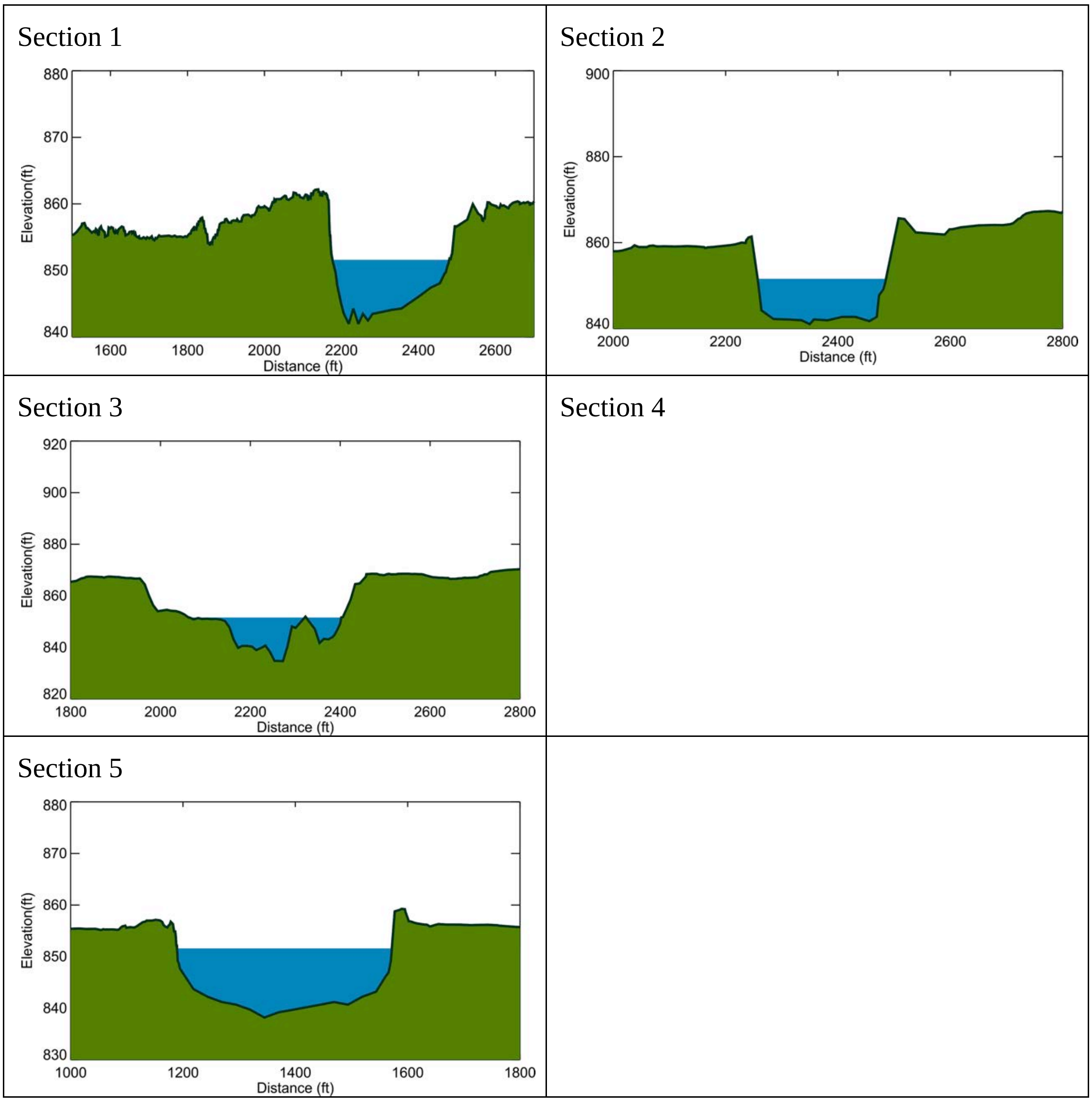

Figure B3. Cross-sections of Raccoon River at Van Meter.

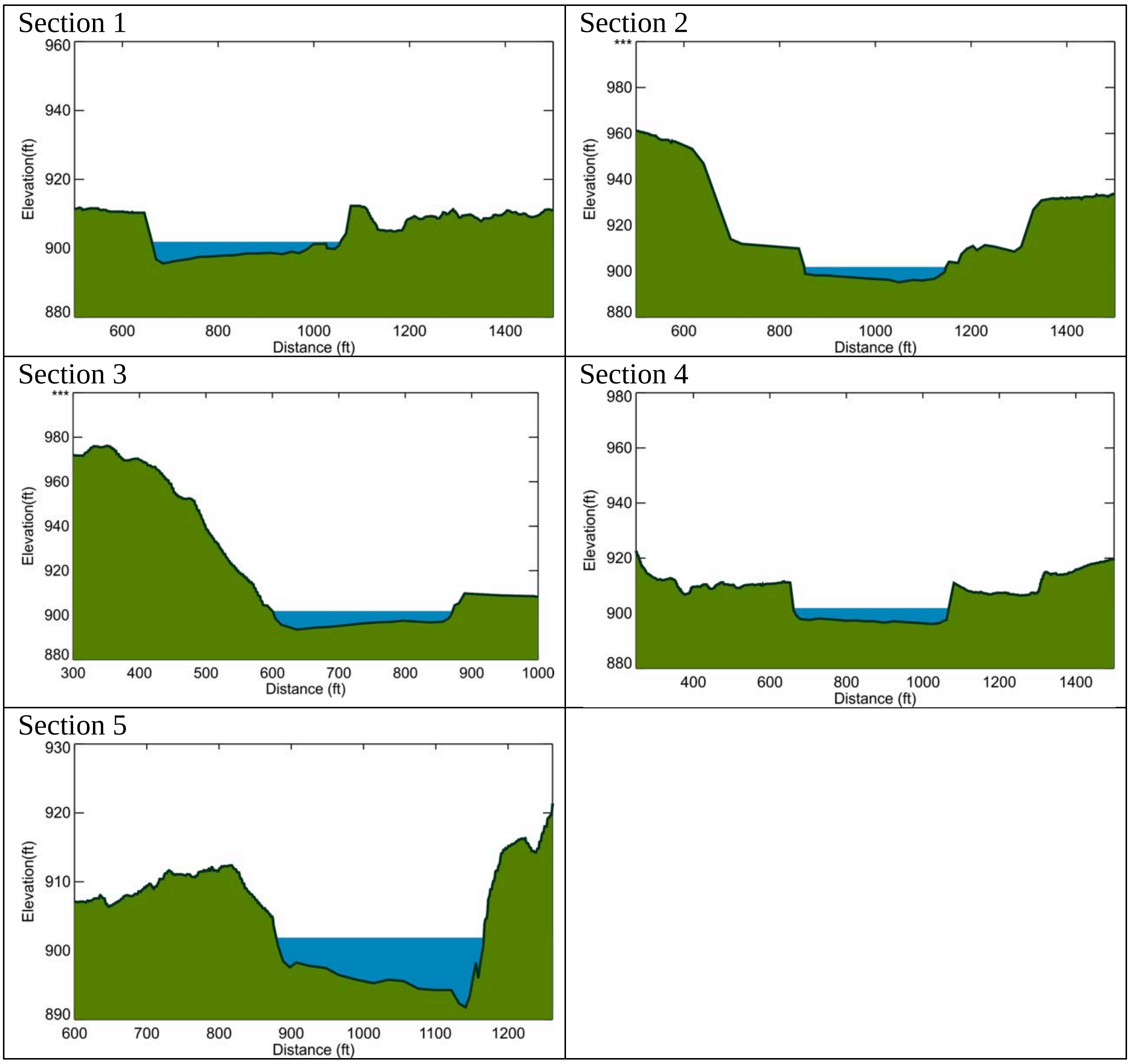

Figure B4. Cross-sections of Des Moines River at Stratford.

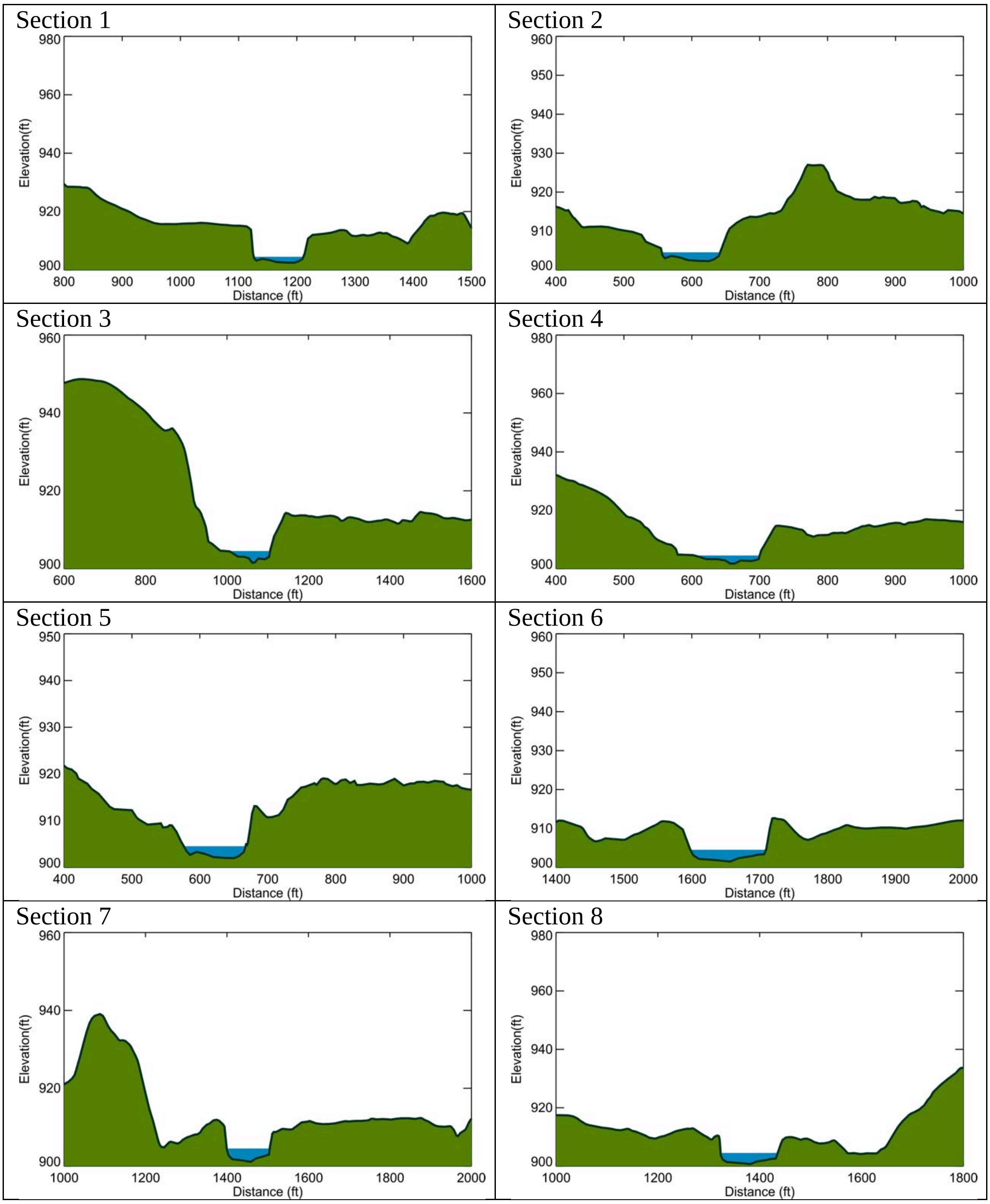

Figure B5. Cross-sections of Maquoketa River at Manchester.

Figures B6 to B10 show the elements required to calculate the slopes of the water surface for different flow trajectories. Two slopes are obtained for each location, one for the points with observed water surface on the left bank of the river (shown in black) and another for the points on the right bank of the river (shown in gray). The x-axis corresponds to the distance of these points from the more upstream cross-section following the river trajectory. The slope values produced for each side of the bank are shown in the top right side of the figure.

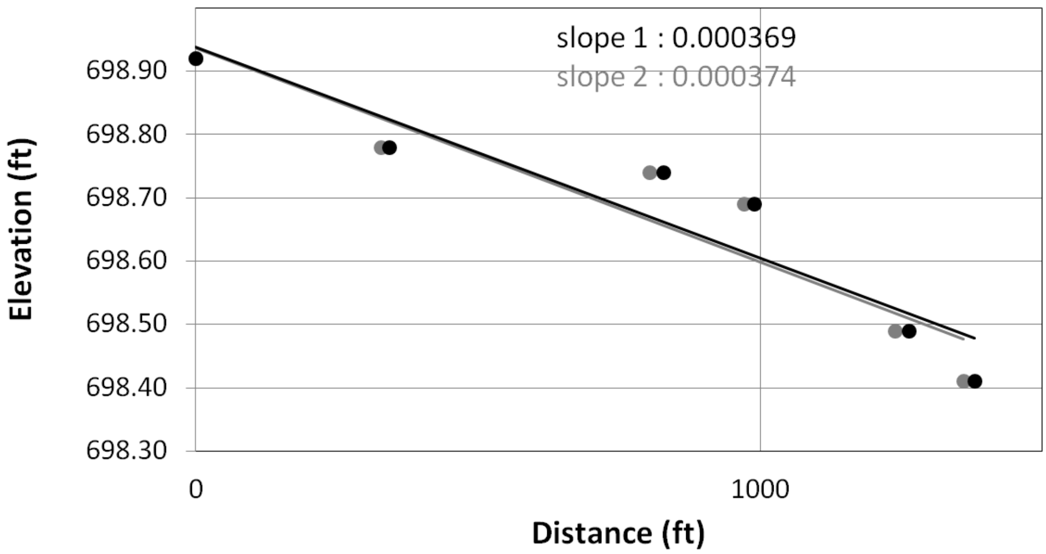

Figure B6. Observed water surface elevations and slope estimation at Clear Creek at Oxford. Black and gray points correspond to surveys of water surface in the left and right bank of the river (facing downstream), respectively. Black and gray lines show the estimated slope.

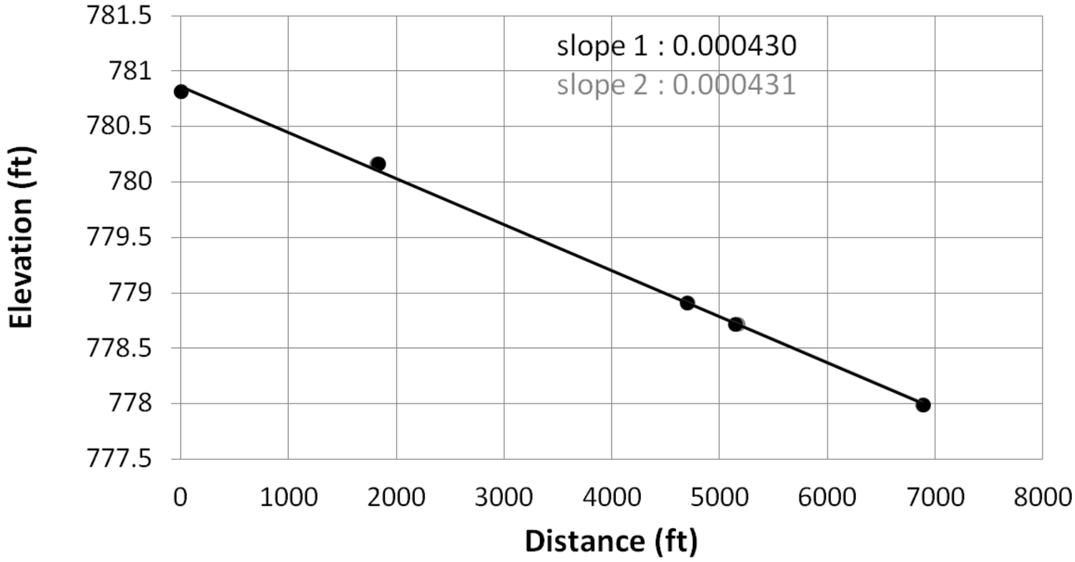

Figure B7. Observed water-surface elevations and slope estimation at South Skunk River at Colfax. Black and gray points correspond to water-surface surveys in the left and right bank of the river (facing downstream), respectively. Black and gray lines show the estimated slope.

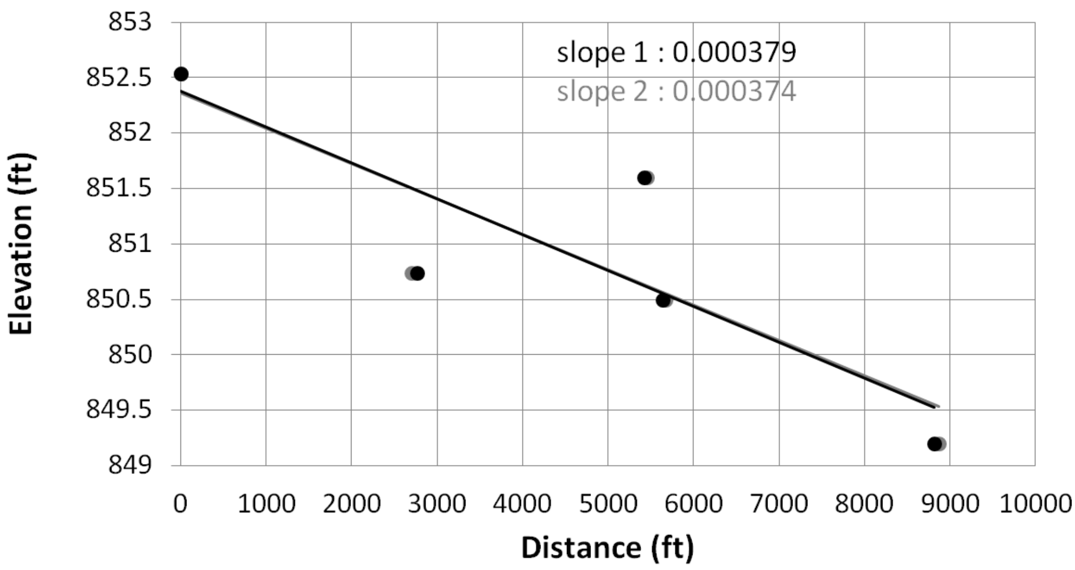

Figure B8. Observed water-surface elevations and slope estimation at Raccoon River at Van Meter. Black and gray points correspond to surveys of water surface in the left and right bank of the river (facing downstream), respectively. Black and gray lines show the estimated slope.

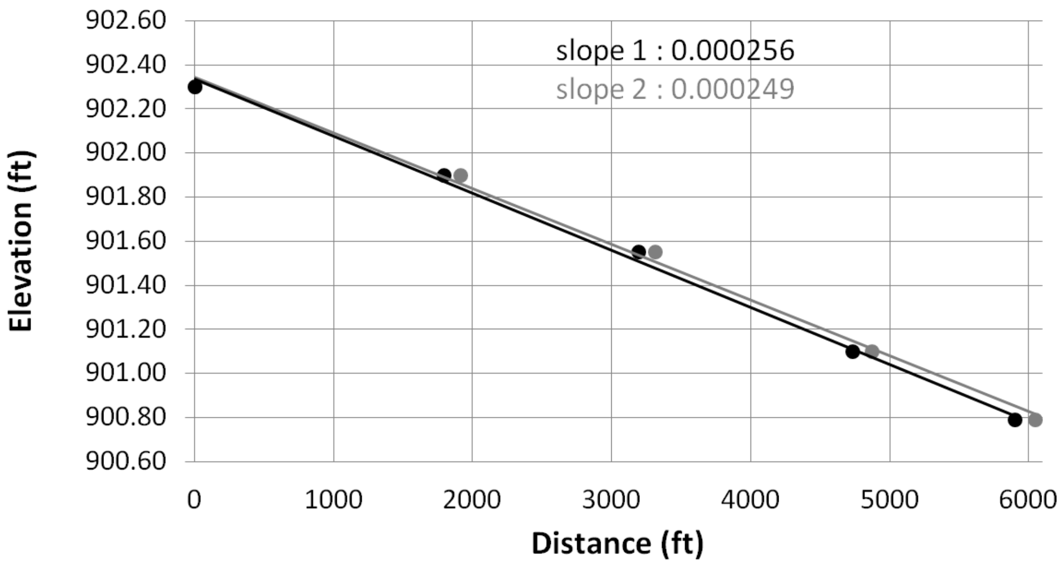

Figure B9. Observed water-surface elevations and slope estimation for the Des Moines River at Stratford. Black and gray points correspond to surveys of water surface in the left and right bank of the river (facing downstream), respectively. Black and gray lines show the estimated slope.

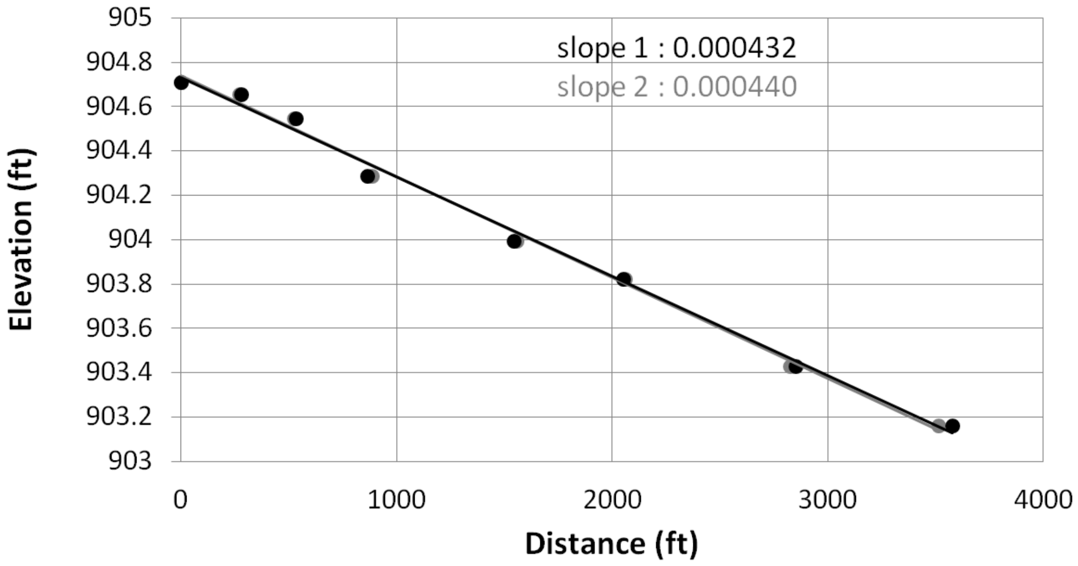

Figure B10. Observed water-surface elevations and slope estimation at Maquoketa River at Manchester. Black and gray points correspond to surveys of water surface in the left and right bank of the river (facing downstream), respectively. Black and gray lines show the estimated slope.

References

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APPENDIX B

SITE SURVEY DATA AND SITE PHOTOS

US Army Corps of Engineers®	Location:	English River at Kalona, Iowa	1
	Description:	Upstream face of bridge taken from XSEC 1 LDB.	April 8, 2015

US Army Corps of Engineers®	Location:	English River at Kalona, Iowa	2
	Description:	Downstream face of bridge taken from XSEC 3 RDB.	April 8, 2015

US Army Corps of Engineers®	Location:	Indian Creek at Marion, Iowa	**3**
	Description:	Upstream face of bridge taken from RDB approximately 40 feet upstream of XSEC 1.	April 8, 2015

US Army Corps of Engineers®	Location:	Indian Creek at Marion, Iowa	**4**
	Description:	Downstream face of bridge taken from top of bank, RDB approximately 40 ft D.S. of XSEC 3.	April 8, 2015

US Army Corps of Engineers®	Location:	Fourmile Creek at Des Moines, Iowa	**5**
	Description:	Upstream face of bridge taken from XSEC 2 RDB at water's edge.	April 7, 2015

US Army Corps of Engineers®	Location:	Fourmile Creek at Des Moines, Iowa	**6**
	Description:	Downstream face of bridge taken from XSEC 4 LDB.	April 7, 2015

US Army Corps of Engineers®	Location:	South Skunk River at Ames, Iowa	**7**
	Description:	Downstream face of bridge taken from approximately 50 feet downstream of XSEC 4.	April 6, 2015

US Army Corps of Engineers®	Location:	South Skunk River at Ames, Iowa	**8**
	Description:	Upstream face of bridge taken from XSEC2.	April 6, 2015

US Army Corps of Engineers®	Location:	Clear Creek at Oxford, Iowa	**9**
	Description:	Upstream face of bridge taken from XSEC 1.	July 27, 2015

US Army Corps of Engineers®	Location:	Clear Creek at Oxford, Iowa	**10**
	Description:	Downstream face of bridge taken from 50 ft downstream of XSEC 2.	July 27, 2015

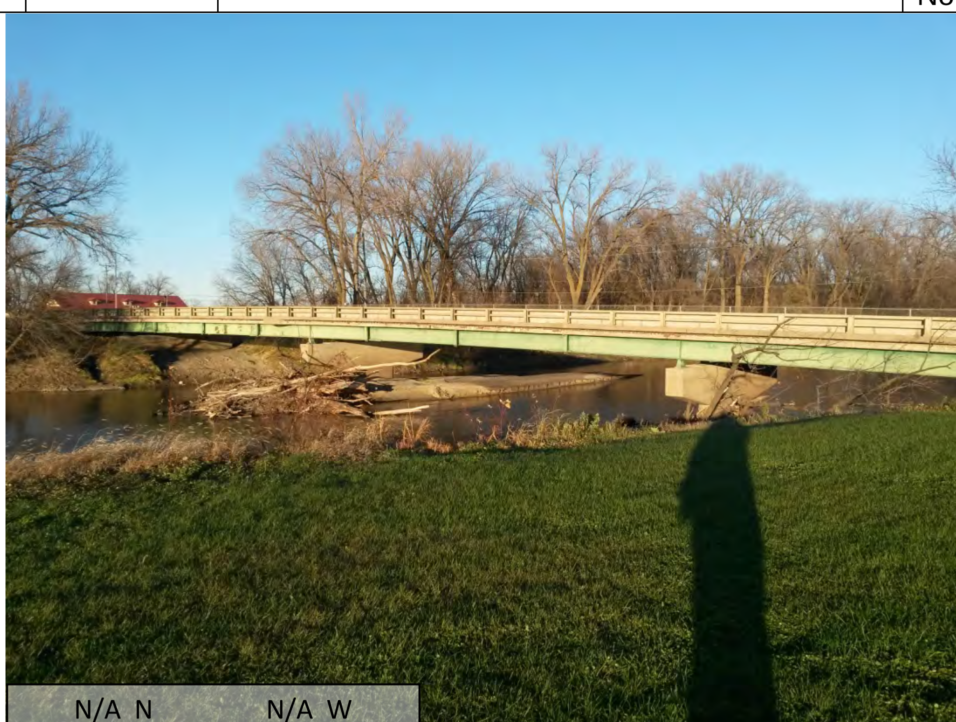
US Army Corps of Engineers®	Location:	Des Moines River near Stratford, Iowa	**11**
	Description:	Upstream face of bridge taken from RDB.	Nov. 17, 2015

US Army Corps of Engineers®	Location:	Des Moines River near Stratford, Iowa	**12**
	Description:	Downstream face of bridge taken from RDB.	Nov. 17, 2015

US Army Corps of Engineers®	Location:	Raccoon River at Van Meter, Iowa	**13**
	Description:	Upstream face of bridge taken from LDB overbank upstream from bridge.	Nov. 18, 2015

US Army Corps of Engineers®	Location:	Raccoon River at Van Meter, Iowa	**14**
	Description:	Upstream face of bridge taken from LDB overbank upstream from bridge.	Nov. 18, 2015

US Army Corps of Engineers®	Location:	South Skunk River at Colfax, Iowa	15
	Description:	Downstream face of bridge taken from LDB overbank.	Nov. 19, 2015

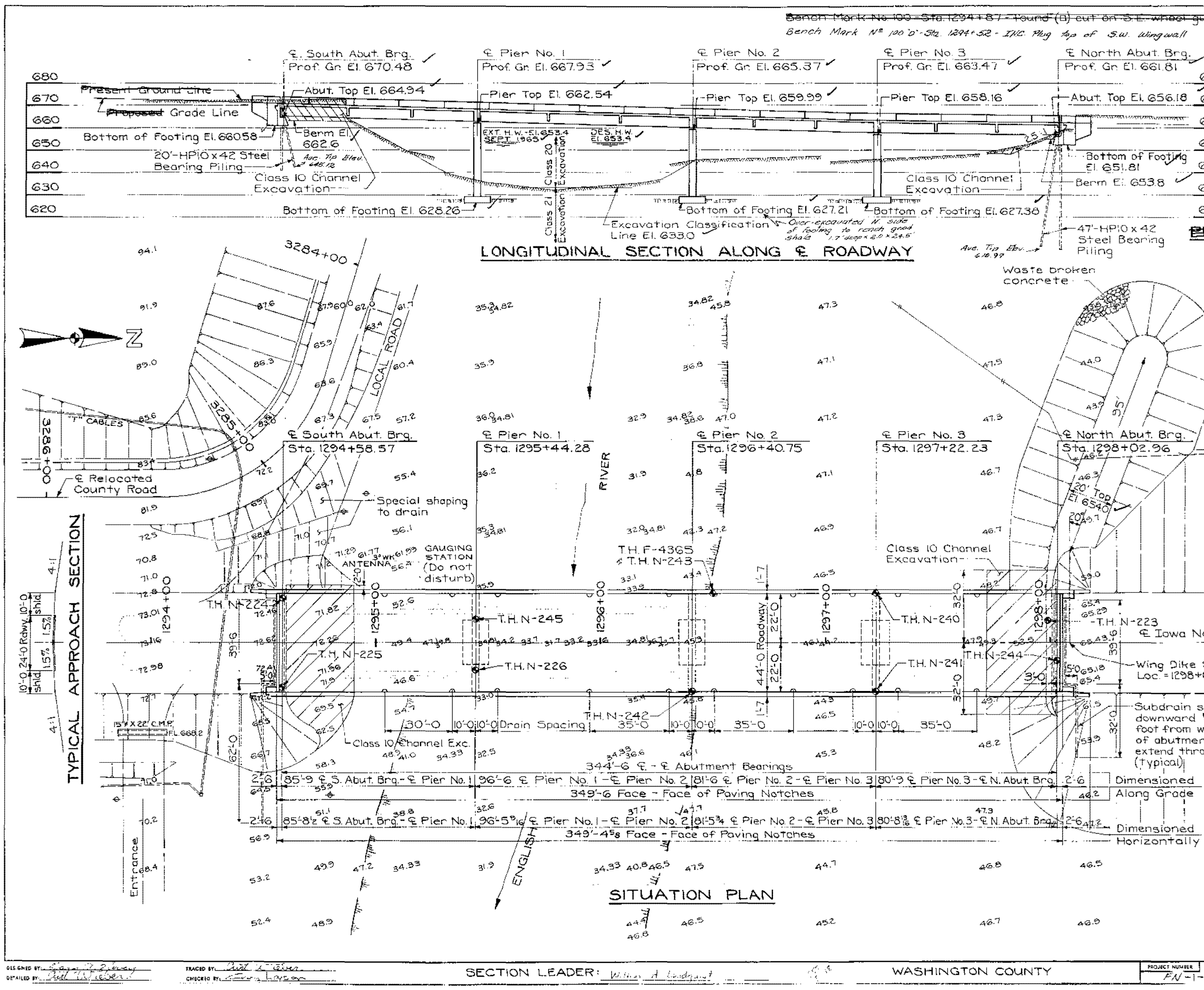


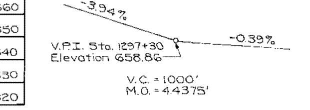
US Army Corps of Engineers®	Location:	South Skunk River at Colfax, Iowa	16
	Description:	Upstream face of bridge taken from RDB overbank.	Nov. 19, 2015

US Army Corps of Engineers®	Location:	Maquoketa River at Manchester, Iowa	**17**
	Description:	Upstream face of bridge taken from RDB at XSEC 608714.0.	Nov. 16, 2015

US Army Corps of Engineers®	Location:	Maquoketa River at Manchester, Iowa	**18**
	Description:	Downstream face of bridge taken from RDB at XSEC 608193.2.	Nov. 16, 2015

APPENDIX C
BRIDGE PLANS





~~PROPOSED~~ GRADE ON IOWA NO. 1

HYDRAULIC DATA

D.A. = 560 square miles
Q_{50} = 21,000 c.f.s.
Q_{100} = 25,000 c.f.s.
Q_{50} Natural Stage = 653.4
Q_{100} Natural Stage = 654.8
Extreme High Water = 653.4
Discharge = 20,000 c.f.s.
Date of Occurrence = September 1965

TRAFFIC COUNT

3110 V.P.D. (1977)
3450 V.P.D. (1980)

I.N.R.C. APPROVAL

No. 77-113
Dated June 6, 1977

LOCATION

Iowa No. 1 over
English River
English River Twp.
T-77N, R-7 & 8W
Section 13 & 18
Washington County

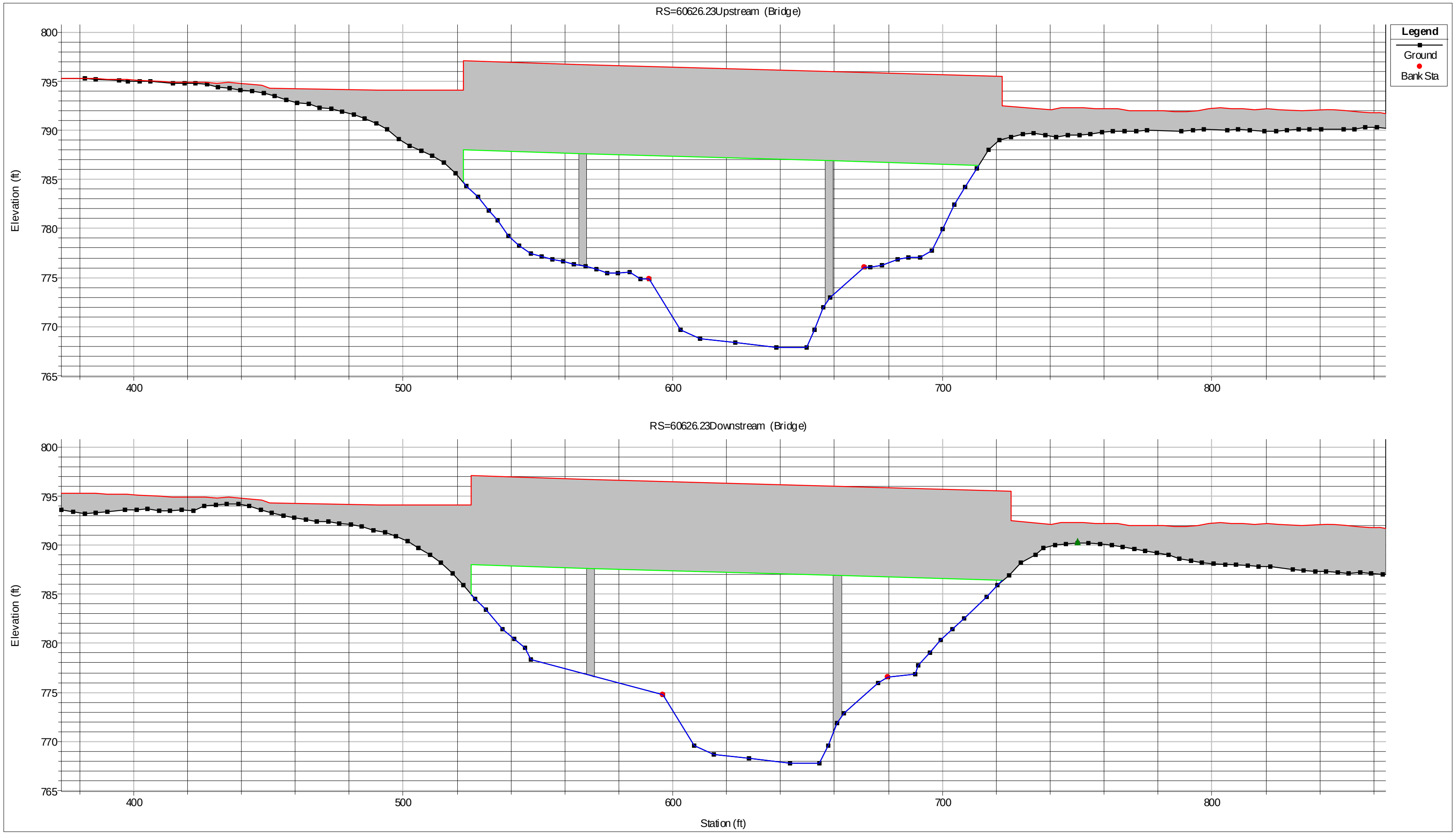
Design for
344'-6 x 44'-0 PRETENSIONED PRESTRESSED CONCRETE BEAM BRIDGE
85'-9 & 80'-9 End Spans 96'-6 & 81'-6 Interior Spans
SITUATION PLAN
Station: 1296+40.75 March 1978
WASHINGTON COUNTY

IOWA DEPARTMENT OF TRANSPORTATION-HIGHWAY DIVISION

Design Sheet No.: 1 **Of** 15 **File No.:** 25921 **Design No.:** 177

DESIGNED BY ______ DETAILED BY ______ TRACED BY ______ CHECKED BY ______ SECTION LEADER: ______ WASHINGTON COUNTY

PROJECT NUMBER	STATE	FED. ROAD DIST. NO.	FISCAL YEAR	SHEET NO.	TOTAL SHEETS
FN-1-4(11)--21-92	IOWA	6		3	17



US Army Corps of Engineers®	Location:	Indian Creek at Marion, Iowa
	Description:	Upstream and downstream XSECs at Marion Blvd. bridge from HEC-RAS model.

August 2011


6618
Bench Mark: Sta. 78157·33' Lt Spike in Power Pole: Elev. 88.82
℄ Brg. West Abut. P/G Elev 74.62
℄ West Pier P/G Elev 75.43
℄ East Pier P/G Elev 76.24
℄ Brg. East Abut. P/G Elev 77.05
Prop. Grade
Existing Ground
Top Berm El. 67.1
2:1 Normal
Bott. Flg. El. 65.14
32' Steel Piles (10 BP42)
Cl 10 Channel Excavation
El. 56.0
D.H.W El. 66.7
Ext. HW El. 68.7
Avg. S.B. 52.7
Exc. Cl. Line Elev 53.7
18' Steel Piles (12 BP53)
Bott. Flg. El. 46.06
Bott. Flg. El. 46.88
Bott. Flg. El. 46.70
18' Steel Piles (10BP42)
℄ SECTION
HYDRAULIC DATA
D.A 316 Sq. Mi.
Area below H.W. 2297 Sq. Ft.
Design Q 14,250 cfs
Ave Velocity 6.2 fps
C 0.62
Stream Slope 6.5 fpm
1.00%
Sta. 69+00 Elev 74.20
GRADE DATA
2-3/4" wire cables
3-galvanized cable clamps and one thimble for each cable. Place thimble on bolt before welding ⅜ ℞.
Existing ¾" cable and post retard. Cut cable and anchor to new abutment as shown. Cost of labor and material is incidental to price bid for other items.
Anchor bolt
N.W. corner E. Abut.
1" plain round rod (A-36)
3x⅜x0'-3 ℞ (A-36)
1⅛" hole
Elev. 64.5
Fine Silty Sand
Medium Gravel
Med. Br. Silty Clay
Black Shale
Green Shale
J-3
Elev. 67.0
Fine Silty Sand
Med. Sand & Gravel
Green Shale
J-4
Elev 74.5
Med. Gravel
Sandy Clay
Fine to Med. Sand
Med. Gravel
Green Shale
J-5
Remove retard ahead of this post
Sta. 69+42.0 ℄ Brg. West Abut.
Sta. 70+22.75 ℄ West Pier
Sta. 71+04.25 ℄ East Pier
Sta. 71+85.0 ℄ Brg. East Abut.
Skunk River
Metal Check dam - UAC.
Top Berm El. 67.1
Cable retard
El. 56.0
Cl. "A" Revetment on berm slope
Class "A" Revetment
Limit of Revetment
Place an amount of broken concrete pavement in this area as directed by the Engineer. Cost included in price bid for Removal Old Pavement.
Exist. Bridge
30°
37.5' Steel Beam Guardrail. By Others.
R=40'
R=25'
℄ Survey
Davit and Curb by others
Future Curbs and approach paving
Sta. 72+27.3±
77°42'
℄ Office Reloc. & ℄ Roadway
Future curbs and approach Paving
55'-0 Roadway
44'-0 Back-Back
75' Steel Beam Guardrail. By Others
J-3
J-4
J-5
N
EXISTING STRUCTURE
To be Removed
Sta. 71+04.1
120'x20' High Truss Br.
DA=316 Sq. Mi.
With 35'x20' I Beam Appr. Span West End.
Concrete high abutment East End, Concrete stub abutment West end, conc. pier and conc. deck.
Appr. spans consists of 8-12" I Beams and 2-12" Channels.
80'-75 80'-9"
81'-5 81'-6"
80'-75 80'-9"
243'-0 ℄-℄ Abutment Bearings
243'-2⅞ Out-Out Paving Notch
PLAN
* Curb to be 12" at Abut. backwall and 6" @ End.
Iowa Natural Resources Council
Approval Order 67-189
Dated 8-29-67
LOCATION
Story County between
Franklin Twp. Sec. 36 &
Washington Twp. Sec. 1
T-83-84 N R-24 W
Over Skunk River
AS BUILT
BY DATE
CHARLES E. WALLER REGISTERED PROFESSIONAL ENGINEER 4064 IOWA
DESIGN FOR 30° SKEW
243' X 55' PRETENSIONED PRESTRESSED CONCRETE BEAM BRIDGE
80'-9" END SPANS 81'-6" CENTER SPAN
CONCRETE FLOOR TUBULAR HANDRAIL
GENERAL PLAN & ELEVATION
CITY OF AMES
PROJ. NO. 02-29518 STA 70+63.5
STORY COUNTY
IOWA STATE HIGHWAY COMMISSION
SEPTEMBER 1967 SHEET 9 OF 51
WALLACE HOLLAND KASTLER & SCHMITZ
CONSULTING ENGINEERS AND PLANNERS
MASON CITY, IOWA ROCHESTER, MINNESOTA

6619

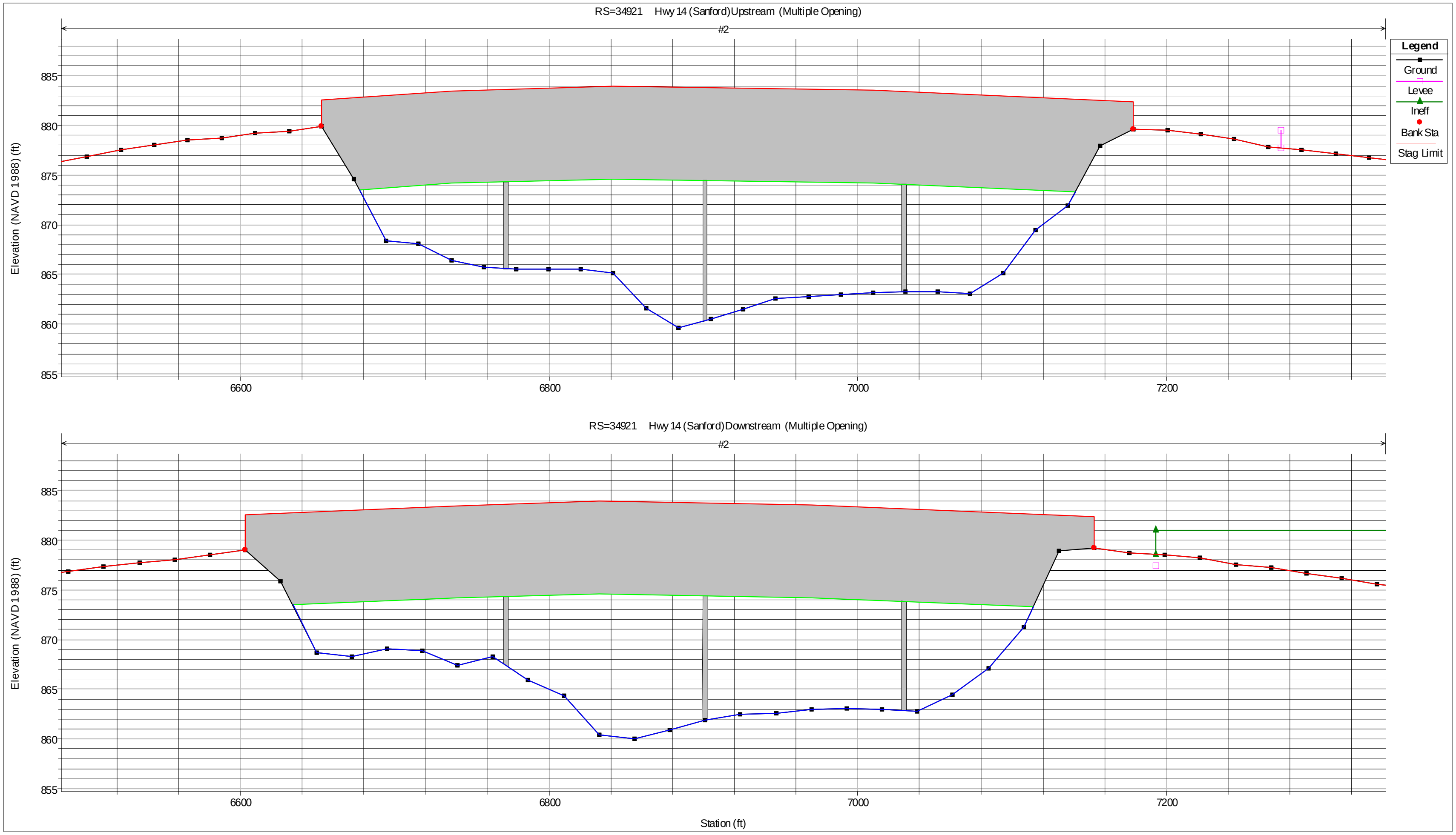
Dimensions shown are at bottom of footing. Batter piling 1:4 in direction shown. Wing footing details are similar; shift bars as required to clear piling.

WALLACE HOLLAND KASTLER & SCHMITZ
CONSULTING ENGINEERS AND PLANNERS
MASON CITY, IOWA — ROCHESTER, MINNESOTA

AS BUILT
BY ___ DATE 4-22-69

CHARLES E. WALLER — REGISTERED — 4064 — PROFESSIONAL ENGINEER — IOWA

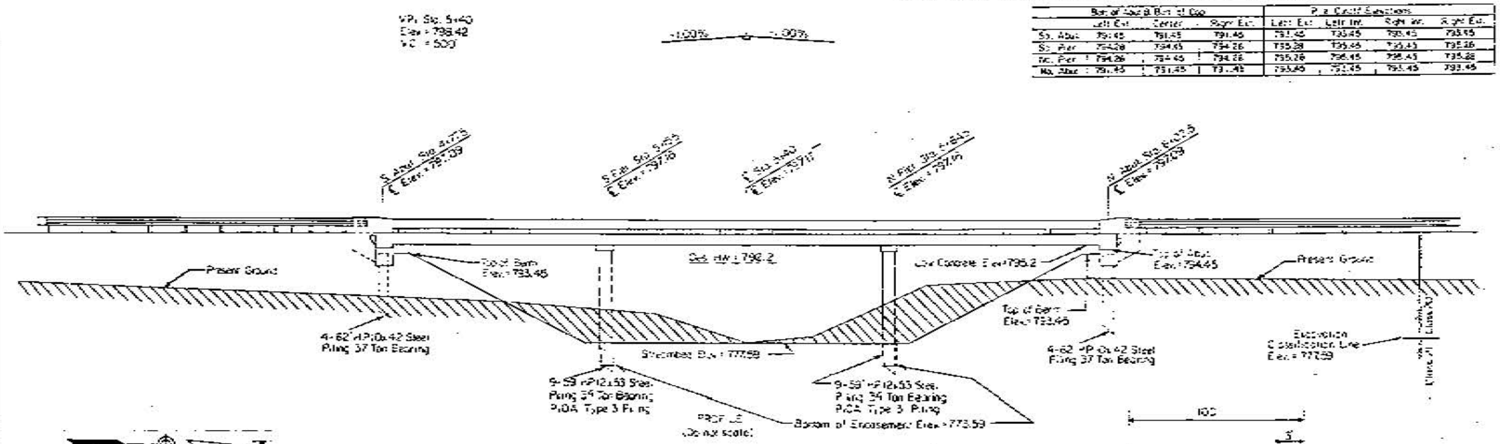
DESIGN FOR 30° SKEW
243' X 55' PRETENSIONED PRESTRESSED CONCRETE BEAM BRIDGE
80'-9" END SPANS — 81'-6" CENTER SPAN
CONCRETE FLOOR — TUBULAR HANDRAIL
WEST ABUTMENT DETAILS
CITY OF AMES
PROJ. NO. 02-29518 — STA. 70+63.5
STORY COUNTY
IOWA STATE HIGHWAY COMMISSION
SEPTEMBER 1967 — SHEET 10 OF 51

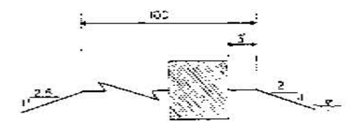


	Location:	Iowa River at Marshalltown, Iowa	
US Army Corps of Engineers®	Description:	Upstream and downstream XSECs at Highway 14 bridge from HEC-RAS model.	July 2014

BENCH MARK: RR spike in P.Pole 154' L of sta 0+00 Elev 600.00

	Bot. of Abut & Bot. of Cap			Pile Cutoff Elevations			
	Left Ext.	Center	Right Ext.	Left Ext.	Left Int.	Right Int.	Right Ext.
So. Abut	791.45	791.45	791.45	793.45	793.45	793.45	793.45
So. Pier	794.28	794.45	794.26	795.28	795.45	795.45	795.26
No. Pier	794.26	794.45	794.26	795.26	796.45	795.45	795.28
No. Abut	791.45	791.45	791.45	793.45	793.45	793.45	793.45

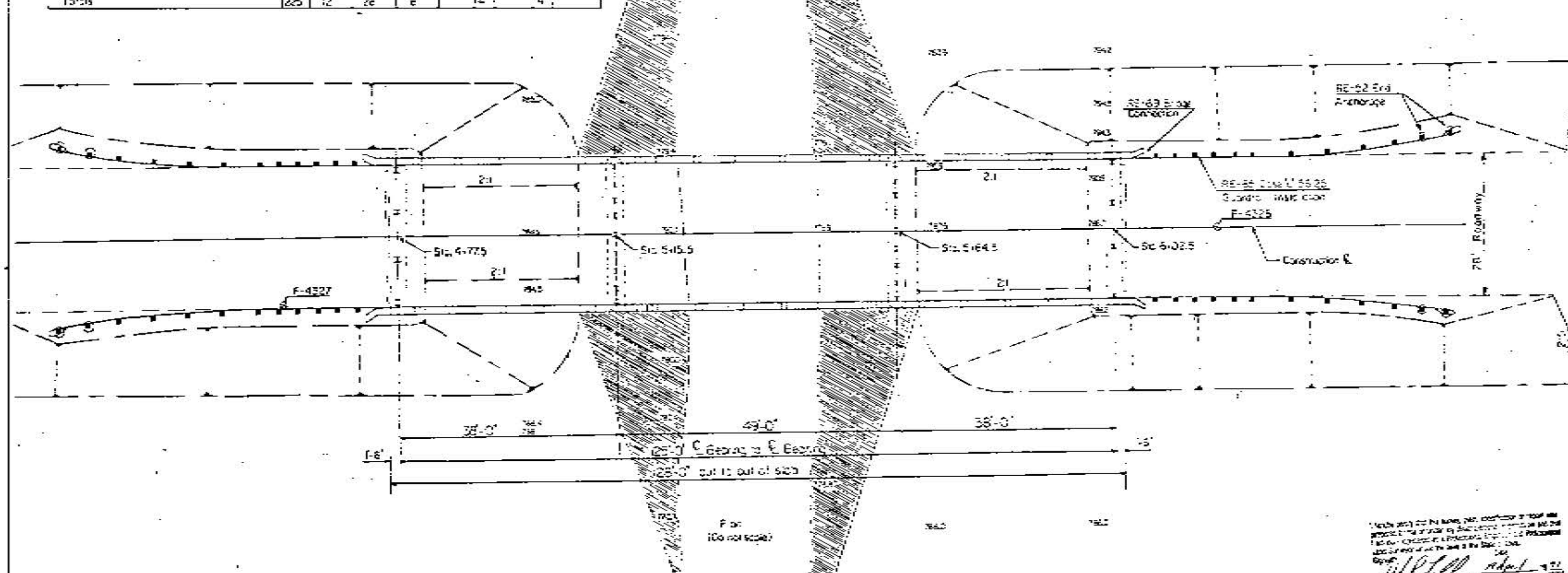




NOTE: Berms must be constructed to normal section shown and Class 20 Excavation removed prior to driving piling.

Tabulation of Steel Beam Guardrail Installation																
Location	Standard	Formed Steel Beam Guardrail					Beam Guardrail Post			Guardrail End Anchorage				
Station	Road Plan	Case	①	Thrie Beam	W Beam	Total	8x10 Single Spacer	8x6 Single Spacer	6x8 No Spacer	End RE-52		RE-27B		Remarks
			LF	LF	LF	LF	No.	No.	No.	Type	No.	Type	No.	
5+40	RE-55	C	56.25	131.25	37.50	225	12	28	8	RE-52	4	RE-27B	4	Bridge
Totals						225	12	28	8		4		4	

Note:
Class 10 Channel Excavation (763 in limits)
Construct channel with 2:1 banks and bottom elev of 777.59 within crosshatched area. See sheet 4



ESTIMATE OF QUANTITIES					
No.	ITEM	UNIT	SUPER	ABUTS	TOTAL
1.	Concrete, Structural "Class-C"	CY	237.0	18.2	255.2
2.	Steel Reinforcing	LBS	58,133	2454	60,587
3.	Rail, Concrete Open	LF	272.0		272.0
4.	Piling, Drive Steel Bearing HP10x42	LF		496	496
5.	Piling, Furnish Steel Bearing HP10x42	LF		496	496
6.	Piling, Drive Steel Bearing HP12x53	LF	1062		1062
7.	Piling, Furnish Steel Bearing HP12x53	LF	1062		1062
8.	Guardrail Formed Steel Beam	LF			150
9.	Guardrail Formed Steel Thrie Beam	LF			125
10.	Guardrail Post Beam	Only			48
11.	Guardrail End Anchorage Beam RE-52	Only			4
12.	Guardrail Bridge Connection RE-69	Only			4
13.	Excavation Class 10 Channel	CY			752
14.	Excavation Class 20	CY		27	27
15.	Piling, Encase Steel Bearing HP12x53	LF	374		374

HYDRAULIC DATA

Drainage Area 39,862 Acres
Design Discharge 6400 cfs
Design Highwater 792.2
Slope Local 5.0 ft/mi.
Slope 10/85 6.5 ft/mi.
Bridge Waterway Area 1162 sq.ft.
Design Velocity 5.6 fps
Q25 = 5355 cfs Stage = 791.6
Q50 = 6400 cfs Stage = 792.2
Q100 = 7600 cfs Stage = 792.7
Q500 = 9720 cfs Stage = 793.4
Extreme Highwater = 793.5 Date June 1990

LOCATION
Section 23, T-80N, R-8W
Oxford Township
Johnson County, Iowa
Over Clear Creek

NOTE:
Contractor may place up to 200 cubic yards of fill material below elevation 780.3 in order to construct a temporary stream crossing and/or accomplish other work necessary to complete construction. Additional fill material may be placed above elevation 780.3 as necessary to complete the work.

125'-0" x 24'-0" Continuous Concrete Slab Bridge
Integral Abutments Monolithic Piers
Station 5+40 Skew 0°
Oxford Township Section 23, T-80N, R-8W
Johnson County
Design Standard J24-87 HS-20-44 Loading
FHWA No. 206.90 County No. E-23-5

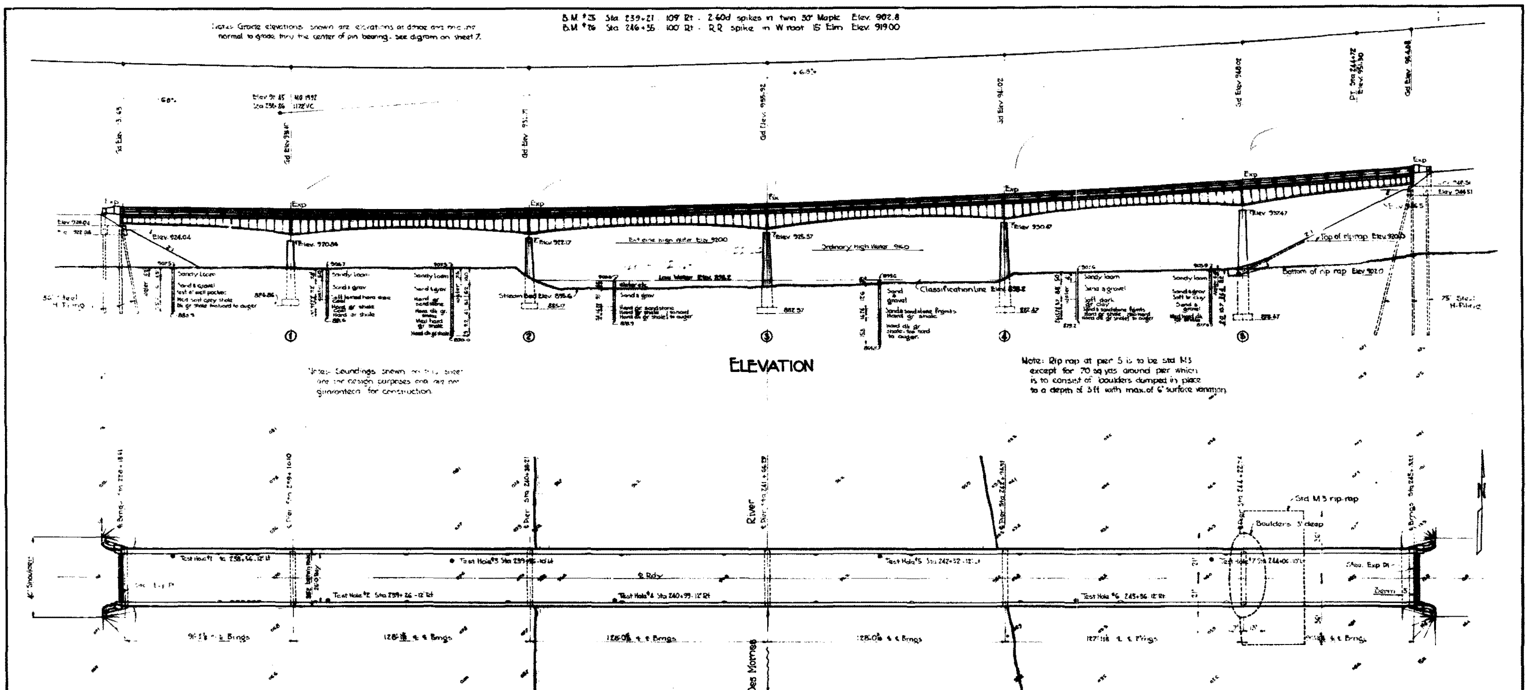
FILE NO. 54439 DESIGN NO. 591 JOHNSON COUNTY

L-E-23-5--73-52

STATE	FED. ROAD DIST. NO.	FISCAL YEAR	SHEET NO.	TOTAL SHEETS
IOWA	[illegible]	99	2	5

Notes: Grade elevations shown are elevations at grade and are the normal to grade thru the center of pin bearing - see diagram on sheet 7.

B.M. #25 Sta. 239+21 109' Rt. - 2 60d spikes in twin 30" Maple Elev. 902.8
B.M. #26 Sta. 246+35 100' Rt. - R.R. spike in W root 15" Elm Elev. 919.00



Notes: Soundings shown on this sheet are for design purposes and are not guaranteed for construction.

Note: Rip rap at pier 5 is to be std. M3 except for 70 sq yds around pier which is to consist of boulders dumped in place to a depth of 3 ft with max. of 6" surface variation.

PLAN

Scale 1" = 25'

D.A. 5265 Sq. Mi. Flat to very Hilly

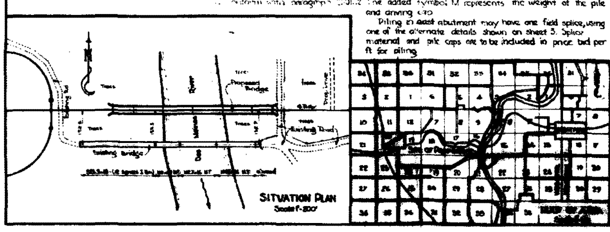
Pile Driving Notes:

Piling shall be driven to a minimum bearing value of 32 Tons and penetration into shale.

A drop hammer of not less than 2500 lbs weight or a steam hammer delivering not less than 7200 ft lbs of energy per blow may be used in driving.

Bearing values, if drop hammer is used shall be determined by the formula, [illegible] in place of the formula in paragraph 2501.2 of the specifications. All symbols and driving conditions [illegible] conform with paragraph 2501.2 The added symbol M represents the weight of the pile and driving cap.

Piling in east abutment may have one field splice, using one of the alternate details shown on sheet 3. Splice material and pile caps are to be included in price bid per ft for piling.



General Notes:

This bridge is designed for H-20-loading and 15# of rdy for future wearing surface. Provision is made for 100% overload with 50% increased stresses.

Berms at ends of bridge are to be built and thoroughly compacted by road contractor before piling are driven.

Std. M3 and boulder riprap as shown at Pier 5 is to be placed by bridge contractor to slope and elevations shown.

Construction is to be in accordance with the Iowa Highway Comm. std specifications 1937 and the following:
1. Special Provision for Painting March 17, 1947.
2. Special Provisions for Construction Projects Div II Oct 16 1945.

Revision: 4-2-46 Structural steel quantities changed
Revision: 3-1-45. End spans lengthened, quantities changed and pile driving note added.
Revision: 4-30-47 Rip rap changed. Revision 12-6-45 Project designation and special provs and quantities changed

TOTAL ESTIMATED QUANTITIES

	Super str	Abutmts	Piers 1-5	Piers 2-3-4	Total
Structural Steel	949478				949478 lb
Reinforcing Steel	1[illegible]686	6106	12799	14785	144376 lb
Concrete	549.5	103.7	209.3	509.1	1571.6 cyd
10" H Piling		[illegible]			1884 L.F.
Rip-rap - M3					280 sq.y
Excavation Cl 3		80	792	80	382 cy
Excavation Cl II			336	618	984 cy
Boulder rip rap					70 sq yd

7 sheets

Location
Section 16
Dayton & Hardin Twps.
Webster Co.
Over Des Moines R.

Design For
695.26' CONTINUOUS STEEL GIRDER BRIDGE
4-128' MAIN SPANS AND 2-91' END SPANS

GENERAL DRAWINGS

Station 241+86 / Federal Aid Proj. 811 (9)

WEBSTER COUNTY

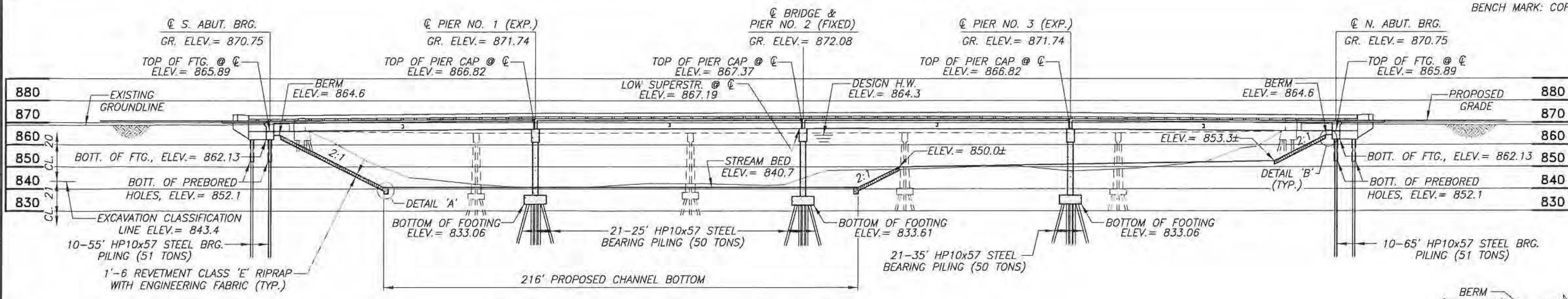
Iowa Highway Commission

Feb. 1944 Sheet 1 of 7 Scales as shown

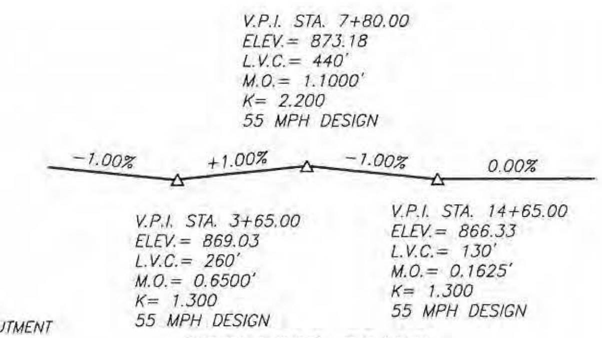
Design 114 Webster File 11[illegible]

Webster IA175 #15

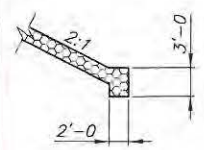
BENCH MARK: COPPER PLUG IN NORTHWEST WING POST OF EXISTING BRIDGE; STA. 10+00, ELEV.= 872.27



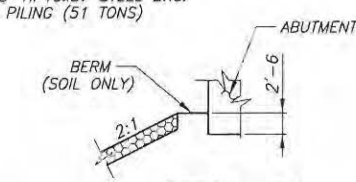
LONGITUDINAL SECTION ALONG ℄ ROADWAY



PROPOSED GRADE

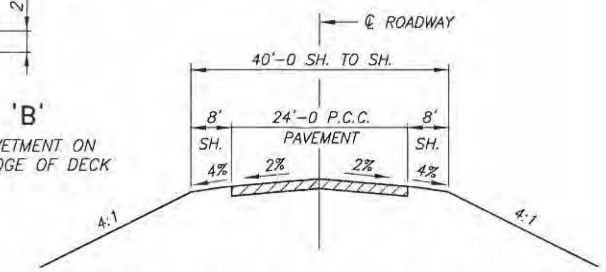


DETAIL 'A'

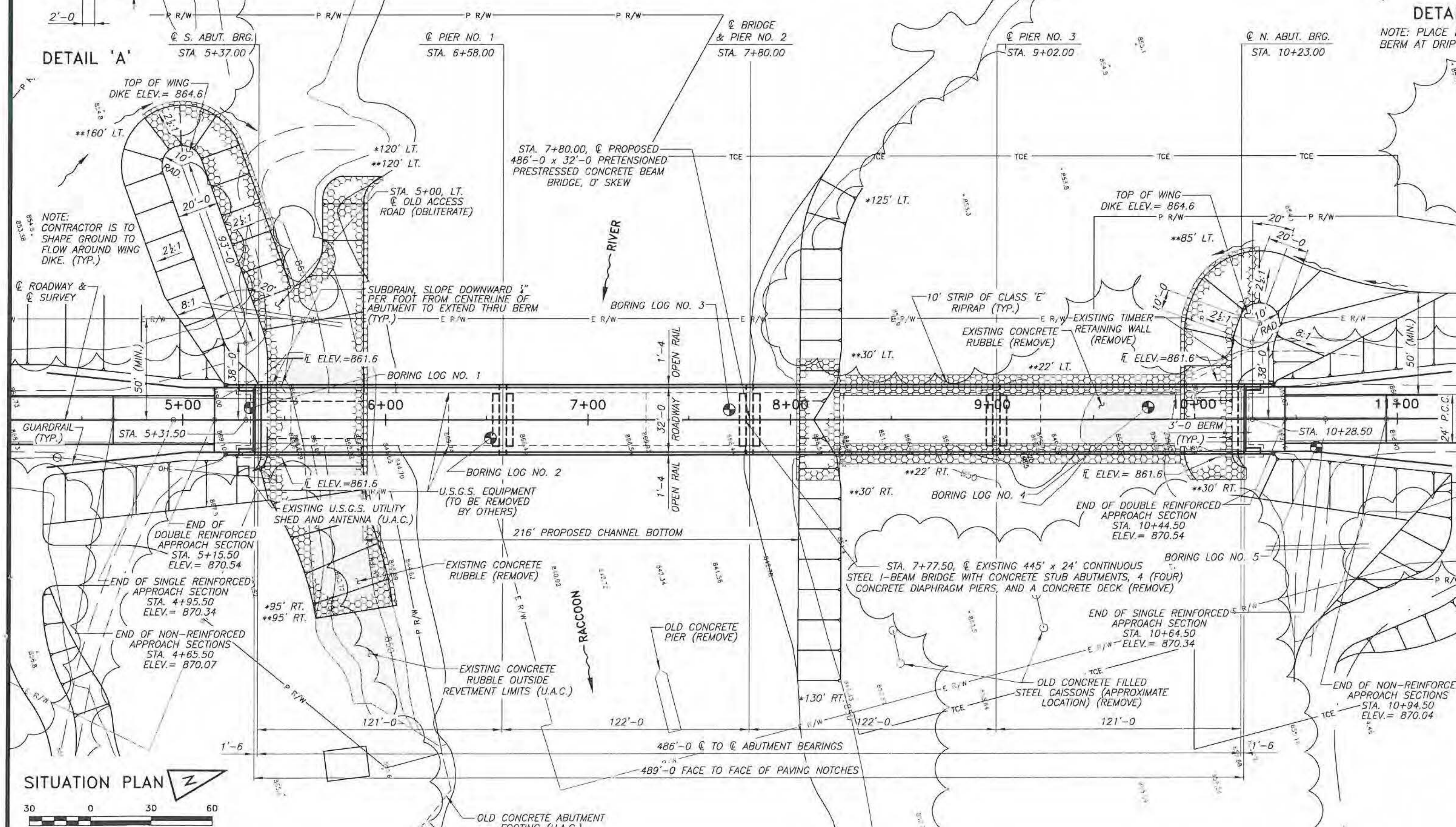


DETAIL 'B'

NOTE: PLACE REVETMENT ON BERM AT DRIP EDGE OF DECK



TYPICAL APPROACH SECTION



SITUATION PLAN

* DENOTES LIMITS OF CLASS 10 (CHANNEL) EXCAVATION.
** DENOTES LIMITS OF CLASS 'E' REVETMENT AND ENGINEERING FABRIC.

LOCATION

CITY OF VAN METER
DALLAS COUNTY
T-78N, R-27W
SECTION 22
VAN METER TOWNSHIP
OVER RACCOON RIVER

HYDRAULIC DATA

DRAINAGE AREA = 3,441 SQ. MI.
DESIGN DISCHARGE = 46,900 C.F.S.
DESIGN HIGH WATER ELEV. = 864.3
MANNING SLOPE = 0.000360 FT./FT.
BRIDGE WATERWAY AREA = 8,094 SQ. FT.
DESIGN VELOCITY = 5.8 F.P.S.
Q25 = 39,900 C.F.S. STAGE ELEV. = 863.0
Q50 = 46,900 C.F.S. STAGE ELEV. = 864.3 (DESIGN)
Q100 = 53,900 C.F.S. STAGE ELEV. = 865.3
Q500 = 70,900 C.F.S. STAGE ELEV. = 867.5
EXT. H.W. ELEV. = 867.5 (JULY 10, 1993)
ANTICIPATED SCOUR ELEV.= 823.1

SEE "GENERAL PLAN" FOR ADDITIONAL INFORMATION.

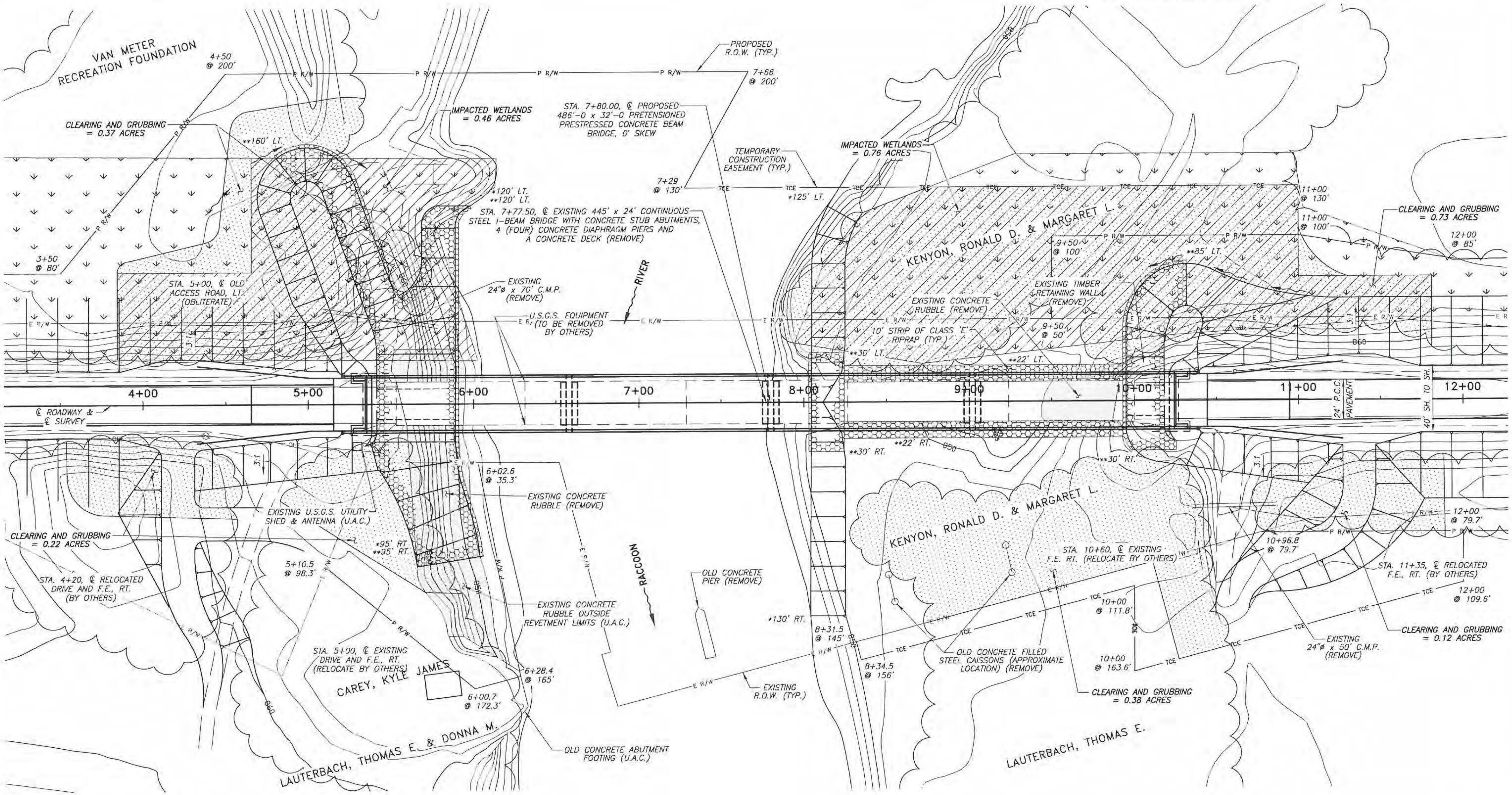
486'-0 x 32'-0 PRETENSIONED PRESTRESSED CONCRETE BEAM BRIDGE

INTEGRAL ABUTMENTS — TEE PIERS
121'-0 END SPANS — 122'-0 INTERIOR SPAN

SITUATION PLAN

STATION 7+80.00 — 0° SKEW
DALLAS COUNTY, IOWA

BENCH MARK: COPPER PLUG IN NORTHWEST WING POST OF EXISTING BRIDGE; STA. 10+00, ELEV.= 872.27



LEGEND

E R/W	EXISTING R.O.W.		EXISTING WETLANDS
P R/W	PROPOSED R.O.W.		IMPACTED WETLANDS
TCE	TEMPORARY CONSTRUCTION EASEMENT		CLEARING AND GRUBBING
OHE	OVERHEAD ELECTRIC LINES		EXISTING REVETMENT
	TREE LINE		PROPOSED REVETMENT

SEE "SITUATION PLAN" FOR ADDITIONAL INFORMATION

GENERAL PLAN

30 0 30 60

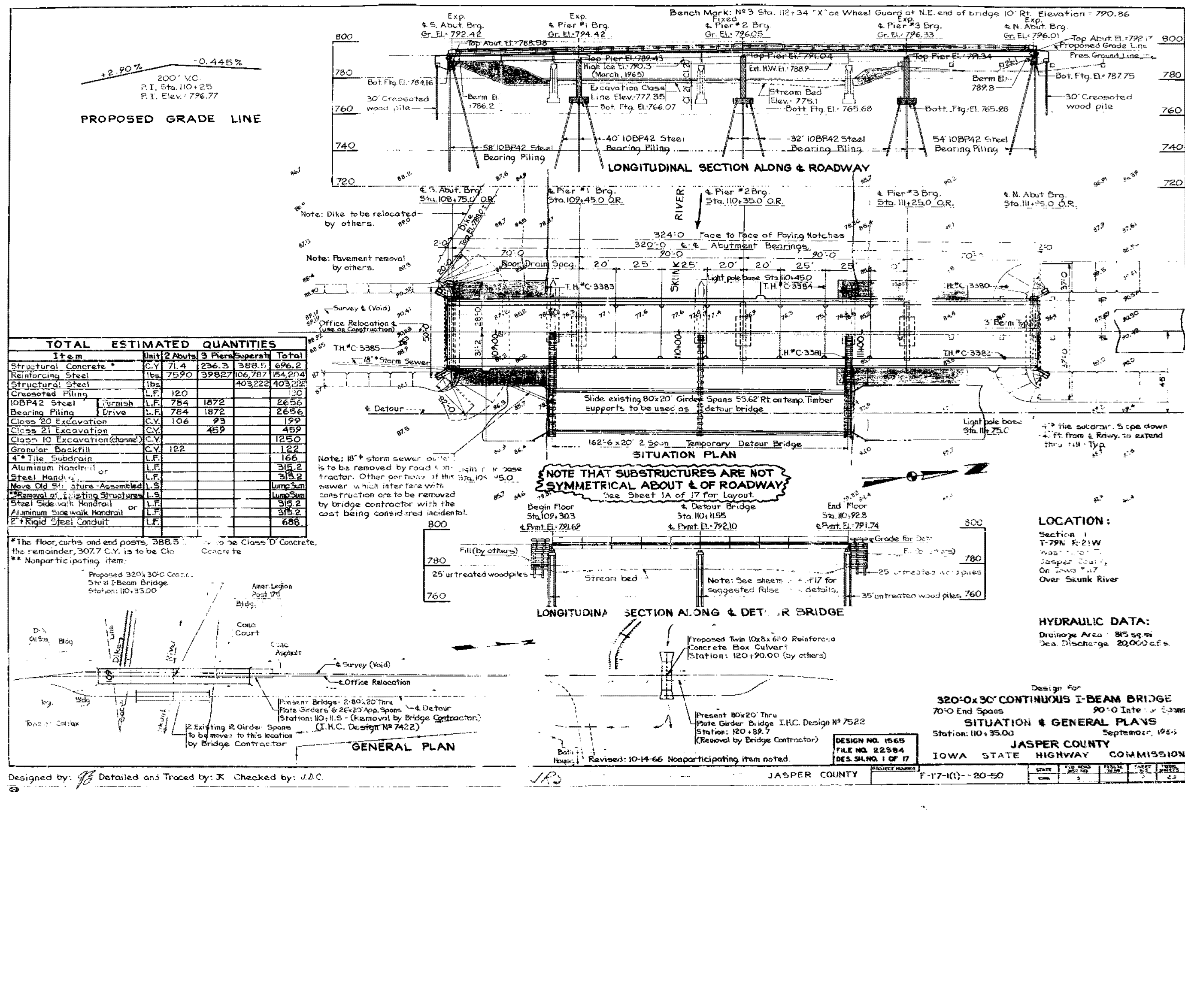
* DENOTES LIMITS OF CLASS 10 (CHANNEL) EXCAVATION.
** DENOTES LIMITS OF CLASS 'E' REVETMENT AND ENGINEERING FABRIC.

486'-0 x 32'-0 PRETENSIONED PRESTRESSED CONCRETE BEAM BRIDGE

INTEGRAL ABUTMENTS — TEE PIERS
121'-0 END SPANS — 122'-0 INTERIOR SPAN

GENERAL PLAN

STATION 7+80.00 — 0' SKEW
DALLAS COUNTY, IOWA



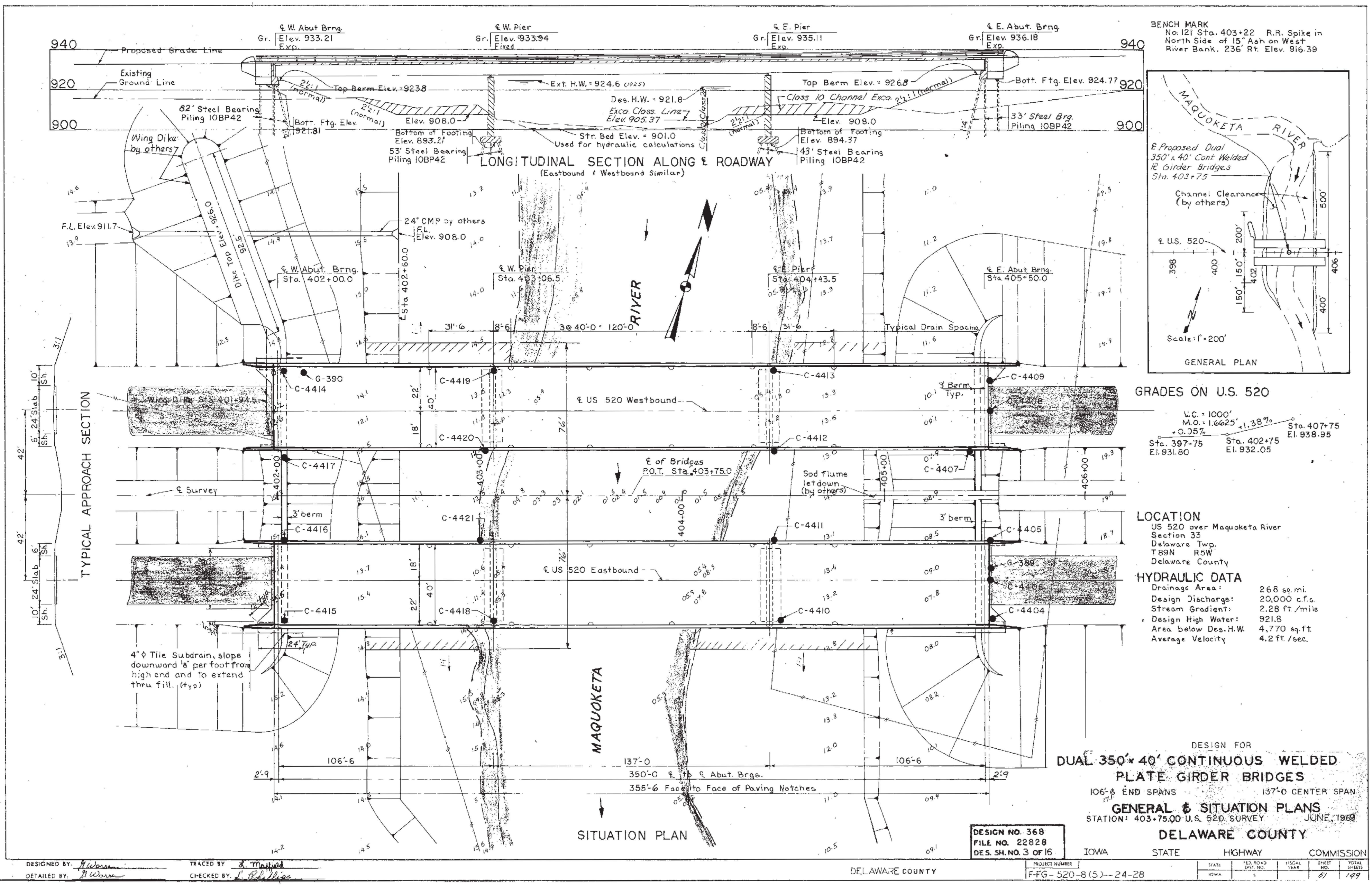
TOTAL ESTIMATED QUANTITIES

Item		Unit	2 Abuts.	3 Piers	Superstr.	Total
Structural Concrete *		C.Y.	71.4	236.3	388.5	696.2
Reinforcing Steel		lbs.	7590	39827	106,787	154,204
Structural Steel		lbs.			403,222	403,222
Creosoted Piling		L.F.	120			120
10BP42 Steel Bearing Piling	Furnish	L.F.	784	1872		2656
	Drive	L.F.	784	1872		2656
Class 20 Excavation		C.Y.	106	93		199
Class 21 Excavation		C.Y.		459		459
Class 10 Excavation (channel)		C.Y.				1250
Granular Backfill		C.Y.	122			122
4" Tile Subdrain		L.F.				166
Aluminum Handrail or		L.F.				315.2
Steel Handrail		L.F.				315.2
Move Old Structure - Assembled		L.S.				Lump Sum
** Removal of Existing Structures		L.S.				Lump Sum
Steel Sidewalk Handrail or		L.F.				315.2
Aluminum Sidewalk Handrail		L.F.				315.2
2" Rigid Steel Conduit		L.F.				688

* The floor, curbs and end posts, 388.5 [illegible] to be Class 'D' Concrete, the remainder, 307.7 C.Y. is to be Cl[illegible] Concrete

** Nonparticipating item.

Designed by: [illegible] Detailed and Traced by: [illegible] Checked by: J.A.C.



LONGITUDINAL SECTION ALONG ℄ ROADWAY
(Eastbound & Westbound Similar)
℄ W. Abut Brng. Gr. Elev. 933.21 Exp.
℄ W. Pier Gr. Elev. 933.94 Fixed
℄ E. Pier Gr. Elev. 935.11 Exp.
℄ E. Abut. Brng. Gr. Elev. 936.18 Exp.
Proposed Grade Line
Existing Ground Line
Top Berm Elev. = 923.8
Ext. H.W. = 924.6 (1925)
Des. H.W. = 921.8
Top Berm Elev. = 926.8
Bott. Ftg. Elev. 924.77
82' Steel Bearing Piling 10BP42
Bott. Ftg. Elev. 921.81
Elev. 908.0
Bottom of Footing Elev. 893.21
53' Steel Bearing Piling 10BP42
Exca. Class. Line Elev. 905.37
Str. Bed Elev. = 901.0 Used for hydraulic calculations
Class 10 Channel Exca.
Bottom of Footing Elev. 894.37
43' Steel Bearing Piling 10BP42
33' Steel Brg. Piling 10BP42
BENCH MARK
No. 121 Sta. 403+22 R.R. Spike in North Side of 15" Ash on West River Bank. 236' Rt. Elev. 916.39
MAQUOKETA RIVER
℄ Proposed Dual 350' x 40' Cont. Welded Girder Bridges Sta. 403+75
Channel Clearance (by others)
℄ U.S. 520
Scale: 1" = 200'
GENERAL PLAN
Wing Dike by others
Dike Top Elev. 926.0
F.L. Elev. 911.7
24" CMP by others F.L. Elev. 908.0
℄ W. Abut. Brng. Sta. 402+00.0
℄ W. Pier Sta. 403+06.5
℄ E. Pier Sta. 404+43.5
℄ E. Abut. Brng. Sta. 405+50.0
Typical Drain Spacing
31'-6 8'-6 3@40'-0 = 120'-0 8'-6 31'-6
RIVER
Wing Dike Sta. 401+94.5
℄ US 520 Westbound
℄ of Bridges P.O.T. Sta. 403+75.0
Sod flume letdown (by others)
℄ Survey
℄ US 520 Eastbound
3' berm
3' Berm Typ.
C-4409 C-4408 C-4407 C-4405 C-4406 C-4404 C-4410 C-4411 C-4412 C-4413 C-4414 C-4415 C-4416 C-4417 C-4418 C-4419 C-4420 C-4421 G-390 G-389
TYPICAL APPROACH SECTION
10' Sh. 24' Slab 6' Sh. 42' 42'
4" ϕ Tile Subdrain, slope downward 1/8" per foot from high end and to extend thru fill. (typ)
MAQUOKETA
106'-6 137'-0 106'-6
350'-0 ℄ to ℄ Abut. Brgs.
355'-6 Face to Face of Paving Notches
SITUATION PLAN
GRADES ON U.S. 520
V.C. = 1000' M.O. = 1.6625' +0.05% +1.38%
Sta. 397+75 El. 931.80
Sta. 402+75 El. 932.05
Sta. 407+75 El. 938.95
LOCATION
US 520 over Maquoketa River
Section 33
Delaware Twp.
T89N R5W
Delaware County
HYDRAULIC DATA
Drainage Area: 268 sq. mi.
Design Discharge: 20,000 c.f.s.
Stream Gradient: 2.28 ft./mile
Design High Water: 921.8
Area below Des. H.W.: 4,770 sq. ft.
Average Velocity: 4.2 ft./sec.
DESIGN FOR
DUAL 350' x 40' CONTINUOUS WELDED PLATE GIRDER BRIDGES
106'-6 END SPANS 137'-0 CENTER SPAN
GENERAL & SITUATION PLANS
STATION: 403+75.00 U.S. 520 SURVEY JUNE, 1969
DELAWARE COUNTY
DESIGN NO. 368
FILE NO. 22828
DES. SH. NO. 3 OF 16
IOWA STATE HIGHWAY COMMISSION
DESIGNED BY
DETAILED BY
TRACED BY
CHECKED BY
DELAWARE COUNTY
PROJECT NUMBER F-FG-520-8(5)--24-28
STATE IOWA SHEET NO. 51 TOTAL SHEETS 149

APPENDIX D
STUDY PROPOSALS

DEPARTMENT OF THE ARMY
ROCK ISLAND DISTRICT, CORPS OF ENGINEERS
CLOCK TOWER BUILDING - P.O. BOX 2004
ROCK ISLAND, ILLINOIS 61204-2004
http://www.mvr.usace.army.mil

Planning, Programs, and
Project Management Division

1 November 2014

USACE Institute for Water Resources
7701 Telegraph Rd (Casey Bldg)
Alexandria, VA 22315

Ms. Lisa Bourget:

In accordance with the provisions of Interagency Nonstructural Flood Risk Management Project Proposal, the Rock Island District of the U.S. Army Corps of Engineers has enclosed the nonstructural flood risk management proposal **Non-structural FRM Iowa Bridge Sensor Rating Curve FRM Demonstration Project.** The nonstructural flood risk management proposal is supported by the study partners (please see the attached messages of support).

The nonstructural flood risk management proposal outcomes of protection of life safety, reduction of property loss, increased resiliency are achieved by promoting shared responsibility, addressing priorities in State or local hazard mitigation plans, and leveraging resources. This is accomplished by leveraging the large amount of recently completed work with a small increment cost to develop and demonstrate bridge sensor rating curves as a flood preparedness tool.

If you have any questions concerning regarding this proposal, please call Mr. Jerry Skalak of our Planning, Programs, and Project Management Division, telephone 309/794-5605 or Mr. Toby Hunemuller of our Engineering Division, telephone 309/794-5222.

Sincerely,

Jerry Skalak,
USACE Iowa Silver Jackets Coordinator
Planning, Programs, and
Project Management Division

Interagency Flood Risk Management Project Proposal Template

1. Project Name:	Non-structural FRM Iowa Bridge Sensor Rating Curve FRM Demonstration Project
2. Interagency Team Name: If not a formally recognized team, list participating organizations.	USACE, Iowa Flood Center, NWS, USGS, IDNR, HSEMD
3. USACE POC: Include name and title.	Toby Hunemuller, Chief Hydrologic Eng. Section; Shirley Johnson, Hydrologist, MVR-EC-HH toby.hunemuller@usace.army.mil; shirley.j.johnson@usace.army.mil
4. Project Description: Describe what the issues are and how the proposed project would address those issues in no more than 200 words.	Iowa's severe flooding in 2008 demonstrated the need for more extensive monitoring of the state's rivers and streams in real time. To address this, the Iowa Flood Center (IFC) developed and maintains a statewide network of stream stage sensors deployed at bridges and designed to measure water surface height. Stage data are transmitted automatically and frequently to the IFC for viewing in real time via the Iowa Flood Information System (IFIS). The IFC maintains a network of 250 stream stage sensors across the state. Support for sensor deployment has come from the Iowa Department of Natural Resources and the Iowa Department of Transportation. This project will leverage the existing IFC bridge sensor network data to demonstrate the need for rating curve development at sensor locations. Study partners (USACE, IFC, NWS, USGS, IDNR, HSEMD) will prioritize state-wide rating curve needs and develop a standard procedure for rating curve data collection by leveraging available data (state LIDAR data, bridge plans). Co-located bridge sensor and USGS gage rating curves will be compared to assess the accuracy of the bridge sensor rating curves. The demonstration study products will be available for flood preparedness planning.

5. Leveraged Funding:

Every proposal must include a table quantifying leveraged resources invested by others for the project, including other federal agencies, state agencies, regional or local agencies. Please note USACE project funding may not be used for construction; any construction must be funded by partners.

Participating agency	Point of contact	Activities/ tasks	Contribution amount	In-kind or cash?	Is this pre-existing work or new work for the project?	Anticipated duration/ date of completion
Iowa Flood Center, NWS,USGS, IDNR,HSEMD	Witold Krajewski, IFC	Methodology and review of rating curve development accuracy	$45,000	In-Kind	Demonstration project of rating curve development for existing bridge sensors	one year from receipt of funding
USACE		Sensor Prioritization , Demonstration Review, and Recommendations	$45,000			one year from receipt of funding

6. Anticipated Outcomes of Proposed Project:

Each project should include anticipated outcomes in at least one of the following three categories. Please respond describing how the project would achieve an outcome, or specify N/A when appropriate (response should be 150 words or less).

Interagency Flood Risk Management Project Proposal Template

Manages Flood Risk: (Protection of life safety, reduction of property loss, increased resiliency.)	The desired outcome for this pilot is the development water level detection tools that the community can use to identify and proactively respond to flood issues. This pilot will provide the components to identify lead times, evacuation plans, equipment, and personnel to respond to a flood event reducing future flood damages and improving life safety. This project will improve the ability to forecast floods by allowing the development of additional forecasting points, and by improving the accuracy of forecast models. By providing better information and reducing the uncertainty about flow levels, the outcome from this project may result in a decrease for the need of structural flood control solutions.
Results in Actions by Others:	This project promotes shared responsibility, addresses priorities in State or local hazard mitigation plans, and leverages resources. These planning tools would increase cooperation and communication in the identification and implementation of regional flood mitigation strategies and increase the capacity of local government and residents to proactively respond to the occurrence of floods.
Results in Reduced Future Expenditures:	The methodology developed in this pilot will be documented and can be used as the framework for other pilots/projects in similar communities across the nation.

7. Funding Information:

Please specify all information required to create the MIPR for FY15 and, as applicable, FY 16 (funds will be disbursed by FY). Please note: maximum request of $100K in FPMS funding.

	Request Amount	Technical POC	Financial POC	Organization Code	Breakdown of Costs (Labor, Contract services, Travel, etc)	Expected Delivery of Funds (Date)
FY 15	$45,000	Shirley Johnson, T. Hunemuller	Laurie Kotecki 309-794-5457	B5L1200	Labor only	January 2015
FY16						

8. Attachments Reminder: A letter of support is required from either a state lead of the Silver Jackets team or study partner indicating that the project is a state priority and describing, 1) how the proposal helps achieve state or community goals, 2) the role the state or partner anticipates taking in the conduct of the project, and 3) the state or partner's ongoing commitment to long-term outcomes. Maps or other graphics may be included as well. Please select yes or no as to whether you have included a support letter.

Yes ☑ **No** ☐

9. Additional Comments:

The University of Iowa

College of Engineering
IIHR—Hydroscience & Engineering
100 C. Maxwell Stanley Hydraulics Laboratory
Iowa City, Iowa 52242-1585 USA
319-335-5237 *Fax* 319-335-5238

October 27, 2014

Shirley Johnson
Hydrologic and Hydraulic Branch (CEMVR-EC-HH)
U.S. Army Corps of Engineers, Rock Island District
Clock Tower Bldg. – P.O. Box 2004
Rock Island, IL 61204-2004

Dear Shirley:

I am writing to express my enthusiastic support for the project you are developing, "Nonstructural Iowa Bridge Sensor Rating Curve FRM Demonstration Project." The project represents a new level of synergy between all the federal, state, and local partners concerned about flood mitigation in the state of Iowa. As evidenced by numerous severe floods in the past two decades—since 1990, Iowa has had more than 20 flood-related Presidential Disaster Declarations—flood monitoring and forecasting remain a high priority for the citizens of the state.

Responding to this need, the Iowa Flood Center, established in 2009, has deployed nearly 250 autonomous stream-stage sensors for monitoring the water levels in streams and rivers. The data are relayed in real-time by cell phone modems and shared with the public via the Iowa Flood Information System web portal. However, the utility of the data would be greatly enhanced if we could convert the stage readings into discharge values. For the general public, this may not be an important issue, but technical agency personnel operate a number of hydrologic models that require conservation of mass and other water quantity considerations.

The proposed project will be a first important step toward achieving this goal. I am excited about the project, as it demonstrates the sharing of resources and expertise among the involved partners for the benefit of the public. The staff of the Iowa Flood Center look forward to working with all federal and state partners to advance our flood forecasting and mitigation capabilities.

Sincerely,

W. Kr

Witold F. Krajewski
Director, Iowa Flood Center
Rose & Joseph Summers Chair in Water Resources Engineering

IIHR Hydroscience & Engineering

October 31, 2014

Mr. Jerry Skalak, CFM
Project Manger
Rock Island District Corps of Engineers
Clock Tower Building
PO Box 2004
Rock Island, Illinois, 61204-2004

Dear Mr. Skalak,

This letter is to express my support for the proposed nonstructural Iowa bridge sensor rating curve FRM demonstration project.

As you are aware, the Iowa Flood Center (IFC) has installed nearly 250 low cost, autonomous stream-stage sensors that provide real-time stream stage data for rivers and streams located throughout the state. While the information provided by these stream sensors is already useful, their value to communities and State/Federal agencies might be greatly increased if they also provided reliable discharge values. If funded, this demonstration project would help determine the usefulness and accuracy of these stream sensors for flood forecasting and flood warning/response purposes, and could be the first step toward providing additional tools that state, federal and local partners could use to reduce flood loses.

This proposal is consistent with the Iowa Department of Natural Resources (IDNR) Floodplain Management Program's goal of protecting life and property through informed decision-making. The Department anticipates involvement by providing project specific data such as LiDAR survey information which would be pertinent to the development of full-valley rating curves. The Department would also provide input on the progress of this project during regular Silver Jackets team coordination meetings and by reviewing and interpreting the results of the demonstration project and communicating the findings as appropriate to agencies and local entities to support informed decision-making in the floodplain. This proposal reflects the collective collaboration required among, State and Federal agencies to address flood risk and to achieve our goal of protecting life and property. The IDNR is currently actively involved in the Silver Jackets team and anticipates this commitment into the future.

If you have any questions regarding this matter, please contact Bill Cappuccio at (515) 281-8942.

Sincerely,

William A. Ehm

William Ehm
Division Administrator
Environmental Services Division

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmosphere Administration
NATIONAL WEATHER SERVICE CENTRAL REGION
7220 NW 101st Terrace
Kansas City, Missouri 64153-2317

Jerry Skalak, Project Manager
U.S. Army Corps of Engineers
Rock Island District
Clock Tower Building
P.O. Box 2004
Rock Island, Illinois 61204-2004

November 6, 2014

Re: Letter of Support

Dear Jerry Skalak:

This letter of support is in regard to the Iowa Flood Center's proposal for Silver Jackets Funding to establish stage-discharge relations ships (rating curves) at select Iowa Flood Center (IFC) stream sensor sites.

National Weather Service (NWS) river forecasting operations are dependent upon both river stage and flow observations to produce timely and accurate forecasts. NWS river forecast models compute and route the volume of watershed runoff in terms of river flow. The NWS river forecast models require continuous adjustment and quality control to ensure the river forecasts are timely and accurate. Model flows must be directly compared to the observed flow at one or more stream gauging stations to maintain an acceptable level of accuracy. Stream gauging stations directly measure river stage; however, a rating curve relationship must be defined to translate river stage into river flow. It is impossible to carry out a direct comparison between the river forecast model and a stream gauge stage without a rating curve.

The development of rating curves at locations where the Iowa Flood Center has installed stage sensors may enhance the delivery of timely and accurate forecasts for existing NWS Advanced Hydrologic Prediction Service forecast points. A denser network of stream gauging stations with rating curves will provide additional data for pre-event model calibration, and the network will facilitate additional quality control of river forecasting models during real-time forecasting operations. These improvements may also provide the opportunity for increasing the number of points at which NWS flood forecasts are issued.

Sincerely,

Wendy L. Pearson

Wendy L. Pearson
Regional Service Support Hydrologist
816-268-3122
Wendy.Pearson@noaa.gov

DEPARTMENT OF THE ARMY
ROCK ISLAND DISTRICT, CORPS OF ENGINEERS
CLOCK TOWER BUILDING - P.O. BOX 2004
ROCK ISLAND ILLINOIS 61204-2004
http://www.mvr.usace.army.mil

Planning, Programs, and
Project Management Division

22 June 2015

USACE Institute for Water Resources
7701 Telegraph Rd (Casey Bldg)
Alexandria, VA 22315

Ms. Lisa Bourget:

In accordance with the provisions of Interagency Nonstructural Flood Risk Management Project Proposal, the Rock Island District of the U.S. Army Corps of Engineers has enclosed the nonstructural flood risk management proposal **Non-structural FRM Iowa Bridge Sensor Rating Curve FRM Demonstration Project Phase II.** The nonstructural flood risk management proposal is supported by the study partners (please see the attached messages of support).

The nonstructural flood risk management proposal outcomes of protection of life safety, reduction of property loss, increased resiliency are achieved by promoting shared responsibility, addressing priorities in State or local hazard mitigation plans, and leveraging resources. This is accomplished by leveraging the large amount of recently completed work with a small increment cost to develop and demonstrate bridge sensor rating curves as a flood preparedness tool.

If you have any questions regarding this proposal, please call Mr. Steve Rumple of our Planning, Programs, and Project Management Division, telephone 309/794-5565 or Ms. Shirley Johnson of our Engineering Division, telephone 309/794-5276.

Sincerely,

Steve Rumple
USACE Iowa Silver Jackets Coordinator
Planning, Programs, and
Project Management Division

Interagency Flood Risk Management Project Proposal Template

☒ Early Consideration (Work will begin in FY 2015) ☐ General Consideration (Work will begin in FY 2016)

1. Project Name:

Non-structural FRM Iowa Bridge Sensor Rating Curve FRM Demonstration Project

2. Interagency Team Name:
If not a formally recognized team, list participating organizations.

USACE, Iowa Flood Center, NWS, USGS, IDNR, HSEMD

3. USACE POC:
Include name and title.

Toby Hunemuller, Chief Hydrologic Eng. Section; Shirley Johnson, Hydrologist, MVR-EC-HH
toby.hunemuller@usace.army.mil; shirley.j.johnson@usace.army.mil

4. Project Description:
Describe what the issues are and how the proposed project would address those issues in no more than 200 words.

Iowa's severe flooding in 2008 demonstrated the need for more extensive monitoring of the state's rivers and streams in real time. To address this, the Iowa Flood Center (IFC) developed and maintains a statewide network of stream stage sensors deployed at bridges and designed to measure water surface height. Stage data are transmitted automatically and frequently to the IFC for viewing in real time via the Iowa Flood Information System (IFIS). The IFC maintains a network of 250 stream stage sensors across the state. Support for sensor deployment has come from the Iowa Department of Natural Resources and the Iowa Department of Transportation. This project will leverage the existing IFC bridge sensor network data to demonstrate the need for rating curve development at sensor locations. Study partners (USACE, IFC, NWS, USGS, IDNR, HSEMD) will prioritize state-wide rating curve needs and develop a standard procedure for rating curve data collection by leveraging available data (state LIDAR data, bridge plans). Co-located bridge sensor and USGS gage rating curves will be compared to assess the accuracy of the bridge sensor rating curves. The demonstration study products will be available for flood preparedness planning.

5. Leveraged Funding:
Every proposal must include a table quantifying leveraged resources invested by others for the project, including other federal, state, regional, or local agencies. USACE project funding may not be used for construction; any construction must be funded by partners.

Participating agency	Point of contact	Activities/ tasks	Contribution amount	In-kind or cash?	Pre-existing work or new work?	Duration/ completion date
Iowa Flood Center, NWS,USGS,	Witold Krajewski, IFC	Methodology and review of rating curve development accuracy	$45,000	In-Kind	Demonstration project of rating curve development	one year from receipt of funding
USACE		Review of rating curve development accuracy	$45,000		Review of rating curve development accuracy	one year from receipt of funding
					Collection of field survey data, Sensor prioritization ,	one year from receipt of funding

Interagency Flood Risk Management Project Proposal Template

6. Anticipated Outcomes of Proposed Project:
Each project should include anticipated outcomes in at least one of the following three categories. Please respond describing how the project would achieve an outcome, or specify N/A when appropriate (response should be 150 words or less)

Manages Flood Risk: (Protection of life safety, reduction of property loss, increased resiliency.)	The desired outcome for this pilot is the development water level detection tools that the community can use to identify and proactively respond to flood issues. This pilot will provide the components to identify lead times, evacuation plans, equipment, and personnel to respond to a flood event reducing future flood damages and improving life safety. This project will improve the ability to forecast floods by allowing the development of additional forecasting points, and by improving the accuracy of forecast models. By providing better information and reducing the uncertainty about flow levels, the outcome from this project may result in a decrease for the need of structural flood control solutions.
Results in Actions by Others:	This project promotes shared responsibility, addresses priorities in State or local hazard mitigation plans, and leverages resources. These planning tools would increase cooperation and communication in the identification and implementation of regional flood mitigation strategies and increase the capacity of local government and residents to proactively respond to the occurrence of floods.
Results in Reduced Future Expenditures:	The methodology developed in this pilot will be documented and can be used as the framework for other pilots/projects in similar communities across the nation.

7. Funding Information:
Please specify all information required to create a MIPR (funds will be disbursed by FY). Note maximum request of $100K FPMS funding.

	Request Amount	**Technical POC**	**Financial POC**	**Organization Code**	**Breakdown of Costs (Labor, Contract services, Travel, etc)**	**Expected Delivery of Funds (Date)**
FY 15 Early consideration proposals only	$20,000	Shirley Johnson, T.	Laurie Kotecki 309-794-5457	B5L1200	Labor only	July/August 2015
FY16						
FY17						

8. Attachments Reminder: A letter of support is required from either a state lead of the Silver Jackets team or study partner indicating that the project is a state priority and describing, 1) how the proposal helps achieve state or community goals, 2) the role the state or partner anticipates taking in the conduct of the project, and 3) the state or partner's ongoing commitment to long-term outcomes. Maps or other graphics may be included as well. Please select yes or no as to whether you have included a support letter. ☑ **Yes** ☐ **No**

9. Additional Comments:

Fields of Opportunities

STATE OF IOWA

TERRY E. BRANSTAD
GOVERNOR

KIM REYNOLDS
LT. GOVERNOR

IOWA HOMELAND SECURITY AND
EMERGENCY MANAGEMENT DEPARTMENT
MARK J. SCHOUTEN, HOMELAND SECURITY ADVISOR
AND EMERGENCY MANAGEMENT DIRECTOR

June 19, 2015

Shirley Johnson
Hydrologic and Hydraulic Branch (CEMVR-EC-HH)
US Army Corps of Engineers, Rock Island District
Clock Tower Bldg – PO Box 2004
Rock Island, IL 61204-2004

Dear Ms. Johnson:

This letter is to express the support of Iowa Homeland Security and Emergency Management Department for the proposed second phase of the Iowa Bridge Sensor Rating Curve flood risk management demonstration project. Phase II will evaluate the rating curve methodology developed in Phase I and enhance and narrow the range of uncertainty and confidence limit bounds of that methodology.

The development of rating curves at locations where the Iowa Flood Center has installed stage sensors will allow for the translation of river stage information into river flow estimates and thereby enhance the delivery of timely and more accurate flood forecasts.

This proposal reflects the collaboration required among State and Federal agencies to sufficiently address flood risk and to achieve a shared goal of protecting life and property. In addition, this proposed work complements recommendations of the Flood Risk Management Working Group of the Iowa Governor's 2014 Long Term Recovery Task Force. The staff of HSEMD look forward to working with all partners in this proposed project to further advance flood forecasting and mitigation capabilities in the State of Iowa.

If you have any questions please contact Tim Kautza at timothy.kautza@iowa.gov; 515-725-9327.

Sincerely,

Patrick J. Hall
Recovery Division Administrator

7900 HICKMAN ROAD / SUITE 500 / WINDSOR HEIGHTS, IOWA 50324-4402 / 515-725-3231
http://www.homelandsecurity.iowa.gov

June 17, 2015

Ms. Shirley Johnson
Hydrologist
Rock Island District Corps of Engineers
Clock Tower Building
PO Box 2004
Rock Island, Illinois, 61204-2004

Dear Ms. Johnson,

This letter is to express my support for the proposed Phase II of the nonstructural Iowa bridge sensor rating curve FRM demonstration project.

As you are aware, the Iowa Flood Center (IFC) has installed nearly 250 low cost, autonomous stream-stage sensors that provide real-time stream stage-only data for rivers and streams located throughout the state. Phase I of this demonstration project developed a rating curve methodology that has been deployed for six (6) existing stream sensors. If funded, Phase II of this demonstration project would continue the evaluation of the accuracy and repeatability of the developed methodology, as well as its applications for flood forecasting and flood warning/response purposes. Phase II would also expand the database for the methodology's assessment by implementing it at four or five additional sensor sites.

This proposal is consistent with the Iowa Department of Natural Resources (IDNR) Floodplain Management & Dam Safety Program's goal of protecting life and property through informed decision-making. The Department anticipates involvement by providing project specific data such as LiDAR survey information which would be pertinent to the development of full-valley rating curves. The Department would also provide input on the progress of this project during regular Silver Jackets team coordination meetings and by reviewing and interpreting the results of the demonstration project and communicating the findings as appropriate to agencies and local entities to support informed decision-making in the floodplain.

This proposal reflects the collective collaboration required among, State and Federal agencies to address flood risk and to achieve our goal of protecting life and property. The IDNR is currently actively involved in the Silver Jackets team and anticipates this commitment into the future.

If you have any questions regarding this matter, please contact Bill Cappuccio at (515) 725-8342.

Sincerely,

William A. Ehm

William Ehm
Division Administrator
Environmental Services Division

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmosphere Administration
NATIONAL WEATHER SERVICE CENTRAL REGION
7220 NW 101st Terrace
Kansas City, Missouri 64153-2317

June 15, 2015

Shirley Johnson, Hydrologist
Hydrologic and Hydraulic Branch
U.S. Army Corps of Engineers
Rock Island District
Clock Tower Building
P.O. Box 2004
Rock Island, IL 61204-2004

Dear Shirley Johnson,

This letter of support is in regard to the Non-structural FRM Iowa Bridge Sensor Rating Curve Demonstration Project Phase II. The National Weather Service (NWS) was an active participant in Phase I and will continue the commitment in Phase II. NWS river forecasting operations are dependent upon both river stage and flow observations to produce timely and accurate forecasts. NWS river forecast models compute and route the volume of watershed runoff in terms of river flow. The NWS river forecast models require continuous adjustment and quality control to ensure the river forecasts are timely and accurate. Model flows must be directly compared to the observed flow at one or more stream gauging stations to maintain and acceptable level of accuracy. Stream gauging stations directly measure river stage; however, a rating curve relationship must be defined to translate river stage into river flow. It is impossible to carry out a direct comparison between the river forecast model and a stream gauge stage without a rating curve.

The results to date from Phase I are encouraging. Phase II will allow the Iowa Flood Center to refine the techniques developed in Phase I and to address the various components of uncertainty. This will increase the reliability of the developed rating curves. The development of rating curves at locations where the Iowa Flood Center has installed stage sensors may enhance the delivery of timely and accurate forecasts for existing NWS Advanced Hydrologic Predictions Service forecast points. A denser network of stream gauging stations with rating curves will provide additional data for pre-event model calibration, and the network will facilitate additional quality control of river forecasting models during real-time forecasting operations. These improvements may also provide the opportunity for increasing the number of points at which NWS flood forecasts are issued.

Sincerely,

Wendy L. Pearson

Wendy L. Pearson
NWS Central Region Deputy Chief for Hydrologic Services

THE UNIVERSITY OF IOWA

COLLEGE OF ENGINEERING
IIHR—Hydroscience & Engineering
100 C. Maxwell Stanley Hydraulics Laboratory
Iowa City, Iowa 52242-1585 USA
319-335-5237 *Fax* 319-335-5238

June 12, 2015

Shirley Johnson
Hydrologic and Hydraulic Branch (CEMVR-EC-HH)
U.S. Army Corps of Engineers, Rock Island District
Clock Tower Bldg. – P.O. Box 2004
Rock Island, IL 61204-2004

Dear Shirley:

I am writing to express my enthusiastic support for the project you are developing, "Bridge Sensor Rating Curve Phase II" which is a follow-up to the "Nonstructural Iowa Bridge Sensor Rating Curve FRM Demonstration Project." During the Demonstration Project (Phase I), a team of hydrologists and engineers from the participating agencies achieved sufficient progress to warrant continued efforts toward developing rating curves for some 250 locations in Iowa. The project represents a new level of synergy between all the federal, state, and local partners concerned about flood mitigation in the state of Iowa. As evidenced by numerous severe floods in the past two decades—since 1990, Iowa has had more than 20 flood-related Presidential Disaster Declarations—flood monitoring and forecasting remain a high priority for the citizens of the state.

The Iowa Flood Center, established in 2009, has deployed nearly 250 autonomous stream-stage sensors for monitoring the water levels in streams and rivers. The data are relayed in real-time by cell phone modems and shared with the public via the Iowa Flood Information System web portal. However, the utility of the data would be greatly enhanced if we could convert the stage readings into discharge values. While for the general public this may not be an important issue, the technical agencies personnel operate a number of hydrologic models for which the rating curves are essential.

The project you are proposing will be an important step toward achieving this goal. I am excited about the project, as it demonstrates the sharing of resources and expertise among the involved partners for the benefit of the public. The staff of the Iowa Flood Center look forward to working with all federal and state partners to advance our flood forecasting and mitigation capabilities.

Sincerely,

W. Kr

Witold F. Krajewski
Director, Iowa Flood Center
Rose & Joseph Summers Chair in Water Resources Engineering