



Prepared by/for:
**Modeling, Mapping,
and Consequences**

Technical Manual for Levees

**Modeling, Mapping, and
Consequences**

June 2026

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SECTION 1—PURPOSE OF LEVEE TECHNICAL MANUAL

The Modeling, Mapping, and Consequences (MMC) Production Center Technical Manual for Levees summarizes the sequence of procedures used by the MMC to complete new levee studies or update existing levee studies. Necessary guidance and relevant technical information is provided for each step in the procedure.

The FY2026 technical manual does not incorporate any procedural changes. Changes to the manual are administrative in nature.

SECTION 2—MODELING, MAPPING, AND CONSEQUENCES

LEVEE POINTS OF CONTACT

Table 2.1. Levee Points of Contact

Section	Points of Contact	Phone	E-mail
Program Management	Holly Porter	601-631-5043	Holly.g.porter@usace.army.mil
Project Manager	John Barnett	601-631-5516	John.I.barnett@usace.army.mil
Technical Manager	Dana Moree	601-631-5365	Dana.M.Moree@usace.army.mil
Mapping	Adrian Christopher Nate Dougherty	816-389-3278 402-995-2278	Adrian.V.Christopher@usace.army.mil Nathan.E.Dougherty@usace.army.mil
Modeling	Dana Moree	601-631-5365	Dana.M.Moree@usace.army.mil
Consequences	Kurt Buchanan Susannah Byrd	304-399-5187 402-670-0159	Kurt.L.Buchannan@usace.army.mil Susannah.E.Byrd@usace.army.mil
Documentation	Tabetha Hesseldenz Brandon Petry	816-389-3474 816-389-2439	Tabetha.S.Barto@usace.army.mil Brandon.A.Petry@usace.army.mil
National Levee Database	Brian Vanbockern Patrick Kline	816-389-3965 816-389-3599	Brian.D.Vanbockern@usace.army.mil Patrick.F.Kline@usace.army.mil

SECTION 3—DEVELOP PROJECT WORK PLANS

Note

The MMC creates levee products for each levee system as defined in the National Levee Database (NLD).

The project manager leads the effort for creating an internal project work plan (PWP) and reaches out to levee modeling technical lead for input. The assigned documentation team member creates the project directories on the MMC file share and the Team SharePoint Site to include required CTS and report templates and initiates the external PWP. More detailed discussion of the MMC levee folder structure can be found in Figure 6.3. The MMC folder structure is delivered to the assigned modeler and used throughout the entire process.

A PWP is developed for all levee projects. The project manager and documentation team coordinate to develop the PWP and the documentation team edits and finalizes the document prior to project kickoff. PWPs are forwarded to the program coordinator for review as needed. The PWP is signed by the program manager, the hydraulic modeling lead, and the district Levee Safety Program Manager (LSPM) after the kickoff meeting.

SECTION 4—PROJECT KICK-OFF MEETING

The MMC project manager schedules a levee project kick-off meeting after the draft PWP is developed. At a minimum, the invitees include the: district LSPM, district Levee Safety Officer (LSO), MMC modeling lead, MMC mapping lead, MMC consequences lead, and MMC documentation lead.

The kick-off meeting clarifies the scope of the study, the schedule, and the budget. Key technical information within the district is identified during the meeting. Primary data sources are identified, such as existing hydraulic models, high-resolution digital elevation models (DEMs), and desired breach locations.

SECTION 5—DOCUMENTATION

The Levee Safety Report and consequences-based top screen (CTS) worksheet are initiated as soon as the PWP is created. The first step is to create a properly named copy of the CTS worksheet template and place it into the MMC team SharePoint project reports directory. The CTS worksheet levee information tab is populated by the documentation team with appropriate titles and pertinent project data from the NLD.

A standard report is written for each levee studied by the MMC. The report summarizes modeling and consequences results and includes an appendix with further mapping details. MMC internal drafts of the reports are stored on and edited from the MMC internal SharePoint site. Folders are organized by year of study assignment (e.g., FY2022-Project_Reports), then by program (CIPR or RA), and there is a folder for each levee system (e.g., Sacramento and Elk Grove_LOP5205000441). Finalized reports are posted to the Corps of Engineers Dam and Levee Safety (CEDALS) site.

Report files shall be edited directly from the internal SharePoint site. This ensures edits from all assigned team members are made to one copy of the document minimizing the amount of technical editing required.

5.1 Develop Draft Report Folder and Initiate the Report

During the project kickoff phase, the assigned MMC documentation team member creates the report project folder on the MMC internal SharePoint site, creates the production folders on the RMC File Share, creates the initial draft of the report and CTS from the current template, initiates the PWP, initiates the model review checklist, and identifies a photo of the levee to use on the cover page. This same photo shall be used for the cover page of the inundation atlases. Photos will be maintained in the project references folder on the RMC File Share.

5.2 Consequence-based Top Screen Worksheet Production

5.2.1 Documentation

During the first step of CTS creation, the documentation member fills in the contact information tab to include the project name, the project manager name, the MMC documentation point of contact, and the levee point of contact.

Documentation is responsible for filling in the current NLD value column of the levee information tab of the CTS worksheet based on information in the NLD and original, project-specific source documents.

After completion of the current NLD column, the CTS worksheet is forwarded to the levee safety program manager for review and concurrence. The LSPM is asked to note discrepancies in the required changes column and include a source for the updated data in the validation/comments column. If discrepancies are noted, the documentation production team member will validate the information based on provided references.

LSPMs are asked to complete the CTS review within two weeks. If discrepancies are found by the LSPM, the LSPM should initiate changes to the NLD.

5.2.2 Hydraulic Modeling

The assigned hydraulic modeler is responsible for filling in their contact information in the contact information tab of the CTS and completing all information in the hydraulics and hydrology (H&H) tab.

5.2.3 Consequences Modeling

The assigned economist is responsible for filling in their contact information in the contact information tab of the CTS and completing all consequences tabs of the CTS.

The CTS worksheet template is designed to guide the consequences team member in drafting language that is suitable for incorporation into the report. The consequences technical lead obtains peer review of the CTS worksheet and finalizes it based on feedback received. To minimize potential for rework, this review is completed prior to technical edit of the report. The consequences team member is required to edit the consequences section of the levee report.

5.2.4 Finalization

The CTS worksheet is considered final after documentation, modeling, and consequences leads have signed off the worksheet review section of the CTS.

SECTION 6—PRE-MODEL MAPPING DATA PRODUCTION

This step generates the internal mapping deliverable needed by the modeler to begin model development. The mapping production team member is responsible for providing the assigned modeler the mapping data necessary for the initial model setup using national data sets as described in Appendix 4.1.1, Pre-Model Data Production Guide. The data is provided to the modeler using the standards described in Appendix 4.3.1, File Schema Guide.

6.1 Projections

The standard projection for all MMC projects within the projection boundaries is: USA_Contiguous_Albers_Equal_Area_Conic_USGS_version. The linear units are set to U.S. feet. The MMC Production Center uses the North American Vertical Datum of 1988 (NAVD 88) for all elevation data within the datum extents.

The standard horizontal projection for Hawaii, Alaska, and Puerto (or other locations where the Albers projection listed above does not reach) is the state plane that the majority for the modeled area is located within.

Alaska is within the range of the NAVD 88 system and will use this datum for all vertical data. The standard vertical datum for Hawaii is local mean sea level (LMSL). The standard vertical datum for Puerto Rico is the Puerto Rico Vertical Datum of 2002 (PRV 02).

Detailed projection parameters are provided in Appendix 4.1.1.

The MMC projection is used for the pre-model data and throughout the modeling process. When alternate projections are in place, some additional steps are needed to add data to the MMC data viewer.

6.2 National Levee Database Levee Data

Levee information from the NLD is provided to all modelers by the mapping technical lead independent of the pre-model data deliverable as described in Appendix 4.1.8. The mapping technical lead coordinates with the NLD database manager and obtains updated NLD data layers at least once a year. The NLD includes information related to the levee centerline. The centerline should be represented as a line element and points containing the elevation from the latest survey of the levee. The mapping technical lead or delegate confirms a levee line of protection (LOP) is available that combines the levee segments with closures and other structures that complete the levee alignment.

From the levee LOP, an XYZM Excel file is generated and delivered with the pre-model data.

Current versions of the HEC-RAS modeling suite (version 6.x) allow for a model to directly pull NLD data as a terrain modification. However, direct data pull as described in this section is still necessary for other aspects of the overall levee breach modeling and mapping efforts.

6.3 Produce Digital Elevation Models

A mapping team member merges base National Elevation Database (NED) and DEM tiles that intersect with the study area and project the DEM to the MMC projection. DEMs are provided in native projection and in the MMC projection. Providing the native projection DEM allows the modeler to project to other than Albers. A general rule for all MMC team members is to minimize the number of projection steps for raster data, as some quality is lost during each step.

The DEM is included in the pre-model deliverable.

6.4 Supplemental Digital Elevation Model Data Research and Processing

The combination of mapping, modeling, and documentation team members gather district data during the project kickoff and further coordination with district points of contact (POCs) to identify relevant H&H data needed for model setup and data that may assist or streamline the modeling process. The mapping production team member identifies existing mapping data that may be of better quality than the national datasets used in the rapid data development process. Of special interest is light detection and ranging (LiDAR) data not already incorporated into the NED or any bathymetric data available that would support surface generation. Scattered cross section bathymetry may be useful to the modeler; however, this should not be incorporated into the elevation models. Supplemental data documentation is delivered to the H&H model for reference. The data research is conducted as a collaborative effort between the modeler and mapping team, in accordance with Appendix 4.1.2, Supplemental Research Guide.

6.5 National Land Cover Database

Modeler will use the latest land coverage information from the National Land Cover Database (NLCD).

6.6 Levee Segment Screening Overview Presentations

The levee screening overview presentation for each of the levee segments that are part of the levee system are included in the pre-model data deliverable. The presentation is available at:

<https://app.mil.powerbigov.us/reportEmbed?reportId=c50e50c1-2ac8-452f-a84a-88fcdf7ba0b8&autoAuth=true&ctid=fc4d76ba-f17c-4c50-b9a7-8f3163d27582&config=eyJjbHVzdGVyVXJsIjoiaHR0cHM6Ly93YWJpLXVzLWVRvZC1pb3dhLXJIZGlyZWV0Lm1pbC5hbmFseXNpcy51c2dvdnNsb3VkyXBpLm5ldC8ifQ%3D%3D>

6.7 Levee Inspections and Levee Screening Level Risk Assessments

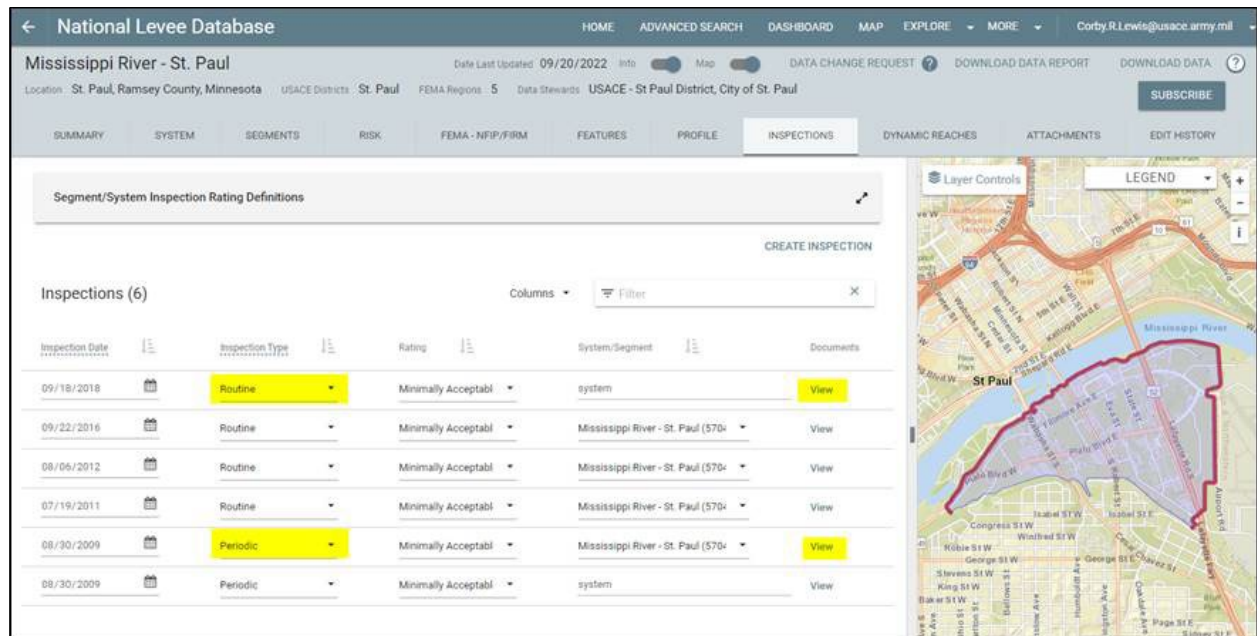
The USACE has an active Levee Inspection and Risk Assessment program and products often contain information that is directly applicable for the MMC Levee Breach Modeling effort. The MMC team lead and modeler should review all products from the most recent inspection and screening level risk assessment materials before the kickoff call. Levee screenings are available at:

<https://lst2.sec.usace.army.mil/leveescreenings>

6.7.1 Accessing Inspection Information

Levee inspection information is accessed through the National Levee Database inspection tab (Figure 6.1). They are available through PDF inspection reports that including summaries and detailed observation notes with images. The observations are also viewable spatially in GIS format through the NLD website. MMC team leads and modelers should contact the NLD team to gain necessary access to this data.

Figure 6.1. National Levee Database Inspection Window



6.7.2 Accessing Levee Screening Information

Levee Screening data is divided into two eras separated by the Levee Screening Tool (LST) version: The LST 1.0 era (2010–2023) and LST 2.0 era (2023–present). Approximately 2,500 levee screenings were completed with LST 1.0, and screening data is available for all USACE authorized levees with few exceptions as well as many non-federal levees. The LST 2.0 system was released in 2023 and updated screening data will become available slowly over time.

Key information from screening level risk assessment that should be incorporated into MMC modeling approach may include highlighted performance concerns, levee embankment materials, foundation materials, erodibility information, estimated first overtopping locations, emergency action plan information, estimated flood depths, estimated arrival times and consequence estimates. In general, the levee risk screenings collected and evaluated information at a course level of resolution with only enough accuracy to screen the levees for level of risk. For example, flood depths for most LST 1.0 screenings used a very simplistic “bathtub” assumption to estimate flood depths. This screening information is a valuable reference point for the MMC modeler for comparison, but it is expected that the MMC levee breach study will be higher resolution and account for many of the nuances that affect the flood characteristics for a reasonable breach scenario.

Table 6.1. Key Data Access Links

Data Source	Link
LST 1.0	https://lst2.sec.usace.army.mil (archived within LST 2.0)
LST 2.0	https://lst2.sec.usace.army.mil
Useful LST 1.0 Technical Summary Report	https://app.mil.powerbigov.us/reportEmbed?reportId=c50e50c1-2ac8-452f-a84a-88fca7ba0b8&autoAuth=true&ctid=fc4d76ba-f17c-4c50-b9a7-8f3163d27582&config=eyJjbHVzdGVyVXJsIjoiaHR0cHM6Ly93YWJpLXVzLWVRvZC1pb3dhLXJlZGlyZWNOIm1pbC5hbmFseXNpcy51c2dvdmNsb3VkYXBpLm5ldC8ifQ%3D%3D
Levee Senior Oversight Meeting Notes	https://usace.dps.mil/sites/KMP-LS/Shared%20Documents/Forms/AllItems.aspx?csf=1&web=1&e=KEazUX&cid=1fc067bd%2D6318%2D48fa%2D8768%2D29ab1fc649f0&RootFolder=%2Fsites%2FKMP%2DLS%2FShared%20Documents%2FLevee%20Senior%20Oversight%20Group%2FMeeting%20Summaries&FolderCTID=0x0120001158B65CDB719C4991DB7FB7D3EC29FA
Screening Presentation Archive on Projectwise (LSOG Meeting Proceedings)	pw:\\coe-wpcwp01dcp.eis.ds.usace.army.mil:RMC02\Documents\Program Management\B-USACE Levee Safety Program\9-Levee SOG\
National Levee Database	https://levees.sec.usace.army.mil/#/

6.8 Review Deliverable

Review the deliverable for content and conformance to the standard defined in Appendix 4.1.11. Use the checklist in Appendix 4.3.2, Pre-model Deliverable Checklist, to ensure all deliverables are included.

6.9 Deliver Data to Assigned Modeler

The mapping production team member packages the data via the MMC file share directory for the project.

The production team lead provides the name of the modeler responsible for each of the assigned study levees. The mapping production team member sends the data to the identified modeler unless the modeling technical lead directs otherwise. Any revisions or additions to datasets should be requested through the mapping production team member and are transferred in the same manner as previously outlined.

6.10 Deliver Research and Acquisition

The project manager notifies the study levee project's division LSO and district LSPM that the project will be studied and requests updated data points of contact to confirm information required from the district.

6.10.1 Pre-Existing Hydraulics and Hydrology Data

The program coordinator checks the MMC project database for existing hydraulic models and contacts the district H&H point of contact to request any available information on the study levee and catalogs any existing data. See Appendix 4.1.2 for additional details.

6.11 Pre-Existing Mapping Data

The mapping team member contacts the district mapping point of contact to request any data relevant to the MMC study and catalogs any existing data according to Appendix 4.1.2.

6.12 Documentation of Findings

The mapping team member provides the documentation of existing data to the modeler. As part of model setup, the modeler determines what information is necessary. In general, all existing H&H data is obtained. Existing mapping data should only be requested if deemed necessary by the modeler.

6.13 Data Transfer

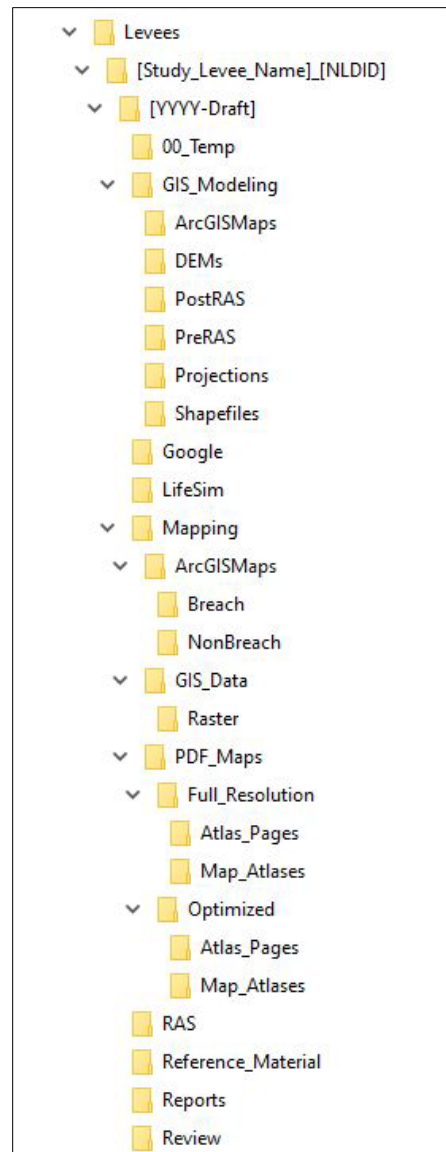
If directed to do so, collect data from districts electronically via the RMCSTORAGE5 file share. If necessary, temporary media or storage devices are used for transferring data.

6.14 Data Review, Processing, and Delivery

The mapping production team member reviews the district-provided mapping data and, after completing required post-processing, delivers necessary mapping data to the assigned modeler.

The mapping team member provides the data within the standard directory structure as outlined in Figure 6.1.

Figure 6.3. Project Directory Structure for Levee Production



SECTION 7—LEVEE HYDRAULIC MODELING

The MMC hydraulic modeling team is tasked with creating geo-referenced hydraulic models capable of producing accurate flood inundation information to support mapping and consequences analysis across a wide range of scenarios. The latest authorized version of the River Analysis System (HEC-RAS) software is applied in all situations. The software is endorsed by the Hydrology, Hydraulics, and Coastal Community of Practice (HH&C CoP) and maintained by the Hydrologic Engineering Center (HEC). Typically, a riverine levee system uses a one-dimensional (1D) modeling approach for the river adjacent to the levee and a two-dimensional (2D) approach for the floodplain areas affected by levee overtopping or breach.

The following sections provide information, guidance, and procedures for completing the hydraulic model for MMC levee analysis. The modeler coordinates with the MMC modeling team lead during the modeling effort and discusses approaches to unique cases.

7.1 Levee Hydraulic Model: Getting Started

The process begins with a review of the base data provided to the hydraulic modeler, additional communication with the district, and development of a clear understanding of the scope of the hydraulic modeling effort. Hydraulic engineers new to the MMC modeling process must become familiar with the software, administrative processes, and the workflow among the interdisciplinary virtual production team. This section provides general information and background on these topics.

7.1.1 Hydraulic Modeler Training Requirements

Successful completion of the hydraulic modeling for an MMC levee breach study requires a high level of training and experience using HEC-RAS software. In addition to practical experience, the following recommended USACE PROSPECT courses are considered essential preparation for modeling team members.

- Unsteady Flow Analysis with HEC-RAS
- Advanced 1D/2D Modeling with HEC-RAS.

7.1.2 Computational Requirements

7.1.2.1 Hardware

Modeling team members are assigned an Army Corps of Engineers-Information Technology (ACE-IT) desktop/laptop with the science and engineering specifications.

7.1.2.2 Software

Table 7.1 provides a list of required software applications. All required software that requires installation is available on the App Portal. Any other software shall be provided by the modeling team lead.

Table 7.1. Software Requirements for Levee Hydraulic Modeling

Application	Version
ArcGIS-Pro (recommended)	
HEC-RAS	6.0 or latest MMC-approved version
Bentley ProjectWise (recommended)	Current ACE-IT version

7.1.3 Data Sources and Data Transmission

7.1.3.1 Key Collaboration Sites

MMC collaboration sites contain program information, reports, documentation, policies, and project data. The collaboration sites support varied types of information intended for varied audiences. Table 7.2 lists links to the key collaboration sites and brief descriptions of their intent.

Table 7.2. Modeling, Mapping, and Consequences Collaboration Sites

Site	Description	Access Information
HQ-USACE: MMC CoP SharePoint Site: https://usace.dps.mil/sites/KMP-MMC	High level information intended for USACE-wide audience. Includes final MMC project reports, project status reports, MMC SOP, and Independent Quality Review comment documentation among other information.	Open Access with USACE CAC
MMC Team SharePoint Site: https://team.usace.army.mil/sites/NWK/pdt/MMC/SharedDocuments/MMCProjectReports/ProjectReportsLevees	MMC internal team collaboration site. This site as a central location for Levee Safety Report creation and review documentation.	POC for Access Rights: Documentation Branch Chief
MMC File Share: Internal Use: \\wpc-netapp3.eis.ds.usace.army.mil\RM\CSTORAGE4 External Use: \\wpc-netapp3.eis.ds.usace.army.mil\RM\CSTORAGE5	File Share location used for transmittal of project datasets as well as general program documents.	POC for Access Rights: Documentation Lead
CEDALS ProjectWise Directory: pw:\\coe-wpcpwp01dcp.eis.ds.usace.army.mil:RMC01\Documents\Projects	Final repository for complete MMC dataset for dam safety studies. Not used during production.	POC for Access Rights: Raymond Rogers, LRH
USACE Flood Inundation Mapping Viewer: https://fim.sec.usace.army.mil/viewer/	Website viewer for geospatial results from hydraulic modeling. All USACE users can view the information.	POC for Upload Access Rights: FIM Help Desk via FIMhelp@usace.army.mil
USACE Flood Inundation Mapping Viewer Uploader: https://fim.sec.usace.army.mil/uploader/	Uploader tool for providing HEC-RAS geometry and model output data (shapefiles, depth grids, inundation mapping, etc.) to the FIM Viewer.	POC for Upload Access Rights: FIM Help Desk via FIMhelp@usace.army.mil
Modeling TEAMS Collaboration Site: https://dod.teams.microsoft.us//channel/19%3adod%3a3f658cbb3eb6440dadffefe12d599be9%40thread.skype/General?groupId=03966626-94be-467a-8851-a0d57b3aac34&tenantId=fc4d76ba-f17c-4c50-b9a7-8f3163d27582	Microsoft TEAMS collaboration site to create collaboration amongst MMC dam and levee safety hydraulic modelers.	POC modeling team lead

7.1.4 Specific Data Sources and Systems for Hydraulic Model Kick-off

The MMC program requires the use of a virtual production team for mapping data production, modeling, consequences assessment, and review. A project folder for each levee is assigned on the MMC Shared Server for each levee study in order to facilitate data transfers and to house all data used for the study throughout the entire process. The folder adheres to a standardized structure and will originate with the

pre-model mapping data prepared by the mapping team (described in Section 5). Non-pertinent and legacy data is not to be uploaded in order to maintain clarity.

The levee project report is a collaborative document that requires inputs from modeling, mapping, consequence, and documentation team members. The MMC team SharePoint site is used during project report creation. The report document is initiated by the documentation team prior to the modeling phase, and the modeler edits the SharePoint version of the document.

7.1.4.1 Scope/Schedule/Budget

The schedule, scope, and budget of the modeling effort is captured in the project work plan described in Section 2. The assigned hydraulic modeler should discuss specifics with the modeling team lead.

7.1.4.2 Funding Requests

Funding requests for MMC levee modeling work are entered through the online funding request system, <https://rmc.sec.usace.army.mil/frs>. Once a new request is initiated, the requester should select the Risk Management Center (RMC) as the funding center.

7.1.4.3 Base Data

A set of base data for use in levee hydraulic modeling is provided to the modeler. The data collection effort is described in Section 5 and includes NLD information, DEM, and existing hydraulic models. It is the responsibility of the hydraulic modeler to review the data provided and to reach out to various sources that may have access to additional applicable data once the modeling process begins.

7.1.4.4 Levee Screening Information

Each levee segment has been through a USACE levee screening process. An overview summary of the screening is captured in the Levee Senior Oversight Group (LSOG) presentation slides, and more detailed data is available through the online Levee Screening Tool (LST). The results and information from the screening should be directly considered during the hydraulic modeling process.

7.1.4.5 Modeling, Mapping, and Consequences Levee Safety Report

The MMC Levee Safety Report is stored on the MMC Team SharePoint site. The hydraulic modeler is responsible for writing Section 4 of the report. This report should be edited in so much as possible on the SharePoint site. This report should never be directly saved as from a local copy, as multiple people could be editing the document at the same time.

7.1.4.6 Consequences Worksheet

The MMC CTS worksheet template is stored on the MMC Team SharePoint site. The hydraulic modeler is responsible for filling in the Contact Info tab and the H&H Data tab in the worksheet. This spreadsheet should be edited in so much as possible on the SharePoint site. This file should never be directly saved as from a local copy, as multiple people could be editing the document at the same time.

7.1.4.7 Hydraulic Model Review Document

The hydraulic model review comments and resolutions are stored on the Team SharePoint site.

7.2 Collection and Inventory of Model Setup Data

After the scope of the modeling effort is established, the first step of the hydraulic modeling process is to take an inventory of the available base data. As described in Section 6, a pre-model dataset that includes NLD geographic information system (GIS) data, NLD levee profile data, land cover data, DEM, and levee

screening information will be included in the production pre-model folder. Additional data from the district may be provided if it was identified and delivered after the kick-off call (section 3).

It is the responsibility of the assigned modeler to examine the quality and completeness of the data provided in the pre-model dataset. The modeler coordinates with the MMC modeling team lead and the district contacts to ensure the best available data is being used as a starting point. The MMC Levee Program typically requires a higher level of modeling detail in the protected area compared other MMC programs.

The following paragraphs outline some of the high-level considerations in terms of base data availability and quality.

7.2.1.1 Digital Elevation Models

The highest quality bare-earth DEM available for the protected area is typically required for levee analysis. Floodplain features such as roadway embankments, underpasses, or large culverts can have a major impact on the modeled flood extent, which highlights the need for high-quality DEMs for levee analysis. The mapping team member seeks out the best available DEM, but the assigned modeler has the responsibility to verify the quality and seek out better data as necessary. Regardless of the source or resolution of the DEM, it is critical that the DEM is high-quality bare-earth data. Consideration shall be given to model file size versus terrain quality. It may be necessary to resample the DEM to a coarser resolution, no coarser than 10-meter, to optimize file size.

7.2.1.2 Existing Hydraulic Models

It is the responsibility of the assigned modeler to ensure that the relevant existing hydraulic models for the area have been obtained. The primary source for existing models is the district POCs, although previous MMC modeling through the dams or Corps Water Management System (CWMS) programs may also be a source. Preference is given to previously calibrated models.

7.2.1.3 Observed Data for Model Calibration.

The assigned modeler is responsible for seeking out available calibration data such as observed high water marks, discharge measurements, rating curves, gage data, etc.

7.2.1.4 Levee Profile Data

The levee profile is primarily based on NLD data. The data is prepared into a convenient format by the MMC mapping team member and provided to the assigned modeler. The assigned modeler is responsible for verifying the accuracy and consistency of the profile compared to any other data that may be available. During the kickoff call, the program coordinator should verify how to model any closure structures or any other unusual levee features (i.e., sleeve levees, non-federal sections, etc.).

7.2.1.5 Levee Background Information

Background information sources such as inspection reports, levee screening data, or as-built drawings may provide valuable information for the modeling process. The assigned modeler seeks out any information that is relevant to the modeling effort.

7.3 Levee Hydraulic Model Geometry—Geometry Files

If available, an existing HEC-RAS model is utilized in the evaluation. Revisions to the model are typically necessary to incorporate the levee profile and the protected area. The levees are defined as lateral structures or storage area connection using NLD data. The protected area is defined with a 2D flow area.

If an existing HEC-RAS model does not exist or if additional detail and changes need to be made to the existing model geometry, changes to existing models are made directly in the HEC-RAS project.

7.3.1 Modeling, Mapping, and Consequences Levee Program Specifications for HEC-RAS Geometry

The HEC-RAS levee breach model project will include a single geometry file. The geometry file used for the analysis must meet the following standards.

7.3.1.1 Projection

The HEC-RAS geometry uses the standard MMC Projection of Albers Equal Area for the continental United States. (Detailed projection data included in Appendix 4.1.1).

7.3.1.2 Vertical Datum

All elevations utilized in the HEC-RAS geometry must be in NAVD 88 datum where available.

7.3.1.3 Downstream Model Extents

Models created by the MMC Production Center extend downstream from the assigned levee to the point of known water surface elevation conditions or where the downstream boundary does not influence the hydraulics at the downstream end of the levee system. Determining this extent may be an iterative process and require the addition of additional downstream modeled area after initial model development. When establishing model extents, downstream sources of significant inflow, such as tributaries, that may have an effect on the downstream water surface elevations are considered. Care is to be taken with a coastal boundary in a riverine condition to ensure that no initial inundation is occurring. For this scenario, a steady boundary condition, such as a mean high water elevation, is recommended to limit the impact of any coincidence of flows. For a coastal model, it is recommended to extend the stage boundary into the ocean where near shore bathymetry-based terrain is available.

7.3.1.4 Upstream Model Extents

Riverine models created by the MMC extend upstream to a point of known inflow hydrograph or at least one mile upstream of the levee system or any structure features that could influence the inflow hydrograph at the upstream end of the levee system. Coastal models extend inward to beyond the point of maximum inundations. See the MMC Technical Manual for Coastal Levees for further information.

7.3.1.5 Cross Sections

Cross sections are named as river miles from the major downstream confluence. Bathymetric data and data from existing models are incorporated when feasible. For areas where channel data is not available, a channel should be approximated based on aerial photography and cut into the cross sections.

7.3.1.6 Interpolated Cross Sections

The use of interpolated cross sections in the final model is no longer considered acceptable; additional cross sections can be extracted using the RAS Mapper or RAS Geometry tools as necessary.

7.3.1.7 Reach Lengths

Reach lengths are adjusted to represent actual flow lengths to properly account for volume in the model computation. For additional guidance and information, see the HEC-RAS User's Manual.

7.3.1.8 Ineffective Flow Areas and Blocked Obstructions

Ineffective flow areas are used to properly account for flood plain storage in locations that do not actively convey flow. The user should set the initial extents of the ineffective areas based on judgment and then refined during calibration, if necessary. The use of blocked obstructions is acceptable for use in HEC-

RAS models when a permanent obstruction exists at a cross section. Both ineffective flow areas and blocked obstructions should not be used arbitrarily for calibration purposes, but only when the geometry is truly representative of the feature. Blocked obstructions are not permitted to be used for subtracting storage volume at cross sections (e.g., behind levees where a model cross section and RAS storage area overlap). For additional guidance, see HEC-RAS User's Manual.

7.3.1.9 Inline Structures (Dams)

Any major flood control dams that may have a major impact on the levee should be considered when modeling the levee system.

7.3.1.10 Bridges

Bridges and culverts on main model reaches are identified in all MMC levee modeling efforts. Bridge data to include in the modeling effort is found from sources such as existing models, FIS, local district, etc. Bridges which are expected to significantly influence hydraulic modeling results should be included explicitly in the model geometry. If bridge data is not readily available and the bridge is not expected to have a significant impact on levee breach model results, an approximation of bridge geometries is acceptable based on limited data from photos and other available sources.

7.3.1.11 Lateral Structures

In most cases, when the study levee is represented with a HEC-RAS lateral structure, a weir/embankment structure connects an upstream 1D river reach with a protected 2D flow area. Lateral structures connected to 2D flow areas have two options to compute flow going over the top of the structure when using the Overflow Computational Method. The flow over the structure can be computed by either the Weir Equation or the Normal 2D Equation Domain. The preferred overland flow computational method uses the Normal 2D Equations, however, current HEC-RAS versions do not allow the simplified physical breach method to properly develop in combination with the Normal 2D Equations weir flow method. Therefore, the weir flow method will be used for any levees breached for MMC levee studies. In addition, the Normal 2D Equation Domain should not be used for structures where the flow over the structure will go into free fall (like a waterfall). The 2D equations cannot solve a stable solution through a waterfall. For these types of situations, the user should choose the Weir Equation option.

7.3.1.12 Levee Alignment and Profile

Top of levee alignment and profile based on the NLD are provided as part of the pre-model dataset. The information is provided in a point shapefile format as well as a text-based table organized in 'XYZM format'. The levee XYZM data is input directly into the HEC-RAS geometry. The elevation locations (X and Y from the pre-model table) are entered into the 'Centerline GIS Coords...' table associated with the levee. The elevation and stationing information (Z and M from the pre-model table) are entered into the Weir/Embankment table for the levee. If the levee is broken into multiple lateral structures or 2D flow area connections, the stationing is maintained (using a non-zero starting station). This step allows the MMC and USACE to establish a length-based stationing for the levee system that can be referenced consistently between the MMC report, MMC model, and other map-based displays. In the case that the stationing data provided is in the wrong direction (downstream to upstream), the modeler should coordinate with the mapping team member. Care should be taken to verify the directionality of the 2D connections when the levee is modeled as a storage area connection.

7.3.1.13 Levee Profile Quality Check

It is the responsibility of the modeler to check the levee profile for inaccuracies. The NLD survey data can include incorrect points that represent something other than the top of levee. Particular attention is given to isolated low spots in the levee that would incorrectly allow flow to overtop the levee. This is common where a roadway temporarily leaves the top of levee centerline or with a closure structure that would be modeled as closed during a flood event. Some manual adjustments may be necessary and should be documented in the levee report.

7.3.1.14 Two-dimensional Flow Areas

HEC-RAS 2D flow areas are used to represent the area behind the levee.

7.3.1.15 Two-dimensional Area Breaklines

Significant interior restrictions to flow, such as road embankments, can have a major impact in the resulting inundation for a levee breach model and are accounted for by modifying the computational mesh using a 2D flow area. Openings or holes in embankments (such as highway underpasses) are also critical to achieving an accurate inundation result.

7.3.1.16 Two-dimensional Flow Area Internal Connections

The use of 2D flow area internal connections is an alternative to the use of breaklines. They have a great advantage in that they allow for the modeling of either gates, culverts, or bridges directly within the structure, which is a convenient method for modeling a roadway embankment with underpasses or in-channel structures. Similar to lateral structures, internal hydraulic structures in 2D flow areas have two options to compute flow going over the top of the structure when using the Overflow Computational Method. The flow over the structure can be computed by either the Weir Equation or the Normal 2D Equation Domain. Generally, the Normal 2D Equation Domain is faster and more accurate but may not be acceptable for true weir-type structures. The Normal 2D Equation Domain should not be used for structures that are high where the flow over the structure will go into free fall (like a waterfall). The 2D equations cannot solve a stable solution through a waterfall. For these types of situations, the user should choose the Weir Equation option. The Normal 2D Equation Domain should not be used for any structures breached during the model simulation.

7.3.1.17 Two-dimensional Grid Spacing

Select appropriate grid spacing for the computational mesh that fits with the area being modeled. This takes trial and error and is discussed during model development. Appropriate grid cell spacing varies based on factors such as the slope of the terrain, number of breaklines used, and practicality of file sizes/runtimes. The specified mesh cell size should be a sufficiently high resolution to accurately capture flood flow routes within the study area and produce stable computations. A number of model iterations should be run during the development process to ensure the most robust and accurate results are produced without over burdening the compute process. If the main river channel is within the 2D extent, a bathymetric surface should be estimated from existing models when feasible. For areas where channel data is not available, a channel should be approximated based on aerial photography and cut into the terrain.

7.3.1.18 Manning's "n" Values

Cross sections contain three of Manning's "n" values: left overbank (LOB), channel, and right overbank (ROB). This standard can be improved when an existing, calibrated model used as a starting point for levee modeling uses more detailed "n" value definition.

7.3.1.19 Manning's "n" Values for Two-dimensional Flow Areas

The primary source for the identification of roughness factors for the 2D flow areas should be the NLCD. Table 7.3 provides a general guide for the assignment of Manning's "n" values based on land cover. The NLCD should be verified with aerial imagery. In some cases, the use of aerial photography to identify land cover and roughness is preferable, especially if there are significant changes to land use types. The "n" values in the table are not meant for very shallow overland flow like those found in hydrologic modeling. For shallow overland flow, typically seen in hydrologic models, roughness values are generally much higher due to the relative roughness compared to the flow depth.

Buildings in the floodplain often have a large effect on flow patterns and roughness but are not accounted for in bare-earth DEMs used for modeling. The “n” values in Table 7.3 assume a bare earth terrain where the values factor in potential obstructions to the conveyance. If the terrain includes obstructions (e.g., buildings) or building footprints are imported as an additional land cover type, the “n” values should be adjusted to account for these differences.

Table 7.3. Guidance for Roughness Values based on National Land Cover Database Land Cover

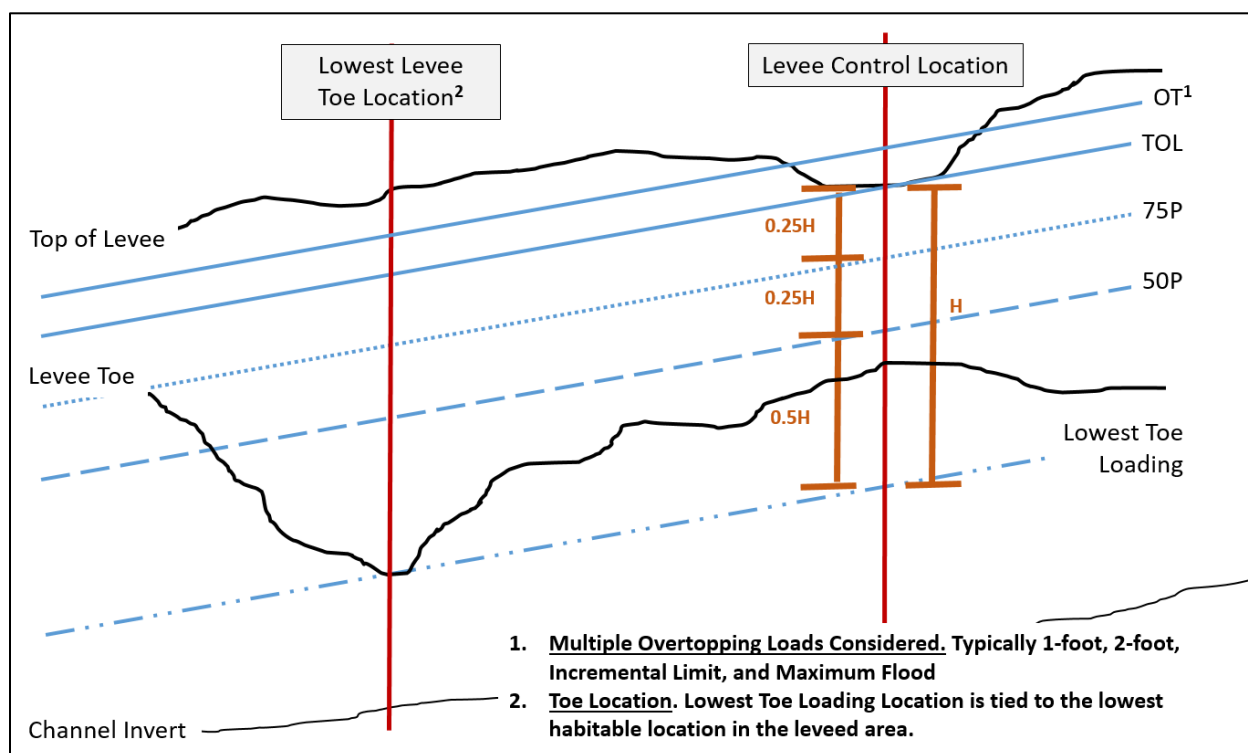
Land Cover ID	Land Cover Description	Manning’s “n”
11	Open Water	0.025–0.05
21	Developed, Open Space	0.03–0.05
22	Developed, Low Intensity	0.06–0.12
23	Developed, Medium Intensity	0.08–0.16
24	Developed, High Intensity	0.12–0.20
31	Barren Land	0.023–0.030
41	Deciduous Forest	0.10–0.20
42	Evergreen Forest	0.08–0.16
43	Mixed Forest	0.08–0.20
52	Shrub/Scrub	0.07–0.16
71	Grassland/Herbaceous	0.025–0.05
81	Pasture/Hay	0.025–0.05
82	Cultivated Crops	0.02–0.05
90	Woody Wetlands	0.045–0.15
95	Emergent Herbaceous Wetlands	0.05–0.085

Source: HEC-RAS River Analysis System 2D Modeling User’s Manual

7.4 Levee Hydrologic Loadings—Flow Files

The flow files for an existing HEC-RAS model used for the analysis or a model developed as part of the levee breach analysis must meet the standards presented in Figure 7.1.

Figure 7.1. Hydrologic Loading Conditions for MMC Levee Breach Analysis (Riverine)



The selected inflow hydrograph is based on the flood of record (with all needed hydraulic inputs) within the vicinity of the levee evaluation site so long as no major changes to the watershed characteristics have taken place since the flood (e.g., urbanization, construction of new dams/levees/channels, modifications to dams/levees/channels). If significant changes have occurred, the selected inflow hydrograph is based on a recent significant flood event that represents current conditions within the watershed. In the selection of the flood hydrograph, floods with larger volume should be selected over those with lower volume. Care should be given to match the shape of the hydrograph to that which would be expected near a top of levee event.

7.4.1 Approaches for Inflow Assumptions for Ungaged Streams

The inflow hydrograph shape used for the primary river that loads the levee being studied is a key input to MMC levee breach modeling projects. In most cases, it is expected that the hydrograph shape will be based on a stream gage in the vicinity of the study area. However, in some cases un-gaged streams will be the primary load source and the hydrograph shape will need to be estimated. The following sections detail the suggested methods for developing the estimate.

- **Transfer from a nearby gage:** This method is based on utilizing data from a nearby gage located within the watershed or a watershed with similar hydrologic characteristics. The discharge and volume frequency of the gage data should be developed in accordance with Chapters 2 and 3 of EM 1110-2-1415, Hydrologic Frequency Analysis, or Guidelines for Determining Flood Flow Frequency (Bulletin 17C). The representative flood hydrograph at a gage can be adjusted to represent the peak discharge and volume associated with the 0.2-percent annual exceedance

probability event. The hydrograph is transferred to the site by applying a relationship that is typically a drainage area ratio.

- **Approximate Rainfall Runoff Model:** This method should be selected in either an ungaged or gaged system where an approximate rainfall runoff model is available. The approximate rainfall runoff model would be described as one that applies estimated or regional runoff parameters without calibration of the model. The adopted inflow hydrograph should be based on the rainfall runoff model results associated with the 0.2-percent annual chance exceedance rainfall event. Acceptable methods could include models developed in accordance with EM 1110-2-1417, Flood-Runoff Analysis.
- **Calibrated Rainfall Runoff Model:** This method should be selected in either an ungaged or gaged system where a calibrated rainfall runoff model is available. A calibrated rainfall runoff model could be described as applying site-specific runoff parameters and calibration of the parameters against historic or other appropriate storm data. The adopted inflow hydrograph should be based on the rainfall runoff model results associated with the 0.2-percent annual chance exceedance rainfall event. Acceptable methods could include models developed in accordance with EM 1110-2-1417.

7.4.2 Hydrologic Loads

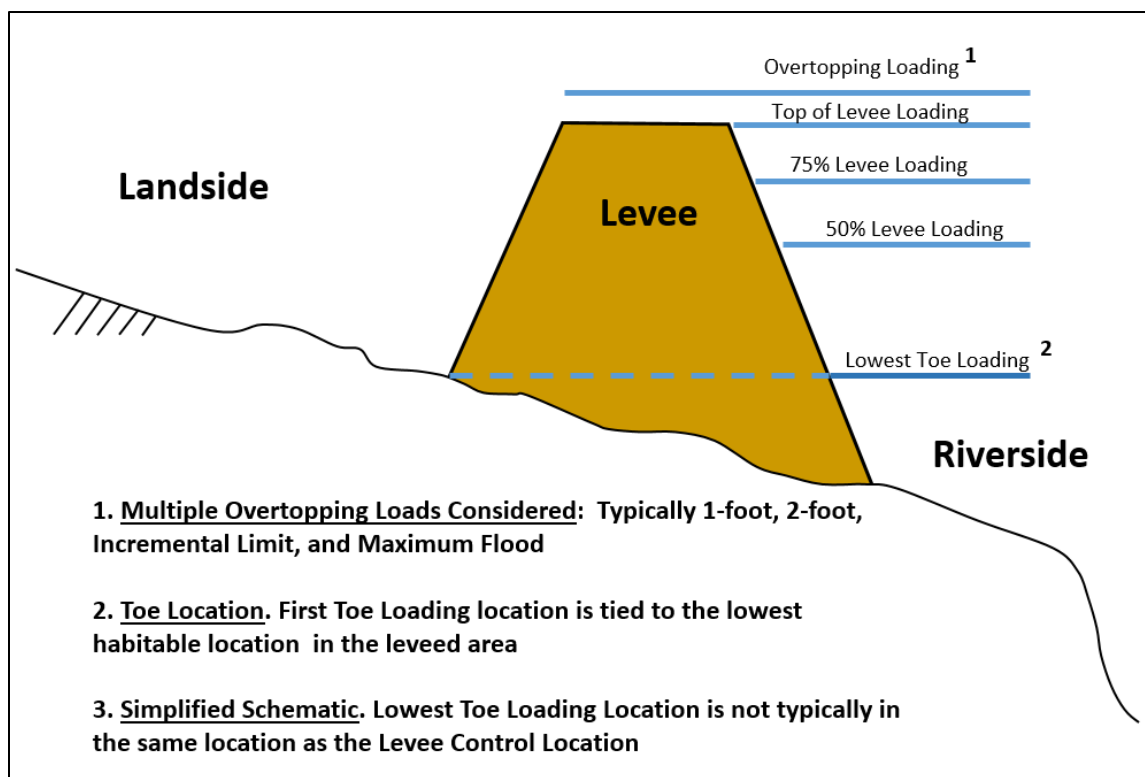
A range of hydrologic load magnitudes on the levee are considered. The loadings are defined based on two critical locations along the levee alignment: the levee control location (LCL) and the lowest levee toe location. The LCL is defined as the location where significant levee overtopping begins. The lowest levee toe location is defined as the location where the levee toe is first loaded and is tied to the lowest habitable location in the protected area. The height (H) of the levee is determined by translating the lowest toe elevation to the LCL location using the slope of the water surface profile from the low toe loading and comparing that translated elevation to the LCL Elevation using the Lowest Toe Loading profile plot or water surface slope. Figures 7.1 and 7.2 illustrate and define the hydrologic loadings for a levee system. For large river systems modeled fully in two-dimensions the slope of the river should be taken from the overbank areas near the levee, rather than in the center of the river. Care should also be taken to account for the differences in levee and river stationing, when selecting the low toe and LCL. The resulting unsteady flow files included in the HEC-RAS project are:

- **50 Percent Levee Load (50P).** Scaled inflow flood hydrograph (e.g., flood of record or a recent significant flood event) producing a maximum water surface elevation that corresponds to 50 percent of the levee height ('H' as calculated from above) at the LCL.
- **75 Percent Levee Load (75P).** Scaled inflow flood hydrograph (e.g., flood of record or a recent significant flood event) producing a maximum water surface elevation that corresponds to 75 percent of the levee height ('H' as calculated from above) at the LCL.
- **Top of Levee (TOL) Load.** Scaled inflow flood hydrograph (e.g., flood of record or a recent significant flood event) producing a maximum water surface elevation that equals the TOL height at the LCL.
- **1-Foot Overtopping Load.** Scaled inflow flood hydrograph (e.g., flood of record or a recent significant flood event) producing a maximum water surface elevation that overtops the levee at the Levee Control Location by 1-foot. Overtopping breaches are only modeled at the LCL location.
- **2-Foot Overtopping Load.** Scaled inflow flood hydrograph (e.g., flood of record or a recent significant flood event) producing a maximum water surface elevation that overtops the levee at the Levee Control Location by 2-feet. Overtopping breaches are only modeled at the LCL location.
- **Incremental Flooding Limit Overtopping Load.** Minimum Scaled inflow flood hydrograph (e.g., flood of record or a recent significant flood event) that causes widespread flooding of the protected area such that the additional flood extent (and depth) caused by a breach of the levee can be considered negligible. Overtopping breaches are only modeled at the LCL location.

- **Maximum Flood Load Overtopping Load.** Extreme flood hydrograph based on a probable maximum flood (PMF) or any other extreme flood estimate available for the levee system. If a PMF is not available, attempt to identify alternate extreme design events. If unavailable, coordinate with the program coordinator to consider alternatives. A typical alternative is a large multiple factor based on an extreme frequency event. If no official frequency data is available, an estimate may be taken from StreamStats (<https://streamstats.usgs.gov/ss/>). Overtopping breaches are only modeled at the LCL location.
- **Lowest Toe Loading Inflow Hydrograph.** A non-breach run that reaches the lowest levee toe is needed as an intermediate step in determining the other loading conditions and should be included in the RAS model delivery.
- **Optional: Base Inflow Hydrograph (unscaled).**

There will be a variety of reasons to adapt the overtopping load cases for individual levee systems and some judgment by the modeler and modeling team lead may be necessary. An additional overtopping location may be selected if overtopping is the risk driver listed in the Levee Screening Tool.

Figure 7.2. Hydrologic Loadings for a Levee System



7.4.2.1 Hydrologic Loading for Coastal Levee Models

See the TM for Coastal Levees for details on coastal loadings. Flood loading for coastal levees is driven by a combination of storm surge and wind driven waves.

Documentation of the modeling effort must include a profile plot of the storm surge versus the top of levee profile that was used to aid in the selection of LCL location. Selection of the LCL should be discussed with the MMC modeling team lead and be clearly documented in the Levee Modeling Report.

7.4.3 Initial Flow Conditions

Initial flow at a cross section is equal to first flow ordinates from the inflow hydrographs upstream of that particular location. Initial flows are only set at flow change locations in the model. It is acceptable to allow the HEC-RAS model to calculate initial flow conditions, provided that the initial inflows are reviewed for stability and accuracy.

7.4.4 Tributary Inflows and Multiple Loading Sources

7.4.4.1 Tributary Inflows

Tributary inflows along the levee reach are considered if they are significant. Complex hydrologic loading scenarios can occur for some levee systems, and discussion with the levee technical lead and district H&H personnel may be required to agree on assumptions for the base modeling effort. It is important the MMC levee model uses a technically sound approach, but it is also important that the scope of work for the MMC modeling effort is well defined and does not expand to include additional hydrologic analysis that is not necessary for a baseline consequence assessment for the levee system. Only a single approach to tributary inflows is used per levee breach analyses.

7.4.4.2 Approaches for Inflow Assumptions for Multiple Loading Sources

When multiple loading sources critical to the levee system loading scenarios, the following general approaches are provided for consideration.

- If unique single event inflow hydrographs for each tributary are available (from either an observed historic event or hydrologic model), apply the same factor to each inflow hydrograph for each loading condition.
- Factor inflows from the tributaries independently to achieve a single flow event that gives a TOL load for each levee reach. Then, apply a consistent factor to this TOL loading to achieve the rest of the loading scenarios. This results in a unique overtopping location for each levee reach (i.e., multiple LCLs).
- Balance inflow factors between the tributaries to result in an equal annual chance exceedance (ACE) for all inflows.

Note

This may result in an event that is less frequent downstream of the confluence than the selected ACE.

- Increasing rainfall through a hydrologic model to determine TOL loading inflow and factor these inflows for the remaining load scenarios.
- Do not include tributary inflows in the loading scenarios. (Appropriate only for minor tributaries.)
- Estimate a tributary hydrograph shape based on basic knowledge of the watershed or nearby stream gage records or other methods. Typically, the timing of the tributary inflows should be coincident with other loading sources, which is appropriate when there is a lack of information for tributary inflows.

7.4.5 Downstream Boundary Conditions

Downstream boundary conditions are set to appropriately model conditions at the downstream extent of the study. A downstream rating curve is used if available. Otherwise, normal depth is used for models with typical riverine characteristics at the downstream boundary. In this case, care should be taken to verify that there are no effects of the downstream boundary at the levee location.

7.4.6 Downstream Coastal Levee Loading

Hydrologic loading for coastal levees is unique from riverine levees. Coastal boundaries typically employ a stage hydrograph with a single value, such as mean high water, for riverine loadings and stage hydrographs for coastal loadings. See the TM for Coastal Levees for further details on coastal loading scenarios.

7.5 Levee Scenarios—Plan Files

Each levee breach scenario modeled for the MMC Production Center is a combination of the hydraulic loading and breach location. Every scenario modeled has a separate HEC-RAS plan file which designates the geometry and flow files associated with the scenario. The plan file also contains information on the simulation time window, computational settings, and breach parameters. The HEC-RAS plan files used for the analysis must meet the standards presented in this section.

7.5.1 Simulation Options and Parameters

7.5.1.1 Simulation Start Date/Time

All simulations begin 02FEBRUARY 2099, at 2400 hours to avoid confusion with actual future flood events and maintain consistency between models.

7.5.1.2 Simulation End Date/Time

The models are run over a duration that appropriately captures the peak stage within the entire protected area and should not run any longer than necessary in order to reduce file sizes and run times.

7.5.1.3 Computation Interval

The computation interval is set to a value that optimizes model stability and run-time. Typical values for levee breach scenarios are between ten seconds and two minutes.

Current versions of HEC-RAS now includes an option for Advanced Time Step Control, which can reduce model runtimes for some models. Use of this option is encouraged for MMC Levee Breach models. Adjusting the time step based on the courant number likely has greatest potential for reducing runtime without extra modeling effort. Relatively consistent cross section spacing throughout the 1D portions of the model may make this option more effective.

7.5.1.4 Hydrograph Output Interval

The hydrograph output interval is set to ensure the peak stage and flow is captured in the 1D hydrographs. Typically, this should be 5–15 minutes.

7.5.1.5 Mapping Output Interval

The mapping output interval ensures arrival time information is appropriately captured in the 2D flow area. This interval directly affects the arrival times utilized in modeling of consequences. The value also is a significant driver of run processing time and files sizes. A 5–15-minute interval should be used for final production runs, although that may be adjusted based on the specific conditions for the project. Typically this interval should be the same as the hydrograph output interval.

7.5.1.6 Detailed Output Interval

The detailed output interval is not critical for MMC levee studies as it is used solely for visualization of the floodwave progression for the 1D reaches. The interval is set to a relatively long interval in order to

reduce post-processing runtime, typically between 15 minutes and 6 hours. Final output interval should be set at six hours or greater.

7.5.1.7 Stage and Flow Output Locations

For MMC Levee analysis, no additional stage and flow output locations are required. However, it is convenient to include key locations such as the cross sections adjacent to the levee breach for reference and review.

7.5.1.8 Equation Set

Production runs typically use the default 2D equation set diffusion wave. However, during the model verification process, it is required the modeler make at least one breach run using the Shallow Water Equation-Eulerian Lagrangian Method (SWE-ELM) set to check for any significant impacts to the flood extent, peak stages, or arrival times when compared to an identical scenario using the diffusion wave equation set. Further information on 2D equations set methods are included in the HEC-RAS 2D User's Manual, section labeled Shallow Water or Diffusion Wave Equations. If changes are significant, the use of the SWE-ELM equation should be considered.

7.5.2 Levee Breach Locations

In order to analyze a range of possible flood scenarios, three breach locations are typically included in MMC levee models. For smaller levee systems where inundation results are not sensitive to the breach location only one or two breach locations are needed while for larger or unique systems, more than three breach locations may be considered. Breach locations will not be the same for all levee systems being modeled, and their selection will follow the general guidelines described in this section.

7.5.2.1 Levee Control Location

The LCL is the location where overtopping first begins to occur. The LCL is determined by comparing the HEC-RAS modeled water surface profile and the top of levee profile. In some cases, the LCL is very clear (e.g., when the levee has a designed overtopping section), while in other cases it is more subjective. Care should be taken to verify that the LCL breaches into an area where flooding can occur. (i.e., not a small area surrounded by higher roadway embankments, or a ditch surrounded by high ground.) Care should also be taken to verify that the LCL is at a location that can be breached (i.e., not at a zero-height levee, also known as high ground).

Note

Isolated low spots in the levee profile should be verified (i.e., ensure they do not represent survey error or bad data in the levee profile). Examples of this include a profile that temporarily slips off of the crest of the levee or missing closure structure information.

7.5.2.2 Selection of Other Breach Locations

A breach at the LCL is always included. Additional locations are labeled by number (Breach Location 2, Breach Location 3, etc.) and are selected after taking into consideration available information such as the integrity of the levee, consequence centers along the levee, and hydraulic characteristics of the levee system. Breach locations to be modeled should be coordinated between the MMC modeling team and the local USACE District Levee Safety Program Manager. The reasoning behind the selection of locations should be concisely documented in the MMC Levee Report. The following list presents possible justifications for selection of individual locations, although it is not comprehensive.

- Maximum Extent of Inundation. A breach location near the upstream end of the levee system may be considered as it may produce the maximum extent of inundation.

- High Consequences. A breach location near the largest population center along the levee system may be considered as it may produce the highest consequences, with priority to life loss, although monetary or resource loss may be considered.
- Location of Performance Concern. Locations with high breach potential may be considered. The primary source of information is the overview slides associated with the levee screening for each segment of the levee system. Multiple locations with identified weaknesses may exist for a levee system.
- Maximum Hydraulic Loading. A breach location with the largest differential between the maximum water surface elevation and the natural interior ground elevation may be considered.
- Upstream Location. A breach location near the upper end of the levee may be considered. This upstream location typically produces a relatively large inundation extent with larger depths than other locations.
- Mid-reach Location. A breach location near the mid-point of the levee alignment may be considered. This location typically produces a representative inundation extent for the system that is not biased toward the more extreme up-stream or down-stream locations.
- Downstream Location. A breach location near the downstream end of the levee system may be considered. This downstream location typically produces a relatively small inundation extent with shallower depths than other locations.

7.5.3 Embankment Levee Breach Characteristics

The simplified physical breach formation method is used to estimate the breach parameters for MMC levee models. The simplified physical method applies the basic assumption that the breach down cutting and widening rates are related to the erodibility of the levee material and velocity of the water flowing through the breach. Unique breach characteristics are estimated for each scenario analyzed.

Direct historic breach information for the levee being studied, if available, is considered as the most accurate estimate of future levee breach parameters. If historic breach parameters are available, the simplified physical inputs are adjusted manually in order to match the historic information.

The MMC standards for the HEC-RAS levee breach parameter inputs are described in the following sections.

7.5.3.1 Simplified Physical Erosion Rates

The simplified physical levee breach method is used for MMC Levee Breach analysis. The method requires an input of a breach widening rate versus velocity relationships (erosion rates). Currently, no widely accepted erosion rates exist for use with this method, but USACE is making progress toward this goal. Current suggested guidance for erosion rates is provided in Appendix 3.1.4, Application of Simplified Physical Breach Method in HEC-RAS. Resulting breach dimensions are carefully inspected after the HEC-RAS simulation to ensure the method produces reasonable results for all scenarios and adjustments are made as necessary. A single consistent dataset should be used for both the widening and down-cutting rates.

7.5.3.2 Maximum Breach Width

The maximum breach width is set to a value large enough such that it does not limit the breach development. If there are physical constraints that would limit breach development (e.g., tie into high-ground, or a well-founded structure), the maximum breach width is set accordingly.

7.5.3.3 Minimum Possible Bottom Elevation

The breach invert is set at approximately the interior land elevation adjacent to the levee at the specific breach location.

7.5.3.4 Breach Side Slopes

The breach side slopes are set to zero (vertical) for MMC levee analysis.

7.5.3.5 Breach Weir Coefficient.

With HEC-RAS version 6.2 the breach weir coefficient was set to 2.0. A value of 2.0 should be used as a base value for all MMC efforts, as this is a slightly conservative value in line with current lateral structure weir coefficients.

For higher level risk assessments or more detailed studies, the HEC-RAS development team and MMC leadership recommend a range of values from 1.0-2.0, with a value of 1.0 producing a smaller inundated area. This variable impacts the velocity through the breach and can also have significant impacts on the breach width when using the physical breaching methodology. Literature review of the paper “Estimates of Discharge Coefficient in Levee Breach Under Two Different Approach Flow Types”, by Seung Oh Lee, Et. Al. and similar research publications should be used to justify this value.

For specialized cases such that the levee is in the direct flow pattern or where significant ponding occurs so that the levee acts more like a dam than a levee, the weir coefficient should follow MMC dam breach methodology (a default value of 2.6).

7.5.3.6 Breach Failure Mode

For all prior-to-overtopping scenarios, the failure mode is set to piping. For the overtopping failure scenario, the failure mode is set to overtopping.

Note

The overtopping failure mode will not always allow a breach to fully form when combined with the simplified physical breach method and a shallow overtopping; therefore, MMC models will apply the piping failure mode for breach scenarios as needed using these model versions. Piping elevations shall remain near the bottom of the levee toe, even for overtopping breaches.

Another issue is the computation of velocities between 1D/2D flow regime. Using the normal 2D equation set is not recommended for any structures being breached. If the normal 2D equation domain is used, the modeler needs to verify velocity versus breach locations manually.

7.5.3.7 Notch Width (overtopping mode only)

Initial notch width for overtopping breaches is set to one foot.

7.5.3.8 Initial Piping Elevation (piping mode only)

Initial piping elevation is set equal to the minimum possible bottom elevation.

7.5.3.9 Initial Piping Diameter (piping mode only)

Initial piping diameter is usually set to one foot.

7.5.3.10 Mass Wasting Feature

The mass wasting option is typically not used for MMC levee models.

7.5.3.11 Trigger of Breach

The breach is triggered during the peak of the hydrograph at the breach location in all cases. This is accomplished using the Set Time trigger method.

7.5.4 Floodwall Breach Characteristics

7.5.4.1 Floodwalls on Natural Ground

Structural I-walls are likely to become unstable due to overtopping. (However, all breachable loadings below TOL will still be performed using the described method) The alignment of the I-wall will likely limit breach width, where connections to closure monoliths, T-walls, levees, or changes in the alignment will act as the likely boundaries to the breach extent. However, landside erosion can also be limited by the duration of overtopping, height of plunge, ground cover at impact location, and time for the area to be inundated with water. The formation time will also be very short, between instantaneous to 15 minutes. The MMC modeler should coordinate final selection of breach size and breach time with either a district structural engineer familiar with the project, or the RMC advisor.

The user-entered data breach formation method is used to estimate the breach parameters for typical L- or T- type floodwalls. Assume that 2 monoliths fail instantly (if monolith width is unknown, assume 40-foot monolith width).

If an unusual wall type is encountered, a supported structure should use the L- or T-wall methodology, while an unsupported structure should use the I-wall methodology.

Direct historic breach information for the floodwall being studied, if available, is considered as the most accurate estimate of future floodwall breach parameters. If historic breach parameters are available, the simplified physical inputs are adjusted manually in order to match the historic information.

7.5.4.2 Floodwalls Located on Top of Earthen Levee

Judgment is made to determine if the structure behaves more as a levee or a floodwall. The more representative method will be used to calculate the breaches.

7.5.5 Breach Repair

Breach repair is generally not used for levee breach projects. The breach repair option is only used at the request of the local district and with information provided from historic events or action plans.

7.6 Levee Hydraulic Model Files Summary

In summary of the detailed sections above, HEC-RAS model plans are developed for each breach location and hydraulic loading condition. The plans should utilize a single geometry file, one of the unsteady flow files, and the breach characteristics associated with the specific breach location and hydraulic loadings. The levee breach is initiated at the peak water surface elevation at the breach location being analyzed for all of the standard scenarios. All scenarios should run to completion and meet requirements provided in the SOP.

Additional requirements for the model dataset are outlined in Section 7.6.1.

7.6.1 Additional Model Requirements

7.6.1.1 Calibration

The HEC-RAS model is calibrated to measured data throughout the modeled area. The calibration efforts could entail unsteady flow simulation to match measured stage hydrograph, high water marks,

overtopping occurrence associated with a previous flood event, or a steady flow simulation to match a measured stage or high water marks. Calibration of a steady flow model typically involves adjustment of the Manning's "n" values and other geometry features to match the observed water surface elevations. Calibration of an unsteady flow model requires geometry adjustments to reproduce the maximum stage of high and low flow events and storage components (cross sections and storage areas) to improve timing and attenuation of the stage and flow hydrographs. Detailed information related to the calibration of a hydraulic model is found in EM 1110-2-1416, River Hydraulics.

It is recognized that calibration data within the floodplain for hypothetical levee breaches are rarely available, and published Manning's "n" values based on land cover typically use 2D flow areas. Calibration efforts for MMC Levee Breach models typically focus on ensuring the river adjacent to the levee is well calibrated to available information for non-breach events.

7.6.1.2 Model Stability and Convergence

Models developed for the MMC Production Center compute with minimal computational error for all scenarios. Instability in unsteady HEC-RAS model runs is probable during initial simulation. It is likely to take the modeler several iterations before instabilities are fully addressed in the model.

7.6.1.3 Files Sizes/Workability

Total file sizes for levee breach products can be very large and, in some cases, can become un-workable and production prohibitive. Take care to ensure model settings are optimized to improve efficiency in term of run-times, data transfer times, and file sizes.

7.6.1.4 Naming Conventions

Modeling guidelines are adopted by the MMC in order to maintain consistency for all hydraulic models created as part of the program. This section provides specific naming conventions and field description information to be used by MMC for levee breach analysis.

- Project File Name and Project Title: The HEC-RAS project file and project title use the MMC Common Name of Levee System (e.g., Hartford, Minot, and Metro Louisville).
- Geometry File Title: All models created for the MMC utilizing a single geometry are named with the MMC Common Name of Levee System (e.g., Hartford, Minot, and Metro Louisville).
- Unsteady Flow File Title: Levee models created for the MMC include up to 8 required unsteady flow files titled: First Toe Load, 50-percent Levee Load, 75-percent Levee Load, Top of Levee Load, 1-foot OT Load, 2-Foot OT Load, Excess Limit OT Load, and Maximum OT Load. The model may optionally include an additional flow file titled Base Inflow Hydrograph (or other appropriate label for the base inflow).

Note

If a sensitivity is performed, this naming convention is used with an appended phrase describing the sensitivity.

7.6.1.5 Plan File Names

A combination of the breach location name and unsteady flow name is used as the plan title for each MMC scenario. Abbreviated naming conventions for the breach locations and flow files are standardized and are used as the Short ID for each HEC-RAS plan. Table 7.4 provides detailed naming conventions.

*Table 7.4. Modeling, Mapping, and Consequences Plan and
Unsteady Flow File Naming Conventions for Levees*

RAS Plan Name	Short ID	Unsteady Flow File Name
Levee Control Location-50% Load	LCL_50P	50% Levee Load
Levee Control Location-75% Load	LCL_75P	75% Levee Load
Levee Control Location-TOL Load	LCL_TOL	Top of Levee Load
Levee Control Location-1ft OT Load	LCL_1FT_OT	1 Foot OT Load
Levee Control Location-2ft OT Load	LCL_2FT_OT	2 Foot OT Load
Levee Control Location-Excess Flooding Limit OT Load	LCL_LIMIT_OT	Incremental Limit OT Load
Levee Control Location-Maximum OT Load	LCL_MAX_OT	Maximum OT Load
Breach Location 2-50% Load	BL2_50P	50% Levee Load
Breach Location 2-75% Load	BL2_75P	75% Levee Load
Breach Location 2-TOL Load	BL2_TOL	Top of Levee Load
Breach Location 3-50% Load	BL3_50P	50% Levee Load
Breach Location 3-75% Load	BL3_75P	75% Levee Load
Breach Location 3-TOL Load	BL3_TOL	Top of Levee Load
No Breach-Toe	NB_TOE	Lowest Toe Load
No Breach-50% Load	NB_50P	50% Levee Load
No Breach-75% Load	NB_75P	75% Levee Load
No Breach-TOL Load	NB_TOL	Top of Levee Load
No Breach-1ft OT Load	NB_1FT_OT	1 Foot OT Load
No Breach-2ft OT Load	NB_2FT_OT	2 Foot OT Load
No Breach-Excess Flooding Limit OT Load	NB_LIMIT_OT	Excess Limit OT Load
No Breach-Maximum OT Load	NB_MAX_OT	Maximum OT Load

7.6.1.6 Removal of Working Outputs from Dataset

The final dataset includes only the relevant output from the final runs and all output from working runs is removed. Particular attention is paid to the DSS output file. As a final modeling step, it is good practice to delete all extraneous plans and output files including the .DSS file and re-run all plans so only HEC-RAS output associated with the final levee breach analysis scenarios is saved. This can also be accomplished by executing a File/Save As to a new location and then re-running all the appropriate MMC plans.

7.6.1.7 Model Description

All models created for the MMC Production Center include a thorough description field to provide potential users with pertinent information. The following items are listed in the HEC-RAS Model Description field (located in main RAS program window):

- Name of Levee
- NLD Levee System ID

- Location of dam and district
- Vertical datum and units
- Horizontal projection and units
- MMC Modeler
- Interim Reviewer
- Final Reviewer
- MMC Modeling Team Lead
- District H&H Contact Person
- Status of model
- Date of last modification
- Program and version
- Controlled Unclassified Information.

7.6.2 Scenario Summary

A typical levee breach model deliverable includes 20 scenarios, as summarized in Table 7.5. A description of the scenario should be included in the plan file, and should include breach number, location, and reason for selection, if applicable, loading scenario and source (i.e., a scaled event).

Note

It is possible that the levee is not loaded above the landside toe at some breach locations for the smaller hydrologic loading events. In these cases, that un-loaded scenario is not included in the model deliverable and the number of runs decreases. The number of scenarios may vary based on the actual number of breach locations selected for the project. There is also commonly a case where a levee is minimally loaded, or due to levee specific hydraulic/geometry loadings, the area behind the levee is already filled with water. In this case, the scenario is included in the model, but marked as non-developing in the report, with no further results reported.

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Table 7.5. Levee Breach Model Deliverable Scenarios

Breach Locations	50% Levee Height	75% Levee Height	Top of Levee Height	1-foot Overtopping	2-foot Overtopping	Excess Flooding Limit Overtopping	Maximum Flood Overtopping
Location 1—LCL	LCL_50P	LCL_75P	LCL_TOL	LCL_1FT_OT	LCL_2FT_OT	LCL_LIMIT_OT	LCL_MAX_OT
Location 2	BL2_50P	BL2_75P	BL2_TOL				
Location 3	BL3_50P	BL3_75P	BL3_TOL				
Non-Breach	NB_50P	NB_75P	NB_TOL	NB_1FT_OT	NB_2FT_OT	NB_LIMIT_OT	NB_MAX_OT

*Also, include Non-Breach Toe Loading Scenario (NB_TOE), although it is not used for consequence analysis

*Optional: Include Non-Breach Base Inflow Hydrograph Scenario

*Overtopping breaches are only modeled at the LCL location.

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7.7 Hydraulic Model Flood Mapping Outputs

After the hydraulic model is reviewed and completed, various mapping outputs are saved to disk using RASMapper by the modeler. The required outputs are described in the following sections.

7.7.1 Depth Grids

A resulting maximum depth grid is stored to disk for each modeled scenario. This process is accomplished using HEC-RAS RASMapper tools. The grids are saved in the default location as a sub-folder within HEC-RAS.

7.7.2 Arrival grids

An arrival grid is stored to disk for each modeled scenario. The process is accomplished using HEC-RAS RASMapper tools. The arrival grid is based on a zero-foot depth threshold and is referenced to the start of the HEC-RAS Simulation. The grids are saved in the default location as a sub-folder within HEC-RAS.

7.7.3 Inundation Boundaries

A resulting maximum extent of inundation boundary shapefile is stored to disk for specific modeled scenarios only. The Top of Levee breach and largest breach scenario are to be computed. This process is accomplished using HEC-RAS RASMapper tools. The shapefile is saved in the HEC-RAS default location, which is a sub-folder within the model directory (e.g., RAS\BL2).

7.7.4 Breach Location Shapefile

The hydraulic modeler creates breach location shapefiles for the project. The MMC projection is used. A text attribute field is added to the shapefile to identify the label for each breach location. A separate attribute identifies the breach location station utilizing the MMC stationing system. The modeler should round to the nearest 10-foot increment for the breach location station reporting. The breach location shapefile is saved to the MMC directory structure (Figure 6.3) for the project under the GIS_Modeling\Shapefiles folder.

7.8 Levee Hydraulic Model Documentation

All levee projects completed for MMC also have a corresponding MMC Levee Report. The report summarizes pertinent aspects of the modeling effort, consequences analysis, and basic map information associated with each scenario. Additionally, each project has a corresponding CTS worksheet that contains key information, inputs, and results for the levee system. The following paragraphs summarize the hydraulic modeler responsibilities for completing relevant sections of the report and worksheet.

7.8.1 Report and Consequence-based Top Screen Worksheet Location

The project report is housed on the MMC Team SharePoint to allow multiple members of the MMC production team to collaborate throughout the production process. As stated in Section 5, the files are initiated on SharePoint by the MMC documentation team before hydraulic modeling begins. Marked up and edited versions of the report are maintained on the SharePoint site at all times.

7.8.1.1 Reporting Breach Initiation Time

In order to create consistency in reported breach times by all members of the MMC production team, a standardized method for reporting breach initiation time is recommended. The breach time for a particular scenario is found by reporting the breach time specified in the plan file. Alternative methods for verifying this data is to open the model's runtime messages or to report the breach initiation time from the DSS file using the HEC-DSSVue program and selecting the "C:" drop down "BREACH-BOTTOM-WIDTH." When viewing the table that is produced for the model run of concern, the first time ordinate is the date and time to report for breach time.

7.8.2 Hydraulic Modeler Responsibilities

The hydraulic modeler completes Section 4 of the Levee Safety Report and the Contact Info and H&H Data tabs of the CTS worksheet located on the SharePoint site as part of the modeling process. The report must be complete prior to the interim model review.

7.8.3 MMC Project PowerPoint Presentations

The MMC project handoff PowerPoint is used to present hydraulic model development, results, assumptions, and issues. The PPT template is placed in the project folder on the team SharePoint project folder. The presentation is created by the modeler following the district model IQR.

The MMC Quality Review PowerPoint is used to present the project to the MMC Director during the quarterly quality review. The modeler or modeling team lead is responsible for filling in the modeling sections of this presentation following district model IQR.

7.9 Hydraulic Model Review Process

Hydraulic model review is an extremely important part of the MMC production process to ensure models consistently represent all project scenarios and the model accurately represents the consequences associated with each scenario. The technical review process consists of an interim review, a compliance review, and a district model review. The scope of each review step, as well as the guidelines for the review, are detailed below.

7.9.1 Interim Model Review

Once the hydraulic modeler ensures the model meets the requirements described in this SOP and all files are uploaded to the appropriate locations, the modeler notifies the modeling team lead that the dataset is ready for interim review. Following are the deliverables required for the interim review:

- Entire HEC-RAS model that meets all SOP requirements, including output files (location: MMC File Share)
- Saved inundation mapping outputs are not required for interim review of the hydraulic model (i.e., depth grids and arrival grids described in Section 7.7)
- Section 4 of the MMC Levee Safety Report completed (location: Team SharePoint Site)
- Contact Info and H&H Data tabs of the CTS worksheet have been completed (location: Team SharePoint Site)
- Model review checklist that includes modeler comments for each review checklist item
- Any additional supporting documentation or references used in the modeling effort to include district correspondence.

The hydraulic model reviewer initiates the review and provides comments back to the hydraulic modeler using the Levee Hydraulic Model Review Checklist populated into the team SharePoint project folder. The Levee Hydraulic Model Review file is used to track comments that are checked throughout the review process and is centrally located on the team SharePoint site.

7.9.2 Interim Review Backcheck and Compliance Review of Hydraulic Model

The hydraulic modeler makes any necessary edits to the model and documents all comments with resolution responses in the Levee Hydraulic Model Review file. After the hydraulic modeler has addressed the interim review comments and all files are uploaded to the appropriate locations, the modeler notifies the modeling team lead that the dataset is ready for backcheck and compliance review. The deliverables and requirements for the compliance review are:

- Entire HEC-RAS model that meets all SOP requirements, including output files (location: MMC File Share)

- Saved inundation mapping outputs (i.e., depth grids and arrival grids, and the breach location shapefile as described in Section 7.7)
- Section 4 of the MMC Levee Safety Report has been completed (location: team SharePoint site)
- Contact Info and H&H Data tabs of the CTS worksheet have been completed (location: team SharePoint site)
- Any additional supporting documentation or references used in the modeling effort
- Entire MMC Levee Project Directory must be organized according to the MMC folder structure as shown in Figure 6.3. This includes all pre-model data as well as the data created during the hydraulic modeling process.

The hydraulic model reviewer performs a back-check for all interim review comments and performs a compliance review to ensure the dataset is complete and all procedural steps have been followed. The backcheck responses and the compliance review are documented in the Levee Modeling Review Checklist file located on the MMC Team SharePoint site.

If there are outstanding comments on the model, the model reviewer contacts the modeler and works toward resolution of all comments. The modeler revisits the dataset as necessary to close the review comments.

7.9.3 District Independent Quality Review of Hydraulic Model

The MMC modeling technical lead is responsible for coordinating a review of the hydraulic model by the district. This typically takes place after the compliance review is complete but may be initiated sooner if the model is nearing completion. The process and documentation of this district IQR is:

- The modeler uploads model data to the district review within the temporary data folder on the MMC File Share site.
- The modeling technical lead notifies the district via e-mail that model is available to be reviewed for designated time period of approximately two to three weeks.
- The comments are documented on the SharePoint site.
- The modeling technical lead schedules a conference call at the end of the review period to discuss any district comments if needed.
- If any significant changes to the model are deemed necessary based on the district review, the modeler makes the necessary changes and the program coordinator and district reviewer perform a compliance review on the final data.

7.10 Model Data Delivery to Consequences and Mapping

After all hydraulic model reviews are closed out, the final dataset is ready for transfer to the consequences and mapping team members. The program coordinator transfers data via the MMC File Share and adheres to the MMC Levee Directory Structure (Figure 6.3) as described in Section 6.17 and includes all pre-model data as well as the data created during the hydraulic modeling process. The program coordinator sends an email description of the dataset and a link to the server location to all POCs listed in Section 2. The hydraulic modeler and any other MMC team members involved in the project are also included in the email distribution list. The deliverables are:

- Entire HEC-RAS model that meets all SOP requirements, including output files (location: MMC File Share).
- Saved inundation mapping outputs (i.e., depth grids, arrival grids, inundation boundaries, and the breach location shapefile as described in Section 7.7).
- Upload depth grids for each scenario to the USACE Flood Inundation Mapping Viewer. The breach location shapefile shall also be uploaded with each breach scenario. Coordination with the Map Viewer team is needed if the project datum is not Albers. Only when each dataset is prohibitively large for data uploads, it is recommended that the flood extent be clipped to the protected area. It is recommended that a single scenario be uploaded to verify

- reasonable upload speeds. If the upload speeds are prohibitively large, it is recommended to reduce the terrain file size and recompute all grids to be uploaded. There are currently several methods to complete this process. Consult with team leads for preferred method.
- Section 4 of the MMC Levee Safety Report is complete (location: team SharePoint site)
 - Contact Info and H&H Data tabs of the CTS worksheet is complete (location: team SharePoint site).
 - Hydraulic model review documentation (location: team SharePoint site).
 - Any additional supporting documentation or references used in the modeling effort (location: MMC File Share, typically in the references directory).
 - MMC project overview PowerPoint presentation.

SECTION 8—CONSEQUENCES MODELING

This section summarizes the process performed by the consequences team member once the consequences team receives modeling internal deliverables.

Specific how-to instruction documents for much of the consequences work can be found on the Consequences Wiki system on the MMC Team SharePoint site:

<https://team.usace.army.mil/sites/NWK/pdt/MMC/consequences/>

8.1 Consequences Model Development

Once the modeling inputs are delivered, a consequences model is developed by a consequences team member. The working copy of the consequences model is housed on the modeling team member's local machine until it is final. At that point, the model and associated files are uploaded to the RMCStorage 4 file share.

A single consequences model is developed for all levee breach scenarios. In some cases, the largest hydrologic event will not cause the largest LL. This can occur when the PAR within the protected area is warned due to expected overtopping prior to when a breach occurs. For hydrologic events that are large enough to result in overtopping, some of the PAR will already be warned and will be leaving the area when the levee breach occurs. While larger hydrologic events won't necessarily cause larger LL, the PAR and economic damage should always increase as the non-breach inflow increases (i.e., overtopping breaches should always show the largest PAR and economic damage).

8.1.1 Structure Inventory

The primary structure inventory is developed from the USACE National Structure Inventory (NSI). The NSI is a data service with a base dataset containing estimated information regarding the locations, building types, population, values, and other relevant information for all residential, commercial, industrial, agricultural, and public and private structures across the nation. The base dataset utilizes parcel data, Census data, Microsoft building footprints, and several other sources that serve as a basis for estimating flood hazard consequences. Population and structure values are estimated from a variety of sources.

The NSI is clipped to the study area (typically, the NLD protected area). The population and dollar values are indexed from their base year to the most recent year available.

See USACE NSI documentation for more information on the current NSI.

8.1.2 Emergency Planning Zones

Emergency planning zones (EPZs) are based on the study area boundary and typically only represent the protected area.

Further information on the development of study area boundaries is available in the Consequences Wiki system.

8.1.3 Arrival Zone Shapefile

An arrival zone polygon shapefile is developed in order to aggregate the consequence results to specific arrival zones in the simulation. The arrival zone polygon delineates the following six zones: 0–1 hour, 1–2 hours, 2–4 hours, 4–8 hours, 8–24 hours, and greater than 24 hours. Arrival zones are only developed for selected OT and TOL scenarios.

Further information on the development of arrival zone polygon shapefiles is available in the Consequences Wiki system and LifeSim training videos.

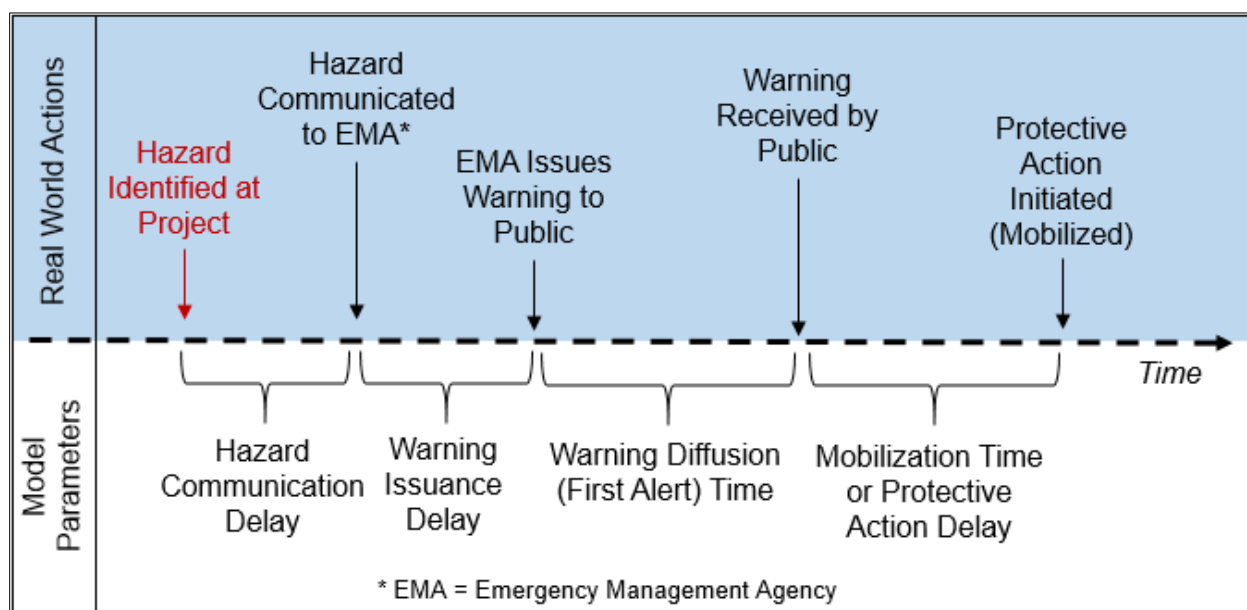
8.1.4 Road Network and Evacuation Destinations

Using LifeSim software, it is possible to simulate evacuation on roadways. A one-quarter mile or greater buffer is added to the existing protected area boundary, creating a polygon that extends beyond the delineated inundation area. This is done in order to capture all of the routes of egress from the protected area boundary. The road network will be imported from OpenStreetMap (another data source can be used if it's determined to be more appropriate). Vertical offsets are added to any road segments with bridges. If computationally prohibitive or no road data is available, evacuation simulation may not be performed. Exclusion of the evacuation simulation requires approval of the MMC Consequences Branch Chief.

8.1.5 Consequence Model Parameters

Figure 8.1 provides a conceptual diagram illustrating the flood warning and evacuation timeline based on real-world actions beginning when a hazard is identified at a project and ending once protective action is initiated.

Figure 8.1. Conceptual diagram illustrating the flood warning and evacuation timeline.



8.1.6 Hazard Identification Relative Time (Alternative Parameter)

The hazard identification value is the time, in hours, from the imminent hazard defined by the selected hydraulic data. Typically, the hazard is identified relative to either the breach initiation time or the initiation of overtopping. Table 8.1 identifies the two standard MMC warning scenarios with different ranges of hazard identification time: minimal warning and ample warning. Minimal warning scenarios have the hazard identification relative time set as a uniform distribution between three hours prior to breach or overtopping and 0.5 hour after breach or overtopping. Ample warning scenarios have the hazard identification relative time set at 24 hours prior to breach or overtopping.

Table 8.1. Standard Modeling, Mapping, and Consequences Warning Scenarios

Warning Scenario	Distribution	Minimum	Maximum
Minimal	Uniform	-3	0.5
Ample	None	-24	-24

8.1.7 Hazard Communication Delay (Alternative Parameter)

The hazard communication delay is the time it takes from when the hazard is identified to when the EPZ representatives are notified. For example, if a breach occurs when no one is observing the project, the emergency managers could be notified one hour after the hazard is identified. The hazard communication delay is set as a uniform distribution between 0.01 to 0.5 hours.

8.1.8 Warning Issuance Delay (Emergency Planning Zone Parameter)

The warning issuance delay is the time it takes from when the emergency managers receive the notification of the imminent hazard to when they issue an evacuation order to the public. The warning issuance delay is set at the preset configuration of Preparedness Unknown, which utilizes a Lindell uncertainty distribution. The delay is randomly sampled from 0–6 hours but is positively skewed such that results from 0–1.5 hours are more likely.

8.1.9 Warning Diffusion/First Alert (Emergency Planning Zone Parameter)

The first alert parameter defines the warning diffusion curve for daytime and nighttime. The diffusion curve represents the rate at which the PAR receive a first warning alert over time relative to the hazard identification. The first alert curves are set at the preset configuration of Unknown, which samples from a uniform uncertainty distribution where the percent of the PAR warned increases up to 100 percent just after 1.5 hours for the upper bound and 6 hours for the lower bound.

8.1.10 Mobilization/Protective Action Initiation (Emergency Planning Zone Parameter)

The protective action initiation (PAI) parameter defines the mobilization curve. The PAI curve represents the percentage of the population which will take protective action over time from when the first alert is received. For areas downstream of the dam the PAI/mobilization curve is set at the preset configuration of Preparedness: Unknown/Perception: Unknown which samples a Pert uncertainty distribution with maximum mobilization rates with a minimum of 76 percent, most likely 97 percent, and a maximum of 100 percent after 72 hours. This curve is used for all EPZs.

8.1.11 Number of Iterations (Simulation Parameter)

The number of iterations determines the number of Monte-Carlo iterations the model will run for each event. The number of iterations is typically set at 2,500, although this can be changed to accommodate long run times if necessary.

8.1.12 Results Summary Polygon (Simulation Parameter)

The results summarization polygons should include the arrival zone polygon shapefile for scenarios where an arrival zone polygon was developed. EPZs can be used as summary polygons for scenarios for which no polygon was developed.

8.2 Running the Consequences Model

The consequences model includes Monte Carlo simulations utilizing uncertainty around public warning issuance, warning diffusion, and protective action initiation. The mean results are used for CTS worksheet inputs; the statistical results of those runs are included as supplementary tables in the workbook.

The consequences model is simulated for all evaluated scenarios. LL and damage results are checked for reasonableness. The individual structure damage report is reviewed for abnormal results.

8.3 Annual Lost Benefits

Comprehensive consequence assessments require estimates of total economic impact. These estimates are developed and documented in the consequence toolbox spreadsheet. The following economic consequence categories should be evaluated:

- Flood risk management
- Other lost benefits.

8.3.1 Flood Risk Management

If flood risk management data is available, an average annual value will be estimated based on historic flood damages prevented. Each district uses either discharge-damage or stage-damage relationships for project areas to estimate flood damage with and without the project; these are reported to Congress on an annual basis. To determine an average annual value, the historical records of damages in each year are indexed to current value and divided by the number of record years to estimate an annual average. If only a cumulative value is available (no annual records), the value is indexed from the midpoint year and divided by the years of project operation to develop the annual.

8.3.2 Other Lost Benefits

Some projects have additional benefits/damages not included as flood risk management which can be reported as other lost benefits.

8.4 Consequences Deliverables

8.4.1 Consequences-based Top Screen Worksheet

A draft CTS worksheet will be on SharePoint in the project folder. This should have the Levee Info (NLD/NID) tab completed by the documentation team and the H&H Data tab completed by the modeler. The consequence team member edits the CTS worksheet in SharePoint and does not create or download a new version of the worksheet. The member adds the economics data to the CTS worksheet that is already posted to the SharePoint site, making sure to maintain all review and source comments on the already completed tabs. This worksheet is used by the documentation lead to validate the consequences portion of the report deliverables.

In addition to adding data from the Consequences Toolbox, life loss results maps, along with other supporting figures from the analysis, are also required in the CTS worksheet.

The consequence team member fills in the Contact Information tab when development is complete. The consequence reviewer will also fill in the Contact Information tab after data is verified and final. The status should be listed as Ready for Econ Review.

8.4.2 Consequences Toolbox

The LifeSim and Lost Benefits Excel toolboxes used to process results are posted to the SharePoint project folder.

8.4.3 MMC Project Handoff PowerPoint Presentation

The MMC project handoff PowerPoint used to present consequence findings during the handoff meeting is developed using the template provided in the MMC Team SharePoint project folder.

8.4.4 Consequences Model Data

The LifeSim model and input data files (not the HEC-RAS model data) are posted to the RMC file share production folders. Recommendation is to not zip the model folder.

8.5 Review Procedures

The economist is required to complete the MMC Consequences Team Checklist and upload the model data prior to technical review. The life loss, damages, and lost benefits estimates are reviewed internally before consequences are considered complete. Reviews are coordinated by the MMC Production Center Consequences Branch Chief.

After the products are reviewed by the QC reviewer, the economist addresses any comments. Once products are approved, the economist uploads the finalized consequences model to the appropriate consequences folder on the RMC file share. The modeler, consequences branch chief, and team leads are informed via email of the upload and location.

The CTS worksheet and model data are reviewed by the consequences QA review team member and details compared to ensure consistency during the report review process. The consequences branch chief notifies modeling, documentation, and project management of project completion.

SECTION 9—LEVEE FLOOD INUNDATION MAPPING

This section discusses the process used to provide inundation mapping data based on model outputs to MMC team members and customers. All steps are performed by the mapping production team member unless otherwise noted.

9.1 Review Hydraulic and Consequences Models

The mapping production team member reviews all H&H and consequences data to ensure consistency and completeness of models and documentation prior to mapping.

9.1.1 Folder Structure

Review the model data folder structure according to Appendix 4.3.1, and complete the model data review checklist in Appendix 4.3.4, Model Data Review Checklist.

9.1.2 Data, Report, and Model

Review the modeling data to include the consequences model, the HEC-RAS model, model output data, and reports to verify the data meet the checklist requirements for data inclusion and the data meet the data structure requirements. Verify the draft report, including modeling input, is available from the project's MMC team SharePoint folder.

9.1.3 Request Additional Information (if needed)

If additional data are needed, the mapping team member requests additional data from the assigned modeler for the study levee. Common missing elements are required model scenarios and model time steps.

9.1.4 Put Data in the Appropriate Location

Once data has been reviewed and the data checklist has been satisfied, the mapping production team member transfers all of the received data to the mapping technical lead for upload to the MMC server.

9.1.5 Develop KMZ Files

Convert the vector modeling data layers to .kmz files for use in Google Earth desktop applications using Google Earth Pro. Save the .kmz files in the Google Earth folder within the MMC file structure.

9.2 Model Data Dissemination

The mapping technical lead makes the data available in complete file format. The data is also viewable through the map viewer, which results in the following for the study area:

- Model data is available within the CEDALS database
- Model KMZ file is available within CEDALS
- Model and mapping data layers are loaded in the USACE Flood Inundation Mapping Viewer.

9.3 Data Loading Preparation

The mapping production team member develops and customizes datasets for use in all MMC Production Center maps.

9.3.1 Map Grids

A mapping grid layout is determined for the levee study, based on the size and orientation of the study. The national grid layer may be used if it is applicable to the study. The mapping team member will determine the sheet numbering and should provide the numbering for review at the mapping kickoff meeting.

9.3.2 Arrival Time and Depth Grids

The levee maps display both arrival and depth information as visual grids on the map sheets. The classification or grouping of time steps and depth ranges are determined by the mapping team member. The arrival time grids may be modified to show only time after levee breach, this is based on the modeled scenario and may be reviewed at the mapping kickoff meeting.

9.4 Sheet Index Map

An overview map is produced to orient the end user to the location of the map sheets relative to the overall inundation and region.

9.5 Export to Portable Document Files

All MMC Production Center projects have Portable Document Files (PDFs) created for the inundation atlas assembly. All files are created according to the mapping production guide.

9.5.1 Export Cover Page

Use the print to PDF functionality within Microsoft PowerPoint to convert the cover page PowerPoint file into a PDF document.

9.5.2 Export Map Notes Page

Template files are used for capturing map notes.

9.5.3 Export Standard and Detail Sheets

Template files and map series are used to generate standard and detail sheet maps.

9.5.4 Export Sheet Index Map

Template files are used to create the overview sheet index map.

9.6 Inundation Atlas Development

The inundation atlas is a consolidated mapping product of all the mapping outputs. See the map production guide for information on the contents of the inundation atlas.

Standard and detail sheets are exported as stand-alone PDF files. The files are stored individually and be combined into the inundation atlas. The file naming and storage parameters described in Appendix 4.1.3, Map Production Guide—Levee Studies, are followed for all PDF files. Individual pages are maintained in full-resolution and optimized formats. The full-resolution files are used to generate the combined inundation atlas PDF file.

The mapping production team member sends both the optimized and the full-resolution versions of the PDF files to the mapping technical lead for distribution and archival purposes.

9.6.1 Combine Pages

Use the Atlas Builder tool on the MMC Utilities Toolbar to combine PDF files into inundation atlases as in Appendix 4.1.3.

9.6.2 Optimize Portable Document Files

After saving a full-resolution version of the inundation atlas, use the optimization tool in Adobe Acrobat Professional to reduce the file size of the inundation atlas for web delivery. Use Appendix 4.1.3 to reference best practices to optimize the PDF map book.

9.7 Map Review (Draft)

The mapping products produced for the MMC are reviewed at two levels within the MMC and, optionally, additional reviews are performed outside the MMC. The internal review is performed by a mapping team member. All products are then provided for Technical Lead Review using a SharePoint hosted review process.

9.7.1 Internal Review

The mapping production team member is responsible for organizing an internal review of the inundation atlas and files used to create the inundation atlas within the mapping production team. The reviewer should review the atlases for cartographic and graphical completeness in accordance with Appendices 4.3.3, Mapping Review Guide, and 4.3.5, Mapping Deliverable Checklist.

9.7.2 Technical Lead Review

The inundation atlas is reviewed in pdf format by an independent reviewer assigned by the mapping technical lead. The checklist in Appendix 4.3.3 is filled out and comments for revision are documented and returned to the original mapping production team member.

The inundation atlas is reviewed initially and all comments are provided to the mapper for edits. The pdf inundation atlas is submitted for a second-round review where it is cleared for MMC and district quality control (QC) review in most cases. In some cases, additional rounds of technical lead review are necessary.

9.7.3 Update mapping product

The mapping production team member updates the map series based on comments from the mapping and modeling reviewers. The inundation atlas is then recreated after editing. Appendix 4.3.5 is used to verify that data is complete for the deliverable product. The revised files are then submitted to the mapping technical lead, who continues with the steps in Appendix 4.1.3 to finalize the pdf product.

9.8 Develop KMZ Files

Use Google Earth Pro to convert the data layers used in the maps to .kmz files for use in Google Earth desktop applications. Save the .kmz files in the GoogleEarth folder within the MMC file structure. All symbolization should match the guidelines set for the mapping process in Appendix 4.1.7, Map Graphics Specifications.

9.9 Final Reviews: Modeling, Mapping and Consequences and District Independent Quality Reviews

The district the levee is located in is offered the opportunity to review all MMC products. The mapping technical lead coordinates with the district LSO and LSPM to begin the review. The pdf inundation atlas, USACE Flood Inundation Mapping Viewer, and MMC file share contents are reviewed, as well as all modeling and consequences products. All comments are recorded and responded to within MMC external SharePoint site.

District review comments are provided to the MMC and addressed by the modeling, mapping, or consequences team members as appropriate. Once final review is complete and all issues are

addressed, the MMC mapping lead converts the suffix of the year root folder name in MMC file share from <Year>-Draft to <Year>-Final.

SECTION 10—FINALIZE MODELING, MAPPING, AND CONSEQUENCES DOCUMENTATION

10.1 Report Completion

Once all sections of the report are drafted, the documentation production lead ensures completeness of the report and passes the report for technical review by the designated subject matter expert (SME).

10.1.1 Report Development

Technical editor ensures CTS information is transferred to report and all sections of report are complete.

10.1.2 Report Map

A documentation team member creates a system map and detailed inundation maps as deemed necessary for inclusion in the report. Data for map creation is located in the RMC File Share GIS folder.

10.2 Report Finalization

After technical and management review, the documentation technical editor performs a technical edit of the document and notifies assigned team members of any comments or discrepancies needing resolved. A PDF is created of the final document and the production lead is notified of completion.

Once the document is final, a PDF is created of the final document and the production lead is notified of completion. The documentation production lead notifies the mapping technical lead that the document is ready for district IQR.

10.3 District Independent Quality Review

Once the report is finalized, the documentation lead notifies the mapping team lead to schedule the district IQR. The district LSPM has two weeks to enter comments to the MMC CoP SharePoint site. IQR comments received are input into the IQR SharePoint list by the project manager. The project manager notifies the assigned team members' comments are available. Comments are resolved by the modeling, mapping, consequences, and documentation leads via input from the assigned team members from the disciplines necessary.

Once the file is sent for IQR, the documentation production lead moves the Word document and the PDF of the pre-IQR report to the levee's Archive folder in preparation for IQR comments.

- Resave the pre-IQR word and PDF files, rename both documents so that the title includes "Sent_to_IQR." Change status to Pre-IQR.
- Move the renamed files to the archive folder.
- Delete the pre-IQR PDF remaining in the project folder.
- Change the status of the pre-IQR Word document to "For IQR updates."

Assigned team members make updates to the Word document using track changes to resolve IQR comments as needed.

Once the comments are resolved, the technical editor edits and finalizes the document and creates a new PDF. Status of these files is Post-IQR final. The documentation production lead notifies the mapping technical lead that the document is ready for backcheck. The documentation production lead also copies a link to the final PDF and pastes it into one of the comments on the IQR site so that the reviewer can quickly reference the revised document while reviewing the responses to comments.

SECTION 11—PROJECT CLOSE-OUT

After the district IQR is closed, the entire project dataset is consolidated and archived. The MMC final levee data is loaded within the CEDALS ProjectWise server as the authoritative record. The MMC mapping production team uploads final program data within the levee project folders.

LIST OF ACRONYMS AND ABBREVIATIONS

1D	one-dimensional
2D	two-dimensional
ACE-IT	Army Corps of Engineers-Information Technology
CoP	community of practice
CWMS	Corps Water Management System
DFIM	digital flood inundation mapping
ESD	Enterprise Service Desk
ESRI	Environmental Systems Research Institute, Inc.
ERDC-ITL	Engineer Research and Development Center-Information Technology Laboratory
FIS	Flood Insurance Study
H&H	Hydraulics and Hydrology
HEC	Hydrologic Engineering Center
HEC-GeoRAS	Geographic River Analysis System
LifeSim	Life Loss Estimation
HEC-RAS	River Analysis System
HH&C CoP	Hydrology, Hydraulics, and Coastal Community of Practice
HSIP	Highway Safety Improvement Program
LBIM	levee breach inundation map
LCL	level control location
LiDAR	light detection and ranging
LNIM	levee non-breach inundation map
LOP	line of protection
LSO	Levee Safety Officer
LSOG	Levee Senior Oversight Group
LSPM	Levee Safety Program Manager
LST	levee screening tool
MMC	Modeling, Mapping, and Consequences
NAVD 88	North American Vertical Datum of 1988
NED	National Elevation Data
NGVD 29	National Geodetic Vertical Datum of 1929
NLCD	National Land Cover Database
NLD	National Levee Database

PDF	Portable Document File
POC	point of contact
PWP	project work plan
QC	quality control
TOL	top of levee
USACE	U.S. Army Corps of Engineers

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