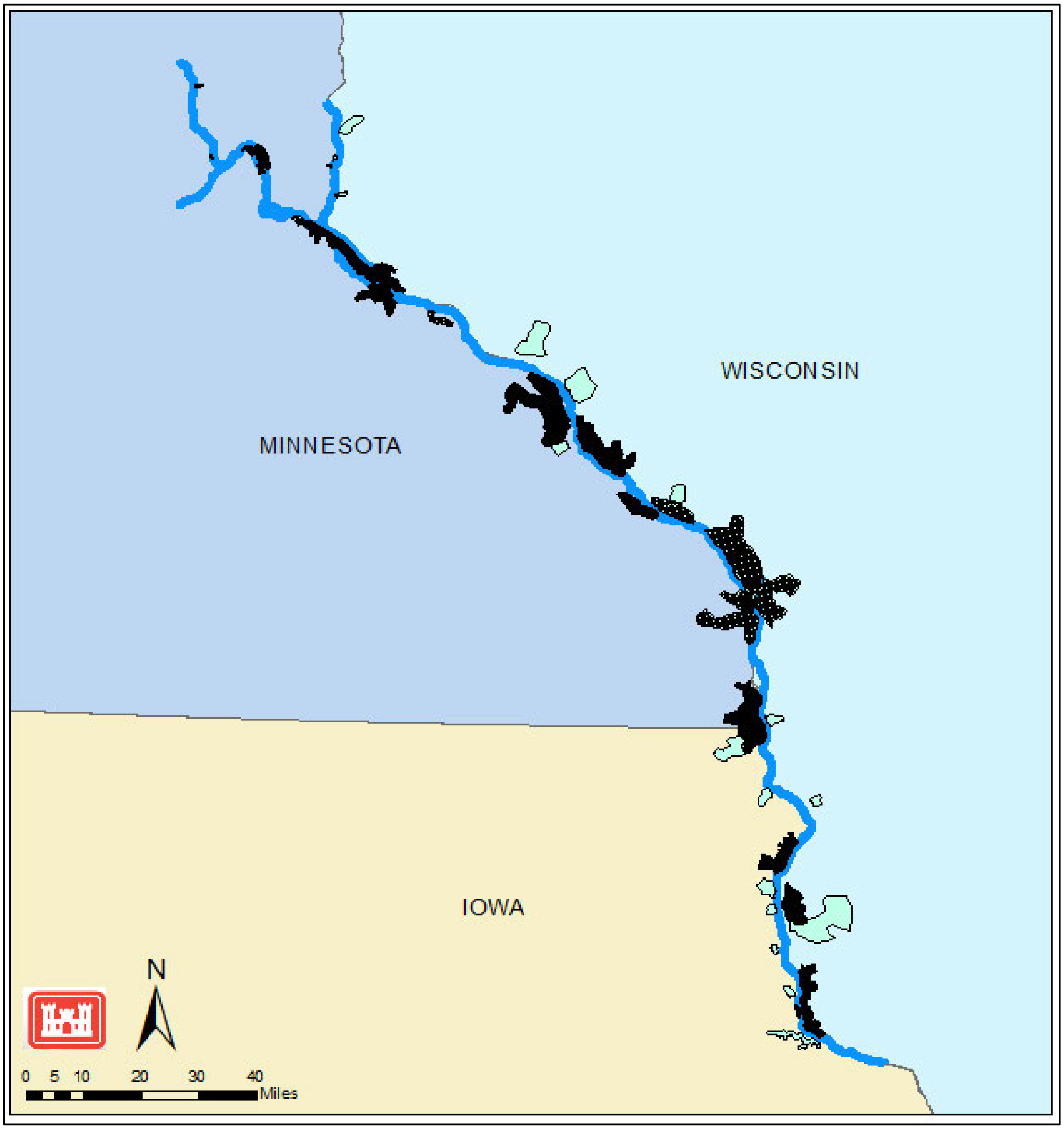
US Army Corps of Engineers ®

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



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EXECUTIVE SUMMARY

The Upper Mississippi River (UMR) watershed has experienced more frequent flood events with increasing damages and threats to human life. The U. S. 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 IV covers the fourth river segment (Anoka, MN, to Guttenberg, IA). The first river segment, Phase I, (from Keokuk, IA to Thebes, IL) was completed in 2018. The second river segment hydraulic model (Guttenberg, IA to Keokuk, IA) is being developed concurrently with this model segment. 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.

Development and calibration of the fourth model segment was funded by the USACE Levee Safety Program. This segment covers 251 river miles of the UMR main stem from the Coon Rapids Dam tailwater in Coon Rapids, Minnesota (River Mile 866.29) to the middle of pool 11, downstream of Guttenberg, Iowa (River Mile 615).

National Levee Database (NLD) levee surveys were completed in 2008 and 2010 for St. Paul 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 approval 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. 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 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 three flood events (2001, 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.

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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 IV 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 IV reach (Coon Rapids, MN, to Guttenberg, 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; 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 and local agencies, and non-governmental organizations (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.

Model Updates

USACE will periodically evaluate the model to determine when it needs updating. Updates to 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 St. Paul District Public Affairs Office at 651-290-5402. 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 analyses, and have not been made available to stakeholders. These models were not used in their entirety to create the UMR FRM hydraulic model, as many of them were created using different software versions and older terrain data. There are features that may have been adopted from these previous efforts.

Two major tributaries to the Mississippi River, the Minnesota River and the St. Croix River, were included in the UMR FRM model. The minimum geographic extents of the tributaries included in this

model are from each tributary's confluence with the Mississippi River upstream to its first flow gage. The tributaries had models that were previously developed and for this effort, those models were combined with the newly developed Mississippi River mainstem model.
In 2004, USACE completed the UMRSFFS, which updated the discharge frequency relationships and water surface profiles for the Mississippi River System upstream of Cairo, Illinois. 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 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.

Geographic Coverage

The UMR FRM Phase IV hydraulic model includes the Mississippi River from the tailwater of the Coon Rapids Dam in Coon Rapids, MN, (River Mile 866.29) to Lock and Dam No. 11 pool (River Mile 596.09), which is downstream of Guttenberg, IA. The model also covers the lower portions of the Minnesota River and the St. Croix River. In total the detailed reaches of the model cover approximately 335 river miles and 13 navigational dams. The Rock Island District is developing the Phase II 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 IV model reach occurred in 1993, 1997, 2001, 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 1D/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. 2D areas were used to capture complicated flows, such as braided channels, secondary channels and leveed areas. Modeling the leveed areas as 2D areas would be 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	Reach Description (e.g., BelowStCroix)
Junction Names	Tributary Name/General Location (e.g., DS StCroix, US GreyCloud)
Storage Areas/2D Flow Area Names	Town/Community Name or Tributary Name (e.g., Afton, BuckCreek)
SA/2D Area Connection Names	General Location Reference (e.g., Dakota, LD9)

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 the conversions at structures and gages within the Phase IV efforts.

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 -0.05 to -0.15 feet. Conversions from MSL 12 to NAVD 88 ranged from -0.28 to -0.69 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 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 Zone 15. The dataset went through a horizontal transformation to convert it to Albers Equal Area Conic before being used in model development.

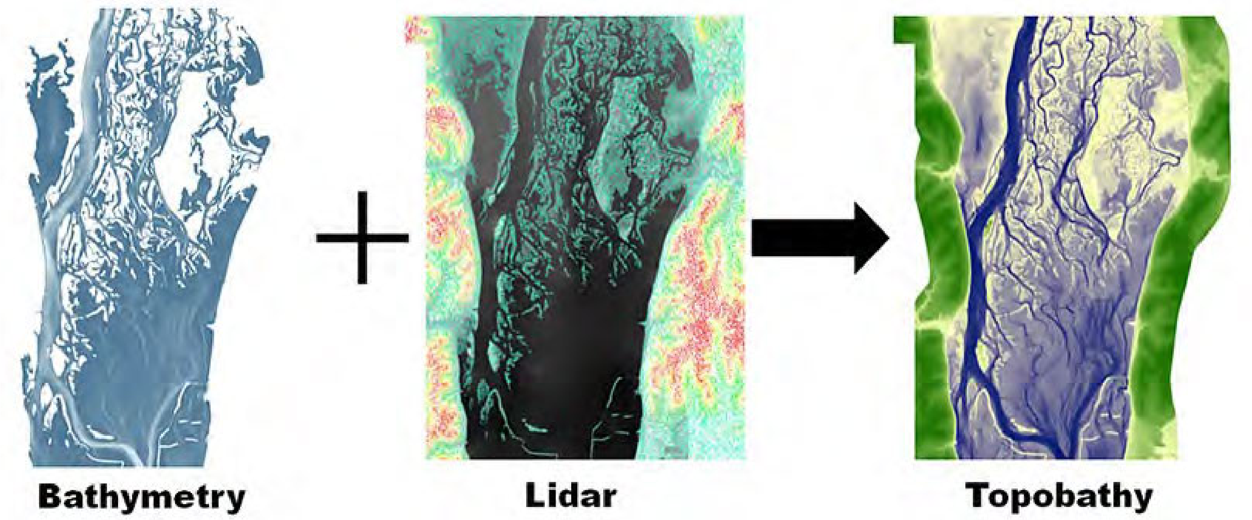

Figure 1. Topobathy Dataset Development (Reference 6)

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) from 2004-2012. 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 1986, 1989-2010, and 2015. 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.

Table 2. Data Sources and Collection Dates for Topobathy Dataset

Location	LiDAR Source	LiDAR Collection Dates	Bathymetry Source	Bathymetry Collection Dates
Pool 2	USACE UMRR	2011, 2012	USACE UMRR	2000, 2008, 2015
Pool 3	USACE UMRR	2009, 2010	USACE UMRR	2008, 2009
Pool 4	USACE UMRR	2004, 2008, 2010	USACE UMRR	1989-1993, 1997, 1998, 2001
Pool 5	USACE UMRR	2004	USACE UMRR	1986, 1991-1993, 1995-2001, 2010
Pool 5A	USACE UMRR	2004, 2008	USACE UMRR	1999, 2003-2010
Pool 6	USACE UMRR	2008	USACE UMRR	2006, 2008, 2010
Pool 7	USACE UMRR	2007, 2008	USACE UMRR	1994, 1995, 1997, 1998
Pool 8	USACE UMRR	2009	USACE UMRR	1989-1992, 1995-1998, 2003-2009
Pool 9	USACE UMRR	2007	USACE UMRR	1996-1999
Pool 10	USACE UMRR	2007	USACE UMRR	1996-1999, 2001, 2010
Pool 11	USACE UMRR	2007	USACE UMRR	1999, 2001-2008, 2010

Supplementary LiDAR data were needed to produce the HEC-RAS model as the UMRR LTRM LiDAR did not extend upstream of Lock and Dam 2 or up the tributaries past the Mississippi River bluff. The supplementary LiDAR data were downloaded from state agencies and ranged from 1-2 meter in horizontal resolution.

Two digital elevation models (DEMs) were created for modeling effort. A finer resolution DEM was created in ArcMap and used with HEC-GeoRAS to generate most of the model geometry (cross-sections, lateral structures, bridge embankments, and other connections). However due to file size issues, the HEC-RAS terrain developed for the study area and used for the geometry of the 2D flow areas needed to be slightly coarser.

Bank Stations

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.

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 the 2D elements of the model, the Manning roughness coefficients were determined directly from the National Land Cover Database (NLCD) 2016 Land Cover file (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 (*HEC-RAS Hydraulic Reference Manual* (Reference 8) and *HEC-RAS 2D Modeling User's Manual* (Reference 9) were used to estimate the initial Manning roughness values. These values were further refined during the model development and calibration.

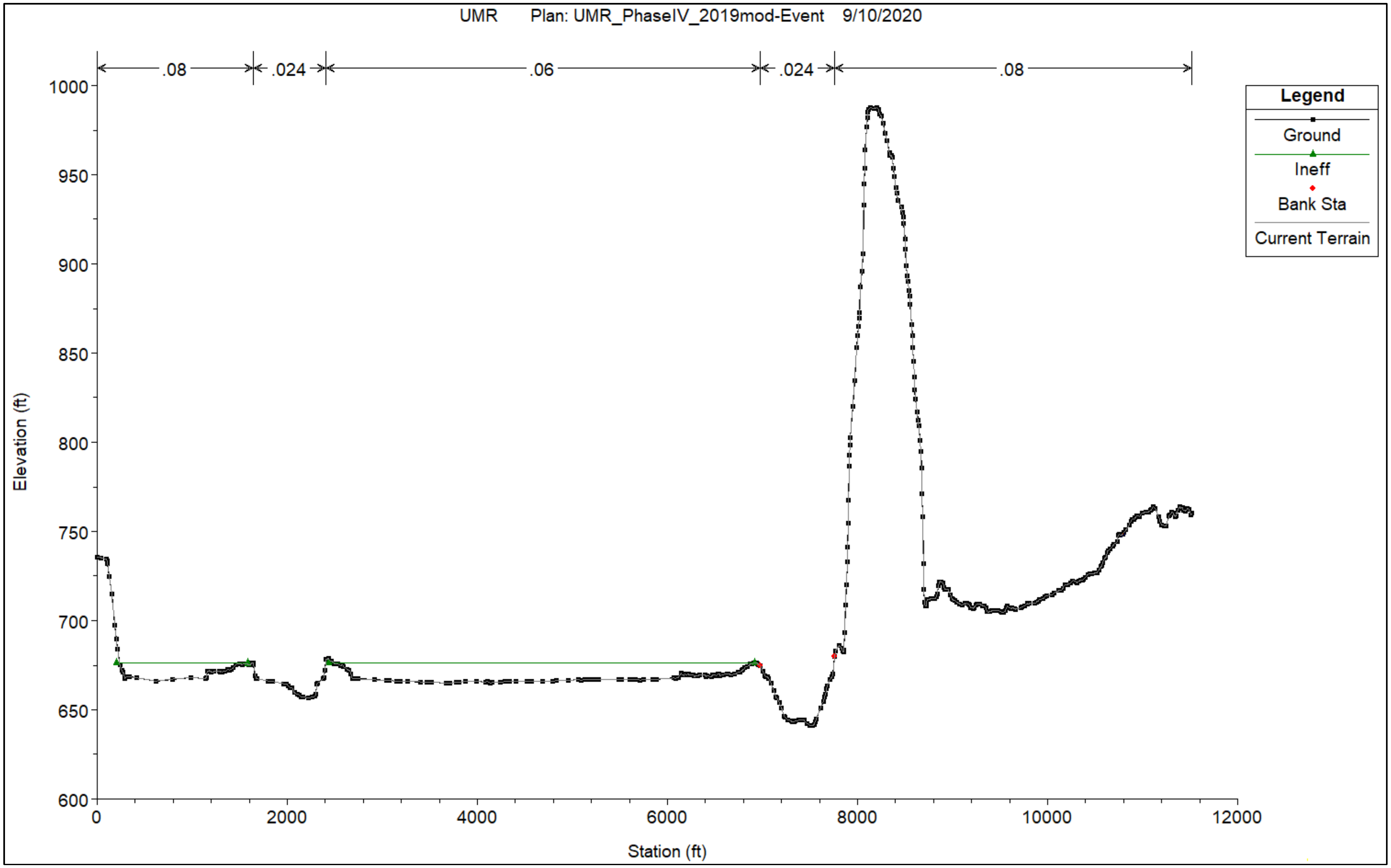

Figure 2. Example Cross Section from HEC-RAS with Manning Roughness Coefficients Displayed Along Top of Cross Section

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"
31	Barren land rock/sand/clay	0.06
82	Cultivated crops	0.06
41	Deciduous forest	0.1
24	Developed, high intensity	0.15
22	Developed, low intensity	0.1
23	Developed, medium intensity	0.08
21	Developed, open space	0.04
95	Emergent herbaceous wetlands	0.06
42	Evergreen forest	0.12
71	Grassland/herbaceous	0.045
43	Mixed forest	0.08
11	Open water	0.035
81	Pasture/hay	0.06
52	Shrub/scrub	0.08
90	Woody wetlands	0.12

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 that fell within the model footprint were included in the HEC-RAS model. Bridge geometries were incorporated from previous modeling efforts, manly from the 2017 CWMS efforts and the 2004 UMRFFS model. Based on the previous model's documentation, the bridge geometries were determined from the best available as-builts, design drawings or estimated. The critical bridge information needed for HEC-RAS includes high and low chord elevations of the bridge deck, pier width, and pier spacing. For most 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, or estimated with the use of aerial imagery. There are locations where bridges or controlling embankments, which may have been removed road or railroad bridges, where modeled as bridges with the bridge deck elevation significantly higher than the embankment and river. In almost all cases, the bridges built over the Mississippi River are significantly higher than most expected flood events and the main governing features would be the overbank approach roads and railways. 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	River Mile	Bridge Name(s)	Type	Low Chord Elevation (ft, NAVD88)
Black	701.74	I-90 Bridge	Vehicle	679.93
Black	700.14	Clinton St Bridge	Vehicle	679.93
Black	699.77	Railroad Bridge	Railroad	679.93
Minnesota	10.28	I-35W (Burnsville) Bridge	Vehicle	740.43
Minnesota	6.715	Old Cedar Ave S Bridge	Vehicle	720
Minnesota	6.68	Highway 77/Cedar Ave Bridge	Vehicle	726.32
Minnesota	3.67	Highway 494 Bridge	Vehicle	725.35
Mississippi	865.06	Highway 610 Bridge	Vehicle	832.93
Mississippi	860.43	I-694 Bridge	Vehicle	837.35
Mississippi	857.75	37th Ave NE Bridge	Vehicle	824.13
Mississippi	857.55	Soo Line Railroad Bridge	Railroad	826.7
Mississippi	856.39	Lowry Ave Bridge	Vehicle	811.42
Mississippi	855.8	Burlington Northern Bridge	Railroad	819.85
Mississippi	855.43	Broadway Ave Bridge	Vehicle	812.2
Mississippi	855.02	Plymouth Ave Bridge	Vehicle	806.86
Mississippi	853.35	I-35W Bridge	Vehicle	798.17
Mississippi	853.28	10th Ave Bridge	Vehicle	800.57
Mississippi	853.15	Northern Pacific Bridge	Railroad	803.1
Mississippi	852.79	MN-122 (Washington Ave) Bridge	Vehicle	805.21
Mississippi	851.74	I-94 Bridge	Vehicle	800.74
Mississippi	851.5	Franklin Ave Bridge	Vehicle	808.49
Mississippi	850.72	Soo Line Railroad Bridge	Railroad	825.49
Mississippi	849.91	Lake Street Bridge	Vehicle	810.04
Mississippi	847.77	Ford Parkway Bridge	Vehicle	805.08
Mississippi	845.6	MN-5 Bridge	Vehicle	845.6
Mississippi	843.23	I-35E Bridge	Vehicle	745
Mississippi	841.37	Chicago and Northwestern Railroad Bridge	Railroad	705.54
Mississippi	840.4	S Smith Ave Bridge	Vehicle	833.75
Mississippi	839.43	Chicago and Northwestern Railroad Bridge	Railroad	758.55
Mississippi	839.23	Robert Street Bridge	Vehicle	727.99
Mississippi	838.77	US Highway 52 Bridge	Vehicle	747
Mississippi	835.76	S St. Paul Railroad Bridge	Railroad	708.47
Mississippi	832.52	Interstate Highway 494 Bridge	Vehicle	752
Mississippi	830.35	Old Rock Island Swing Bridge	Railroad	705.65
Mississippi	814.04	US Hwy 61 Bridge	Vehicle	731.6
Mississippi	813.68	Hastings Railroad Bridge	Railroad	698.2
Mississippi	790.56	MN, Highway 63	Vehicle	716
Mississippi	760.22	Wabasha-Nelson Bridge	Vehicle	716
Mississippi	725.85	Winona St Bridge	Vehicle	706.38
Mississippi	725.66	Historic Wagon Bridge	Walking	699.95
Mississippi	701.73	Interstate Highway 90 Bridge	Vehicle	709.94
Mississippi	699.77	Railroad Bridge	Railroad	679.93
Mississippi	697.58	US Hwy 61 Bridge	Vehicle	695.84
Mississippi	663.36	Black Hawk Bridge	Vehicle	659.85
Mississippi	634.7	Marquette–Joliet Bridge	Vehicle	679.85
St Croix	22.05	New Hwy 36 Bridge	Vehicle	760

St Croix	17.35	Hudson RR Bridge	Railroad	691.31
St Croix	16.13	I-94 Bridge	Vehicle	714.08
St Croix	0.35	US-10 Bridge	Vehicle	703.22
St Croix	0.28	Prescott RR Bridge	Railroad	689
Vermillion	10.56	County 18 Blvd Bridge	Vehicle	687.53
Vermillion	5.38	Prairie Island Bridge	Vehicle	688.26
Vermillion	1.81	Railroad Bridge	Railroad	687.31

Inline Structures

Inline structures, which included navigation dams and other bridges 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. It should be noted that at Lock and Dam 10, the HEC-RAS operations are based on hinge-point operations, where the actual operations are based on a tertiary operations and therefore at low flows below about 90 kcfs, the water surface profiles may be incorrect. Table 5 lists the lock and/or dam structures included in the model geometry with the associated river mile.

Table 5. Lock and Dams Included in UMR FRM Hydraulic Model Geometry

River Mile	Lock and Dam/Inline Structure Name
854.18	Upper St. Anthony Falls Horseshoe Dam
854	Upper St. Anthony Falls Spillway Dam
853.49	Lower St. Anthony Falls Dam
847.6	Lock and Dam 1
815.19	Lock and Dam 2
796.88	Lock and Dam 3
752.83	Lock and Dam 4
738.15	Lock and Dam 5
728.49	Lock and Dam 5a
714.26	Lock and Dam 6
702.47	Lock and Dam 7 and Onalaska Dam
679.24	Lock and Dam 8
647.95	Lock and Dam 9
647.95	Lock and Dam 10

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 and in areas of complicated flow patterns. 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 2D flow 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/2D Connections

National Levee Database (NLD) levee surveys were completed in 2008 and 2010 for USACE St. Paul District. The latest available NLD elevation data was applied to the lateral structures and 2D connections 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 NOT included in the levee elevations. The closure structure station-elevation data is based on the topobathy terrain. During high flow model simulation runs, water will break out into leveed areas. 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 St. Paul District’s NLD database in the summer 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/2D connections were used to allow flow to pass between 1D storage areas/2D flow areas. Lateral structures and 2D connections that represent levees primarily used the surveyed existing (NLD) levee elevations. For this hydraulic model, all levees are represented as lateral structures and 2D connections, but not all lateral structures and 2D connections are levees. Non-levee lateral structures and 2D connections 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 and 2D connections were originally developed in HEC-GeoRAS to obtain georeferenced elevations and then were subsequently imported into the HEC-RAS model. 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

Two major gaged tributaries, the Minnesota River and the St. Croix River, were included as separate routing reaches explicitly in the UMR FRM hydraulic model, with the remainder of the tributaries modeled with 1D storage areas, or 2D areas. Tributary model reaches extend from the confluence of the Mississippi River upstream to at least where the most downstream USACE or USGS gaging location, Savage, MN, for the Minnesota River, and Stillwater, MN, for the St. Croix River. 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. USACE used previously developed HEC-RAS models that were used as a part of other studies and projects which include Corps Water Management System (CWMS) models.

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. Confluences between rivers are modeled as junctions. The computation mode used at most junctions was the Force - Equal Water Surface Elevations. The tributary 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.

Several tributary models were not modeled with separate reach lengths, including the Wisconsin and Chippewa Rivers. These rivers had no preexisting models, so it was determined that these reaches would be modeled with the use of 1D storage areas and 2D areas that spanned sufficiently upstream of the confluence with the Mississippi River. With the use of 1D storage areas and 2D areas, the timing from these tributaries will not be captured as accurately as a modeled reach, but they will be sufficient enough so that the HEC-RAS model will produce accurate hydrographs and profiles along the Mississippi River. Table 6 lists the gaged tributaries and how they were placed within the model.

Table 6. Gaged Tributary Inflows of the UMR Model

State	Tributary and Gage Location	Input Location (River Mile/Storage Area/2D Area)	Gage Drainage Area (sq mi)
MN	Minnehaha Creek in Minneapolis, MN	Minnehaha Creek Storage Area	176
MN	Minnesota River at Savage, MN	Cross Section 843.9	16,900
MN/WI	St. Croix River at Stillwater, MN	Cross Section 811.39	7,650
MN	Vermillion River near Empire, MN	LD 3, Pool 2D Area	129
MN	Cannon River at Welch, MN	Cannon River Storage Area	1,340
WI	Chippewa River at Durand, WI	Chippewa River 2D Area	9,010
WI	Trempealeau River at Dodge, WI	Trempealeau River Storage Area	643
WI	Black River near Galesville, WI	LD7-1 2D Area	2,080
IA	Upper Iowa River near Dorchester, IA	Upper Iowa River Storage Area	770
WI	Wisconsin River at Muscoda, WI	Prairie du Chien 2D Area	10,400

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 at a specific cross section, storage area or 2D area. During the modeling process, the NCRFC was consulted into how to best input and scale the inflow between the locations within the model. For instance, it was determined that the Guttenberg inflows be split between the PrairieduChien 2D area at 67%, and the remaining 33% be placed in cross section 616.17. Table 7 lists the locations of ungaged inflow to the model and how they were placed into the HEC-RAS model.

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.

Table 7. NWS North Central River Forecast Center Ungaged Inflows of the UMR Model

Location Name	Input location (River Mile/Storage Area/2D Area)	Inflow Type
Rice Creek Total	Rice Creek Storage Area	Lateral Inflow
St. Paul - Ford Plant Local	847.82	Lateral Inflow
St. Paul - Smith Ave Bridge Local (20%)	841.96	Lateral Inflow
Hastings/Lock and Dam 2 Local	814.41	Lateral Inflow
Prescott Local	811.36	Lateral Inflow
Red Wing/Lock and Dam 3 Local	797.5	Lateral Inflow
Wabasha Local	761.88	Lateral Inflow
La Crosse River Total	LD7-2 2D Area	Flow Hydrograph
Alma Local	753.59	Lateral Inflow
Whitewater Total	Whitewater River Storage Area	Lateral Inflow
Zumbro River Total	Kellogg 2D area	Flow Hydrograph
Minnesota City Local	738.3	Lateral Inflow
Winona/Lock and Dam 5a Local	728.63	Lateral Inflow
Winona Local/LD5a Local	726.15	Lateral Inflow

Trempealeau/Lock and Dam 6 Local	714.53	Lateral Inflow
La Crescent/Lock and Dam 7 Local	702.12	Lateral Inflow
Root River Total	LD7-3 2D Area	Flow Hydrograph
La Crosse Local	697.98	Lateral Inflow
Brownsville Local	681.3	Lateral Inflow
Lansing Local	663.18	Lateral Inflow
Lynxville/Lock and Dam 9 Local	648.48	Lateral Inflow
Yellow River Total	Yellow River Storage Area	Lateral Inflow
McGregor Local	633.68	Lateral Inflow
Guttenberg/Lock and Dam 10 Local (67%)	Prairie du Chien 2D Area	Flow Hydrograph
Guttenberg/Lock and Dam 10 Local (33%)	616.17	Lateral Inflow

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 (Appendix E). As of July 2020, no high water mark data were provided for use in model calibration. Available gage data was used exclusively for 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 three specific historic events. It 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 2 minutes and the time step for the 2D flow areas was also 2 minutes. The historic events selected for calibration are the flood events of 2001, 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

	Lock and Dam No. 2		Lock and Dam No. 10	
Calibration Events	**Peak Flow (cfs) (est AEP)**	**Date**	**Peak Flow (cfs) (est AEP)**	**Date**
2001	141,000 (~0.01)	28APR01	271,000 (~0.01)	21APR01
2014	101,000 (~0.04)	27JUN14	190,000 (~0.1)	04JUL14
2019	105,000 (~0.04)	01APR19	240,000 (~0.03)	27APR19

As the calibration process progressed, it became apparent that it was going to be very difficult to calibrate well to all of the available USGS flow data for two of the three historic events. Ungaged inflow, which is a larger percentage of the total river flow in the upper portion of the Mississippi River, is an estimated model input and was identified as the likely reason for the flow calibration challenges. The ungaged inflows seem reasonable for the 2014 flood event, which is the smallest of the historic events used for calibration, but they appear too high between USGS gage at Red Wing, MN, and the USGS gage at Winona, MN, for the larger 2001 and 2019 flood events. To help correct the differences in flows between the Red Wing and Winona gages, the ungaged flows were removed and only gaged tributary flows between these two gages were used. Figures 3 and 4 show the comparisons between the original flows and the modified flows for the 2001 and 2019 events at Winona, MN, USGS gage.

The modified 2001 (2001MOD) and 2019 (2019MOD) flow inputs were adopted for the remainder of the calibration process.

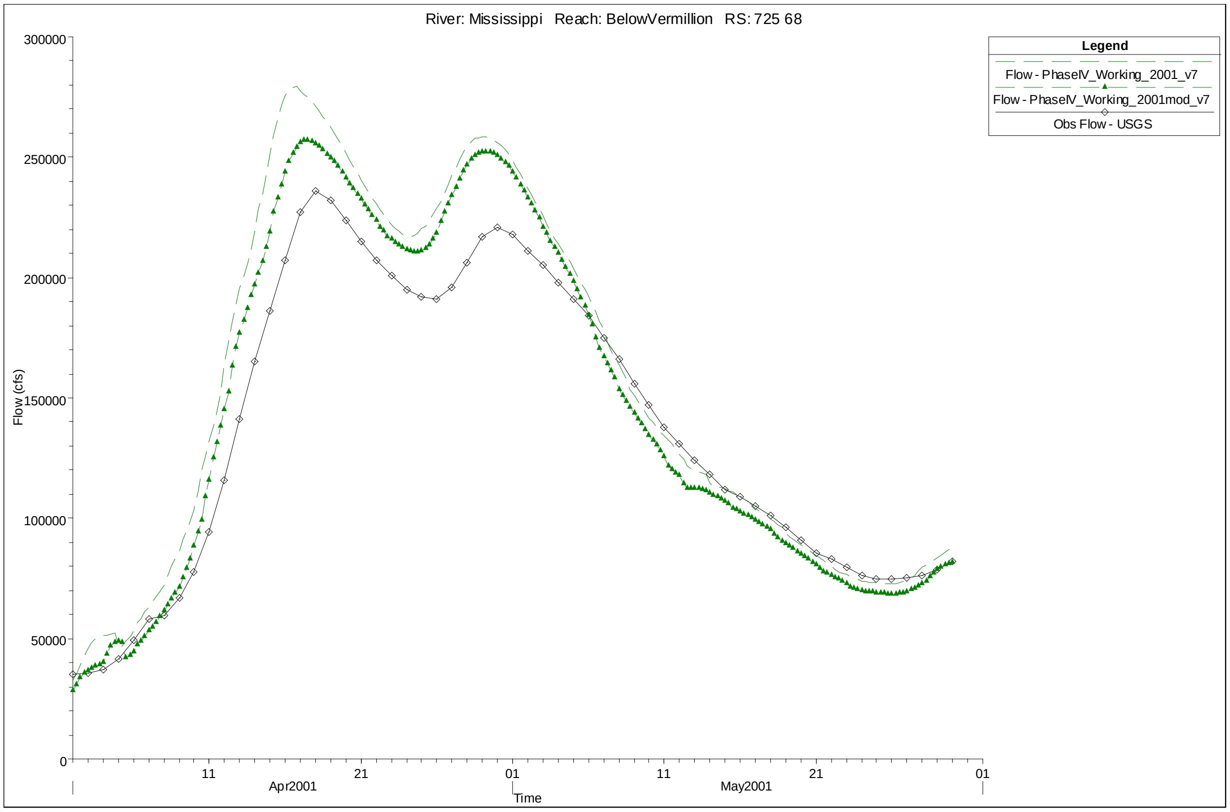

Figure 3. 2001 Original and Modified Flows vs Observed Flows at Winona, MN

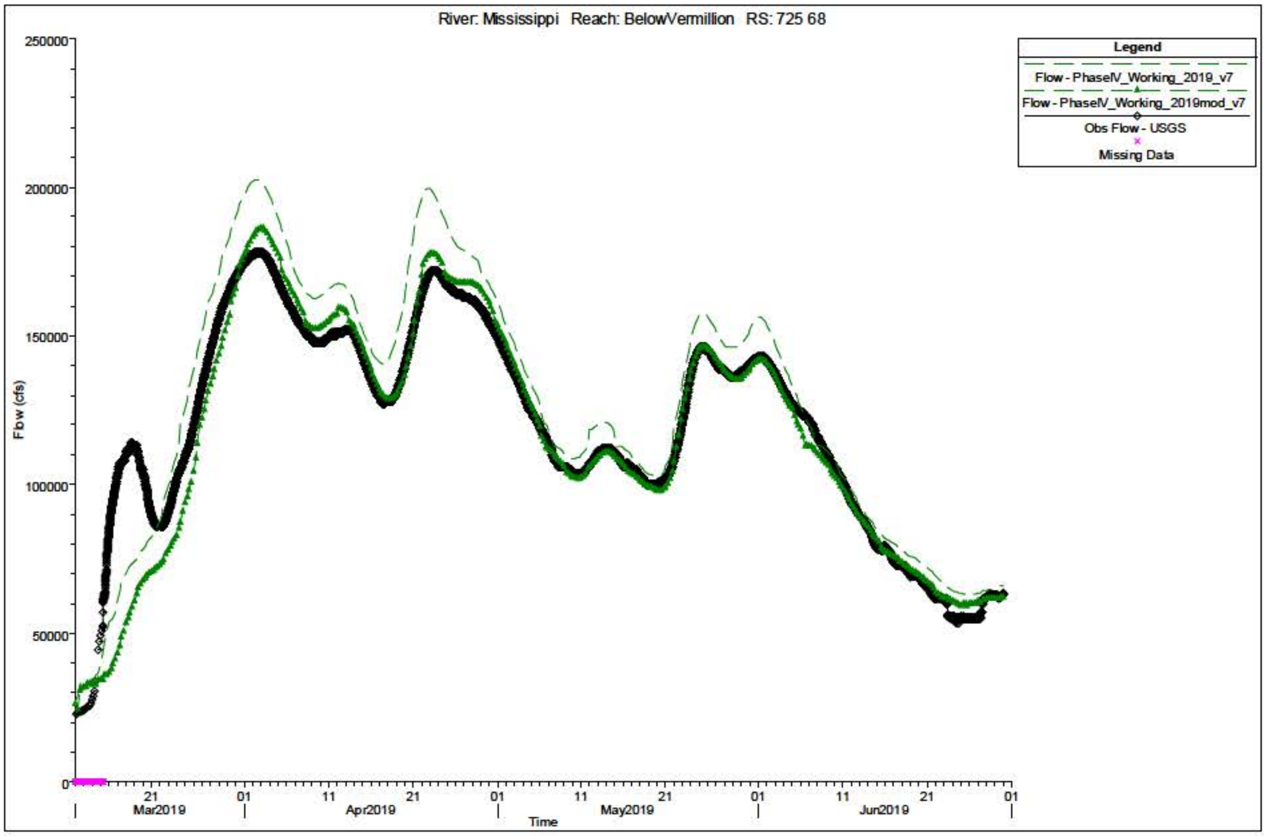

Figure 4. 2019 Original and Modified Flows vs Observed Flows at Winona, MN

Boundary Conditions- Calibration

The upstream boundary condition for the mainstem Mississippi River at the tailwater of the Coon Rapids Dam, MN, river mile 866.29, is a flow hydrograph of observed data for the respective flood event from the Mississippi River at Hwy 610 in Brooklyn Park, MN, USGS gage. A flow hydrograph is also used as the upstream boundary condition for all of the gaged tributaries where data was available. The downstream boundary condition on the mainstem Mississippi River at Pool 11 is a rating curve obtained from the Phase II model at the same cross section. Table 9 lists the gage locations along the Mississippi River.

Table 9. Gage Data Locations Along the UMR

Location	River Station	Operating Agency	Data Types
Highway 610 in Brooklyn Park, MN	864.83	USGS	Flow
St. Paul, MN	839.25	USGS	Stage, Flow
South St. Paul, MN	833.63	USACE	Stage
Lock and Dam 2 Pool	815.43	USACE	Stage, Flow
Lock and Dam 2 Tailwater	814.98	USACE	Stage
Hastings, MN	813.69	USGS	Stage, Flow
Prescott, WI	811.27	USGS	Stage, Flow
Lock and Dam 3 Pool	797.08	USACE	Stage, Flow
Lock and Dam 3 Tailwater	796.75	USACE	Stage
Red Wing, MN	790.93	USGS	Flow
Lake City, MN	722.6	USACE	Stage

Wabasha, MN	760.52	USACE	Stage
Lock and Dam 4 Pool	753.12	USACE	Stage, Flow
Lock and Dam 4 Tailwater	752.6	USACE	Stage
Alma, WI	749.83	USACE	Stage
Lock and Dam 5 Pool	738.3	USACE	Stage, Flow
Lock and Dam 5 Tailwater	737.92	USACE	Stage
Lock and Dam 5A Pool	728.63	USACE	Stage, Flow
Lock and Dam 5A Tailwater	728.27	USACE	Stage
Winona, MN	725.68	USGS	Stage, Flow
Lock and Dam 6 Pool	714.53	USACE	Stage, Flow
Lock and Dam 6 Tailwater	714.03	USACE	Stage
Lock and Dam 7 Pool	702.55	USACE	Stage, Flow
Lock and Dam 7 Tailwater	702.28	USACE	Stage
La Crosse, WI	697.98	USACE	Stage
Brownsville, MN	689	USACE	Stage
Lock and Dam 8 Pool	679.38	USACE	Stage, Flow
Lock and Dam 8 Tailwater	679.03	USACE	Stage
Lansing, IA	663.18	USACE	Stage
Lock and Dam 9 Pool	648.03	USACE	Stage, Flow
Lock and Dam 9 Tailwater	647.67	USACE	Stage
McGregor, IA	633.28	USGS	Stage, Flow
Clayton, IA	624.72	USGS	Stage
Lock and Dam 10 Pool	615.27	USACE	Stage, Flow
Lock and Dam 10 Tailwater	615.04	USACE	Stage

Breach Analysis Parameters

The NLD levees within the study area did not overtop for the three historic events modeled. Therefore, a levee breach analyses was not conducted.

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. Improvement to stage reproduction were mainly achieved through adjustments to roughness values, ineffective areas and weir coefficients. In the 2D areas, Manning's roughness values were set to the values shown in Table 3. For 1D cross-sections, in general, a single Manning's n value was assigned to the channel and the left and right overbank areas, but horizontally varied Manning's n value were used where the channel is braided or where a significant secondary channel exists. For each cross section the initial Manning's n value assignment was based on a general assessment of land cover using aerial imagery. General adjustments to Manning's roughness values provided the first level of adjustments. If further calibration was needed, ineffective flows were reassessed and weir coefficients were adjusted.

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 HEC-RAS and with the use of spreadsheets. The profile plots in Appendix C-2 include symbols and abbreviations to reduce text on the plots. 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.

HEC-RAS Model Files

The HEC-RAS model consists of many different files, but the main files are the project, geometry, unsteady flow and plan files. The main files that make up the Phase IV model for the existing conditions are listed in Table 10.

Table 10. Geometry, Unsteady Flow, and Plan Files Used in the UMR FRM Hydraulic Model

Geometry Files	Unsteady Flow Files	Plan Files
UMR_PhaseIV	NCRFC_Inflows_2001	UMR_PhaseIV_2011-Event
	NCRFC_Inflows_2001mod	UMR_PhaseIV_2019mod-Event
	NCRFC_Inflows_2014	UMR_PhaseIV_2014-Event
	NCRFC_Inflows_2019	UMR_PhaseIV_2019-Event
	NCRFC_Inflows_2019mod	UMR_PhaseIV_2019mod-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: Policy and Procedural Guidance for Processing Requests to Alter USG Army Corps of Engineers Civil Works Projects Pursuant to 33 USC 408, which was updated to EC 1165-2-220 on 10 September 2018. 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 H of EC 1165-2-220 outlines the procedures required to complete the Hydrologic and Hydraulic System Performance Analysis. 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: Review Policy for Civil Works. Participation from state, Federal, and NGO stakeholders was incorporated into the review process. The following section describes the reviews.

USACE DQC Reviews

A DQC Review was performed at the 25% and 75% model milestones by an engineer in the St. Paul District. The 25% review consisted of a general review of the geometry layout, and the 75% review consisted of reviewing the calibrated model.

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.

North Central River Forecast Center (NCRFC) provided quality review comments on the model. Many of the comments were resolved, including adding an additional gage location, questioning inflow locations and LiDAR accuracy. There were comments that were not fully addressed. These comments revolve around extending the modeling further upstream to forecast locations. While the value of extending the models further upstream for this purpose is obvious, these requests fell outside of the project's scope of work. To resolve these comments the NCRFC provided alternatives, such as scaling, redistributing and splitting the inflows.

USACE Modeling, Mapping and Consequences 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 three flood events (2001, 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, 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.

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