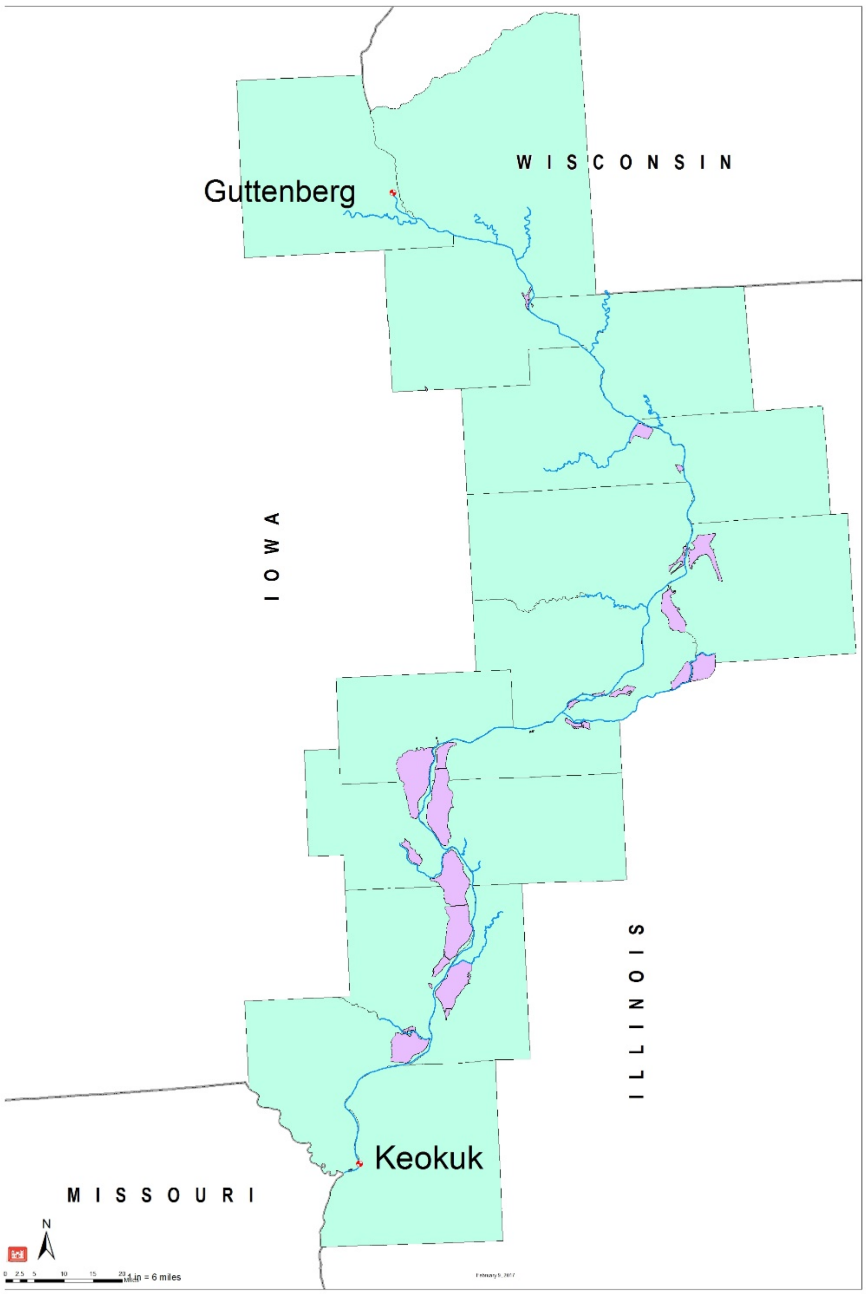
UPPER MISSISSIPPI RIVER PHASE II
FLOOD RISK MANAGEMENT
EXISTING CONDITIONS HYDRAULIC MODEL
DOCUMENTATION REPORT



September 2020

EXECUTIVE SUMMARY

The Upper Mississippi River (UMR) watershed has experienced more frequent flood events with increasing damages and threats to human life. The US Army Corps of Engineers (USACE) utilizes the risk framework to assess, communicate, and manage risk. In the last ten years, the USACE Levee Safety Inspections, Levee Assessments and Levee Screenings have identified a number of flood risk factors and considerations that warrant the collective re-evaluation of Flood Risk Management (FRM) strategy. An updated hydraulic model provides a better understanding of how floodwaters are carried by the system in its current condition.

USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) software, modeling software that is common to water resources professionals, was chosen as the platform for this updated FRM hydraulic model. Specifically, version 5.0.7 of HEC-RAS was used. This model will be referred to as the UMR FRM hydraulic model.

The UMR FRM hydraulic model is divided into four river segments. This report for Phase II covers the second river segment (Guttenberg, IA, to Keokuk, IA). The first river segment, Phase I, (from Keokuk, IA, to Thebes, IL) was completed in 2018. The third river segment hydraulic model is proposed to be completed in the near future and is for the Illinois Waterway from Joliet, IL, to the confluence with the Mississippi River. The fourth river segment hydraulic model (from Anoka, MN to Guttenberg, IA) is being developed concurrently with this model segment.

Development and calibration of the second model segment was funded by the USACE Levee Safety Program. This segment covers 251 river miles of the UMR main stem from Mississippi River Lock and Dam 10 at Guttenberg, IA, (River Mile 615) to Mississippi River Lock and Dam 19 at Keokuk, IA, (River Mile 364).

National Levee Database (NLD) levee surveys were completed in 2007/2008 and 2016 for U.S. Army Corps of Engineers (USACE) Rock Island District. The use of the NLD data in this model does not alter the congressionally authorized elevation for individual levee systems or constitute retroactive USACE Section 408 for levees that may have been altered.

The UMR FRM hydraulic model represents existing conditions. An updated existing conditions hydraulic model for the UMR is an essential tool to understanding the flood risks that currently exist to the river communities and is a critical first step for the development of systemic FRM strategy. This new existing conditions model is a tool that can lead to better and more consistent characterization of flood risk. The hydraulic model will improve flood preparation and response, real time river forecasting and real time inundation mapping.

The need for a common modeling tool is supported by a diverse stakeholder group including local communities, the bordering states, and non-governmental organizations (NGOs). It will serve as a catalyst for development of a more collaborative and holistic FRM strategy for the region. The UMR FRM hydraulic model was developed in collaboration with state/Federal technical experts and with regular input from stakeholders. It is envisioned that many of the stakeholders will utilize this model for their own applications and analyses as they pertain to FRM. Potential uses and applications of the model include: flood risk management analyses (structural/non-structural), state flood plain management, levee sponsor Section 408 levee alteration studies, and flood response operations.

FEMA acknowledges that the UMR FRM hydraulic model cannot be used to produce an update or replacement of the 2004 Upper Mississippi River System Flow Frequency Study (UMRSFFS) and FEMA's regulatory products in its current state. The UMR FRM hydraulic model has the best available information and will be available for public use. As a result, additional coordination between the flood plain managers at the local, state and Federal levels is recommended before using the UMR FRM hydraulic model for project permitting (i.e. no-rise) purposes.

Development of the UMR FRM hydraulic model was a collaborative effort by Federal and state agencies, facilitated by USACE Rock Island District. The UMR FRM hydraulic model leveraged the ongoing Corps Water Management System (CWMS) water control focused modeling effort by using the CWMS model as a base model. The UMR FRM hydraulic model differs from the CWMS model by having more detailed features, additional cross sections, and bluff to bluff coverage of the entire floodplain.

HEC-RAS is widely used by hydraulic engineers with state and Federal agencies and by architect/engineering consultants making it the preferred tool for flood risk management analysis, planning, and decision making. There was no previous model of the UMR that was developed with software that is as widely used and accepted as HEC-RAS. The major updates to this model include higher resolution terrain data, inclusion of bridges, 2D flow areas, and updated levee survey data. The model has undergone rigorous technical review to ensure accuracy and reliability.

The model geometry was developed using a digital terrain layer comprised of the best available LiDAR (Light Detection and Ranging) terrain data and bathymetry data. The United States Geological Survey (USGS) Upper Midwest Environmental Sciences Center (UMESC) topobathy (topography + bathymetry) dataset for the UMR provided much of the necessary terrain and bathymetry data. The topobathy dataset is a combination USACE collected LiDAR and bathymetry data, supplemented with other surveyed bathymetry datasets. For the UMR modeling the topobathy datasets were supplemented with state LiDAR data for tributary reaches and more recent USACE collected bathymetry, where available. The calibrated existing conditions model uses one set of parameters that produce reasonable results for four flood events (2001, 2008, 2014, and 2019). The existing levee elevations represent the sum of all activities (flood fighting, repairs, dredge material placement, approved and unapproved alterations) that have occurred over time. The goal of this model is to provide a common tool using the best available data and software that can reasonably recreate a range of events that have occurred or may occur in the future to assess system performance and flood risk management strategies.

The model contains a single geometry file representing the existing condition levees as determined by the most recent NLD survey. There are a handful of systems that were not included in the NLD survey because they were not federally constructed or not in the PL 84-99 Program. The digital terrain dataset was used to determine the levee profile for these systems.

The UMR FRM hydraulic model will help provide consistent and reliable answers on potential impacts caused by changes in the river. It will replace multiple models currently in use, leading to better and more consistent flood risk management. The model utilizes unsteady flow hydrographs and provides a base condition to efficiently evaluate proposed actions and resulting changes in flood risk.

TABLE OF CONTENTS

INDEX OF TABLES

INDEX OF FIGURES

APPENDICES

Introduction

Objective

The objective of the Upper Mississippi River (UMR) Flood Risk Management (FRM) hydraulic model is to serve as a tool to assist the U.S. Army Corps of Engineers (USACE) and other Federal and state agencies in UMR system flood risk management, Section 408 alteration requests, planning studies, and watershed studies. The hydraulic model was developed and calibrated with existing levee elevations based on the most recent National Levee Database (NLD) survey information. A limited number of levees were not in the PL 84-99 system and therefore did not have NLD survey information. For these levees, the digital terrain data were used to determine existing levee elevations. Refer to Appendix A-1 for overview maps of the Phase II model extents.

Background

Floodplain management decisions for the UMR are in part based on information obtained from hydraulic model results. Most of the hydraulic models that have been previously developed for the mainstem Mississippi River are limited in geographic extent to the immediate study area. Although this approach has its benefits, it does not allow a regional approach for FRM decision making. This new UMR FRM hydraulic model is an improvement over previous pool based models because of the large geographic extent and continuity across multiple navigation dams.

This Hydraulic Model Documentation Report is specific to the Phase II reach (Guttenberg, IA, to Keokuk, IA) of the UMR FRM hydraulic model. The other three phases of the UMR FRM Hydraulic Model will each have an associated Hydraulic Model Documentation Report.

Federal/State Agency Coordination

Multiple web meetings and conference calls were held between USACE and the stakeholders which included Federal and state agencies. Federal and state technical team members included Iowa, Illinois, Missouri, Minnesota, and Wisconsin Department of Natural Resources (DNR); Federal Emergency Management Agency (FEMA); United States Geological Survey (USGS); National Weather Service (NWS) North Central River Forecast Center (NCRFC); and the Iowa Flood Center (IFC).

Non-Governmental Organization (NGO) Coordination

Multiple web meetings and conference calls were held between the USACE and the NGO stakeholders. NGO stakeholders included Upper Mississippi River Basin Association (UMRBA); Upper Mississippi Illinois and Missouri River Association (UMIMRA) and consultant Klingner and Associates; Neighbors of the Mississippi River and consultant Crawford, Murphy, Tilly; American Rivers; The Nature Conservancy; and Two Rivers Levee and Drainage District.

User Guide

Model Availability and Use

This model is available by request to Federal, state, local agencies, and NGOs along with their engineering consultants. Model users should consult with the appropriate state/local/Federal floodplain managers before using this model for regulatory purposes. This is a complex hydraulic model. As a result, only experienced and qualified hydraulic engineers with advanced HEC-RAS training should use this model to ensure appropriate model inputs and accurate model results. This report and appendices are not intended to be a substitute for the HEC-RAS User's Manual, HEC-RAS Applications Guide, or formal HEC-RAS training and experience.

As stated above, this model has been developed as an FRM and is not currently designed or calibrated for sediment transport, water quality, steady state flow modeling, or river training structure analysis. It also was not specifically developed to recreate the 2004 Upper Mississippi River System Flow Frequency Study (UMRSFFS) or update floodway limits. This model is a good starting point and will provide the base condition for the aforementioned modeling efforts, but it would require appropriate changes and updates by an experienced HEC-RAS hydraulic modeler. This model cannot directly replace the 2004 UMRSFFS as there are significant differences between the modeling software used for the two studies. Please refer to the "Previous Studies/Models" section of this report for more information.

While ecological analyses regarding water velocities, water depths, where water goes in the floodplain and how long it stays in the floodplain may be possible with this UMR FRM hydraulic model, a trained and experienced HEC-RAS hydraulic modeler should be consulted to determine whether the model is appropriate for the intended ecological analyses.

The UMR FRM hydraulic model was developed and calibrated as a regional model; therefore USACE recommends maintaining the model in its entirety. However, it is anticipated that organizations may request this model for a variety of applications, and changes to the model may be desired. One common practice may be to reduce this regional model to a reach of the river that encompasses the specific area of interest. When the model is parsed in this way, an experienced HEC-RAS modeler will need to define the appropriate upstream and downstream boundary locations and conditions.

Another application may be to explore "what if" scenarios by modifying the existing conditions model and comparing alternatives to the "no action" alternative. These scenarios often involve modifying structures in the channel or floodplain (islands, closing dikes, levees, etc.). For these model runs, an HEC-RAS hydraulic modeler will need to make a copy of the model geometry and then incorporate the changes into the model geometry to create the alternative scenario. It is not technically correct to simply remove one or more regulatory structures from the model and then analyze that altered model as a "without project" or "natural" condition.

<u>Model Updates</u>

USACE will periodically evaluate the model to determine when it needs updating. The potential need to update the model may require significant changes in system hydrology or topography. Users of the model who believe it requires an update as a result of improved data or new construction should contact the USACE Rock Island District Corporate Communications Office at 309-794-5729. Updates to the UMR FRM hydraulic model may require a separate source of funding depending on the magnitude and scope of the model changes.

Previous Studies/Models

There have been numerous hydraulic models developed for portions of the UMR mainstem, but as stated above, most of these models were developed for a specific geographical reach of the river and for a specific study. Many of these models were for internal USACE projects, such as dam break analysis, and have not been made available to stakeholders. These models were not used to create the UMR FRM hydraulic model, as many of them were created using different software versions and older terrain data.

Major tributaries to the Mississippi River are included in the UMR FRM model. Some of these tributaries had models that were previously developed and for this effort were combined with the newly developed Mississippi River mainstem model. For the other tributaries that had no previous models, new approximate models were created. The approximate models used the most up-to-date terrain data for the cross sections, but used approximate channel data due to the lack of available hydrographic data.

In 2004, USACE completed the UMRSFFS, which updated the discharge frequency relationships and water surface profiles for the Mississippi River System upstream of Cairo, IL. The model used for the UMRSFFS was developed in the late 1990s using the One-Dimensional Unsteady Flow Through a Full Network of Open Channels (UNET) software. UNET does not have a user-friendly graphical user interface and therefore was not able to be used by a wide range of people. The UNET model incorporated elevation data from a photogrammetry-based Digital Terrain Model (DTM) and best available digital bathymetric data, both of which are substantially coarser and less complete than the currently available LiDAR-based Digital Elevation Model (DEM) and bathymetric datasets.

Also, the interaction between the river and levee areas was limited to user defined upstream and downstream overtopping/breach locations points using simplified linear routing. The UNET model was suitable, and the state of the art tool at the time, for determining the flow frequency profiles, but due to software limitations, the UNET model used for the UMRSFFS was less capable for detailed floodplain analysis when compared to the current capabilities of HEC-RAS. The scope of work for this UMR FRM hydraulic model does not include an update or comparison to the 2004 UMRSFFS. The UMRSFFS was a multi-year study to update the hydrology of the river system, while the UMR FRM hydraulic model is a tool intended for floodplain/flood risk management.

USACE completed the UMR FRM Phase I Hydraulic Model from Keokuk, IA, to Thebes, IL, in 2017. The model development and calibration process is similar between Phase I and Phase II and both models were developed to serve similar purposes.

Geographic Coverage

Phase II of the UMR FRM hydraulic model extends bluff to bluff from the tailwater of Lock and Dam 10 at Guttenberg, IA, (River Mile 615) to the tailwater of Lock and Dam 19 at Keokuk, IA, (River Mile 364). This covers 251 river miles, includes 9 navigation dams and is located within the Rock Island District. The St. Paul District is developing the Phase IV UMR FRM hydraulic model concurrently to ensure consistency between the models. There is one pool of overlap between the Phase II and Phase IV models, Pool 11. This overlap is needed to move the Phase IV model boundary a sufficient distance downstream to reduce the boundary's impact on computations at Lock and Dam 10. The Phase II model governs in this overlapping reach. The major tributaries (gaged streams) to the Mississippi River are modeled as separate reaches from the tributary's confluence with the Mississippi River upstream to the first USGS flow gage. Minor tributaries are input as lateral inflows. Besides 1D cross-sections for the mainstem river channel, the model includes 2D flow areas for leveed areas and 1D storage areas for other backwater areas.

Flood History

The Mississippi River has experienced numerous major flooding events throughout the last century. Recent significant floods in the Phase II model reach occurred in 1993, 2001, 2008, 2011, 2014 and 2019. The magnitude and frequency of these spring snow melt and summer rainfall flood events have highlighted the flood risk that is a major concern for the numerous cities, towns, and agricultural areas within the Mississippi River floodplain.

HEC-RAS Model Development

HEC-RAS Version 5.0.7 2D Modeling Computer Program

HEC-RAS is a hydraulic modeling program developed by the USACE Hydrologic Engineering Center (HEC) (Reference 1). The UMR FRM hydraulic model combines 1D and 2D elements into a single unsteady flow model. The 1D elements of the model include cross-sections representing the river channels and overbank areas, storage areas for non-leveed backwater areas, and connections between different model elements. The leveed areas are modeled as 2D flow areas, which is beneficial in the analysis of any levee overtopping or breach events.

Methodology

Model development consisted of building the model geometry, properly assigning the inflow data, and defining boundary conditions resulting in model simulations that reflect the current conditions of the river and provide the most representative water surface information with minimal error. The geometry was developed by using both HEC-RAS and HEC-GeoRAS. HEC-GeoRAS is a group of ArcGIS tools that process geospatial data to be used with HEC-RAS (Reference 2). Many features in the model geometry were first processed in HEC-GeoRAS, imported into HEC-RAS, and then further developed in HEC-RAS. The features that were developed in HEC-GeoRAS include the river centerline, cross sections, inline structures, bridges, lateral structures, flow paths, storage areas, storage area connections and ineffective flow areas. 2D flow areas and breaklines within the 2D flow areas were developed with the HEC-RAS Geometry Editor.

The naming conventions for different model geometry features were kept consistent for each type of feature. For example, all river reaches were named with the same convention. Table 1 lists the different types of features and naming convention used for each.

Table 1. HEC-RAS Model Geometry Naming Conventions

Feature Type	Naming Convention
River Names	River Name w/o “River” (e.g., Mississippi)
Reach Names	Tributary Name “ ” Tributary Name (e.g., Turkey Grant)
Junction Names	Tributary Name/Initials “ ” Mainstem Name/Initials (e.g., Apple Miss)
Storage Areas/2D Flow Area Names	Common Levee Name or Combination of River Name, River Station and Side of River (e.g., GreenBay, Miss 563.5R)
SA/2D Area Connection Names	Upstream Area Name “_” Downstream Area Name (e.g., Drury_M451L)

Datum Information

The horizontal projection for the UMR FRM hydraulic model is Albers Equal Area Conic. The geographic coordinate system is North American Datum (NAD) 1983 and the linear unit is U.S. feet. The vertical datum for the model is the North American Vertical Datum (NAVD) of 1988 in U.S. feet.

All model inputs that were originally referenced to Mean Sea Level (MSL) 1912 or National Geodetic Vertical Datum (NGVD) of 1929 were converted to NAVD 88. Appendix B lists conversions by river mile through the model reach.

The conversion factors from NGVD 29 to NAVD 88 were determined from the computer software program Corpscon or were developed from surveys at specific gage locations. Corpscon was developed by the former U.S. Army Topographic Engineering Center which is now the Army Geospatial Center.

The vertical accuracy of the Corpscon conversions between NGVD 29 and NAVD 88 is 2 cm (one sigma) (Reference 3). For model inputs that were originally referenced to MSL 12, historic conversions were used to convert the values to NGVD 29 from which the Corpscon conversions were used to further convert to NAVD 88.

Throughout the geographic range of the model, the conversions from NGVD 29 to NAVD 88 ranged from -0.26 to -0.04 feet. Conversions from MSL 12 to NAVD 88 ranged from -0.74 to -0.54 feet throughout the model.

Model Geometry

Cross sections

The HEC-RAS model cross section locations are generally consistent with the locations used in the 2004 UMRSFFS model and are spaced every quarter mile to half mile. The cross sections extend from bluff to bluff across the river valley or to the limits defined by storage/2D areas. Cross sections were added to or revised in the model upstream and downstream of any inline structures or bridges and whenever additional cross sections were deemed necessary during the calibration process. Cross sections are stationed along the Mississippi River mainstem based on the river miles upstream of the Ohio River, consistent with the river miles shown in Inland Electronic Navigation Charts. Using river miles for model stationing maintains consistency between the UMR Model Phases and historic gage locations.

Terrain and Bathymetry Data

The geometry cross sections were updated with the best available LiDAR (Light Detection and Ranging) terrain data and bathymetry data. The United States Geological Survey (USGS) Upper Midwest Environmental Sciences Center (UMESC) topobathy (topography + bathymetry) dataset for the UMR (Figure 1) was supplemented with state LiDAR data and more recent USACE collected bathymetry. The topobathy dataset was developed with a vertical datum of NAVD 88 and a horizontal datum of NAD 83 Universal Transverse Mercator (UTM) Zone 15. The dataset went through a horizontal transformation to convert it to Albers Equal Area Conic before being used in model development.

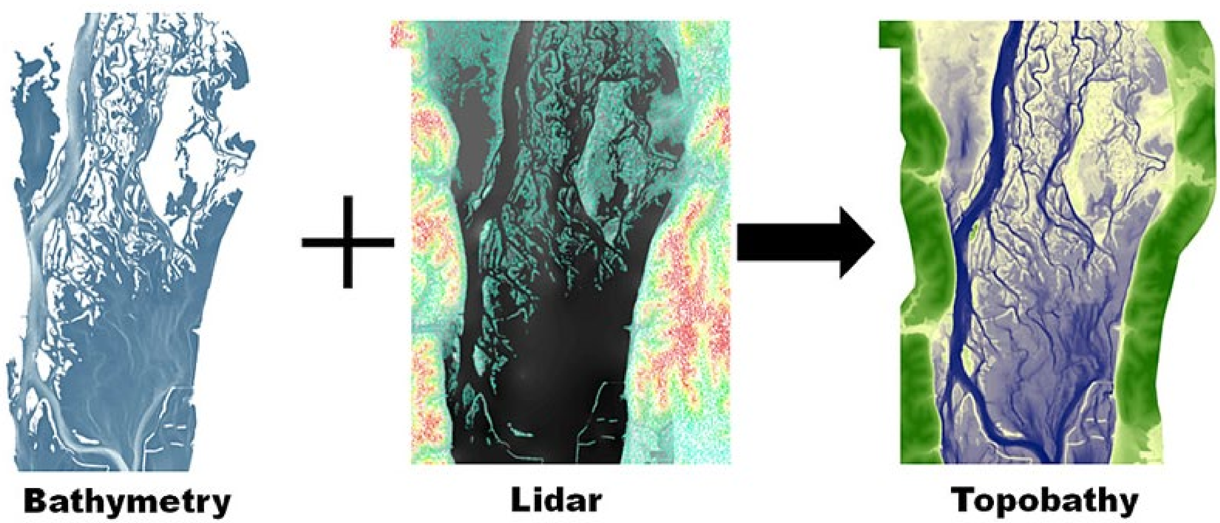


Figure 1. Topobathy Dataset Development (Reference 6)

This topobathy dataset combines LiDAR elevation data and bathymetry data into one dataset to create a seamless elevation surface (Reference 6). The LiDAR elevation data that were inputs to the topobathy dataset were collected by the USACE Upper Mississippi River Restoration (UMRR) Long Term Resource Monitoring (LTRM) in 2007 and 2011. These data were collected bluff to bluff with a 1 meter horizontal resolution. The LiDAR metadata reports an uncertainty of up to 0.6 feet.

The bathymetry data that were inputs to the topobathy dataset were collected either directly by USACE personnel or through USACE UMRR funding from 1989-1991, 1993, 1994, 1997-2008, 2010, and 2011. These data were collected with single beam and multibeam echosounders and were interpolated to produce a DEM at a 2 meter horizontal resolution. The LiDAR data was resampled at a 2 meter resolution and combined with the bathymetry surface to create the final 2 meter resolution topobathy dataset. The bathymetry of the topobathy datasets was supplemented with USACE collected bathymetry that contains more recent survey data. Table 2 lists the data sources and collection dates for the topobathy and supplemental USACE datasets.

Supplementary LiDAR data were needed to produce tributary HEC-RAS models as the UMRR LTRM LiDAR did not extend up the tributaries past the Mississippi River bluff. The supplementary LiDAR data were downloaded from state agencies and were 1 meter in horizontal resolution. Where LiDAR data was not available, USGS 3DEP 10 meter resolution DEM was incorporated.

<u>Bank Stations</u>

Bank stations are defined to identify the three conveyance zones within the channel cross section. The definition and location of cross section bank stations is typically dependent upon modeler experience and preference. For the UMR FRM hydraulic model, bank stations were initially set based on inspection of geometry and terrain breaks. The bank stations were confirmed, or in some cases revised, when Manning's roughness values were added with the inspection of land use areas. Further modification of bank stations occurred during model calibration and the technical review.

Table 2. Data Sources and Collection Dates for Topobathy and USACE Datasets

Location	LiDAR Source	LiDAR Collection Dates	Topobathy Bathymetry Source	Topobathy Bathymetry Collection Dates	USACE Supplemental Bathymetry Collection Dates
Pool 11	USACE E.G.	11/08/2007	USACE UMRR	1999, 2001-2008, 2010	1999-2017
Pool 12	USACE UMRR	11/10/2007	USACE UMRR	1998-2004, 2006-2008, 2010	2003-2017
Pool 13	USACE UMRR	11/12/2007	USACE UMRR	1989-1991, 1993, 1994, 1997	1999-2017
Pool 14	USACE UMRR	11/13/2007	USACE UMRR	1999-2008, 2011	1999-2017
Pool 15	USACE UMRR	11/30/2011-12/1/2011	USACE UMRR	1999-2000, 2002-2003, 2005-2008, 2010	2000-2017
Pool 16	USACE UMRR	11/30/2011-12/1/2011	USACE UMRR	1999-2000, 2002-2008, 2010	1998-2017
Pool 17	USACE UMRR	11/30/2011-12/2/2011	USACE UMRR	1999-2001, 2003-2008, 2010	2000-2016
Pool 18	USACE UMRR	12/1/2011, 12/2/2011, 12/16/2011	USACE UMRR	1999-2008, 2010	1999-2017
Pool 19	USACE UMRR	11/7/2007, 12/16/2011	USACE UMRR	1999, 2001-2008, 2010	2001-2017

Manning Roughness Coefficients

Manning roughness coefficients are included in the model geometry differently for the 1D and 2D elements of the model. For the 1D elements of the model, the Manning roughness coefficients vary horizontally to include different n-values for the channel and the overbank areas (Figure 2). Given the uncertainty in determining these values, they are used as calibration parameters during the calibration process. For both the 1D and 2D elements of the model, the Manning roughness coefficients were determined using the National Land Cover Database (NLCD) 2011 Land Cover file (2011 Edition, amended 2014) (Reference 7). Table 3 correlates the land cover ID and description with the Manning roughness coefficient used in the UMR FRM hydraulic model. Two guidance documents [*Technical Manual for Levees, MMC* (Reference 8) and *HEC-RAS 2D Modeling User's Manual* (Reference 9)] were used to estimate the Manning roughness values. The model roughness was further refined using Flow-Roughness factors during the model calibration.

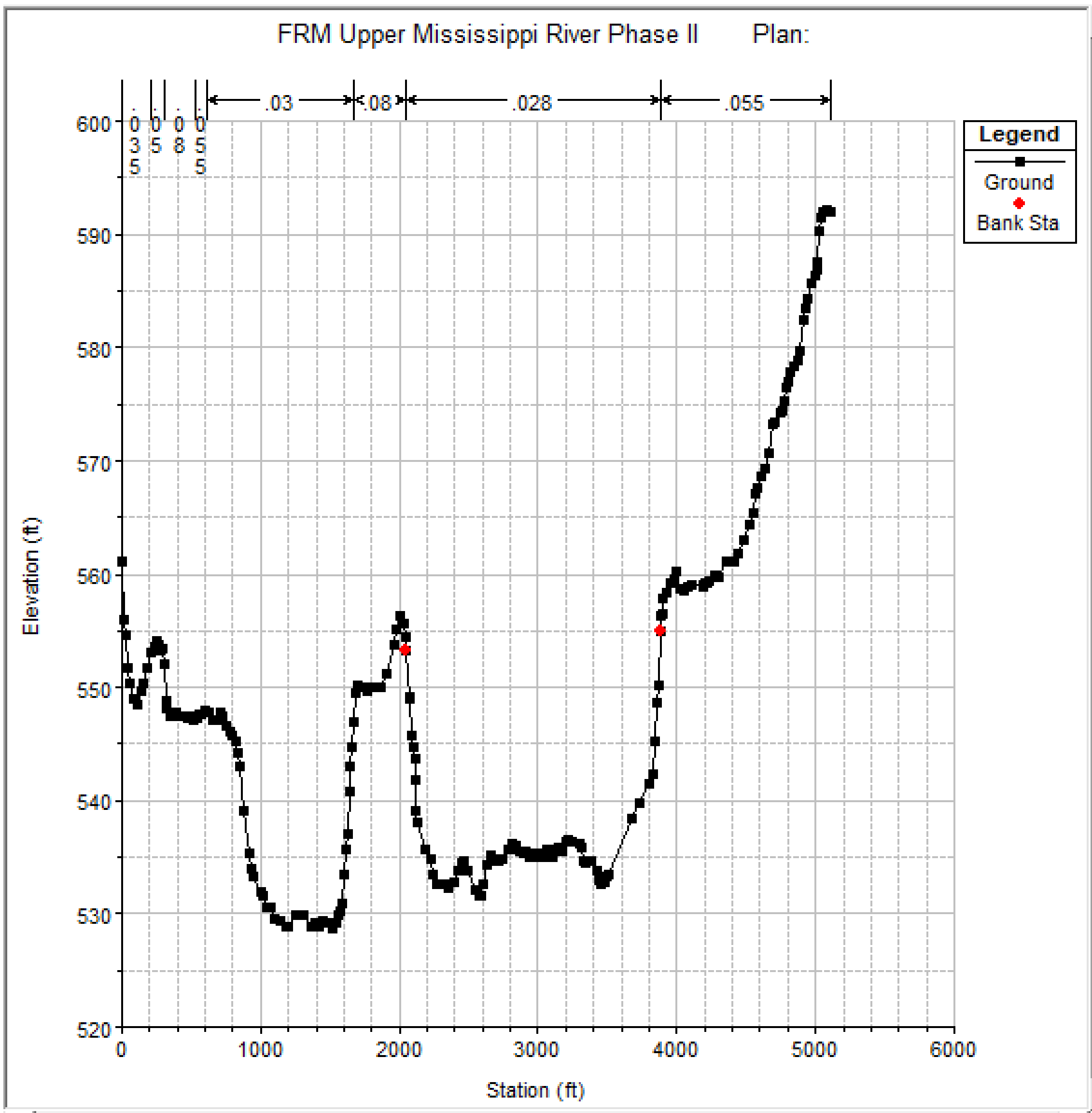


Figure 2. Example Cross Section from HEC-RAS with Manning Roughness Coefficients Displayed Along Top of Cross Section

Table 3. Manning's Roughness Coefficients Used in the UMR FRM Hydraulic Model Based on National Land Cover Database

Land Cover ID	Land Cover Description	Manning's "n"
NA	Main Channel	0.025-0.028
11	Open Water/Side Channels	0.028-0.035
21-24	Developed	0.05-0.65
31	Barren Land	0.03
41-43	Forests	0.16-0.19
52	Shrub/Scrub	0.1
71, 81, 82	Agricultural	0.055-0.06
90	Woody Wetlands	0.08
95	Emergent Herbaceous Wetlands	0.07

Ineffective Flow Areas

In HEC-RAS, ineffective flow areas are defined as areas of a cross section that will contain water that is not actively being conveyed. Ineffective flow areas are often used for portions of a cross section that will be occupied by water, but the velocity of that water, in the downstream direction, is close to or equal to zero. Ineffective flow areas occur around bridge embankments, levees, or similar topographic features that protrude into the normal flow area. The boundary of these areas are defined by the cross section stationing and the maximum elevation of the ineffective portion of the flow area. The use of ineffective flow areas is highly dependent on the experience of the modeler, their interpretation of the geometry and the corresponding stream conveyance. This means that there is not a single, established standard for their use in a given cross section. Therefore, the collaborative efforts of several modelers on the UMR FRM hydraulic model team determined the placement of ineffective flow areas in this HEC-RAS model. The model technical reviews also resulted in several revisions to the ineffective flow areas, based on the highly experienced technical reviewers that were involved in the process.

Bridges

All bridges on the mainstem Mississippi River were included in the HEC-RAS model. Bridge geometries were determined from the best available as-built or design drawings. The critical bridge information needed for HEC-RAS includes high and low chord elevations of the bridge deck, pier width, and pier spacing. When bridges were comprised of one or more vertical curves, the geometry data for the bridge decks were approximated as multiple straight line segments for input into HEC-RAS. The available bridge plans and as-built drawings differed in their clarity and completeness. For some bridges, the required geometry information was explicitly stated in the plans. For others, certain geometric values had to be measured from the plans using the provided scale. Table 4 lists the bridges included in the geometry for the UMR FRM hydraulic model. The low chord elevation listed in Table 4 represents the low chord over the main channel used in the HEC-RAS model.

Table 4. Bridges Included in UMR FRM Hydraulic Model Geometry

River Mile	Bridge Name(s)	Type	Low Chord Elev. (ft, NAVD88)
581.3	US-61/151 & City Island Bridge	Vehicle	702.4
579.9	Illinois Central Railroad Bridge	Railroad	619.1
579.3	Dubuque Bridge (Highway 20)	Vehicle	663.3
537.8	Savanna Bridge (Highway 52/64)	Vehicle	649.5
535	Sabula Railroad Drawbridge	Railroad	605.1
520	North Clinton Bridge (Highway 136)	Vehicle	642
518.1	Clinton Highway Bridge (Highway 30)	Vehicle	646.3
518	Clinton Railroad Draw Bridge	Railroad	595.8
495.4	Interstate 80 Bridge	Vehicle	653.8
485.8	Iowa-Illinois Memorial Dual Bridges (Interstate 74)	Vehicle	635.6
482.9	Rock Island Railroad and Highway Drawbridge	Vehicle/Railroad	620.2
482.1	Centennial Highway Bridge (Highway 67)	Vehicle	619.3
481.4	Crescent Railroad Bridge	Railroad	576.9
478.3	I-280 Bridge	Vehicle	618.6
455.9	Highway 92 Bridge	Vehicle	608.6
427.9	Keithsburg Railroad Drawbridge	Railroad	553.5
404.2	Burlington Highway Bridge (Highway 34)	Vehicle	590.4
403.1	Burlington Railroad Drawbridge	Railroad	545.1
383.9	Fort Madison Railroad Bridge	Railroad	538.7

Inline Structures

Inline structures, which included navigation dams and other hydropower dams are included in the UMR FRM hydraulic model and are discussed in the subsequent sections.

Navigation Dams

The navigation dams on the Mississippi River were included in the model geometry. The navigation dams are internal boundary conditions within the UMR FRM hydraulic model. The geometric properties of each dam was derived from pertinent data in the USACE water control manuals and supplemented by USACE design drawings. The operational controls used as boundary conditions in the model were developed from the operational guidance provided in the USACE water control manuals. For the flood events simulated in the model, the navigation dam gates are commonly at open river conditions, with the gates raised to their full open position The gates of the navigation dams are controlled by the HEC-RAS Navigation Dams option which automatically raises and lowers the dam gates to maintain the regulatory pool elevations during model simulation. This allows the model to run a wide range of flow values without the user having to adjust any of the navigation dam parameters. Table 5 lists the lock and dams/inline structures included in the model geometry with the associated river mile.

Other Hydropower Dams

Two hydropower dams on separate channels within Sylvan Slough were also included in the model geometry. These two dams, independently owned and operated by the City of Moline, IL, and the Rock Island Arsenal produce electricity and are integral in maintaining the navigation pool upstream of Mississippi River Lock and Dam 15. The structures and operations of each dam are not detailed in the model. Simple operation rules are used to allow a consistent outflow through each dam while maintaining the navigation pool upstream. Large flood events may overtop these dams or the embankments surrounding each dam.

Table 5. Mississippi River Dams Included in UMR FRM Hydraulic Model Geometry

River Station	River	Dam/Inline Structure Name
583	Mississippi River	Lock and Dam 11
556.7	Mississippi River	Lock and Dam 12
522.4	Mississippi River	Lock and Dam 13
493.3	Mississippi River	Lock and Dam 14
485	Sylvan Slough	Moline Hydropower
484.5	Sylvan Slough	Rock Island Arsenal Hydropower
482.9	Mississippi River	Lock and Dam 15
457.2	Mississippi River	Lock and Dam 16
437.1	Mississippi River	Lock and Dam 17
410.5	Mississippi River	Lock and Dam 18

River Training Structures

UMR river training structures, including wing dams, were initially constructed in the late 1800s and early 1900s. They were constructed as part of the effort to transition from the 4-foot navigational channel authorization to the 6-foot navigational channel authorization. With a few exceptions, wing dams ceased to be constructed on the pooled portions of the UMR as the lock and dams were constructed in the 1930s per the 9-foot channel authorization.

HEC-RAS model cross sections are located every quarter mile to half mile. Between two cross sections, there may be a single wing dam, an entire wing dam field, or no wing dams. Multiple HEC-RAS cross sections would need to be developed at each structure location to model a wing dam in detail. Modeling wing dams with this level of detail is beyond the scope of this project as this model was developed for high flow scenarios to compare the effects of FRM alternatives. In these extreme flows, the wing dams will be highly submerged and have little effect on the hydraulics of the river. The model was not intended to reproduce small-scale, near-field effects the wing dams may have on local water surface profiles. Modifications to this model for evaluating low flows in which the river training structures could influence the water surface profiles will be dependent on the intended purpose and scope of the low flow simulations. The river has adapted to the presence of the wing dams and this is reflected in the channel geometry. Therefore, the wing dams were not explicitly included in the model geometry for this reach.

Storage Areas/2D Flow Areas

HEC-RAS 2D modeling was used for areas behind levees. The 2D flow areas are each comprised of a mesh in which computations occur at each cell and cell face during the model run. This representation allows the model to more accurately represent the dynamic conveyance and spatially varied water surface in the leveed area as compared to a 1D storage area which uses a simple elevation-storage relationship and allows only a single water surface elevation throughout. 1D storage areas were used in the model to represent minor tributaries and overbank areas that are directly connected to the mainstem river and not behind levees. The 2D flow areas include breaklines where needed. Breaklines are used to delineate hydraulically significant structures (e.g., raised road grades or railroad grades) that will affect the flow of water. The cell sizes in the 2D flow areas were as large as reasonably possible to reduce model run time. As a result some of the topographic features within the flow areas are not captured. The user should carefully evaluate the use of any inundation mapping for the leveed areas based on local knowledge. The UMR FRM hydraulic model uses the Diffusion Wave equation to calculate flow in all of the 2D flow areas. The Diffusion Wave equation was used instead of the Full Momentum (Saint Venant) equation because the flow in the 2D areas in this model is driven almost exclusively by gravity and friction. The

Full Momentum equation takes into account the acceleration of the flow, but in the UMR FRM hydraulic model, accounting for acceleration does not provide noticeable improvements in model results and greatly increases computational run time.

Levees/Lateral Structures

National Levee Database (NLD) levee surveys were completed in 2007/2008 and 2016 for USACE Rock Island District. The 2016 NLD survey in Rock Island focused on the mainstem levees along the Mississippi. The NLD elevations for the tieback levees are based on the 2007/2008 data in Rock Island District. The latest available NLD elevation data was applied to the lateral structures that represent levees in the HEC-RAS model and represents existing levee elevations. The use of the NLD data in this model does not alter the congressionally authorized elevation for individual levee systems or constitute retroactive USACE approval of the altered levee by bypassing the formal Section 408 process. A limited number of levees were not in the PL 84-99 system and therefore did not have NLD survey information. For these levees, the Topobathy terrain data were used to determine existing levee elevations. Closure structures were included in the levee elevations to prevent model simulations from overtopping at known closure locations. The existing levee elevations were used in the model development and model calibration to best align with the conditions of the calibration event. The existing levee elevations were exported from the NLD in the spring of 2017.

Lateral structures were used in HEC-RAS to allow flow to pass between a river reach and a 2D flow area or between a river reach and a 1D storage area. Storage area connections were used to allow flow to pass between 1D storage areas/2D flow areas. Lateral structures that represent levees primarily used the surveyed existing (NLD) levee elevations. For non-Federal levees that are not in the PL 84-99 system and did not have NLD data, terrain data were used to determine the levee elevations. For the UMR FRM hydraulic model, all levees are represented as lateral structures, but not all lateral structures are levees. Non-levee lateral structures represent embankments (roads/railroads) or zero-height weirs. The elevations for these lateral structures were derived from the underlying terrain data. Zero-height weirs are the same elevation as natural ground and are used to transfer flow between geometry elements. The lateral structures were originally developed in HEC-GeoRAS to obtain georeferenced elevations and then were subsequently imported into the HEC-RAS model. Lateral weir coefficients follow the guidance in the HEC-RAS 2D User Manual. Weir coefficients for zero-height weirs range from 0.2-0.5 while weir coefficients for elevated embankments range from 0.5-2.0 depending on the height of the embankment (Reference 9).

Tributaries

Major tributaries (gaged streams) were included as separate river reaches explicitly in the UMR FRM hydraulic model. Tributary models extend from the confluence of the Mississippi River upstream to the first USGS flow gage. The tributaries were included in the model to route flow from the tributary's most downstream flow gage, to include the effects of flow accumulation, timing and volume, to its confluence with the Mississippi River. Two types of tributary models were incorporated into the UMR FRM hydraulic model. USACE leveraged previously developed HEC-RAS models that were used as a part of other studies and projects, including Corps Water Management System (CWMS) models. However, several tributary models were not available and needed to be developed within the budget and time constraints of the UMR FRM hydraulic model. As a result approximate models were developed for these locations and that process is described below. Table 6 lists the tributaries that are included in the model.

Previously developed HEC-RAS tributary models were appended to the UMR FRM hydraulic model with minimal changes to the tributary reach. Bridges from previously developed tributary models are included in the model with no additional effort to verify or update the bridge geometry. These models were developed using the best available data at the time of the study or project. However the tributary models were not re-calibrated as part of the scope of the UMR FRM hydraulic model.

Approximate models were developed for the remaining gaged tributaries that did not have any previously developed HEC-RAS models. The terrain data used to develop each approximate tributary model floodplain geometry were 1 meter resolution LiDAR data. Some of the LiDAR data were acquired at a time of year when tributary flows were low, so some of the channel geometry was captured along with the floodplain geometry. Some of the tributaries did not have any bathymetric data, so the channel geometry that was not delineated by LiDAR had to be approximated. The tributaries that had associated HEC-2 models used the channel geometry from the HEC-2 models for the updated HEC-RAS models. For the tributaries that did not have an HEC-2 model, the channel geometries were estimated.

Bridges for the approximate tributary models were included if bridge information was available from previous HEC-2 models. Bridges were estimated where no reference bridge information was available, using the terrain data to provide the pertinent embankment elevations.

All confluences between rivers reaches are modeled as junctions. The junctions of the UMR FRM model use one of the two available computation modes. The Force - Equal Water Surface Elevations mode was used where the cross sections of the connected reaches were sufficiently close to the junction and the water surface on these cross sections could be assumed equal. The Energy Balance computation mode was used for junctions with longer distance between cross sections of the connected reaches or where the water surface slope across the junction would be too large to assume equal water surfaces.

Table 6. Tributaries of the UMR That Are Explicitly Included in the FRM Hydraulic Model
Models with asterisk (*) are approximate models.

Tributaries to the Mississippi River		River Mile [1]	Drainage Area @ Gage (sq mi)	Modeled Length of Reach (mi.)
State	**Tributary and Gage Location**			
IA	Turkey River at Garber, IA*	608.1	1,545	19.6
WI	Grant River at Burton, WI*	593.2	269	11.2
WI	Platte River near Rockville, WI*	588.2	142	15.4
WI/IL	Galena River at Buncombe, WI*	565	125	20.1
IA	Maquoketa River near Maquoketa, IA*	548.6	1,553	27.9
IL	Apple River near Hanover, IL*	545.1	246	14.6
IA	Wapsipinicon River near De Witt, IA*	506.8	2,336	18.5
IL	Rock River near Joslin, IL	479.1	9,549	27
IA	Iowa River at Wapello, IA	434.4	12,500	15.6
IL	Edwards River near New Boston, IL*	431.2	445	5.2
IL	Pope Creek near Keithsburg, IL*	427.8	174	3.9
IL	Henderson Creek near Oquawka, IL*	409.9	432	20.4
IA	Skunk River at Augusta, IA*	396	4,312	10.6

[1] Mississippi River Mile at Junction

Ungaged Inflows

The Upper Mississippi River has areas of ungaged inflow. To supplement the gaged inflow hydrographs in the hydraulic model, the NWS North Central River Forecast Center (NCRFC) provided estimated ungaged inflow hydrographs for each of the modeled flood events for each of the ungaged Mississippi River sub-basins within the modeled reach. The NCRFC model routes the flows within each sub-basins to an outlet location on the main stem Mississippi River. These ungaged inflow hydrographs are added to the model at the NCRFC outlet location through the use of a lateral inflow boundary condition. Table 7 lists the locations of ungaged inflow to the model.

Table 7. NCRFC Ungaged Inflow Locations Along the Mississippi River

Location Name	River Station	Inflow Type
Dubuque Local	582.7	Lateral Inflow
Bellevue Local	556.91	Lateral Inflow
Sabula Local	536.44	Lateral Inflow
Camanche Local	511.61	Lateral Inflow
LeClaire Local	496.81	Lateral Inflow
Rock Island Local	482.67	Lateral Inflow
Muscatine Local	455.04	Lateral Inflow
Keithsburg Local	426.49	Lateral Inflow
Gladstone Local	409.27	Lateral Inflow
Burlington Local	403.5	Lateral Inflow
Keokuk Local	365.13	Lateral Inflow

HEC-RAS has an ungaged computation method that is able to develop ungaged inflow estimates. Experience has indicated this method can result in model instabilities, hydrograph timing issues, and longer simulation times. The team determined that the NWS NCRFC discharge estimates would be utilized for the model.

HEC-RAS Model Calibration

All inflow hydrographs for the calibration events reflect observed data from USACE or USGS streamflow gages. The model was calibrated to observed stage and flow hydrographs throughout the entire model runtime to include high and medium stages and flows. The model peak stages were calibrated to the peaks of the observed stage hydrographs. A request for high water mark data was sent to UMRBA, UMIMRA, and to County Emergency Management Agencies (Appendix E). As of June 2020, no high water mark data were provided by organizations for use in model calibration. However, high water mark data were available from the USGS for the 2008 flood event. These data were used in conjunction with the available gage data to perform the model calibration.

The model was developed using the best available data. The datasets may not reflect the exact conditions for specific flood events. For example, the available topobathy datasets may not exactly represent the conditions during the 2019 event since the bathymetric data was collected prior to the 2014 Flood that may have affected the bathymetry. Model performance through the calibration process is intended to provide a model that reasonably replicates historic events and serves as the best available tool to discuss systemic performance to develop a regional flood risk management strategy. The long term stage trends and normal stage-flow variations were not analyzed. Throughout this reach, the geomorphology of the Mississippi River is relatively stable throughout high and low flow events. It is expected that this model and its associated Manning roughness values and flow roughness factors will be applicable and produce reasonable model results for a range of flow events for the foreseeable future. This reach of the Mississippi River will most likely experience seasonal roughness variations and if this model is to be used to analyze winter floods, it may need to be re-calibrated with seasonal roughness variations included.

Model Uncertainty

The datasets used to develop the model all contain uncertainty and errors within the data. As a result the parameters used for calibration will reflect the compilation of the uncertainties from the input datasets. For example, the observed USGS flow hydrographs use rating curves that are developed from measured flows. These measured flows include relatively few measurements during high flow events. Therefore, there is higher uncertainty in the observed flow hydrographs near the peak flows than during normal flow conditions.

Another known uncertainty in the input data is the National Weather Service (NWS) ungaged inflow data. While this inflow data represents the best available data and is more reliable than alternative methods (drainage area ratio, HEC-RAS ungaged computation method), the NWS ungaged inflow data are estimates and therefore contain some uncertainty.

The topobathy dataset also includes uncertainty in the vertical accuracy from the original LiDAR and bathymetry data. The LiDAR metadata reports a 95% confidence accuracy of less than 1.0 feet while the bathymetry data vertical accuracy is published as +/- 0.5 ft as per ASPRS Class III Standards.

Calibration

Calibration Events

The UMR FRM hydraulic model was calibrated to four specific historic events and was not calibrated to a flow associated with a specific return interval (e.g., 100-yr flood). A comparison of this model with the 2004 UMRSFFS is outside the scope of this project. The historic events that were chosen were events that flooded the overbank areas and loaded the levees.

The computational time step for the calibration runs was 5 minutes for the 1D reaches and ranged between 10 and 50 seconds for the 2D flow areas, using 2D time slicing correlated to general mesh spacing for each 2D flow area. The historic events selected for calibration are the flood events of 2001, 2008, 2014, and 2019. Table 8 contains a summary of information regarding the peak discharge, date the peak discharge occurred, and estimated Annual Exceedance Probability (AEP) probability for the event at the location specified based on the information contained in the 2004 UMRSFFS.

Table 8. Historic Flood Events Used for Model Calibration

Calibration Events	Peak Flow (cfs) – LD 10 (est AEP)	Peak Flow Date – LD 10	Peak Flow (cfs) – LD 19 (est AEP)	Peak Flow Date – LD 19
2001	271,000 (~0.01)	21 April 2001	345,000 (~0.02)	15 May 2001
2008	167,000 (~0.20)	13 Jun 2008	433,000 (~0.002)	17 Jun 2008
2014	190,000 (~0.1)	4 July 2014	394,000 (~0.01)	7 July 2014
2019	241,000 (~0.04)	27 April 2019	470,000 ( )	30 May 2019

Boundary Conditions- Calibration

The upstream boundary condition for the mainstem Mississippi River at Lock and Dam 10 at Guttenberg, IA (RM 615) is a flow hydrograph of observed data for the respective flood event. A flow hydrograph is also used as the upstream boundary condition for all of the gaged tributaries. The downstream boundary condition on the mainstem Mississippi River at Keokuk, IA (RM 364) is a normal depth slope at the tailwater of Lock and Dam 19. Table 9 lists the gage locations along the Mississippi River.

Table 9. Gage and Reference Data Locations Along the Mississippi River

Location	River Station	Operating Agency	Data Types
Lock and Dam 10 Tailwater	615.1	USACE	Stage, Flow
Lock and Dam 11 Pool	583.19	USACE	Stage, Flow
Lock and Dam 11 Tailwater	582.99	USACE	Stage, Flow
Dubuque, IA	579.91	USACE	Stage
Lock and Dam 12 Pool	556.75	USACE	Stage, Flow
Lock and Dam 12 Tailwater	556.61	USACE	Stage, Flow
Lock and Dam 13 Pool	522.59	USACE	Stage, Flow
Lock and Dam 13 Tailwater	522.47	USACE	Stage, Flow
Beaver Slough (Clinton)	517.25	USACE	Stage
Camanche (Clinton)	512.02	USGS	Stage, Flow, Rating Curve
Lock and Dam 14 Pool	493.43	USACE	Stage, Flow
Lock and Dam 14 Tailwater	493.31	USACE	Stage, Flow
Lock and Dam 15 Pool	483.12	USACE	Stage, Flow
Lock and Dam 15 Tailwater	482.74	USACE	Stage, Flow
Fairport, IA	463.59	USACE	Stage
Lock and Dam 16 Pool	457.22	USACE	Stage, Flow
Lock and Dam 16 Tailwater	457.11	USACE	Stage, Flow
Muscatine, IA	453.15	USACE	Stage
Lock and Dam 17 Pool	437.18	USACE	Stage, Flow
Lock and Dam 17 Tailwater	437.08	USACE	Stage, Flow
Keithsburg, IL	427.63	USACE	Stage
Lock and Dam 18 Pool	410.46	USACE	Stage, Flow
Lock and Dam 18 Tailwater	410.39	USACE	Stage, Flow
Burlington, IA	403.18	USACE	Stage
Fort Madison, IA	383.99	USACE	Stage
Lock and Dam 19 Pool	483.12	USACE	Stage, Flow

Breach Analysis Parameters

Initially for all calibration events, levees that overtopped were assumed not to breach. After the initial calibration, recorded breach data was to be added to the model to improve calibration. Of the four simulated flood event the 2008 event was the only event where levees breached within the modeled reach. Breach data (breach date, width, and depth) were available for 2008 event and were included in the model simulation. The mainstem portions of the levees in Rock Island are generally constructed of sand resulting in full loss of section as a result of overtopping.

Calibration Method

Model calibration focused on reproducing flow and stage hydrographs at the gage locations along the Mississippi River. USGS flow and stage data and USACE stage data are considered the best sources of data. Unlike USGS flow data, USACE flow data is based on rating curves that are not routinely checked and improved based on regular discharge measurements. USACE flow data was used in the calibration effort, but the use of reasonable model parameters and reproducing stage hydrographs were deemed more important than reproducing the USACE flow hydrographs. Improvements to stage reproduction were mainly achieved through adjustments to roughness values. Manning's roughness values were based on the suggested values shown in Table 3. The roughness values for 2D areas are distributed based on the NLCD and applied geospatially in the HEC-RAS software. For the 1D cross section roughness values were distributed horizontally across each cross section based on NLCD using HEC-GeoRAS. General adjustments to Manning's roughness values provided the first level of adjustment. Flow-Roughness values, which provides adjustment to model roughness specified by flow ranges, provided the second level of adjustment. Tables of Flow-Roughness factors were added to the model geometry between each stage gage location. These factors were used to refine the stage calibration. The range of flow roughness factors varies from 0.8 to 1.2. A summary of these factors is presented in Appendix C-3.

Calibration Plots

Profile plots and hydrographs were created to display the results of calibration and are included in Appendices C-1 and C-2. These plots were created with the open-source software R using the package ggplot2. Note a few hydrographs are missing because the observed hydrograph is not available. The existing levee elevations on the profile plots were associated to river miles to display properly on the graph. This association was completed in ArcGIS. For the high water marks that are displayed on the profile plots, the gage peak stages are plotted at the same river mile as a gage, whereas the surveyed high water marks do not occur at gage locations. The profile plots in Appendix C-2 include symbols and abbreviations to reduce text on the plots. Table 10 describes the symbols used in the profile plots.

Table 10. Symbols and Abbreviations Used in Appendix C-2

Symbol	Description
●	High Water Mark – Color corresponds to flood event
#	Levee is Non-Federal Segment – Terrain Data
*	Levee is Non-Federal Segment - NLD

Appendices C-1 and C-2 displays hydrographs and profile plots with reference River Stations as determined by the HEC-RAS model centerline and stationing for each gage location. The HEC-RAS model stationing may be slightly different than the river mile for the gage as shown on navigation charts or other websites that display the gage location in river miles. These sources show the river mile of the gage location as associated with the navigation sailing line.

Sensitivity and Uncertainty

USACE Engineer Regulation (ER) 1105-2-101 (Reference 10) states "No project or action that is proposed, evaluated, adopted, and implemented, can completely eliminate or mitigate flood risks. Further, the information used to estimate flood risk, formulate and evaluate plans, and determine the results of the analyses is uncertain." The scope of work and funding for this project does not include a sensitivity and uncertainty analysis of key inputs, parameters, and model results for the UMR FRM hydraulic model. Uncertainties exist in natural environment systems due to many factors which may include (but are not limited to): variability in the time of year in which flood events occur, discharge contributions from ungaged portions of the river, the ability of instruments to accurately measure discharge during flood events (Reference 11), and assumptions that are made to fill in missing data such as levee breach initiation, timing, and final dimensions.

The model was developed and calibrated using deterministic methods to establish a single set (average) of parameters (Manning's "n", weir coefficients, junction computation mode etc.) and inputs (LIDAR, bathymetry, regulating structures, dam operations, inflow hydrographs, etc.). The model is well suited for use in discussing and developing planning level alternatives for FRM strategies. However, additional effort will be needed in the future to evaluate and assess statistical performance, resiliency, and long-term risk in accordance with USACE regulations and guidance which require the use of HEC-FDA (Flood Damage Assessment).

USACE Engineer Manual (EM) 1110-2-1619 (Reference 12) defines the procedure for determining the uncertainties of the performance of Flood-Damage Reduction plans, the discharge-probability function, and the stage-discharge function. Many factors can result in stage uncertainty and may include: cross section data, debris and obstructions, bed form and sediment transport, backwater effects, survey error, and measurement error. Additional functions may need to be evaluated depending on the scope and extent of follow-on studies.

Table 11 lists all the geometry files, unsteady flow files, and plan files contained in the existing conditions model.

Table 11. Geometry, Unsteady Flow, and Plan Files Used in the UMR FRM Hydraulic Model

Geometry Files	Unsteady Flow Files	Plan Files
UMR PhaseII Geometry	2001 Event	2001 Event
	2008 Event	2008 Event
	2014 Event	2014 Event
	2019 Event	2019 Event

HEC-RAS Model Applications

Section 408 System Performance Analysis

Discussions and scoping for this model initiated in 2014, as multiple drainage and levee districts were evaluating the feasibility of altering their levee systems, which would require USACE approval through the 33 USC 408 (Section 408) program. USACE guidance was in development that describes the process and risk assessments needed to comply with Engineering Circular (EC) 1165-2-216. As a result of the Section 408 process and guidance, discussions with state, Federal and NGO stakeholders were initiated that would ultimately align the support and develop the scope of work for a UMR FRM hydraulic model that could serve as the starting point for follow-on studies and Section 408 alteration requests by Drainage and Levee Districts. Non-Federal levee system alterations are required to follow applicable state floodplain regulations and are exempt from the Section 408 requirements. Appendix F of EC 1165-2-220 (Reference 13) outlines the procedures required to complete the Hydrologic and Hydraulic System Performance Analysis. EC 1165-2-216 was updated to 1165-2-220 on 10 September 2018. It is envisioned this existing conditions model will serve as a starting point for future Section 408 System Performance Analyses.

Quality Control

The review plan was developed in accordance with the requirements of EC 1165-2-217 (Reference 14). Participation from states/Federal/NGOs was incorporated into the review process. The following section describes the reviews.

USACE DQC Reviews

A District Quality Control Review was performed at the 75% model completion by an engineer in St. Paul. The 75% review consisted of reviewing the calibrated model using the existing levee condition.

State/Federal Technical Team Review

In addition to participating on the multiple coordination webinars, the state/Federal technical team was presented the opportunity to review the model and modeling report. Each agency was responsible for using their own funding to perform the reviews. One review period was provided for the state/federal technical team, after completion of the USACE 75% DQC review and concurrent with the USACE MMC ATR review.

USACE Modeling, Mapping and Consequences (MMC) Production Center ATR Review

The USACE MMC is responsible for providing modeling, mapping, and consequence support for all of USACE. The MMC maintains a virtual production team that produces hydrologic and hydraulic models that are used for risk based assessments for the Corps Water Management System (CWMS) along with the Dam and Levee Safety Programs. The MMC has been responsible for establishing many model development standards and have served as reviewers for H&H model reviews throughout USACE.

USACE MMC reviewed the model and report concurrently with the state/Federal technical team review, after USACE 75% DQC review was complete.

Summary

It is the responsibility of the non-Federal sponsor to complete the Section 408 alteration request and receive USACE approval prior to making physical changes to the levee. Discussions and scoping for this model initiated in 2014 as multiple drainage and levee districts were evaluating the feasibility of altering their levee systems which would require USACE approval through the 33 USC 408 (Section 408 program). USACE guidance was in development that describes the process and risk assessments needed to comply with EC 1165-2-220 (Reference 13). As a result of the Section 408 process and guidance, discussions with state, Federal and NGO stakeholders was initiated that would ultimately align the support to develop the scope of work for the UMR FRM hydraulic model that could serve as the starting point for follow-on studies and Section 408 alteration requests by Drainage and Levee Districts.

The calibrated existing conditions model was developed using the best available NLD data and uses one set of parameters that are representative of four flood events (2001, 2008, 2014, and 2019). The goal of this tool is to provide a common model using the best available data and software that can reasonably recreate a range of events that have occurred or may occur in the future to assess system performance and flood risk management strategies.

The use of the NLD data in this model does not alter the congressionally authorized elevation for individual levee systems or constitute retroactive USACE approval of the altered levee by bypassing the formal Section 408 process. The existing levee condition represents the sum of all activities (flood fighting, repairs, dredge material placement, approved and unapproved alterations) that have occurred over time. Model simulations and water surface profiles were developed for four flood events (2001, 2008, 2014, and 2019).

This existing conditions hydraulic model is a tool to more accurately evaluate and communicate impacts as a result of changes to the system that have occurred or will be proposed in future Section 408 alteration requests. The hydraulic model will improve flood preparation and response, real time river forecasting and real time inundation mapping. The need and applications for a UMR FRM hydraulic model is strongly supported by neighboring states, local communities, and NGOs.

REFERENCES

1. Hydrologic Engineering Center, February 2016. *HEC-RAS River Analysis System User's Manual,* U.S. Army Corps of Engineers, Davis, CA

2. Hydrologic Engineering Center, May 2012. *HEC-GeoRAS GIS Tools for Support of HEC-RAS using ArcGIS® 10*, U.S. Army Corps of Engineers, Davis, CA

3. Topographic Engineering Center, August 2004. *Corpscon Version 6.x Technical Documentation and Operating Instructions*, U.S. Army Corps of Engineers, Engineer Research and Development Center, Alexandria, VA

4. U.S. Army Corps of Engineers, 01 March 2009. *ER 1110-2-8160, Policies for Referencing Project Elevation Grades to Nationwide Vertical Datums*, Washington, D.C.

5. U.S. Army Corps of Engineers, 31 December 2010. *EM 1110-2-6056, Standards and Procedures for Referencing Project Evaluation Grades to Nationwide Vertical Datums*, Washington, D.C.

6. U.S. Army Corps of Engineers' Upper Mississippi River Restoration (UMRR) Program Long Term Resource Monitoring (LTRM) element. 2016, UMRR Pool 19 through Open River South Topobathy: La Crosse, WI, https://www.umesc.usgs.gov/

7. U.S. Geological Survey, 20141010, NLCD 2011 Land Cover (2011 Edition, amended 2014) - National Geospatial Data Asset (NGDA) Land Use Land Cover, U.S. Geological Survey, Sioux Falls, SD.

8. Modeling, Mapping, and Consequences, January 2017. *Technical Manual for Levees, Modeling, Mapping, and Consequences*, U.S. Army Corps of Engineers

9. Hydrologic Engineering Center, February 2016. *HEC-RAS River Analysis System 2D Modeling User's Manual*, U.S. Army Corps of Engineers, Davis, CA

10. U.S. Army Corps of Engineers, 1 March 1996. *ER 1105-2-101 Risk-Based Analysis for Evaluation of Hydrology/Hydraulics, Geotechnical Stability, and Economics in Flood Damage Reduction Studies*, Washington, D.C.

11. Hirsch, R. M., and J. E. Costa (2004), *U.S. Stream Flow Measurement and Data Dissemination Improve, Eos Trans. AGU, 85(20), 197–203, doi:* http://dx.doi.org/10.1029/2004EO200002.

12. U.S. Army Corps of Engineers, 1 October 2013. *EM 1110-2-1619 Risk Analysis for Flood Risk Management Studies*, Washington, D.C.

13. U.S. Army Corps of Engineers, 10 September 2018. *EC 1165-2-220 Policy And Procedural Guidance For Processing Request To Alter US Army Corps of Engineers Civil Works Projects Pursuant to 33 USC 408*, Washington, D.C.

14. U.S. Army Corps of Engineers, 20 February 2018. *EC 1165-2-217 Water Resources Policies and Authorities Review Policy for Civil Works,* Washington, D.C.