



Prepared by/for:

**Modeling, Mapping,
and Consequences**

Technical Manual for Dams

**Modeling, Mapping, and Consequences
Fiscal Year 2027**

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SECTION 1—FY2027 MODELING, MAPPING, AND CONSEQUENCES TECHNICAL MANUAL FOR DAMS UPDATES

This section summarizes the Modeling, Mapping, and Consequences (MMC) Production Center standard operating procedures (SOP) updates between the fiscal year (FY) 2027 SOP technical manuals.

- Dams with previous Periodic Assessments meeting established MMC modeling and documentation standards will be studied using a reduced scope process. The reduced scope process is further outlined in Section 2.1.2.
- Modeler conducts research to see if new terrain exists.
- Model scenario.

The approach currently practiced by the MMC for dam breach modeling is to use the USACE Hydrologic Engineering Center software suite with primary use of the River Analysis System (HEC-RAS) and RAS Mapper. The LifeSim consequences model uses the results from the hydraulic models to compute life loss.

SECTION 2—INITIAL PROCEDURES FOR DAMS

This section summarizes the initial sequence of procedures used by the MMC Production Center to complete a new flood risk management or navigation dam study and update to an existing dam study.

Deliverables from a dam breach study include of a hydraulic model developed using River Analysis System (HEC-RAS) software, consequences modeling developed using Life Loss Estimation (LifeSim) software, a Hydraulic Modeling and Consequences Assessment Summary (HMCAS) report, a fully developed consequences-based top-screen spreadsheet, and a map atlas. Appurtenant structures will be modeled as part of the main project model, receive separate documentation, and be included in the project's map atlas.

2.1 Levels of Effort Determination

The level of effort is dependent on the study purpose and program requirements. Table 2.1 lists general determining factors for the level of effort.

MMC subject matter experts from each discipline examine existing products, program requirements, and technology developments, as well as time, resource, and funding allowances to determine the optimal level of study effort for each project proposed for each fiscal year.

The MMC director holds final determination on level of study effort. Engineering judgement, modifications to projects, and program management considerations are accounted for when determining level of effort.

Whether the study is an initial study or an update to an existing study, the initial step is district coordination, and the existing kickoff meeting checklist is updated to determine if new or supplemental data exists that should be used during the update. All district model independent quality review (IQR) comments and mapping/documentation IQR comments should be reviewed for items that were deferred to future study. The existing digital elevation model (DEM) should be evaluated by the MMC modeler and modeling team lead to determine if the elevation data has been updated since the previous study. The assigned modeling production team member evaluates any existing modeling provided by the district. The evaluation is based on map projection, file structure, model layout, and model setup to determine to what extent it meets current MMC modeling guidelines. The evaluation is reviewed by the modeling team lead; a recommendation will be made regarding whether to use the existing model or create a new one.

Table 2.1. Modeling, Mapping, and Consequences Level of Study Determination (sheet 1 of 2)

	Full Study	Reduced Effort	Partial Effort	No Update	Differences
Model Detail (i.e., incorporation of new 2D areas, additional cross sections, model layout refinement)	No previous periodic assessment conducted; Previous hydraulic model uses FLO2D; No previous completed modeling report or CTS worksheet; Substantial effort required to meet MMC standards (technological improvements, changes to methodology).	Previous full MMC study post 2014; Adequate HEC-RAS model available; Defensible documentation of previous MMC products.	Utilize existing model, post 2014; identify if a model scenario(s) needs to be added to the existing model.	Review model and determine no updates are required.	Less detail in non-critical areas. Strongly relies on existing model geometry (better versus good enough).
Hydraulic Model	Full Suite of MMC Scenarios.	Full Suite of MMC Scenarios.	Determine if a New Scenario(s) is necessary.	None.	None.
Terrain	Best Available.	Existing or Best Available.	Existing.	None.	Existing Terrain will be used for Reduced Effort if best available requires significant changes to model geometry.
Duration Relationship	Updated Duration Relationships.	Existing Duration Relationships Will Be Used.	Existing Duration Relationships Will Be Used.	None.	10-percent Duration Exceedance Pool Elevation is not updated.
Mapping-Model Refinement	Detailed Model Refinement for Mapping.	Limited Model Refinement for Mapping.	Minor Model Refinement or Add New Scenario(s).	None.	Minor gaps or cutoffs in inundations can be expected.
Breach Wave Timing	Breach Wave Timing Table in Report	No Breach Wave Timing in Report	Only new Scenario(s) for Breach Wave Timing.	None.	Breach Wave Timing is available in mapping products, consequences presentation, and hydraulic model results.

Consequences	Full Consequences Suite of Deliverables	Full Consequences Suite of Deliverables	Consequences for new Scenario(s).	Only update if HEC-FIA was used.	None
CTS	Full CTS	Partial CTS	Existing CTS, Add New Data	Only update if HEC-FIA was used.	No Pertinent Data tab, no H&H Timing tab

Table 2.1. Modeling, Mapping, and Consequences Level of Study Determination (sheet 2 of 2)

	Full Study	Reduced Effort	Partial Effort	No Update	Differences
Documentation	HMCAS, HMCAS NAV, ASH	Memo, Memo with ASH	Update Existing Report with New Data.	Only update with latest HEC-LifeSim consequence data per customer request.	Memo provides only summary of updates to existing hydraulic and consequence modeling efforts; no modeling or detailed consequence results.
Mapping	Full Mapping Deliverable	Partial Mapping Deliverable	Review to Confirm if updated Maps are Required.	Only update by customer request.	Full Mapping Deliverable Minus KMZ Files and Custom Annotation
Risk Database	Full Project Data Entry	Limited Project Data Entry	Gaps in Data.	None.	Gaps in Data

2.1.1 Full Effort Study

A full modeling and documentation effort may be recommended if MMC modeling products have not been updated in over 10 years and/or fall well short of current technical, administrative, or other MMC process standards or requirements.

Projects for which no MMC effort has been performed will always require a full modeling effort subject to the project type, ownership, and purpose/hazard classification.

A Full Effort is subject to all requirements called for in the latest MMC Technical Manual for Dams.

Examples

- An early MMC study effort (2009-2013) that has had no subsequent modeling update may require a full update. These studies may fall short of current technical standards and documentation requirements. In many cases, updates may not have been performed due to risk assessment or associated modification studies since the original modeling effort. If hydraulic and consequences models from these studies cannot be located, or if documentation related to the original or subsequent consequences modeling efforts are limited, a Full Effort may be recommended.
- A Full Effort may also be recommended if substantial hydraulic modeling edits are required.

It should be noted that the age of a study is neither a pre-requisite nor an automatic qualifier for a Full Modeling Effort. Its consideration should be limited only to the general study requirements of a given time in terms of breadth of scope relative to current requirements and needs.

A Full Effort is subject to all requirements called for in the latest MMC Technical Manual for Dams.

2.1.2 Reduced Effort Study

To decrease costs, a Reduced Scope may be appropriate if existing products are largely adequate and hydraulic model updates will be relatively minor. A Reduced Scope recommendation also requires a previous CAR, HMCAS, or other detailed modeling report where a consequences modeling effort has been previously and fully documented.

Example:

- A Reduced Scope may be appropriate for a “Second Round” PA. If existing hydraulic modeling for the dam or, more likely, for another project within the same watershed, has been updated within the last few years, limited model refinements may be needed for adequate consequences analysis and mapping.

The study process and products are the same as Full Efforts except for the following:

Technical

- Model edits (if any) should generally be limited to areas that may affect the consequences estimate.
- Edits resulting in a substantial increase in simulation time should be minimized where possible.
- Less strict adherence to technical best practices or guidance that, with confidence, will not affect the consequences estimate. Such items may be project specific.
- May tailor scenarios per district request based on previous risk evaluations and/or PA results.
- Limited model efforts focused on inundation mapping details that would not affect useability/appropriateness as an EAP mapping product. Such efforts would address cosmetic concerns only. Examples include efforts that address very minor cut-offs or gaps in mapping that may not be noticeable at a published map scale or performing in-channel terrain modifications so that a channel will be shown “wet” at low flows.

- If an update of duration relationships is not needed to determine the Normal High Pool, then use the most recent model elevation. (Caveat: if there has been a significant structure modification, then discuss the physical changes with district personnel to determine if the Normal High Pool requires a review and update as necessary.)

Nontechnical/Administrative

- To reduce duplication of model results and project background narratives, a Memo for Record (MFR) will be used to document the modeling effort instead of a HMCAS. Model edits, assumptions, and limitations are documented. Modeling results are published in the CTS and the former CAR, HMCAS, or other detailed modeling reports, are referenced for additional information.
- The Pertinent Data and H&H Timing worksheets in the CTS will not be filled out. Timing information will be provided upon request.

All other products and activities, such as review activities and study processes, are the same as a Full Effort.

2.1.3 Partial Update

A partial update, which is less than a reduced scope project, is recommended when existing hydraulic modeling products (post-IES or other) will adequately support updated consequences and/or mapping.

Examples:

If a risk assessment (with Top of Dam) was completed since the last MMC modeling effort, a partial update may be recommended if the following conditions apply:

- The hydraulic model and associated documentation are available and adequate.
- No changes to results would be expected with updated hydraulic modeling.
- The hydraulic modeling was performed in HEC-RAS version 5.0 or later.

Updated consequences (using the former hydraulic model output) will still be needed unless the former consequences analysis (e.g. LifeSim) was completed using current standard datasets/hazard curves, assumptions, and approach.

Updated mapping will also be needed unless developed as part of the risk assessment.

Hydraulic modeling efforts for a Partial Update may include selection of the most appropriate scenarios to carry forward for consequences / mapping, development of mapping data, and documentation in a MFR.

Although no hydraulic model review activities will be necessary if no modeling updates are performed, all other typical processes and products are needed. Hydraulic modeling support is still required for development of presentation slides and upload of mapping data to the FIM viewer.

2.1.4 No Update

If recently completed MMC modeling and mapping products are available for the given project, no update may be needed.

A MFR is required to document supporting findings and reference the former modeling and mapping products.

2.2 Develop Scoping Document

The scoping document serves as a record for scoping decisions and supporting data/assumptions. It is also useful as a resource for the hydraulic modeler.

2.2.1 General review and selection of existing models

2.2.1.1 Research available models:

- Note the latest MMC modeling effort including the hydraulic/consequences model version and year.
- Note whether a CAR or HMCAS has been developed and verify the hydraulic model is located in CEDALS and/or the RMC4 project folder.
- Are there any “defer to future study” comments in the IQR database?
- Is the latest set of inundation/EAP maps based on this modeling effort?
- *(Recommendation: Copy pertinent data tables for the subject project from WCM or former CAR/HMCAS for quick or future reference)*
- Check for and note more recent system or CWMS/RIM models (can use the FIM viewer). Document study type/year and any important modeling details relevant to potential use, such as model origin.
- Check for MMC development of modeling for risk assessments funded under “WEDGE” (2018-2020 update). Review associated documentation. Determine model origin and edits made to the model.

2.2.1.2 Review model layout and flood extent

- How does MH peak pool elevation compare to TOD elevation? Based on judgement (and any other additional data), how likely will the existing model “width” or downstream extent capture flooding from a TOD Breach scenario?
- Use expert judgment on the time and cost considerations if geometry requires expansion. Reach out to program manager and technical lead.
- If district requests to use an internal model, MMC should verify and compare the district model against the latest MMC model to confirm it can or should be used.
- Is model layout reasonable? Could a different layout or modeling approach (such as 2D) substantially change modeling results?

2.2.1.3 Other model scoping considerations with use of selected model(s)

- Consider terrain used in the best available model(s). Is it known whether the terrain was incorporated in the geometry or just used in mapping? Is this something that needs to be done? If so, then to what extent (the whole model, part of the model (consider consequences location(s), etc)
- Qualifiers:
 - If the existing model is complex, do not assign this to a first-time modeler.
 - Require the modeling technical leads to determine the scope and complexity of projects prior to making assignments.
- What is the simulation run-time of the best available existing model?
- Could run-time change with recommended edits?
- Is run-time production prohibitive with expected funding availability or study requirements?

2.2.1.4 Based on research, recommend the model (or models) to start with; highlight important details related to study costs

- PMF updates
 - Document the origin of the MH inflow hydrograph from the last modeling effort.
 - Review the last PA or risk assessment report for PMF/IDF updates and note the level of detail (and review if known) of the updated analysis.

- Note how the peak IDF pool elevation compares to the TOD elevation. If the updated IDF elevation overtops the dam, reconsider findings in 1(b).
- Risk drivers
 - Review of the latest PA or risk assessment report for the risk driver failure modes
 - Determine whether the typical MMC breach modeling approach can be used to reasonably represent risk drivers or will different or additional breach parameters/scenarios be needed.
 - For PA reports, review Chapter 7 for discussion relating to the appropriateness of MMC assumptions for each risk driver.
 - *(Recommendation: 1) Note critical loading conditions for each risk driver. If additional scenarios are expected to be scoped, costs of MH vs NH simulations (for example) may not be an insignificant consideration. 2) Note whether the team adjusted consequences from the mean MMC estimate for potential consideration in study scoping.)*
- Consequences
 - Review of the latest consequences analysis results. What is the magnitude and where are the locations of the consequences? This should be a major consideration regarding the detail, type, and extent of recommended model edits.
 - *(For example, if consequences are near the dam, additional model detail is not needed in downstream areas. Or if consequences are exceptionally large due to overwhelming flood depth, model refinement in these areas are likely unnecessary.)*
 - Can information be inferred regarding the likelihood of the consequences category changing with this update? Consider previous consequences modeling software and hazard curves, PAR vs LL, location of PAR (near vs far from project), depth of flooding in areas with LL, other. At this time, model scoping decisions should generally not be affected by these considerations. Once consequences are recalculated, having these considerations documented may help internal calibration in the future where such considerations may be valuable.)
- Appurtenant/Associated Structures
 - Does the project have any associated structures documented in the National Inventory of Dams (NID).
 - If an associated structure exists, has it been previously modeled with documentation in an Appurtenant Structure Report?
 - Consider additional efforts associated with combining hydraulic model geometries for breach analysis for the dam and structure (if necessary and if needed)
 - Consider all other items above as necessary.
- Does the project have any features (saddle dams/dikes) that are not in the NID, but have been found to be risk drivers for the project?
 - If such a feature exists, additional breach scenarios are generally needed if the breach simulation of the main dam is not representative. Consider differences in breach parameters, reservoir volume above the breach invert, and location of the PAR.
 - *(Additional breach scenarios for only the critical loading condition(s) of the risk driver failure mode should be scoped.)*

2.2.1.5 Scoping Recommendations

- Provide the recommended general study type (Full, Reduced, Partial, None) with reasons for selection. Next document important findings relating to the cost estimate as well as hydraulic modeling recommendations/approach. Document the following:
 - What model(s) should be used.
 - Note whether “pre-model” terrain may be needed.
 - What model geometry edits or modifications are needed or recommended (Such as: new 2D, combination of model geometries, re-cut geometry to new terrain, extension of storage/rating curves to higher elevations, extending cross sections / storage areas / downstream model extent, additional or modification of features representing levees with data from NLD...).
 - What edits are NOT needed (if known).
 - If additional plans are expected, would sensitivity simulation(s) suffice, or will additional consequences results and formal documentation be needed?
 - *(For projects with structural (monolithic/gate) and embankment-related risk drivers, the additional scenarios may need full documentation)*
 - Note whether a standard or non-standard breach modeling approach is expected. If a risk assessment provides for site specific parameters, these should generally be used in-lieu of regression equations for base scenarios.
 - Provide other important items that may affect study costs, such as simulation time or unknowns regarding model instabilities.
 - Are there any project-specific or district-specific recommendations, such as advanced coordination regarding breach parameters, coincident flows, or project operation?
 - Provide any other recommendation to the modeler based on review efforts regardless of whether it will impact scoping decisions. **The reviewer is now the most knowledgeable resource related to the modeling effort. The modeler may have limited modeling or MMC experience, and any preliminary insight could be valuable.**

2.3 Fill Out Cost Estimate Worksheet

- Obtain the latest Cost Estimate Worksheet from the MMC Dams Program Manager.
- Standard costs for study type, modeling subtasks, and review activities are included in the spreadsheet.
- Select the study type and fill out the worksheet based on findings and recommendations provided in the Scoping Document. Care should be taken to only make additions/changes in cells marked for “extra” item costs. Costs can be added or removed in these cells. Provide description of changes to standard values in an empty cell(s).
- Provide Scoping Document and Cost Estimate Worksheet to MMC Dams Program Manager.

2.4 Adopt Scope and Cost Estimate

The MMC Dams Program Manager will schedule a Model Scoping Meeting to discuss scope recommendations with other MMC Modeling and Consequences leads. Review findings, major recommendations, and study costs will be presented. Any aspect related to the modeling effort can be modified based on the discussion. The outcome of this meeting will be formal adoption of the final scope/cost estimate.

2.5 District Coordination

The first step of a new study, following work acceptance by the MMC Director, begins with the project manager (PM) leading development of the project work plan (PWP), MMC Kickoff Meeting Checklist

completion, and district coordination. The district Dam Safety Program Manager (DSPM) and Dam Safety Officer (DSO) are contacted by the PM or documentation lead to complete the initial MMC Kickoff Meeting Checklist. The checklist outlines details regarding available dam specifications, manuals, previous models, and data. The DSPM and DSO recommend district points of contact for the facility project manager, hydrology and hydraulics (H&H) engineer, geographic information systems (GIS) specialist, and economist, if resources exist. The PM utilizes this information and works with the MMC project delivery team (PDT) to complete the PWP. The PWP will include an initial description of the work to be conducted by the MMC and the projected schedule for each work item. The MMC PDT and district points of contact (POCs) walk through the PWP during the project kickoff meeting. The district will have an opportunity during the kickoff to describe existing project criteria and conditions to begin modeling the dam or appurtenant structure assigned to the MMC.

2.5.1 Develop Project Work Plan

The PM is the lead to create an external and internal PWP, and coordinate with the modeling technical lead for input. The documentation lead will create the project directories on the MMC file share and MMC Team SharePoint Site. More detailed discussion of the MMC dams folder structure can be found in Appendix 4.3.1. The MMC folder structure will be delivered to the assigned modeler and used throughout the entire process.

2.5.1.1 External Project Work Plan

An external PWP will be developed for the dam project. The documentation team will develop the PWP and provide it to the PM for revision. Prior to the kick-off project, the PM will notify the members of the kick-off meeting of information that will be required to fill out the dam PWP.

2.5.1.2 Welcome Packet

A welcome packet will be developed by the modeling lead for the dam project. It provides contact information for the modeling team lead, funding amounts, project-specific information, and internal schedules. The packet will be provided to the modeler via email.

2.5.2 Project Kick-off Meeting

The MMC PM will schedule a project kick-off meeting after the draft external PWP has been developed. At a minimum, the invites will include: the district DSPM, district DSO, MMC modeling lead, assigned MMC modeler, MMC mapping lead, and MMC consequences lead.

The kick-off meeting will clarify scope of the study as well as the schedule and budget. The MMC PM and modeler will discuss key technical information with the district personnel, and these technical details will be highlighted within the PWP. Primary data sources will also be identified, such as existing hydraulic models, high-resolution DEMs, and project datum conversions.

If it is determined that the mapping section needs to produce updated terrain during the kickoff, the modeler should send the study extent to the mapping team lead in the form of a GIS file (i.e., shapefile, feature class, GeoJSON, etc.). If a recommended source for the terrain data is discussed (i.e., state website, district data, etc.), that information should also be passed to the mapping team lead.

Figure 2.1. Modeling, Mapping, and Consequences Delivery File Structure

Repository Search Results > Albeni Falls Dam (ID00319) > 2025																							
View Models (0) Repository: Albeni Falls Dam (ID00319) Program: MMC Purpose: Dam Structure: Albeni Falls Dam Group: USACE-MMC Store: MMC-Storage Size: Index repository for size calculation Last Indexed: Not indexed Last Updated: Thu, 20 Jun 2024 13:24:51 GMT	Filter... <table> <thead> <tr> <th>☐</th><th colspan="2">File Name</th></tr> </thead> <tbody> <tr> <td>☐</td><td></td><td>A._Pre-Model_Data</td></tr> <tr> <td>☐</td><td></td><td>B._Interim_Review</td></tr> <tr> <td>☐</td><td></td><td>C._Compliance_Review</td></tr> <tr> <td>☐</td><td></td><td>D._District_Review</td></tr> <tr> <td>☐</td><td></td><td>E._Final_Model</td></tr> <tr> <td>☐</td><td></td><td>F._References</td></tr> </tbody> </table>		☐	File Name		☐		A._Pre-Model_Data	☐		B._Interim_Review	☐		C._Compliance_Review	☐		D._District_Review	☐		E._Final_Model	☐		F._References
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☐		D._District_Review																					
☐		E._Final_Model																					
☐		F._References																					

2.5.3 Projections and Datums

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 Rico (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).

The mapping team will provide a PRJ file prior to modeling beginning. This file is maintained in the production pre-model data folder. The modeler will place the PRJ file into the RAS folder.

Appendix 4.1.1 provides detailed projection parameters.

The MMC projection is used for 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.

2.5.4 Create Centerline and Banklines

Digitize the river centerline and banklines from the study dam downstream, following the guidelines set in Appendix 4.1.1. If previous studies included coincident digitizing, the previously completed data may be used.

The dam will be located using the National Inventory of Dams (NID) database. The location will be verified against the most current aerial imagery available (see Appendix 4.1.1).

The Environmental Systems Research Institute (ESRI) world imagery service is used to digitize the centerline and banklines at a scale of 1:15,000 from the dam to the downstream extent provided in the PWP. If the centerline is stopped at a confluence, the centerline should proceed downstream past the confluence to account for any impacts at that confluence. The objective of this guideline is to minimize the chance of developing additional data later, and in many cases a longer study reach is developed than will need to be modeled.

2.5.5 Create Study Area

Create a study area boundary based on the digitized centerline or the preliminary depth grid (see Appendix 4.1.1). The preliminary depth grid would ensure backwater areas are captured. The depth grid is converted to a polygon and buffered by a specified distance.

The study area is used to define the maximum DEM extent to be included for modeling; the study area will include areas 20 miles from either side of the river centerline as well as cover the entire pool of the study lake at the top of dam (TOD) elevation.

There is some subjectivity in the creation of the study area; care should be taken to include all areas that could be inundated and include all areas provided in the downstream extent provided in the PWP. Overestimate the extent of the study area—the modeler can eliminate extraneous elevation data during the modeling phase. Underestimating the extent of the study area will cause the modeler to request additional data, which will cost time and effort.

The study area is included in the pre-model data deliverable.

2.5.6 Producing Digital Elevation Models

Merge source DEM tiles that intersect with the study area and project the DEM in the MMC projection. DEMs will be provided in native projection and in the MMC projection. Providing the native projection DEM allows the modeler to use a projection 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. Appendix 4.1.1 details the DEM production steps.

The DEM is included in the pre-model data deliverable.

2.5.7 Creating Preliminary Depth Grid

Create a preliminary depth grid in the MMC projection by developing a triangulated irregular network (TIN) that represents an elevated water surface (WS) that is intersected with the DEM to estimate the floodplain extent. See Appendix 4.1.1 for details.

The preliminary depth grid is included in the pre-model data deliverable.

2.5.8 Top of Dam Contour Polygon

The TOD contour polygon represents the maximum pool behind the study dam at the TOD elevation. The polygon is generated by intersecting a raster dataset representing the WS and the study digital elevation model. The resulting raster depth grid is then re-classified to represent either inundated area or non-inundated area. Convert the re-classified raster to a polygon feature class and delete the non-inundated area features from the resulting data set. See Appendix 4.1.1 for details.

The TOD contour polygon is included in the pre-model data deliverable.

2.5.9 National Levee Database

Levee information from the National Levee Database (NLD) is provided to all modelers by the mapping technical lead independent of the pre-model data deliverable. 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 will need to confirm a levee line of protection (LOP) is available that combines the levee segments with closures and other structures that complete the levee alignment.

2.5.10 Creating .aprx File

Create an .aprx file with the following layers:

- Conversion points
- Centerline
- Banklines
- Study area
- TOD contour polygon
- Preliminary depth grid
- Native and MMC-projected DEM
- ESRI Layers—street map, imagery, and topography
- Vertical datum conversion grids.

Appendix 4.1.1 details the .aprx production steps. The .aprx file is included in the pre-model data deliverable.

2.5.11 Review Deliverable

Review the deliverable for content and conformance to the standard defined in Appendix 4.1.1. Use the checklist in Appendix 4.3.2; ensure all deliverables are included.

2.5.12 Deliver Data to Assigned Modeler

The mapping production team member will package the data and post it to the project production folder in the model library. The PM and Modeling Team Lead shall be copied on the transmittal email to the modeler.

The mapping team member sends the data to the identified modeler unless the Modeling Team Lead directs otherwise. Any revisions or additions to datasets should be requested through the mapping production team member and will be transferred in the same manner as described above.

Once the deliverable is provided to the modeler, the task in the schedule database “Pre-Model” is complete.

2.5.13 Load Data in Modeling, Mapping, and Consequences Geodatabase

The mapping technical lead will save a full copy of the deliverable in the MMC Production Center Pre-Model Data Geodatabase. See Appendix 4.1.3 for more information on the geodatabase schema.

2.5.14 Update Project Schedule

The mapping team lead shall communicate status regularly, especially at task completion, to the PM. The PM will mark the task as complete.

2.6 Pre-Model Geographic Information System Data Production

While most new projects only require an updated DEM as part of the pre-model data, if needed, this step generates the internal GIS deliverable needed by the modeler to begin model development.

The mapping production team member is responsible for providing the assigned modeler with the GIS data necessary for the initial model setup using national data sets as described in Appendix 4.1.1. The data will be provided to the modeler using the standards described in Appendix 4.3.1. Appendix 4.1.11 describes the methods used to determine if additional efforts are required to include levee elevations from the National Levee Database (NLD) in the pre-model DEM.

2.6.1 Create File Structure

The documentation team member creates the MMC folder structure in the model library. The pre-model data is delivered to the assigned modeler via the model library. Figure 2.1 is an example of the MMC folder structure.

Pre-model data is posted to the project folders located on the model library (<https://model-library.sec.usace.army.mil/model-library>). Assistance with the model library is available through the help desk at mlhelp@usace.army.mil.

2.7 Supplemental Data Research and Processing

The modeling team members will coordinate with district POCs to identify relevant H&H data needed for model setup and data that may assist or streamline the modeling process. Such data may include existing models or information pertaining to previous risk assessments, such as risk driving failure modes and associated consequences modeling assumptions. If necessary, the mapping production team will identify existing GIS data that may be of better quality than the national datasets used in the rapid data development process. To warrant processing costs, care should be taken to ensure that elevation data identified are sufficiently better than the 3D Elevation Program (3DEP). Of special interest is light detection and ranging (LiDAR) including 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.

If bathymetric surveys are available for downstream impoundments, especially when there is a chance for a cascading failure, the survey should be considered for inclusion to the base DEM. Availability of bathymetric survey data should be coordinated with the modeling and mapping team during pre-model data development. Supplemental data documentation is delivered to the modeler for reference. Large-scale dams with the potential to overtop downstream structures will be modeled and named according to the cascading dam and pool elevation. The HMCAS (Table 3.5) and/or MFR report and CTS worksheet (H&H Data tab) will capture the cascading scenario-elevation and if it overtops the downstream structure to include color-coding: green (no) and red (yes). The data research will be conducted as a collaborative effort between the modeler and the mapping team in accordance with Appendix 4.1.2.

2.7.1 Deliver Research and Acquisition

The PM should notify the study dam project's district DSO and DSPM that the project will be studied and request updated data POCs to confirm the information in the MMC Kickoff Meeting Checklist.

2.7.2 Existing Hydraulics and Hydrology Data

Modeler will contact the district H&H POC to request any available information on the study dam. Copy the modeling team lead and PM on any communications. Catalog any existing data. See Appendix 4.1.2 for additional details.

2.7.3 Existing Geographic Information System Data

Mapper will contact the district GIS POC to request any data relevant to the MMC study. Copy the PM on any communications. Catalog any existing data according to Appendix 4.1.2.

2.7.4 Documentation of Findings

As part of model setup, the modeler determines what information is necessary. In general, all existing H&H data should be obtained. Existing GIS data should only be requested if deemed necessary by the modeler.

2.7.5 Data Transfer

Data from districts can be transferred electronically via the MMC file share. If necessary, data can be transferred via file transfer protocol (FTP) using the Safe Access File Exchange site. If necessary, temporary media or storage devices can be used for transferring data.

- File Share: \\wpc-netapp3.eis.ds.usace.army.mil\RMCSSTORAGE5
- Safe Access File Exchange (DoD SAFE): <https://safe.apps.mil/>.

2.7.6 Data Review, Processing, and Delivery

The mapping production team will review the district-provided GIS data and, after completing required post-processing, will deliver necessary GIS data to the assigned modeler. Any GIS data is processed following the standard procedures defined in Appendix 4.1.1.

2.7.7 Update Project Schedule

The mapping production team member shall communicate status regularly, especially at task completion, to the PM. The PM will mark the task as complete.

SECTION 3—MODELING

This process begins with modeling production team member research of the MMC Kickoff Meeting Checklist, additional communication with the district, and model setup using the pre-model GIS data deliverable. Completed hydraulic models and hydraulic data for consequences models are finalized and sent to consequences and mapping team members for further processing and product development.

Communication with the district begins after the MMC Kickoff Meeting Checklist has been sent. The PM contacts district personnel to discuss the PWP and schedule the project kickoff meeting. The PM confirms the initial estimates of work schedule and design parameters prior to beginning the modeling process. The final PWP is filed in the project SharePoint folder.

Meeting modeling expectations will be documented by modeling team leaders using the following metrics: model quality and meeting project schedule due dates. Modeling team leads are available to assigned modelers to provide guidance on measurable MMC metrics (for metrics definitions, see Appendix 1.7).

3.1 Modeling Procedural Outline

- Develop Project Work Plans—Provide Modeling Extent
- Project Kickoff Call with District—Coordinate Modeling Information
- Collection and Inventory of Model Setup Data
- Begin Development of CTS Worksheet on SharePoint
- Begin Hydraulic Modeling Documentation
- Begin Model Setup
- Develop MMC Non-breach Scenarios
- Develop MMC Breach Parameters
- Develop MMC Breach Scenarios
- Develop Sensitivity or Non-standard, District-requested Scenarios as needed (kept and labeled in the final model)
- Generate Required Mapping Products for all Scenarios
- Complete CTS, Draft Report, and Quality Review Checklist
- Internal MMC Model Review
- Upload Preliminary Inundation Maps to the FIM Viewer
- District Model IQR
- Update Final Inundation Maps to the FIM Viewer as Necessary
- Update CTS, Final Report, and PowerPoint Presentations
- Hydraulics Model Report Review
- Final Model Approval.

For more details describing each step, see the MMC program management and modeling SOP appendices.

3.2 Model Development

3.2.1 Getting Started with Modeling

Modeling files and results are key MMC Production Center products that feed the consequences, documentation, and mapping production efforts. Product development is complex and time consuming; this effort is the most demanding phase of the MMC Production Center process. In most instances, an unsteady HEC-RAS one-dimensional (1D) and/or two-dimensional (2D) model will be developed in support of the MMC program. This section of the SOP outlines HEC-RAS 1D and 2D hydraulic model development within the MMC Production Center.

3.2.2 Hydraulic Modeler Training Requirements

To successfully complete hydraulic modeling for an MMC dam breach study, an elevated level of training and experience using HEC-RAS software is required. In addition to practical experience, the following USACE PROSPECT courses are highly recommended to prepare modeling team members.

- Steady Flow with HEC-RAS
- Unsteady Flow Analysis with HEC-RAS
- Advanced 1D/2D Modeling with HEC-RAS
- H&H for Dam Safety Studies.

The MMC training plan is available on the Team SharePoint site for additional information on required and recommended classes and experience.

3.2.3 Computational Requirements, Data Resources, and Data Transmission

The following section outlines the resources needed for model development as well as information on MMC SharePoint collaboration sites which house the latest MMC program guidance. Information on data transmission for the modeling, mapping, and consequence production process is also covered in this section.

3.2.3.1 Hardware

The team members need to be assigned a USACE ACE-IT desktop/laptop, through their local procurement procedure, which has the Science and Engineering specifications.

3.2.3.2 Software

The MMC team members will not receive administrative rights on assigned equipment. If a user has a need for software installation, the ACE-IT Service Track system and App Portal will be used to enter a request. Modelers should use the latest approved version of all software applications in most cases. Modeling team lead can provide guidance on software versions.

Table 3.1. Software Applications for Modeling, Mapping, and Consequences Hydraulic Modeling

Application	Version
ArcGIS Pro (recommended)	3.X
HEC-RAS	6.5 or latest approved version for MMC efforts
HEC-DSSVue	3.0 or latest approved version for MMC efforts

3.2.3.3 Collaboration Sites

Table 3.2. Modeling, Mapping, and Consequences Production Center Collaboration Sites

Collaboration Site	Use	Accessibility
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/default.aspx	MMC internal team collaboration site. This site is a central location for Dam Safety Report creation and reviewing documentation.	POC for Access Rights: Documentation Branch Chief
Model Library https://model-library.sec.usace.army.mil/model-library	Location 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 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 FIMhelp@usace.army.mil
Modeling TEAMS Collaboration Site https://dod.teams.microsoft.us/l/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

The MMC program requires the use of a virtual production team for GIS data production, modeling, consequence assessment, and review.

A production folder is assigned to each study dam in the model library. The production folder houses all data used for the study throughout the entire process. The production folder adheres to a standardized structure and originates with the pre-model GIS data prepared by the mapping team.

It is important that all data in the production folder adheres to the standardized folder structure presented in Figure 2.1. Non-pertinent and legacy data is not to be uploaded to the model library production folder.

Once the production process is complete, final project data and reports are uploaded to the MMC data viewer and the CEDALS ProjectWise server described in Section 4.1.4 of this document.

3.2.3.4 Scope/Schedule/Budget

The schedule, scope, and budget of the modeling effort is captured in the work plans described in Section 2. The assigned hydraulic modeler discusses specifics with the modeling team lead. The work plans are loaded to the project folder on the MMC Team SharePoint site.

3.2.3.5 Funding Requests

Funding requests for MMC levee modeling work are entered through the online funding request system (FRS). Appendix 1.5 provides guidance on the use of the FRS.

The FRS can be accessed at: <https://rmc.sec.usace.army.mil/frs/inbox>.

3.2.4 Collection and Inventory of Data for Modeling

3.2.4.1 Sources of 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 2.4, the pre-model dataset that includes NLD GIS data, NLD levee profile data, land cover data, DEM, and dam pertinent information will be included. Additional data from the district may be provided if identified during the kick-off call.

It is the responsibility of the assigned modeler to examine the quality and completeness of the pre-model dataset. The modeler should coordinate with the MMC mapping team lead and the district contacts to ensure the best available data is being used from the beginning.

New unsteady HEC-RAS models will be prepared utilizing existing USACE and local data (when available) to supplement new model inputs derived from the pre-model GIS dataset. Because of the large scale of the models and simulation requirements, it is important only to use data sources that are not cost or time prohibitive and will improve model accuracy. Once the modeler receives the data from the mapping team, the modeler should review the data to get an overview of the entire study to be performed.

Data for MMC studies will come from three sources: existing district data, existing MMC models, and the pre-model GIS data package.

3.2.4.2 Existing District Data

Much of the pertinent data regarding the dam and area downstream comes from the district office in which the dam is located. Data should be requested from the district using the MMC Kickoff Meeting Checklist (Section 2.1), the project kickoff meeting, and subsequently, a follow-up with the district POCs. This checklist is sent to the district of the subject dam to catalogue the information that is available for the dam. This worksheet informs the modeler of what existing data is available. The modeler will then make a data call to the district contact noted on the MMC Kickoff Meeting Checklist to request the data pertinent to model development. At a minimum, information required for MMC Dam breach modeling will include the dam water control manual (WCM), daily period of record pool elevation dataset (or a previously developed pool elevation duration exceedance curve), and information related to the latest approved PMF or design flood study.

Existing district data may include, but is not limited to:

- Project WCM
- Emergency Action Plans (EAPs)
- Spillway adequacy studies
- Probable maximum flood (PMF) analysis
- Previous risk assessment or modification study reports
- Conversion factor for datum conversion from project datum to NAVD 88
- Water surface and thalweg profiles
- High-water marks
- Existing dam breach inundation mapping/GIS files
- Elevation duration exceedance and frequency curves
- Rating curves—spillway/gates
- Existing hydraulic models
- Lake elevation/storage curves
- Other existing model data
- Cross section data (from existing models)
- Bathymetric data
- Stream flow records (flow and stage; data storage system [DSS] format preferred)
- Reservoir period of record (DSS format preferred)
- Study dam design memorandum
- Study dam engineering drawings
- Levee data
- Project design reports
- Existing ground surface data
- Inspection reports
- Federal Emergency Management Agency (FEMA) Flood Insurance Studies (FIS).

3.2.4.3 Pre-Model Geographic Information System Data

For new studies, standard pre-model data will be provided to the modeler by the mapping production team. See Section 2.4 in this document for additional information regarding pre-model data development. Pre-production data will include the following information:

- DEM
- Digitized stream centerline
- Digitized banklines
- Hillshade
- TOD contour
- Preliminary inundation grids (upstream and downstream)
- NLD geodatabase
- ESRI ArcGIS Online Services (Imagery)
- ArcGIS Pro .apr file containing the above data.

The digitized stream centerline and banklines should be verified by the modeler. If changes or corrections are made by the modeler the mapping team should be notified in order to maintain a consistent dataset for the production process.

3.2.4.4 Developing Supplemental Geographic Information System Data

The most common beneficial enhancements to the pre-model GIS dataset are incorporating bathymetric data into the DEM, “burning in” levee elevations, and using topographic data sources that are better than what is available in the 3DEP. These enhancements may be performed by either the assigned modeler or the mapping production team member. However, exact steps to follow are contingent upon the format, quality, content, projection(s), and datum(s) of the source datasets. Extreme care must be taken during

processing to limit the introduction of errors into the final compiled elevation model. For further information on pertinent data included in dam breach models refer to the RAS Mapper user's manual and the HEC-RAS 2D modeling user's manual, which details physical features that can be incorporated into HEC-RAS geometry using RAS Mapper.

3.2.5 Update Project Work Plan

The documentation team updates the PWP with data received from the district. If the district does not provide additional information, the MMC will utilize initial estimates and design parameters identified prior to beginning the modeling process.

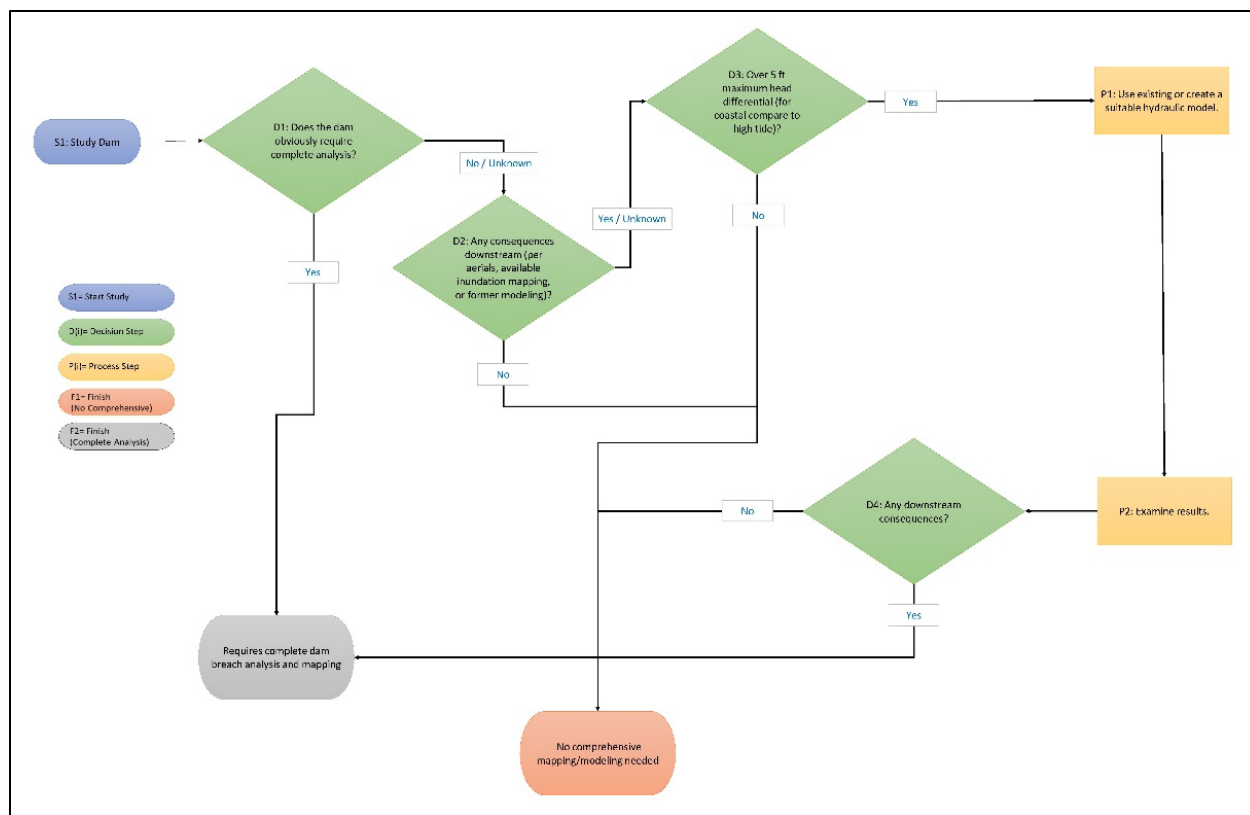
3.3 Navigation Dam Screening

For certain types of navigation dams and other dams, such as flood retarding structure and hurricane protection barriers, downstream flooding, and consequences due to dam breach may be negligible, limiting the need for, or the benefits of, modeling and inundation mapping. As a result, screening is required for all projects where incremental consequences are not expected. Typically, these structures are classified as significant or low hazard within the federal hazard potential classification system for dams. Often, the screening for a high-hazard dam ends at the first step and a full study is required.

A screening assessment tool has been developed to quickly estimate whether dam breach for these assets may result in incremental consequences, which will drive the need for modeling and mapping. Figure 3.1 demonstrates the step-by-step flowchart required for screening navigation dams. Benefits lost and other economic consequence estimations will be conducted for all projects, regardless of modeling and mapping needs.

The companion flow chart elements have alphanumeric identifiers. The narrative sections that follow correlate to these identifiers. Elements labeled D(i) indicate decision elements, P(i) indicate process elements, and F(i) indicate final elements.

Figure 3.1. Modeling, Mapping, and Consequences Model Screening Process



Note

The modeler is expected to use engineering judgment while using this screening process and should err on the side of conservatism when a decision point is unclear. The engineer is encouraged to use all available data, reports, and institutional knowledge to make informative decisions about each step. Any major deviation from the screening process requires appropriate coordination from MMC technical leads.

D1: DOES DAM OBVIOUSLY REQUIRE COMPLETE ANALYSIS?

This first decision box is the common-sense test. If, due to obvious downstream incremental hazards, a dam should have a full analysis completed, the modeler can end the screening process at this step and flag the dam for further analysis. An example of a dam obviously requiring complete analysis is a high-head dam (>40 feet head differential) with a population center immediately downstream.

D2: ANY DOWNSTREAM CONSEQUENCES (PER AERIALS, AVAILABLE INUNDATION MAPPING, OR FORMER MODELING)?

The modeler should utilize current aerial photography or land use mapping to determine if there are potential consequences in the downstream routing reach. Research into whether potential population at risk (PAR) or life loss (LL) exists based on aerials, available inundation mapping, or former modeling. The engineer should use judgment regarding the length of the downstream reach.

If no potential downstream consequences are expected and the engineer is confident that the base mapping is accurate, the engineer selects no and the process for this dam ends and no comprehensive mapping or modeling is needed. Conversely, a yes or unknown continues the process.

D3: OVER FIVE FEET MAXIMUM HEAD DIFFERENTIAL (FOR COASTAL, COMPARE TO HIGH TIDE)?

The modeler uses design or operational documents, topographic mapping, or other readily available information to determine if the maximum head differential across the dam is more than five feet (for most low head and navigation dams the largest differential will occur during non-flood conditions). If yes, the screening process continues to P1. If not, comprehensive mapping or modeling are not needed.

Background: Compilation of results from previously completed dam breach analyses have shown the maximum breach flood wave height for low head dams is approximately 40 percent of the total head differential at the time of breach. Five feet was chosen because it translates to approximately a two-foot maximum flood wave which is deemed to be generally low hazard in consequence analysis in terms of static depth considerations.

The modeler should use judgment at this phase. If, for example, there is a low-lying area with potential consequences immediately below a five-foot head differential dam, further analysis may be warranted.

P1: USE EXISTING OR CREATE A SUITABLE HYDRAULIC MODEL.

The modeler researches whether or not an existing model is available and suitable to produce a dam breach. If available, the modeler simulates a dam breach and routes the breach hydrograph downstream. The engineer could truncate an existing model to the area of interest and execute the model to estimate inundation elevations. If no model is available, the modeler will create a suitable simplified model for this effort.

P2: EXAMINE RESULTS.

The modeler should review available breach inundation results to include RAS Mapper inundation mapping results and reported stage and discharge results at downstream gages.

D4: ANY DOWNSTREAM CONSEQUENCES?

If the model simulation identifies potential incremental consequences, a complete dam breach analysis and consequences mapping will be recommended (F2).

If the model does not identify potential incremental consequences, no comprehensive mapping or modeling is needed (F1).

F1: NO COMPREHENSIVE MODELING/MAPPING NEEDED

This step reveals that the navigation dam is unlikely to cause significant damages should a dam breach occur. Comprehensive analysis is not required. Lost benefit evaluation is completed without comprehensive hydraulic modeling. Screening level inundation mapping is completed.

F2: REQUIRES COMPLETE DAM BREACH ANALYSIS AND MAPPING

This step reveals that the study dam may pose significant risk to downstream hazards should a dam breach occur. Complete dam breach analysis and mapping is required.

3.4 Model Development for Flood Risk Management and Navigation Dams

3.4.1 Overview of Model Development

The current state of practice in hydraulic modeling for USACE projects utilizes HEC suite of software and associated GIS tools for model development, simulation, and processing of results for use in

consequences analysis and floodplain mapping. The software is endorsed by the Hydrology, Hydraulics, and Coastal Engineering (HH&C) COP and maintained by HEC.

The goal of the MMC modeling team is to create geo-referenced unsteady 1D and 2D models capable of producing accurate mapping and consequence analysis across a wide range of scenarios. Most dams modeled as part of the MMC program are located in a typical riverine system where a 1D modeling approach is appropriate. However, some projects may have conditions where a 2D model is more appropriate which include extremely flat areas, large interior areas, complex topography with multiple flow paths, and/or highly urbanized areas. In general, the preferred methodology for these cases is to utilize 2D modeling methodology.

The key products delivered by the MMC Production Center's modeling team members for dam safety projects are as follows:

- Geo-referenced hydraulic model capable of simulating a full range of hydrologic loading and breach and non-breach scenarios.
- Breach and non-breach scenario model results and mapping output.
- Formal documentation of the hydraulic modeling effort.

3.4.2 General HEC-RAS Model Set Up for Modeling, Mapping, and Consequences

Modeling specifics have been adopted by the MMC to maintain consistency and integrity for all models created as part of the program. This section will cover HEC-RAS model specifics such as naming conventions and description field information used by the MMC.

- Naming Conventions. All models created for the MMC Production Center will have specific naming conventions to provide consistency across the MMC program.
- Project Name. The HEC-RAS project file is named with the project name: "<NID_Name_of_Dam>_NIDID" Example: TuttleCreek_KS00000.
- Geometry Name. All models created for the MMC utilize a single geometry with the following naming convention: "<Name_of_Dam>_MMC_Geometry"
- Projection. The HEC-RAS geometry uses the standard MMC Projection of Albers Equal Area (detailed projection data included in the pre-model production folder and Appendix 4.1.1).
- Vertical Datum. HEC-RAS geometry elevations must be in feet using the North American Vertical Datum (NAVD 88).

Each scenario, breach and non-breach, created for the MMC Production Center will have a separate plan file named as detailed in the table that follows. Detailed description of these scenarios is presented in Section 3.5.5. Depending on whether the dam is a run-of-river navigation dam or flood risk management dam, each dam loading condition will share an unsteady flow file named according to the Tables 3.2 to 3.4.

Table 3.2. Flood Risk Management Dam Breach and Non-breach Scenario Plan and Unsteady Flow File Naming Conventions

RAS Plan Name	Short ID	Unsteady Flow Data Name
Top of Dam Pool-Breach	TOD Breach	Top of Dam Pool
Top of Dam Pool-Non-breach	TOD Non-breach	Top of Dam Pool
Maximum High Pool-Breach	MH Breach	Maximum High Pool
Maximum High Pool-Non-breach	MH Non-breach	Maximum High Pool
Intermediate High Pool-Breach	IH Breach	Intermediate High Pool
Intermediate High Pool-Non-breach	IH Non-breach	Intermediate High Pool
Top of Active Storage-Breach	TAS Breach	Top of Active Storage
Top of Active Storage-Non-breach	TAS Non-breach	Top of Active Storage
Normal High Pool-Breach	NH Breach	Normal High Pool
Normal High Pool-Non-breach	NH Non-breach	Normal High Pool
Maximum High Pool-Breach Sen	MH Breach Sen	Maximum High Pool

Note: District-requested non-standard scenarios have a RAS Plan Name of Elevation ###_#-Breach and Elevation ###_#-Non-breach and a short ID of ###_# Breach and ###_# Non-breach.
SWE-ELM sensitivity scenarios have a RAS Plan Name of Maximum High Pool-Breach SWE and a short ID of MH Breach SWE.

Table 3.3. Navigation Dam Breach and Non-breach Scenarios (Not Screened Out) Plan and Unsteady Flow File Naming Conventions

RAS Plan Name	Short ID	Unsteady Flow Data Name
Top of Dam Pool-Breach	TOD Breach	Top of Dam Pool
Top of Dam Pool-Non-breach	TOD Non-breach	Top of Dam Pool
Maximum High Pool-Breach	MH Breach	Maximum High Pool
Maximum High Pool-Non-breach	MH Non-breach	Maximum High Pool
Intermediate High Pool-Breach	IH Breach	Intermediate High Pool
Intermediate High Pool-Non-breach	IH Non-breach	Intermediate High Pool
Navigation Pool Channel Capacity-Breach	NPC Breach	Nav Pool Channel Capacity
Navigation Pool Channel Capacity-Non-breach	NPC Non-breach	Nav Pool Channel Capacity
Normal Navigation Pool-Breach	NP Breach	Normal Nav Pool
Normal Navigation Pool-Non-breach	NP Non-breach	Normal Nav Pool
Maximum High Pool-Breach Sen	MH Breach Sen	Maximum High Pool

Note: District-requested non-standard scenarios have a RAS Plan Name of Elevation ###_#-Breach and Elevation ###_#-Non-breach and a short ID of ###_# Breach and ###_# Non-breach.
SWE-ELM sensitivity scenarios have a RAS Plan Name of Maximum High Pool-Breach SWE and a short ID of MH Breach SWE.

- **HEC-RAS Model Description.** All models created for the MMC Production Center include a thorough description field providing potential users with pertinent information. The following items are listed in the HEC-RAS Model Description field:
 - Name of dam
 - NID 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
 - Date of last modification
 - Program and version
 - Controlled Unclassified Information (CUI).

The HEC-RAS model geometry represents the physical constraints over which flow from the dam breach scenario will be routed. To have a complete model, hydrologic loading inputs and conditions across a given time window must also be developed for analysis. A range of loading conditions within the reservoir are developed and simulated.

A HEC-RAS flow file is required to specify inflow hydrographs, downstream flow conditions, and gate operations at the dam. Specifics regarding model flow files for MMC models are presented in Section 3.4.4.1.

A HEC-RAS plan file is required to set the time constraints, computational settings, and model output for each modeled scenario. In addition, the breach plan is housed within the plan file. Specifics on the model plan files for MMC models is presented in Section 3.4.4.2.

The combination of geometry, flow, and plan files is used to compute each model scenario. The model scenarios for MMC efforts are presented below.

3.4.3 HEC-RAS Model Geometry Set Up for Modeling, Mapping, and Consequences Models

3.4.3.1 Projections and Model Extents

- Projections. The standard projection for all MMC projects is as follows:
 - USA_Contiguous_Albers_Equal_Area_Conic_USGS_version.
 - The linear units are set to U.S. Feet.
 - The MMC Production Center will use the NAVD 88 for all elevation data.
 - Detailed projection parameters and exceptions are provided in Section 2.4.2 and Appendix 4.1.1.
- Downstream Model Extents. The downstream model extent will be discussed during the model planning process. Initial estimates of the downstream extent may be obtained from inundation areas identified within existing EAP and other studies for the study dam or other dams along the same river reach. Depending on district feedback, the model may extend past the current EAP or extend downstream from the assigned dam to the point of no significant damages or until floodwaters are no longer out of bank, or to a location where the flood conditions are the same for the breach and non-breach scenario. The initial estimate will be provided in the PWP. Determining this extent may be an iterative process and require model extension after initial model development. When establishing model extents, downstream sources of significant inflow, such as tributaries, that may affect the dam breach flood wave should be considered.

- Upstream Model Extents. Models created by the MMC Production Center include the area inundated upstream of the study dam due to the rise in pool level for a given scenario can be fully mapped in the inundation mapping process and can be considered in the consequence analysis. This requires delineation of the entire reservoir area at the highest hydrologic loading condition (MH or TOD pool) level. A shapefile defining the potential upstream inundation area is supplied with pre-model GIS data to aid in digitization of the area.
- Studies Ending in a Downstream Reservoir. In the case that significant damages end at a downstream reservoir, the controlling dam shall be included in the model, along with necessary downstream cross sections to properly model the structure. The dam should be operated according to the water control manual for the inflow conditions.
- Studies Ending at a Downstream Confluence. In the case where the model study ends at a downstream confluence with a major river, the model should not stop at the confluence but should include a portion upstream and downstream of the major river to prevent sudden drops in the WS elevation at the confluence.
- Studies Ending along the Coastline. In the case that the model ends along the coastline, the model should extend beyond the coastline, and the downstream boundary condition should be set to the mean high water (MHW) or tidal time series (coordinate with district) in that area. The MHW can be found for several stations on the National Oceanic and Atmospheric Administration (NOAA) Tide and Currents website: <https://tidesandcurrents.noaa.gov/>.

3.4.3.2 HEC-RAS Geometry

Standard pre-model GIS data is used as the base for building the HEC-RAS model when an appropriate existing model is not available. DEMs and all shapefiles shall be developed in accordance with specifications set in Section 1.4.

Web imagery data sources linked to the HEC-RAS application are used for development in RAS Mapper.

- **Data Processing.** RAS Mapper processes the model framework. For specifics on how to use RAS Mapper, the modeler should refer to the HEC-RAS 2D Modeling User's Manual. Typical model data to be processed in RAS Mapper may include, but is not limited to:
 - Stream centerline
 - Cross sections
 - Flow paths
 - Bank lines
 - 2D flow areas
 - Lateral structures
 - 1D storage areas
 - Storage area connections
 - Inline structures
 - Bridges/Culverts
 - Ineffective flow areas
 - Blocked obstructions.

Note

A stream centerline shapefile may be provided by the mapping team for use in the model. The assigned modeler may adjust the initial centerline as necessary. If changes to the stream centerline occur during the modeling process, coordination with the mapping team must ensure consistency between the model and the mapping. The mapping production team is available to assist upon request.

- One-Dimensional Model Geometry.

Models for the MMC Production Center generally include only one geometry file. To provide consistency across the program, the following model geometry specifications have been adopted (see the HEC-RAS User's Manual for additional guidance).

- Cross Sections. Cross sections should be spaced in accordance with guidance listed in the table that follows. Cross sections will be named as river miles from major downstream confluence. Bathymetric data and data from existing models should be 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. The channel should be sized to carry the full regulatory discharge as described in the water control manual.

Table 3.4. Recommended Cross Section Spacing

Channel Bed Slope (per river mile)	Cross Section Spacing (feet)
2 feet or less	2,000–2,500
2–10 feet	1,500
10 feet or greater	500–1,000

- Interpolated Cross Sections. Interpolated cross sections are only used temporarily to facilitate model stability. Interpolated cross sections are converted to geo-referenced cross sections for the final model delivery.
- Reach Lengths/Flow Paths. Reach lengths and flow paths are to be adjusted to represent actual flow lengths to properly account for volume in the model computation.
- Manning's "n" Values. Manning's "n" values shall be increased immediately downstream of the dam to account for accumulation of debris and turbulence created during the breach. As general guidance, Manning's values can be doubled in this area. Cross sections should contain a minimum of three of Manning's "n" values: left overbank (LOB), channel, and right overbank (ROB). For additional guidance, see the HEC-RAS Hydraulic Reference Manual.
- Ineffective Flow Areas. Ineffective flow areas are to be used in locations that do not have effective flow to properly account for floodplain storage.
- Blocked Obstructions. The use of blocked obstructions is acceptable for use in MMC models when an obstruction exists at a cross section. Blocked obstructions are not permitted to be used for subtracting storage volume at cross sections where permanent obstructions do not exist.
- Bridges and culverts. Bridges and culverts are generally not modeled as part of MMC Production Center efforts for dam breach analysis; however, bridges that may significantly influence hydraulic modeling results should be included when practical. If bridge data is not available and the embankments will have a significant impact on flood levels, the embankments should be at least modeled by placing a cross section on top of the embankment. However, bridge data may be readily available from the district or can be found from existing models. An approximation of bridge geometries is acceptable based on limited data from photos and other available sources.
- Lateral Structures/Downstream Levees. Lateral structures may be needed to model levees, road embankments, and overland flow connected to a backwater storage area. Levees available in the NLD are provided as part of the pre-model GIS data and will be included in all MMC models. If additional data is needed, all NLD data requests will be met by the mapping technical lead assigned to the study dam.

- Levees are assumed not to breach for MMC Production Center dam breach studies. The lateral structure representing the levee shall incorporate profile and alignment data extracted from the NLD. For additional information see Appendix 4.1.8.
 - Levees identifiable within the terrain data may be included in the model.
 - For lateral structures connected to overland flow, backwater areas, the weir crest shape should use the zero-height option, and the weir coefficient should be between 0.1 to 1.0. Overland flow is less efficient than weir flow so the weir coefficient should be lowered to account for the lower efficiency.
 - Lateral structures connected to 2D flow areas have two options to compute flow going over the top of the structure (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 good 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.
- Overbank Storage Areas. Floodplain and backwater storage are an important aspect of dam breach analysis and flood routing. Storage can be modeled by adding HEC-RAS storage areas in the model coupled with a lateral structure, extending cross sections up tributaries coupled with ineffective flow areas, or by adding an additional reach up the tributary.
 - When there is significant population in a backwater storage area, it should be modeled using a 2D flow area instead of using cross sections with ineffective flow.
 - 1D storage areas and 2D flow areas are named as river miles to include the river name and overbank (e.g., Susq Riv 16 IL) in accordance with their location along the river reach.
 - For the MMC program, tributaries inundated by at least 10 miles of backwater flooding or containing a USACE-operated dam are to be modeled as separate reaches in the model.
 - Reservoirs. Reservoirs can be modeled in several ways within HEC-RAS. The reservoir can be modeled with a 1D storage area, a 2D flow area, or cross sections. The last two methods require bathymetric data (surveyed or approximated) to produce reasonable results. For most MMC models, reservoirs are modeled as 1D storage areas since bathymetric data is usually limited for reservoirs. When 1D storage areas are used, the latest storage curves (i.e., elevation versus volume curve) are used unless bathymetric data exists which could then be used to calculate a new storage curve. If the existing curve does not capture the elevation-volume relationship up to the TOD or the MH pool level (whichever is higher), other sources can be used to supplement the elevation-volume relationship. Most USACE projects have storage curves in their WCM.
 - Inline Structures (Dams). Dams should be modeled as inline structures. Operating data should be obtained from the corresponding structure's WCM.
 - Gates. All gates in a study dam shall be represented in the inline structure. Rating curves from the district or district references corresponding to each gate should be input into the model as user-defined curves. Published curves may need to be extrapolated to maximum simulated pool elevations. Any extrapolated gate curves should be documented. For cases where rating curves are not available and other gate types are used (e.g., sluice, radial, overflow, etc.) adjustments to the appropriate coefficients should be made in order to reasonably target known stage/discharge

relationships. Gate locations in the HEC-RAS model should approximately correspond to their physical location in the dam.

Gate operations will correspond to the WCM as well as practical specific to the loading conditions studied. Elevation control and rules are the preferred methods of operation; however, certain scenarios may be appropriately modeled using time series control. For additional guidance, see the HEC Hydraulic Reference Manual, which provides information on gate modeling options within HEC-RAS.

- Two-Dimensional Model Geometry

The standard 2D computational engine currently used by the MMC Production Center is the latest approved version of HEC-RAS.

- Breaklines. Significant interior restrictions to flow such as road embankments can have a major impact in the resulting inundation within a 2D flow area and must be accounted for by modifying the computational mesh using a 2D flow area breakline. The inclusion of openings within such embankments (such as highway underpasses) is also critical to achieving an accurate inundation result.
- 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 or culverts directly within the structure, which is a convenient method for modeling a roadway embankment with underpasses. Internal hydraulic structures in 2D flow areas have two options to compute overtopping flow (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 good 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.
- Grid Spacing. Select appropriate grid spacing for the computational mesh that fits with the area being modeled. This takes some trial and error. 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.
- Time Step Options. It may be necessary to use a different computation time step for the 2D flow area than the 1D river reach. This can be controlled by entering a value for number of time slices under 2D flow options for each 2D flow area.
- Equation Set. Initial production runs typically use the default 2D equation set diffusion wave. It is required that the modeler make at least one run using the Shallow Water Equations—Eulerian-Lagrangian Method (SWE-ELM) equation 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. If there are significant differences between the two runs, the modeler should discuss equation selection with the modeling team lead in respect to funding and schedule. For reduced effort studies, opportunities to use the SWE-ELM option may be limited if simulation times are exceptionally long.

For breach analysis, the flood wave rises and falls extremely quickly and the change in velocity (acceleration) is dramatic both over time and spatially. The diffusion wave equations exclude the local (changes in velocity with respect to time) and convective (changes in velocity with respect to distance) acceleration terms. These terms are extremely important to model rapidly rising flood waves.

- Boundary Conditions. Appropriate boundary conditions should be added to the 2D computational grid when needed to prevent artificial pooling. Similar to 1D modeling, coastal areas should consider a stage hydrograph for a downstream boundary.

- Channel Bathymetry and Terrain Modification. If channel bathymetry is not included in the terrain where 2D flow areas are implemented and it is expected that the bathymetry could impact the water surface elevations, it is recommended that bathymetry is included in the terrain. If bathymetry data is not available, previous 1D models having bathymetry data may be used to create a bathymetric surface or bathymetry data can be estimated from aerial or other reference material to create an estimated bathymetric surface. Additionally, terrain modification tools exist in RAS Mapper to correct or supplement existing terrain.
- Spatially Varied Manning's "n" values. It is recommended that the roughness values should be varied spatially in 2D flow areas. This can be accomplished by either drawing 2D area Manning's "n" regions or importing a land coverage dataset within RAS Mapper in HEC-RAS. A recommended source for land cover is the National Land Cover database (NLCD) which can be downloaded from the Multi-Resolution Land Characteristics Consortium (<http://www.mrlc.gov/>). Typical ranges for Manning's "n" values for some of the NLCD Land Cover types are provided in the table below. The "n" values in Table 3.5 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. In addition, the "n" values in Table 3.5 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 imported as an additional land cover type, the "n" values should be adjusted to account for these differences. In some cases, the use of aerial photography to identify land cover and roughness may be preferable if there are significant discrepancies between current land use and those shown in the land cover database.

Table 3.5. Land Cover Data

NLCD ID	Land Cover Description	Manning's "n" Value Range
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

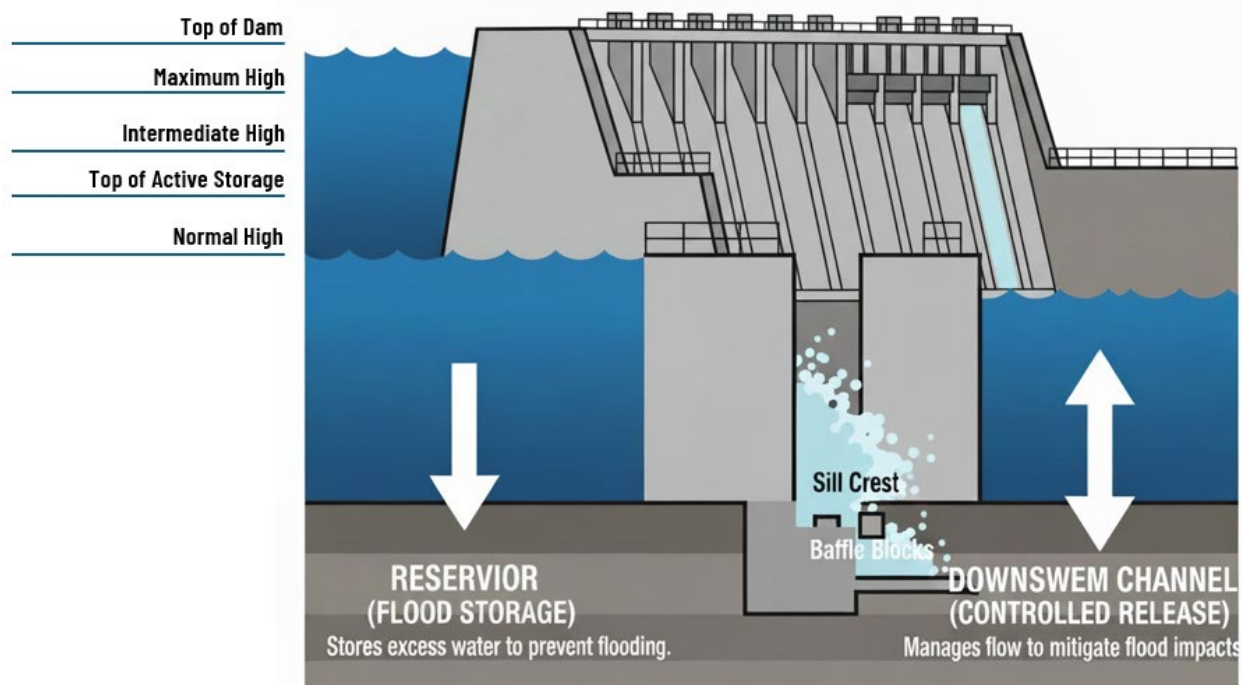
Source: HEC-RAS River Analysis System 2D Modeling User's Manual.

For additional details on HEC-RAS 2D, see the HEC-RAS 2D Modeling User's Manual.

3.4.4 Flood Risk Management Dams—Pool Relationships

The MMC established a standard set of five modeling scenarios covering a range of pool elevations, representing minimum and maximum normal operating conditions as well as select extreme loading conditions designed to capture the upper limit of potential downstream consequences (Figure 3.4). The MMC program considers alternative scenarios for flood risk management, dry flood risk management, navigation, and other dams such as flood retarding structures and hurricane protection barriers as needed.

Figure 3.4. Flood Control Dam Scenario—Pool Relationships



- **Top of Dam (TOD) Pool.** An unsteady flow simulation for non-breach and breach scenarios is modeled for the TOD pool water level. The starting reservoir pool will correspond to the initial elevation used for MH. Reservoir inflow will be the scaled IDF hydrograph from the MH scenario. The scaled hydrograph will be developed based on trial and error but will not exceed a factor of 2.0. This event includes utilizing all surcharge storage and results in significant increases in discharge above downstream channel capacity based on the physical properties of the project and/or operation procedures from the latest WCM.

The TOD scenario corresponds to the lowest surveyed point of the dam. If a TOD survey is not provided, the design crest elevation should be used. If the dam has a parapet wall, the top of the parapet wall is selected unless the parapet wall was only designed to meet freeboard requirements.

- **Maximum High (MH) Pool.** An unsteady flow simulation for non-breach and breach scenarios is modeled for the MH pool water level. The most current inflow design flood hydrograph, antecedent pool, and routing will be provided by the district. If an antecedent pool is not provided, the pool should be set to the TAS pool. The computed maximum pool should coincide with the district routing. If the maximum pool cannot be met, the reasons for the inconsistent routing should be included in the report. If the antecedent event causes downstream flooding, additional coordination with the consequence team members is recommended.

The MH scenario corresponds to the peak inflow design flood (IDF) elevation. This scenario is associated with the occurrence of an extreme flood event and routed using the emergency operation procedures from the WCM. It includes full utilization of available conservation, flood, and surcharge storage. Allowances for freeboard, wind setup, wave run up, and wedge storage (due to sloping reservoir WS) are typically not considered. Typically, spillway discharge will occur during the MH scenario resulting in significant downstream inundation for both breach and non-breach conditions.

- Intermediate High (IH) Pool. An unsteady flow simulation for non-breach and breach scenarios is modeled for the IH pool water level. The starting reservoir pool will correspond to the initial elevation used for MH. Reservoir inflow will be a scaled IDF hydrograph. The scaled hydrograph will be developed by trial and error. Gate operation procedures from the latest water control manual will be applied to the hydrograph routing.

The IH scenario corresponds to an elevation that would occur in an unusual event, specifically an elevation that corresponds to a maximum peak discharge approximately halfway between the maximum TAS discharge and the lower of the maximum MH or TOD pool discharge. It does include some surcharge storage and will likely result in a significant increase in discharge above downstream channel capacity based on the physical properties of the project and/or operation procedures from the latest WCM.

- Top of Active Storage (TAS) Pool. An unsteady flow simulation for non-breach and breach scenarios will be modeled for the TAS water level. Starting reservoir pool will correspond to the 10-percent duration exceedance pool elevation. Reservoir inflow will be a scaled inflow design flood hydrograph. This hydrograph will be developed by scaling the MH hydrograph using trial and error to produce a peak pool equal to the TAS elevation. Gate operation procedures from the latest WCM will be applied to the hydrograph routing.

The TAS scenario corresponds to the highest elevation which can be obtained under normal regulated operating conditions for authorized purposes (i.e., without damaging releases). This scenario is associated with the occurrence of an unusual flood event. It does not include surcharge storage but should represent the pool elevation that, if exceeded, would result in significant increase in discharge based on the physical properties of the project and/or operation procedures from the latest WCM. The term active storage has similar meaning as the terms full pool and flood control pool. For typical flood risk management dams with uncontrolled spillways, the TAS corresponds to the emergency spillway crest elevation. For dams with controlled or gated spillways, the TAS commonly corresponds to an elevation that, if exceeded, the gates would begin to release damaging discharge. For some cases this may be at or near the top of the spillway gates.

- Normal High (NH) Pool. An unsteady flow simulation for non-breach and breach scenarios is modeled for a NH water level, the 10-percent duration exceedance pool elevation. The starting reservoir pool will correspond to the 10-percent duration exceedance pool elevation. Reservoir inflow will be a constant inflow hydrograph as required to maintain the 10-percent duration exceedance pool under normal gate operations.

The NH scenario elevation corresponds to the ten percent exceedance duration pool elevation (exceeded about 10 percent of the time or 36 to 37 days per year on average) which can be obtained under normal regulated operating conditions. This scenario represents a relatively high, but normal, pool condition which can be expected to occur every year. This scenario is not associated with the occurrence of a flood event.

- Table 3.6 lists the hydraulic and hydrologic loading conditions for each breach scenario to be analyzed for flood risk management dams.

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Table 3.6. Modeling, Mapping, and Consequences Model Scenario Matrix (sheet 1 of 2)

Model Scenarios	Inflow Requirements	Initial Pool	Breach Pool Elevation	Breach Mode	Time of Breach
TOD Pool (Breach)	Scaled IDF hydrograph not to exceed a factor of 2.0	Same initial pool as that used in the MH scenario	Top of Dam Crest (Section 3.4.4)	Piping	Breaches occur at time of peak elevation
TOD Pool (Non-breach)	Scaled IDF hydrograph not to exceed a factor of 2.0	Same initial pool as that used in the MH scenario	N/A	N/A	N/A
MH Pool (Breach)	IDF hydrograph	As specified in scenario narrative	Peak pool elevation produced by design inflow	Overtopping or piping for elevations less than TOD	Breaches occur at time of peak elevation
MH Pool (Non-breach)	IDF hydrograph	As specified in scenario narrative	N/A	N/A	N/A
IH Pool (Breach)	Scaled IDF hydrograph producing a maximum discharge approximately halfway between the TAS and the lower of MH or TOD downstream discharges	Same initial pool as that used in the MH scenario	Elevation corresponding to a maximum discharge approximately halfway between the TAS and the lower of MH or TOD downstream discharges	Piping	Breaches occur at time of peak elevation
IH Pool (Non-breach)	Scaled IDF hydrograph producing a maximum discharge approximately halfway between the TAS and the lower of MH or TOD downstream discharges	Same initial pool as that used in the MH scenario	N/A	N/A	N/A
TAS (Breach)	Scaled IDF hydrograph that produces the TAS elevation	10% exceedance duration pool	TAS	Piping	Breaches occur at time of peak elevation

Table 3.6. Modeling, Mapping, and Consequences Model Scenario Matrix (sheet 2 of 2)

Model Scenarios	Inflow Requirements	Initial Pool	Breach Pool Elevation	Breach Mode	Time of Breach
TAS (Non-breach)	Scaled IDF hydrograph that produces the TAS elevation	10% exceedance duration pool	N/A	N/A	N/A
NH Pool (Breach)	Constant inflow hydrograph as required to produce the 10% duration exceedance pool under normal gate operations	10% duration exceedance pool	10% duration exceedance pool elevation	Piping	24 hours after model initiation
NH Pool (Non-Breach)	Constant inflow hydrograph as required to produce the 10% duration exceedance pool under normal gate operations	10% duration exceedance pool	N/A	N/A	N/A

3.4.4.1 Flow Files for Modeling, Mapping, and Consequences Flood Risk Management Dam Scenarios

Modeling of dam breach and non-breach scenarios requires inflow hydrographs for areas both upstream of the dam and inflow hydrographs for downstream tributary reaches. Inflow conditions into the reservoir and coincident tributary flow into the modeled reach downstream of the dam can have a significant impact on consequence determination in a dam breach analysis. In addition to consequence estimation, these inflow hydrographs should be used to ascertain the appropriateness of the model for future use in Risk Assessments (RAs). Following are inflow conditions, antecedent pool levels, and downstream boundary conditions for MMC scenarios.

- Inflow Hydrographs. Inflow hydrographs and reservoir operations for the study dam will be consistent between breach and non-breach scenarios for each loading condition. Dams located downstream may be modeled with different operational procedures between breach and non-breach scenarios if up-to-date emergency release procedures exist in the respective WCM.

Inflow hydrographs for reservoirs upstream of the study dam are presented for each loading condition:

- TOD Pool. Scaled IDF hydrograph producing TOD elevation under emergency gate operations defined by the WCM. Scaling of the IDF can be either smaller or larger than the IDF used for the MH Pool scenario.
- MH Pool. Latest reviewed IDF hydrograph—Multiple IDF routings may be available for a study dam. Older studies commonly refer to IDF as the spillway design flood (SDF) or reservoir design flood. Some dams may include an updated IDF based on the probable maximum flood (PMF) scenario. The MH pool scenario uses the inflow hydrograph as shown in the WCM or provided by the district resulting from a finalized study.
- IH Pool. Scaled IDF hydrograph producing an elevation that corresponds to maximum discharges approximately halfway between maximum TAS discharge and maximum MH pool discharge with gate operations defined by the WCM.
- TAS Pool. Scaled IDF hydrograph producing the TAS elevation under normal operations.
- NH Pool. Constant inflow as required to maintain the 10-percent duration exceedance pool under normal operations.

Hydrograph ordinates will be scaled by a constant factor through an iterative process until the desired pool elevation for the particular loading condition is obtained.

Note

For standard MMC scenarios, the MMC will only consider those operations of upstream projects incorporated in the latest reviewed IDF.

- Antecedent Pool Levels. Antecedent pool levels for reservoirs upstream of the study dam are presented for each scenario below:
 - TOD Pool: Same initial pool as that used for the MH scenario.
 - MH Pool: Pool elevation used in routing the IDF hydrograph. If an antecedent pool is not provided, the pool should be set to the TAS pool.
 - IH Pool: Same initial pool as that used for the MH scenario.
 - TAS: 10-percent duration exceedance pool level.
 - NH Pool: 10-percent duration exceedance pool level.

Note

Initial pool levels for MMC scenarios that come from duration exceedance curves should be obtained from the USACE district or calculated based on current operational procedures and most current pool data available. For reduced effort studies, unless the project has had operational changes since the previous study, the 10-percent duration exceedance pool used in the existing model will be retained.

- **Downstream Flow Conditions.** Lateral or uniform inflow hydrographs shall exist in the model at significant confluences to produce base flow conditions downstream of the study dam. The magnitude of the inflow shall be consistent with the scenario being modeled. For instance, without detailed information, the base flow condition will be defined by stream conditions ranging from average daily releases for NH, to channel capacity for TAS and IH. The values will be input as a constant inflow based on stream gage statistics or appropriate data based on availability. Gage data used for calibration can also be used for developing statistics or obtaining reasonable values. For the MH and TOD scenarios, the most up-to-date data available shall be used for defining lateral or uniform inflow hydrographs, such that the data is readily available or can be determined within a reasonable timeframe such that the expected modeling schedule does not require adjustment. Multiple methods to develop lateral or uniform inflow hydrographs can be used to determine model sensitivity to different flow rates. These methods include but are not limited to:
 - Use of a readily available runoff model for the reach utilizing appropriate rainfall data coincident with the reservoir inflow event.
 - Use of 50-percent or 10-percent annual chance exceedance flow rates (either peak flow rates or duration specific) through Bulletin 17C techniques or appropriate regional regression equations.
 - Use of the residual runoff method and an appropriate spatial distribution, and rainfall reduction factors that are coincident with the reservoir inflow event.
 - Development of lateral inflow based on the highest historical flow value measured along the tributary reach, but not less than bank full capacity.

Gages should be used to calibrate the model to ensure that initial stages and flows are within an acceptable range and do not produce flooding conditions at the start of the simulation. Gage data may be obtained from the following sites:

- NWS: <http://water.noaa.gov/>
- USGS: <http://maps.waterdata.usgs.gov/mapper>
- USGS: <https://waterwatch.usgs.gov/>
- USACE: <http://www.rivergages.com>.

For additional guidance on how to incorporate gage rating data into HEC-RAS for calibration, see the HEC-RAS User's Manual.

- **Initial Flow Conditions.** Initial flow at a cross section should be equal to the added first flow ordinates from the inflow hydrographs upstream of that particular location. Initial flows should only be set at flow change locations in the model.
- **Gate Operations.** Gate operations will reasonably represent WCM guidance for the given dam. Elevation control and rules are the preferred methods of operation; however, certain scenarios may be appropriately modeled using time series control.
- **Downstream Boundary Conditions.** Downstream boundary conditions will be set to appropriately model conditions at the downstream extent of the study. Normal depth will generally be used for models with typical riverine characteristics at the downstream boundary. For areas affected by tidal influences, the downstream boundary condition should

be set to the MHW in that area. The MHW can be found for several stations on NOAA's Tide and Currents website (<https://tidesandcurrents.noaa.gov/>). Other boundary conditions may be used with approval from the modeling team lead.

3.4.4.2 Plan Files for Modeling, Mapping, and Consequences Flood Risk Management Dam Scenarios

Every scenario modeled for the MMC Production Center will have a separate HEC-RAS plan file. The plan file contains data designating the geometry and flow files associated with the model scenario. The plan file also contains information on the simulation time window and computational settings. Breach parameters are also stored within the plan file for breach scenarios. Each model created for the MMC Production Center will contain a plan file for each of the ten standard scenarios (five breach and five non-breach). Table 3.2 identifies plan and flow file naming conventions.

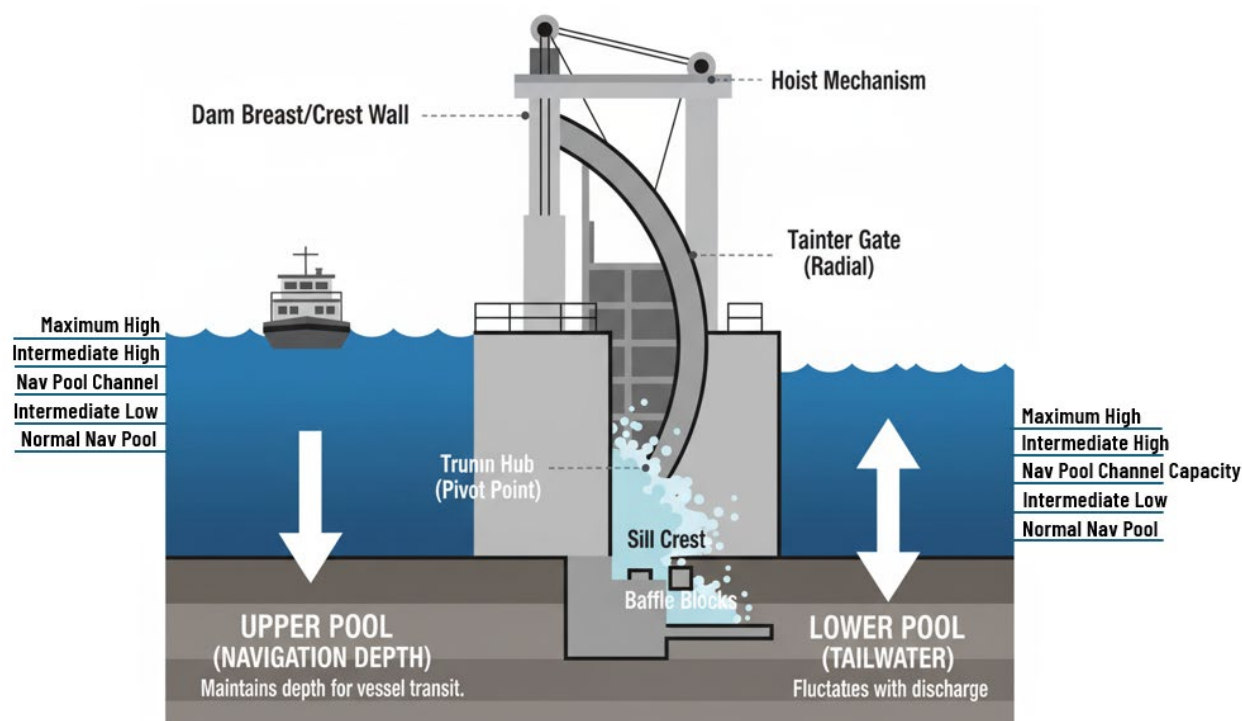
- Simulation Times. Computational times for the MMC Production Center model plans should adhere to the following specifications:
 - Computation intervals are generally set between 1 and 60 seconds to satisfy the Courant condition. The Advanced Time Step Control option in HEC-RAS allows for the use of a dynamic time step using one of two criteria: based upon a maximum/minimum Courant number or using a time series of divisors at defined dates/times. Using this feature may decrease the overall HEC-RAS computation time by utilizing a smaller time step only when depths and velocities are changing rapidly; at all other times, a larger time step can be utilized.
 - Hydrograph output interval should be set to ensure the peak stage and inflow is captured in the output hydrographs. Typically, this should be 5–15 minutes. For each scenario, the breach and non-breach output intervals must match. This value must match the mapping output interval.
 - Detailed output intervals can be set to larger intervals compared to the hydrograph and mapping output intervals; however, there may be cases where a smaller detailed output interval could be needed to help troubleshoot problems. Small, detailed output intervals can produce longer post-processing times and exceptionally large output files that can sometimes become unmanageable.
 - The mapping output interval should be set to ensure that arrival time information is appropriately captured. This interval directly affects the arrival times utilized in the modeling of consequences. The mapping output interval matches the hydrograph output interval.
- Simulation Start Time. All simulations should begin February 2, 2099, at 2400 hours to avoid confusion with actual flood events and maintain consistency between models.
- Simulation End Time. Simulations should run until the peak of the flood wave has been routed through the model extent and WS elevations at the most downstream cross section have begun to recede. The simulation end time should be the same for both the breach and non-breach scenarios.
- Stage and Flow Output Locations. For MMC dam analysis, all location nodes are selected. If output size becomes an issue, modeler is to ensure data output is appropriate for review and documentation purposes. Stage and flow output locations are recommended at a minimum for the main study reach.
- For additional guidance, see the HEC-RAS User's Manual.

3.4.5 Navigation Projects—Pool Relationships

The MMC established a standard set of five loading conditions covering a range of pool elevations, representing minimum and maximum normal operating conditions as well as select extreme loading conditions designed to capture the upper limit of potential downstream consequences (Figure 3.5).

The MMC completes a screening of all navigation projects (Section 3.3). This section applies to those projects requiring complete dam breach analysis and mapping.

Figure 3.5. Navigation Dam (Not Screened Out) Scenario—Pool Relationships



- **Top of Dam (TOD) Pool.** An unsteady flow simulation for non-breach and breach scenarios is modeled for the TOD pool water level. The starting reservoir pool will correspond to the initial elevation used for MH. Reservoir inflow will be the scaled IDF hydrograph from the MH scenario. The scaled hydrograph will be developed based on trial and error. This event includes utilizing all surcharge storage and results in significant increases in discharge above downstream channel capacity based on the physical properties of the project and/or operation procedures from the latest regulation procedures.

For navigation projects including an earthen embankment, the TOD scenario corresponds to the lowest point of the embankment crest. If a TOD survey is provided, the surveyed low point elevation is used. If the structure does not have an earthen embankment, the TOD scenario corresponds to the lowest elevation at which overtopping occurs for any damming surface not designed to overtop.

- **Maximum High (MH) Pool.** An unsteady flow simulation for non-breach and breach scenarios will be modeled for the MH pool water level. The most current design flood hydrograph, antecedent pool, and routing will be provided by the district. If an antecedent pool is not provided, the pool should be initially set to the navigation pool channel capacity (NPC) pool and then adjusted until the district-provided maximum pool is met. The MH scenario corresponds to the maximum design flood elevation. This scenario is associated with the occurrence of an extreme flood event and routed using the emergency operation procedures from the WCM.
- **Intermediate High (IH) Pool.** An unsteady flow simulation for non-breach and breach scenarios will be modeled for the IH pool water level. Starting reservoir pool will correspond to the same initial pool as used for the MH scenario. Reservoir inflow will be a scaled IDF hydrograph. The scaled hydrograph will be developed to produce a peak pool that

corresponds to a downstream maximum peak discharge approximately halfway between the maximum NPC peak discharge and the lower of the maximum MH or TOD peak discharge. Gate operation procedures from the latest water control manual will be applied to the hydrograph routing.

This scenario is associated with the occurrence of an unusual flood event. It results in significant increase in discharge above downstream channel capacity based on the physical properties of the project and/or operation procedures from the latest WCM.

- Normal Pool Channel Capacity (NPC) Pool. An unsteady flow simulation for non-breach and breach scenarios will be modeled for the navigation pool with discharges equal to the downstream channel capacity. Starting reservoir pool will correspond to the normal navigation (NN) pool elevation. Reservoir inflow will be a scaled IDF hydrograph. The scaled hydrograph will be developed to produce a peak pool equal to the NPC loading. Gate operation procedures from the latest WCM will be applied to the hydrograph routing.

The NPC scenario corresponds to the highest elevation which can be obtained under normal regulated operating conditions that allow releases equal to the downstream channel capacity. This scenario may or may not be associated with the occurrence of a flood event.

- Normal Navigation (NN) Pool. An unsteady flow simulation for non-breach and breach scenarios will be modeled for a NN pool level under normal operating conditions. Starting reservoir pool will correspond to the NN pool elevation. Reservoir inflow will be a constant inflow hydrograph as required to produce the NN pool under normal gate operations. Gate operation procedures consistent with the latest WCM will be applied to the hydrograph routing.

This scenario represents a normal pool condition. This scenario is not associated with the occurrence of a flood event.

- Table 3.7 lists the hydraulic and hydrologic loading conditions for each breach scenario to be analyzed for navigation dams.

Table 3.7. Modeling, Mapping, and Consequences Model Scenario Matrix for Navigation Dams (sheet 1 of 2)

Model Scenarios	Inflow Requirements	Initial Pool	Breach Pool Elevation	Breach Mode	Time of Breach
TOD Pool (Breach)	Scaled IDF hydrograph not to exceed a factor of 2.0	Same initial pool as that used in the MH scenario	Top of Dam Crest (Section 3.4.5)	Piping	Breaches occur at time of peak elevation
TOD Pool (Non-breach)	Scaled IDF hydrograph not to exceed a factor of 2.0	Same initial pool as that used in the MH scenario	N/A	N/A	N/A
MH Pool (Breach)	IDF hydrograph	As specified in scenario narrative	Peak pool elevation produced by design inflow	Overtopping or piping for elevations less than TOD	Breaches occur at time of peak outflow
MH Pool (Non-breach)	IDF hydrograph	As specified in scenario narrative	N/A	N/A	N/A
IH Pool (Breach)	Scaled IDF hydrograph producing a maximum discharge approximately halfway between the NPC and the lower of MH or TOD downstream discharges	Same initial pool as that used in the MH scenario	Elevation corresponding to a maximum discharge approximately halfway between the NPC and lower of MH or TOD downstream discharges	Piping	Breaches occur at time of peak outflow
IH Pool (Non-breach)	Scaled IDF hydrograph producing a maximum discharge approximately halfway between the NPC and the lower of MH or TOD downstream discharges	Same initial pool as that used in the MH scenario	N/A	N/A	N/A

Table 3.7. Modeling, Mapping, and Consequences Model Scenario Matrix for Navigation Dams (sheet 2 of 2)

Model Scenarios	Inflow Requirements	Initial Pool	Breach Pool Elevation	Breach Mode	Time of Breach
NPC (Breach)	Scaled IDF hydrograph that produces downstream discharges equal to channel capacity	NN pool	Highest elevation obtained under normal regulated operating conditions allowing releases equal to the downstream channel capacity	Piping	Breaches occur at time of peak outflow
NPC (Non-breach)	Scaled IDF hydrograph that produces downstream discharges equal to channel capacity	NN pool	N/A	N/A	N/A
NN Pool (Breach)	Constant inflow hydrograph as required to produce the NN pool under normal gate operations	NN pool	NN pool	Piping	24 hours after model initiation
NN Pool (Non-breach)	Constant inflow hydrograph as required to produce the NN pool under normal gate operations	NN pool	N/A	N/A	N/A

3.4.5.1 Flow Files for Modeling, Mapping, and Consequences Navigation Project Scenarios

Modeling of dam breach and non-breach scenarios requires inflow flood hydrographs for areas both upstream of the dam and inflow hydrographs for downstream tributary reaches. Inflow flood conditions into the reservoir and coincident tributary flow into the modeled reach downstream of the dam can have a significant impact on consequence determination in a dam breach analysis. In addition to consequence estimation, these inflow hydrographs should be used to ascertain the appropriateness of the model for future use in RAs. Presented below are inflow conditions, antecedent pool levels, and downstream boundary conditions for MMC scenarios.

- **Inflow Hydrographs.** Inflow hydrographs and reservoir operations for the study dam will be consistent between breach and non-breach for all scenarios. Dams located downstream may be modeled with different operational procedures between breach and non-breach scenarios if up-to-date emergency release procedures exist in the respective regulation manual.

Inflow hydrographs for reservoirs upstream of the study dam are presented for each scenario below:

- **TOD Pool.** Scaled IDF hydrograph producing TOD elevation under emergency gate operations defined by the regulation manual. Scaling of the IDF can be either smaller or larger than the IDF used for the MH Pool scenario.
- **MH Pool.** Latest reviewed IDF hydrograph—Multiple IDF routings may be available for a study dam. Older studies commonly refer to IDF as the spillway design flood (SDF) or reservoir design flood. Some dams may include an updated IDF based on the probable maximum flood (PMF) scenario. The MH pool scenario uses the inflow hydrograph as shown in the regulation manual or provided by the district resulting from a finalized study.
- **IH Pool.** Scaled IDF hydrograph producing an elevation that corresponds to discharges approximately halfway between channel capacity and the lower of the maximum MH or TOD discharges with gate operations defined by the regulation manual.
- **NPC.** Scaled IDF hydrograph producing the required navigation pool elevation under normal operations producing discharges equal to the downstream channel capacity.
- **NN Pool.** Constant inflow hydrograph as required to produce the NN pool under normal operations.

Hydrograph ordinates will be scaled by a constant factor through an iterative process until the desired pool elevation and discharge for the particular scenario is obtained.

Note

For standard MMC scenarios, the MMC will only consider those operations of upstream projects incorporated in the latest reviewed IDF.

- **Antecedent Pool Levels.** Antecedent pool levels for reservoirs upstream of the study dam are presented for each scenario:
 - **TOD Pool:** Same initial pool as that used for the MH scenario.
 - **MH Pool:** Pool elevation used in routing the IDF hydrograph. If an antecedent pool is not provided, the pool should be set to the NPC.
 - **IH Pool:** Same initial pool as that used in the MH scenario.
 - **NPC:** NN pool level.
 - **NN Pool:** NN pool level.
- **Downstream Flow Conditions.** Lateral or uniform inflow hydrographs shall exist in the model at significant confluences to produce base flow conditions downstream of the study dam. The

magnitude of the inflow shall be consistent with the scenario being modeled. For instance, without detailed information, the base flow condition will be defined by stream conditions ranging from average daily releases for NN and IL, to channel capacity for NPC and IH. The values will be input as a constant inflow based on stream gage statistics or appropriate data based on availability. Gage data used for calibration can also be used for developing statistics or obtaining reasonable values. For the MH scenario, the most up-to-date data available shall be used for defining lateral or uniform inflow hydrographs, such that the data is readily available or can be determined within a reasonable timeframe such that the expected modeling schedule does not require adjustment. Multiple methods to develop lateral or uniform inflow hydrographs can be used to determine model sensitivity to different flow rates. These methods include but are not limited to:

- Use of a readily available runoff model for the reach utilizing appropriate rainfall data coincident with the reservoir inflow event.
- Use of 50-percent or 10-percent annual chance exceedance flow rates (either peak flow rates or duration specific) through Bulletin 17C techniques or appropriate regional regression equations.
- Use of the residual runoff method and an appropriate spatial distribution, and rainfall reduction factors that are coincident with the reservoir inflow event.
- Development of lateral inflow based on the highest historical flow value measured along the tributary reach, but not less than bank full capacity.

Gages should be used to calibrate the model to ensure that initial stages and flows are within an acceptable range and do not produce flooding conditions at the start of the simulation. Gage data may be obtained from the sites listed:

- NWS: <http://water.noaa.gov/>
- USGS: <http://maps.waterdata.usgs.gov/mapper>
- USGS: <https://waterwatch.usgs.gov/>
- USACE: <http://www.rivergages.com>.

For additional guidance on how to incorporate gage rating data into HEC-RAS for calibration, see the HEC-RAS User's Manual.

- Initial Flow Conditions. Initial flow at a cross section should be equal to the added first flow ordinates from the inflow hydrographs upstream of that particular location. Initial flows should only be set at flow change locations in the model.
- Gate Operations. Gate operations will reasonably represent to the regulation manual for the given dam. Elevation control and rules are the preferred methods of operation; however, certain scenarios may be appropriately modeled using time series control.
- Downstream Boundary Conditions. Downstream boundary conditions will be set to appropriately model conditions at the downstream extent of the study. Normal depth generally will be used for models with typical riverine characteristics at the downstream boundary. For areas that are affected by tidal influences the downstream boundary condition should be set to the MHW in that area. The MHW can be found for several stations on NOAA's Tide and Currents website (<https://tidesandcurrents.noaa.gov/>). Other boundary conditions may be used with approval from the modeling team lead.

3.4.5.2 Plan Files for Modeling, Mapping, and Consequences Navigation Dam Scenarios

Every scenario modeled for the MMC Production Center will have a separate HEC-RAS plan file. The plan file contains data designating the geometry and flow files associated with the model scenario. The plan file also contains information on the simulation time window and computational settings. Breach parameters are also stored within the plan file for breach scenarios. Each model created for the MMC Production Center will contain a plan file for each of the ten standard scenarios (five breach and five non-breach). Table 3.3 lists the plan and flow file naming conventions.

- Simulation Times. Computational times for the MMC Production Center model plans should adhere to the following specifications:
 - Computation intervals are generally to be set between 1 and 60 seconds to satisfy the courant condition. The Advanced Time Step Control option in HEC-RAS allows for the use of a dynamic time step using one of two criteria: based upon a maximum/minimum Courant number or using a time series of divisors at defined dates/times. Using this feature may decrease the overall HEC-RAS computation time by utilizing a smaller time step only when depths and velocities are changing rapidly; at all other times, a larger time step can be utilized.
 - Hydrograph output interval should be set to ensure the peak stage and inflow is captured in the output hydrographs. Typically, this should be 5–15 minutes. For each scenario, the breach and non-breach output intervals must match. This value must match the mapping output interval.
 - Detailed output intervals can be set to larger intervals compared to the hydrograph and mapping output intervals; however, there may be cases where a smaller detailed output interval could be needed to help troubleshoot problems. Small, detailed output intervals can produce longer post-processing times and exceptionally large output files that can sometimes become unmanageable.
 - The mapping output interval should be set to ensure that arrival time information is appropriately captured. This interval directly affects the arrival times utilized in the modeling of consequences. The mapping output interval matches the hydrograph output interval.
- Simulation Start Time. All simulations should begin February 2, 2099, at 2400 hours to avoid confusion with actual flood events and maintain consistency between models.
- Simulation End Time. Simulations should run until the peak of the flood wave has been routed through the model extent and WS elevations at the most downstream cross section have begun to recede. The simulation end time should be the same for both the breach and non-breach scenarios.
- Stage and Flow Output Locations. For MMC dam analysis, stage and flow output locations are required at a minimum for the main study reach.
- For additional guidance, see the HEC-RAS User's Manual.

3.4.6 Special Considerations—Pool Relationships

- Appurtenant Structures. Appurtenant structures are relatively common among USACE dams. Examples of such structures include upstream/within-pool levees protecting communities from high pool conditions or wing dikes and saddle dikes that act as an extension of the damming surface away from the main embankment. All dams to be modeled by the MMC should be screened for the inclusion of appurtenant structures. Reference to the NID, the WCM, and/or discussion with the DSPM of the district are among the actions that can be taken to determine whether appurtenant structures exist for a project. The determination about modeling an appurtenant structure is made based on whether or not the structure has its own consequence zone, has potential life loss different from the main structure, is considered the most likely structure to fail, or is deemed the highest risk driver for the project. Appurtenant structures must have their own NIDID to be modeled. Any of the base scenarios for the main dam that significantly load the appurtenant structure should be modeled to determine potential consequences. For some cases this may only include the higher loading conditions depending on the toe elevation of the appurtenant structure.
- In-Pool Levees (Appurtenant Structure). Levees located in a reservoir and assigned within the NID will be modeled. This applies for the standard MMC scenarios loading the toe of the levee and an additional scenario equal to a loading at the top of levee (TOL). Reservoir inflow is a scaled inflow design flood hydrograph. The scaled hydrograph is developed by scaling the MH hydrograph using trial and error to produce a peak pool equal to the TOL pool. In

some cases, an in-pool levee may be modeled more appropriately with the MMC TM for Levees. This may be the case for an in-pool levee that has a loading source other than (or in addition to) the pool, long levees where breach location may be critical, or high consequence potential. The decision of which TM to follow is made in coordination with the modeling and consequences leads and the district.

- Dams Located Downstream of the Studied Dam. Downstream dams should be operated according to the WCM for the dam. If modeled scenarios on the dam being assessed create conditions exceeding the storage or discharge capacity of the downstream dam(s) and overtopping occurs, the downstream dam(s) should be considered for breach. The MH and TAS scenarios will be the only scenarios considered for a cascading breach scenario. TOD, IH, and NH are not considered for cascading breach. Breach of the downstream dam occurs at the peak overtopping elevation unless the overtopping exceeds five feet, in which case the breach triggers at a maximum of five feet of overtopping. Modeling assumptions and consequences for the cascading scenario are documented as additional information in the documentation deliverable and CTS spreadsheet. Cascading breach is not required for small water supply or run of river navigation dams that would not change incremental consequences.

Table 3.8. Modeling, Mapping, and Consequences Plan and Unsteady Flow File Naming Conventions for Cascading Dam Breach Scenarios

RAS Plan Name	Short ID	Unsteady Flow File
Maximum High Pool–Breach Cascading	MH Breach Cascading	Maximum High Pool
TAS Pool–Breach Cascading	TAS Breach Cascading	Top of Active Storage Pool

- Dams with Previous Periodic Assessments or Risk Assessments. For dams having a previous PA or RA, the MMC modeler should determine if risk driving failure modes are represented by standard MMC breach parameters. For failure modes adequately documented to reflect substantially different breach parameters than those derived by standard MMC assumptions (such as with a gate failure, an earthen breach versus an MMC-modeled concrete monolith breach, or use of physically based breach calculations), an additional breach scenario incorporating representative breach parameters is developed. The breach is modeled for the most appropriate standard loading condition for the given failure mode. As much as practical, all risk driving failure models are modeled given the need to model the full range of loading conditions, limited resources, and value consistent with the MMC approach and reporting. Decisions shall be made through coordination with the modeling and consequences team leads and district POCs as necessary. Use the established plan naming format (as seen in Tables 3.2–3.3) to determine name for additional non-standard scenarios; add a unique identifier to the end of the plan name.
- Standard 3 Dams. For dams designated as standard 3 in ER 1110-8-2 (FR), where the IDF is less than the PMF, the full PMF is routed as a sixth scenario. This is to verify incremental consequences are not expected with the full PMF. This only applies for Standard 3 dams that are not screened out and for which full products are developed. Use the established plan and unsteady flow file naming format (as seen in Tables 3.2–3.3) to determine name for additional non-standard scenarios; add the unique identifier PMF to the end of the plan name.
- Dry Flood Risk Management Dams. Scenarios for dry FRM dams are the same as modeled for normal FRM dams. If the reservoir is dry for a particular event, this should be noted in the report. In cases where the reservoir remains dry for the NH pool, a special scenario is developed to capture a loading condition halfway between TAS and the 10-percent duration exceedance pool elevation. The starting reservoir pool corresponds to the 10-percent duration exceedance pool elevation. Reservoir inflow will be a scaled inflow design flood hydrograph. The scaled hydrograph will be developed by scaling the MH hydrograph using trial and error to produce a peak pool equal to the Intermediate Low-Dry-Pool (ILD). This

additional scenario is named the Intermediate Low-Dry Pool (ILD). Use the established plan and unsteady flow file naming format (as seen in Tables 3.2–3.3) to determine name for additional non-standard scenarios; add unique identifier ILD to the end of the plan name.

Site-specific scenarios that may impact consequence estimation may also be considered on a case-by-case basis; these scenarios will be reviewed and approved by the MMC branch chiefs.

3.5 Breach Parameter Estimation for Modeling, Mapping, and Consequences Models

Breach parameters for the breach scenarios should follow the guidance presented below. It is recommended that the modeler successfully executes a non-breach scenario model run before running the breach scenario.

If the project has both an earthen and a concrete section, conduct a MH breach scenario on each as a comparison to evaluate which scenario provides the largest inundation. The results are used as a consideration when determining which segment to model further.

- Earthen Dams. All earthen dams will use the <MMC_Breach_Parameters.xls> spreadsheet to calculate breach formation time (t_f) and breach bottom width (W_b). This spreadsheet calculates four sets of breach parameters using the following four regression equations: MacDonald and Langridge-Monopolis, Froehlich (1995a), Froehlich (2008), and Von Thun & Gillette (1990). Because each scenario modeled for MMC will have different loading conditions, a separate tab within the spreadsheet has been developed for each scenario. MMC guidance for using the breach spreadsheet is as follows:

- Breach inverts should be set to the elevation of the downstream streambed for all scenarios unless specified differently in the project kickoff meeting or follow-on coordination with the district. The breach invert should be consistent across all breach scenarios.
- Do not average breach parameters computed by the spreadsheet for use in the model. Select one set of equations that seem reasonable using engineering judgment. The selected equation should be used for all breach scenarios at the dam.
- Use the breach formation time that was calculated by the selected equation.
- Formation time of breach should typically fall in the range of 0.1–4 hours. However, longer formation times may be reasonable, especially for dams with significant volume.
- Breach width should typically be one to five times the height of dam (check the bottom width of the dam between abutments; in some cases, this may limit the breach bottom width).

For earthen appurtenant structures protecting areas with limited volume, the simplified physical breach modeling method should be used. For detailed information, see Appendix 3.1.4.

- Concrete Dams. All concrete gravity dams are to have a breach width equal to one to six monoliths of the study dam. For concrete arch dams, assume the entire dam is breached. The breach width of an arch dam is the distance between the abutments.
- HEC-RAS breach data editor requirements for the MMC are:
 - Breach progression should utilize the sine wave option. For additional guidance, see Technical Document (TD) 39, Using HEC-RAS for Dam Break Studies.
 - Manning's "n" values immediately downstream of the dam should be increased to simulate accumulated debris and turbulence in the channel.
 - Breach mode is to be piping for scenarios not overtopping the dam. The piping elevation should be set to the breach invert.

- For FRM dams, it is recommended the trigger for breach scenarios be set to “Set Time” in the HEC-RAS Breach Data Editor. The time should correspond to the peak water surface elevation achieved in the equivalent non-breach scenario. For navigation dams, the breach trigger should correspond to the time of peak outflow for the equivalent non-breach scenario. However, the NH pool for flood risk management dams and NN pool for navigation dams breach initiation times will be set to 03 FEB 2099 at 2400 since they will maintain a steady pool and flow for the duration of the non-breach scenario.

3.6 HEC-RAS Model Execution and Model Output

Models developed for the MMC Production Center should compute all scenarios with minimal computational errors. Instability in unsteady HEC-RAS model runs is probable during initial simulation. It is likely to take several iterations before instabilities are fully addressed in the model. The acceptable level of computational error is relative to the specifics of the project being modeled, but acceptable values will be addressed during the model review period and can be discussed with the production team lead.

HEC-RAS has an option to run in a mixed-flow regime mode. This mode is discouraged unless engineering judgment determines the system is a mixed-flow regime river system. If mixed flow is used it should be selected for both breach and non-breach scenarios and reasons for its use should be discussed in modeling portion of the documentation report. For further guidance see the HEC-RAS User's Manual.

3.6.1 HEC-RAS Model Output and Review

Once the model is stable for all scenarios, it is ready to begin the review phase. To maintain clarity in the data and reduce potential error in data interpretation, the MMC adopted the following standards on output data.

HEC-RAS model output is stored in model output files (.O1), HEC-Data Storage System (.DSS) format, and Hierarchical Data Format, version 5 (e.g., *.g0n.hdf and *.p0n.hdf). It is imperative that models delivered for review, and ultimately all final deliverables, contain only output data for the finalized scenario runs. Ideally, all scenarios should be written to a single DSS file rather than having a separate DSS file for each scenario. However, depending on data constraints, separate DSS files may be needed.

All stage and output locations should be selected in the model plan file under the options/stage and flow output locations. Changes in flow or stage at the beginning of the model run must be addressed. These drops create problems in the consequence and mapping stages of the MMC production process. These drops are typically caused by differences in initial flow conditions, gate settings, or cumulative inflows upstream of a particular location. Initial flow at a cross section should be equal to the added first flow ordinates from the inflow hydrographs upstream of that particular location. Initial flows should only be set at flow change locations in the model.

The following model output checks should be performed to ensure the model is accurately computing flows and WS elevations at all cross sections:

- Unexpected changes in WS occurring before the breach wave arrival should be resolved.
- All model output profiles should be reviewed for WS spikes and energy grade spikes.
- Simulations should run until the peak of the flood wave has been routed downstream through the entire model extent.

3.6.1.1 Removal of Working Outputs from Dataset

The final dataset should include only the relevant output from the final runs and all output from working runs should be removed. Once the model has been finalized, delete all extraneous plans and output files

ensuring the .DSS file includes only the final simulation. This can be accomplished by executing a “File/Save As” to a new location and re-running all final scenarios.

3.6.1.2 HEC-RAS Model Output Deliverable

An example of final MMC Production Center HEC-RAS model deliverables for an FRM dam is listed below. File extension numbers .01 may vary from the following example. Green text should be modified for specific projects.

- Name of Dam–NIDID.prj
- Name of Dam MMC–Geometry.g01
- Top of Dam Pool–Breach.p01
- Top of Dam Pool–Non-breach.p02
- Maximum High Pool–Breach.p03
- Maximum High Pool–Non-breach.p04
- Intermediate High Pool–Breach.p05
- Intermediate High Pool–Non-breach.p06
- Top of Active Storage–Breach.p07
- Top of Active Storage–Non-breach.p08
- Normal High Pool–Breach.p09
- Normal High Pool–Non-breach.p10
- Top of Dam Pool.u01
- Maximum High Pool.u02
- Intermediate High Pool.u03
- Top of Active Storage.u04
- Normal High Pool.u05
- Name of Dam–MMC.DSS.

Corresponding run (.r01), output (.o01), and hdf (.p01.hdf and .g01.hdf) files should also be included.

The following deliverables are produced by RAS Mapper.

- Terrain. The final terrain dataset(s), typically in the default “Terrain” folder, should be included with other model files.
- Depth Grids. A resulting maximum depth grid must be stored to disk for each modeled scenario. This process will be accomplished using HEC-RAS RAS Mapper tools. The grids will be saved in the default location as a sub-folder within the HEC-RAS folder.
- Water Surface Elevation Grids. A resulting maximum water surface elevation grid must be stored to disk for each modeled scenario. This process will be accomplished using HEC-RAS RAS Mapper tools. The grids will be saved in the default location as a sub-folder within the HEC-RAS folder.
- Inundation Boundaries. A resulting maximum extent of inundation boundary shapefile will be stored to disk for each modeled scenario. This process will be accomplished using HEC-RAS RAS Mapper tools. The shapefile will be saved in the default location as a sub-folder within the HEC-RAS folder.
- HEC-RAS Geometry Shapefiles. River, cross sections, 1D storage areas, and 2D flow area perimeters should be exported from RAS Mapper and placed in a “Shapefiles” sub-folder created in the HEC-RAS folder.
- Location of Mapping Outputs. The above files will be saved in the HEC-RAS folder within the MMC standard folder structure.

See the HEC-RAS 2D Modeling User’s Manual for further information.

3.6.2 Consequences-based Top Screening–Pertinent Data, H&H Data, and H&H Timing Tabs

All modelers will complete the pertinent data tab, the H&H data tab, and the H&H timing tab, and fill in contact information for the modeler in the MMC contact info tab during the initial stages of the modeling process. On the pertinent data tab, the modeler will validate the values within column C, and in column H enter the date, his or her first and last name initials, and the resource where the numeric or textual value was found (e.g., 8/28/19 AB: WCM, pg. 4). If a change is made, column H should include the data that was changed (e.g., Changed from 32,000). Resource information is a critical piece of information to have during the product review stage. The modeling lead will review the completed H&H data and sign off as the reviewer in the MMC contact info tab.

If modeled peak elevations differ from targeted elevations for each scenario, input calculated values from the HEC-RAS model into the CTS worksheet and report. With the exception of the datum conversion, elevation values are rounded to one decimal place. Flows less than 1,000 should be rounded to the nearest 10; flows greater than 1,000 should be rounded to the nearest 100.

The modeler should use the CTS worksheet facility info tab to fill in tabular values in the documentation report. In using this strategy, the MMC products will be consistent for the district customer use.

3.6.3 Modeling Documentation

All models will have corresponding documentation. For dam breach studies, a report summarizes pertinent aspects of the modeling effort associated with each scenario. For full studies, the modeler should fill in the change table on page ii of the report indicating the date the report was developed or changed.

The report template is housed in the MMC Team SharePoint project folder because multiple members of the MMC production team collaborate to prepare the report throughout the production process. Marked up and edited versions of the report are to be maintained on SharePoint at all times.

For full studies, pertinent model data is inserted within the report that is on the MMC SharePoint website and provided for both the interim and compliance review.

A summary of model assumptions should be included within the report.

3.6.4 Reporting Breach Initiation Time

To create consistency in reported breach times by all members of the MMC production team, a standardized method for reporting breach initiation time has been adopted. The breach time for a particular scenario is found by opening the HEC-RAS models and selecting the “View Runtime Messages” in the options menu of the breach plan file. The time of breach initiation will be reported in the runtime messages for the selected breach plan.

3.6.5 Reporting Breach Wave Arrival Time

The breach wave arrival time is calculated by comparing hydrographs at a given location for breach and non-breach scenarios. The two hydrographs plotted together should be identical until the time at which the WS elevation in the breach hydrograph rises above the non-breach hydrograph, indicating increased flows as a result of the breach. A difference of two feet between hydrograph values has been chosen as the indicator value for the breach wave arrival.

3.6.6 Model Review Processes

Model review is an extremely important part of the MMC production process. Several review steps are required to ensure models consistently represent all project scenarios and models accurately represent

the consequences associated with each scenario. A review checklist is used to track comments through the review process. The review checklist lives with the model and is used throughout the entire review process (i.e., interim review and final review). A copy of the review checklist is available in the SharePoint project folder.

The model itself will go through a series of three internal technical reviews (listed below) during the production process.

- Initial Progress Review Team Web Meeting
- Interim Review. The delivery will include the following:
 - Working model with all modeled scenarios as specified in Sections 3.4.4–3.4.6.
 - Output files for all scenarios. Model reviewer ensures floodplain inundations for all scenarios are accurately representing flooding conditions.
 - Modeling sections of the report pertinent to review at this level should be filled out. Reports are edited from the project folder on the MMC Team SharePoint site.
 - The following CTS worksheet tabs should be filled out: MMC Contact Info, Pertinent Data, and H&H Data.
 - Quality review checklist with modeler comments section completed for all comments. This will ensure all aspects of the model to be reviewed have been addressed by the modeler.
 - Dam Breach equation spreadsheet.
 - WCM(s) and other reference material to include developed data (i.e., duration curves, extended rating curves, calculation data sets, hydrology data, period of record data, etc.).
- Compliance Review. The delivery will include the following:
 - Working model with standard MMC scenarios as specified in Sections 3.4.4–3.4.6.
 - Output files for all scenarios.
 - Modeling sections of the report should be filled out. Reports are edited from the project folder on the MMC Team SharePoint site.
 - Previously completed CTS worksheets should be updated as appropriate, and the H&H Timing worksheet should be completed.
 - Quality review checklist with Resolution of Reviewer Comments by Modeler section completed for all comments.
 - Dam Breach equation spreadsheet.
 - WCM(s) and other reference material to include developed data (i.e., duration curves, extended rating curves, calculation data sets, hydrology data, period of record data, etc.).
 - Mapping data written to file.
- District Model IQR. Once the modeling team leader confirms compliance review is complete, the modeling IQR lead makes a decision regarding additional items that need addressed or if the model is complete and ready to proceed to district review. If no additional review is needed the model is sent by the modeling IQR lead to the district DSPM and H&H POC for IQR. Depth grids are loaded to the USACE FIM Viewer (for additional information, see the guide Uploading Data for Dams). The following steps are completed for preparation and result of model IQR:
 - Model data is reviewed and standardized within the MMC folder structure displayed in Figure 2.1.
 - All data is uploaded via a transfer system available to the district by the modeling team lead.

- **[District Model IQR]** Modeling IQR lead packs the CTS worksheet, PDF of the draft report, IQR checklist, and model data within a zip file and notifies district by email that model is available to be reviewed for a designated time period.
- Comments are posted by the district to the MMC CoP SharePoint IQR Comment Database.
- Model data, report, and CTS will be updated based on model IQR district comments.
- The MMC project handoff PowerPoint is used to present hydraulic model development details, findings, and assumptions. The PPT template is in the Team SharePoint project folder. The PPT is filled in by the modeler following 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 leader is responsible for filling in the modeling sections of this presentation following district model IQR.

3.6.7 Final Model Approval

The model team leader will submit the model report to the modeling IQR lead after a technical review of the documentation and CTS is accomplished. The following steps are taken to officially finalize a modeling effort:

- The modeling team lead and modeling IQR lead verify the CTS worksheet MMC Contacts tab verifying a model review has been accomplished and all IQR updates included.
- The modeling team lead verifies all comments in the MMC Quality Review Checklist have been addressed and closed.
- The modeling team conducts a final format review to standardize project data within the MMC folder structure displayed in Figure 2.1.
- The modeling team lead verifies the latest modeling data is uploaded to the model library (E. Final Model).
- **[PMQR]** The modeling IQR lead notifies the project manager to conduct a project management quality review (PMQR).
- The modeling IQR lead completes the MMC Quality Review Checklist, Modeling QA Checklist tab, to ensure all modeling activities are completed.
- The modeling IQR lead notifies the model report reviewer via email that the final model is available to begin model report review.
- **[MRR]** The model report reviewer completes a review of the report, CTS, and HEC-RAS model. Comments are coordinated with the modeler and modeling team lead. The model, report, and CTS are updated as needed.
- **[Econ start]** The modeling IQR lead notifies the project manager, consequences lead, and documentation lead notifying them the project is ready for technical edit and consequence modeling.
- **[MRR Edit]** The report undergoes a model report review edit by the documentation team before being finalized. Comments are coordinated with the modeler and modeling team lead. The model, report, and CTS are updated as needed.
- **[MRR complete]** The documentation lead notifies the project manager and the mapping technical lead via email when the report is model report review complete and ready for the mapping and documentation product discussion.
- If comments from the mapping peer review significantly change modeling or consequence estimates, the model IQR lead or modeling team lead will be immediately notified to incorporate corrections. The modeling production process is not complete until the mapping and documentation IQR is complete.

SECTION 4—CONSEQUENCES

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/>

4.1 Structure Inventory

The primary structure inventory is developed from the USACE National Structure Inventory (NSI). 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. The population and dollar values are indexed from their base year to the most recent year available. If possible, structures within the highest non-damaging inundation zone are redistributed outside of that zone.

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

4.1.1 Emergency Planning Zones

Emergency planning zones (EPZs) are based on the study area boundary and include polygons which delineate the in-pool area and any downstream double warning area. This is accomplished by combining the study area with the non-breach inundation boundary (typically the MH and IH non-breach scenarios). When double warning is not required (typically TAS and lower), any EPZ file can be used. If multiple scenarios with different non-breach inundation areas require double warning, those scenarios use separate EPZs.

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

4.1.2 Damage Reaches Shapefile

A damage reaches polygon shapefile is developed in order to aggregate the consequence results to specific damage reaches in the simulation. The damage reaches polygon delineates the following six reaches: in-pool, 0–3 miles, 3–7 miles, 7–15 miles, 15–60 miles, and greater than 60 miles.

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

4.1.3 Town/City Area Shapefile

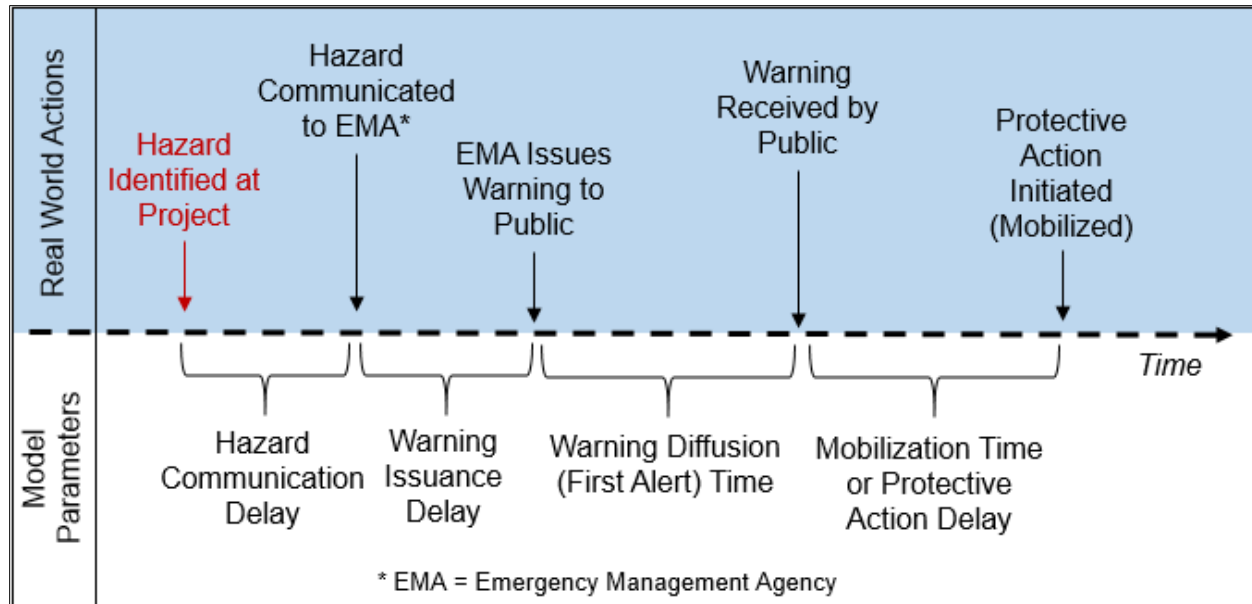
A nationwide town/city area shapefile developed using Census data is intersected with the study area. The resulting polygons are extracted to a new file and used in the simulations to aggregate consequence results. Use the CTS H&H timing tab to inform which cities should be selected. Recommend using no more than ten cities.

4.1.4 Road Network and Evacuation Destinations

Evacuation on roads will typically not be modeled on a standard MMC dam breach assessment. Exceptions may be made when evacuation will be a known risk driver.

4.1.5 Consequence Model Parameters

Figure 4.1. Conceptual diagram illustrating the flood warning and evacuation timeline.



4.1.6 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 breach initiation time. There are two different 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 two hours prior to breach and the time of breach (-2 to 0 hours). Ample warning scenarios have the hazard identification relative time set as a uniform distribution between six hours prior to breach and two hours prior to breach (-6 to -2). In-pool areas and non-breach areas on double warning scenarios are set at least 72 hours prior to the simulation start in order to allow for maximum mobilization. Warning times for in-pool and non-breach zones should be in a 24-hour increment relative to the breach in order to maintain an equivalent daytime/nighttime population distribution in the results.

Table 4.1. Standard Modeling, Mapping, and Consequences Warning Scenarios

Warning Scenario	Distribution	Minimum	Maximum
Minimal	Uniform	-2	0
Ample	Uniform	-6	-2
In-pool and Non-breach Zones	None	Approximately -72 hours prior to simulation start (on a 24-hour increment relative to breach)	

4.1.7 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.

4.1.8 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 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.

4.1.9 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 receives a first warning alert over time relative to hazard identification. The first alert curves are set at the preset configuration of Unknown, which samples from a uniform uncertainty distribution where the percentage 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.

4.1.10 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.

4.1.11 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.

4.1.12 Results Summary Polygon (Simulation Parameter)

The results summarization polygons should include the damage reach polygon shapefile and the town/city area shapefile. EPZs should also be used as a summary polygon. This requires running each load level in a separate simulation based on which EPZ that scenario uses.

4.2 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. Typically, H&H only provides data for the maximum non-damaging scenario (often TAS non-breach) for use in calibration. With approval of the Consequences Team Lead, this is reported as zero in the CTS worksheet when it is known to be a non-damaging event.

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.

In some cases, the largest hydrologic event will not cause the largest LL. This is due to the surprise factor that occurs when the PAR downstream of the dam is warned prior to dam breach. For hydrologic events that are large enough to result in non-breach releases that exceed the downstream channel capacity, some of the PAR will already be warned and will be leaving the area when the dam breach occurs. While larger hydrologic events won't necessarily cause larger LL, the PAR and economic damage should always increase as the non-breach or breach release increases (i.e., MH should always show the largest PAR and economic damage).

4.3 Facility Repair Costs and Project Benefits Foregone

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:

- Facility (asset) repair or replacement costs
- Water supply
- Hydropower
- Flood risk management
- Navigation
- Recreation
- Other lost benefits

4.3.1 Facility (Asset) Repair or Replacement Costs

Repair costs are estimated based on the original construction cost of the project. That cost is indexed to current value, and then a percentage of that updated cost is used as the repair cost. Typically, 33 percent is used, however, if 4 times the dam height divided by the dam length is greater than 33 percent (meaning it is likely to destroy more than 33 percent of the dam), the higher percentage may be used to reflect a higher repair/replacement cost. More detailed estimates from a risk cadre or other analysis may also be used.

4.3.2 Water Supply

Annual water supply benefits are based on the project's total contracted yield in millions of gallons per day (MGD) and the average contract cost of water storage reallocation acre per foot. The average reallocation costs are based on post-1986 reallocation contracts which have been judged as the best way

to estimate willingness to pay for water using the data available on a national scale. To estimate the annual value, the total contracted yield in MGD is converted to acre-feet per year, and the national average post-1986 reallocation cost per acre foot indexed to current price level is applied to estimate the annual value. Population served by water supply is estimated by assuming 1,200 gallons per day (GPD) per person unless better data is available.

Water supply intakes within navigation pools typically are not contracted with USACE, meaning there is often no data on the number of withdrawals and how intakes are impacted by pool loss. Therefore, the value of water supply within navigation pools will not be estimated unless data is available. However, known water users may be listed under critical infrastructure impacted by project breach.

The annual value of irrigation water of evaluated projects will be based on the Federal cost for irrigation by project from the Institute for Water Resources (IWR) Water Supply Database report. The price levels of the Federal cost for irrigation in this table are those at the time the project was built. Unless otherwise indicated, it will be assumed the price level is that of the year the project was completed for purposes of this estimate. The Corps' Water Supply Handbook indicates that a 30-year period of analysis is used to calculate annual costs of irrigation water supply. The federal discount rate for water supply is obtained from the annual Economic Guidance Memorandum for discount rates. The annual value of irrigation will be the Federal Cost to Irrigation indexed to current price level and amortized over a 30-year period (using the appropriate federal discount rate).

4.3.3 Hydropower

Annual lost hydropower benefits are based on a five-year average annual hydropower production amount and a regional average electricity price. The annual hydropower production for the last five years is obtained from the enterprise data warehouse (EDW) for every federal hydropower project in order to estimate the average annual kilowatt hours (KWh) generated at each project. The electricity price is obtained from the Energy Information Administration (EIA) which provides regional average electricity prices weighted by residential, commercial, and industrial uses. That average price represents the average cost of the most likely alternative power supply in the case of hydropower loss.

4.3.4 Flood Risk Management

An average annual value is used to measure the lost benefits based on historic flood damages prevented that are calculated for the Annual Flood Damage Report. Each district uses either discharge-damage or stage-damage relationships for areas downstream of the dam 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.

4.3.5 Navigation

Lost navigation benefits are sourced from the Shipper Carrier Costs (SCC) data prepared by the Planning Center of Expertise for Inland Navigation (PCXIN). The SCC provides a basis for estimating the impact of unscheduled lock closure or disruption to navigation as a result of loss of navigable pool or lock closure. The SCC data provides navigation impacts based on transportation savings rates for outage durations ranging from a single day to an entire year.

4.3.6 Recreation

Annual recreation benefits lost due to breach are based on project average annual visitation and unit day value (UDV) per visit. Estimates are developed for the project pre-breach (existing condition) and post-

breach; the lost benefit is the increment between those two conditions. Average annual visitation is obtained from the most recent five years of the Visitation Estimation & Reporting System (VERS) records. Visitation is then broken out into general recreation and general hunting and fishing using percentages developed from the recreation activities on the value to the nation website. UDV scores for each recreation sub-area are pulled from RecBEST and a visit-weighted average UDV is developed to represent the entire project (pre-breach condition). The total visitations for the post-breach condition are estimated by assuming a percentage loss based on activity; water-based visits are reduced by 100 percent, while non-water-based visits are reduced by 50 percent. UDV scores are also reduced by 80 percent in the post-breach condition, except for the availability of opportunity which remains unchanged. The UDV values are based on the latest version of the annual Economic Guidance Memorandum (EGM) for Recreation Unit Day Values.

4.3.7 Other Lost Benefits

Some projects have benefits/damages that will not be included in the categories above. An example is non-federal hydropower plants just downstream of a dam. This would not be included in the hydropower lost benefits if it is not an authorized purpose of the project but can be included in the other lost benefits section because loss of the plant is an economic impact that needs to be included in the overall consequence estimate.

4.4 Consequences Deliverables

4.4.1 Consequences-based Top Screen Worksheet

A draft CTS worksheet will be on SharePoint in the project's folder. This should have the facility info tab completed by the documentation team and the pertinent data and H&H data tabs 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, a life loss results map of the TAS breach life loss results, along with other supporting figures from the analysis, is also required in the CTS worksheet.

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

4.4.2 Consequences Toolbox

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

4.4.3 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.

4.4.4 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.

4.5 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, repair cost, 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 approved by the branch chief, the economist addresses any comments. At this time, 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 5—DOCUMENTATION

5.1 Modeling, Mapping, and Consequences—Reports

A standard report is written for each dam studied by the MMC summarizing modeling and consequences results. MMC internal drafts of the reports are stored on and edited within the MMC Team SharePoint project folders. Reports differ for each project type. The documentation team is responsible for working with the project manager to ensure the correct report template(s) and CTS spreadsheet are available. The documentation team will load any report template that may be needed to the project folder (e.g., HMCAS, HMCAS NAV, ASH etc.). This reduces confusion relating to current templates or type of reports to develop for the project.

The report template(s) associated with each project are loaded to the MMC Team SharePoint project folder.

The report files shall be edited directly from the MMC Team SharePoint project folder. This ensures edits from all assigned team members are made to one copy of the document.

Project folders are organized by project name, then by fiscal year. Upon district acceptance, final reports and CTS worksheets are loaded to the final project folder on CEDALS ProjectWise server during project closeout.

5.1.1 Develop Draft Report Folder and Initiate the Report

During the project kickoff phase, the MMC documentation production lead creates the project folder within the MMC Team SharePoint site and includes current, relevant templates. A production folder is created for the project on the RMC file share and references, including a cover photo and the archived IQR database spreadsheet from the previous study, are stored in folder F. References. The cover photo shall be used for the cover pages of the project work plan, the report, and the inundation atlases.

The assigned documentation team members will initiate the project work plan, fill in the CTS facility tab, and populate initial data in the report template.

5.1.2 Draft Consequences Input

The assigned consequences team member prepares the consequences data and updates the CTS worksheet on the MMC Team SharePoint project folder. 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 assigns internal review of the CTS worksheet and finalizes it based on feedback received. This review should be completed prior to entering consequences content within the report to minimize potential for rework. The CTS worksheet and model data are reviewed by the consequences QA review team member and details are compared to ensure consistency during the report review process.

5.1.3 Draft Modeling Input

The modeler is responsible for using the CTS and model output values to draft the modeling portions of the documentation reports. A modeling data documentation review is conducted by the model review team prior to a technical edit of the report by the documentation team.

5.1.4 Draft Mapping Input

The assigned documentation team members will develop the system and detail maps for the reports.

5.1.5 Technical and Management Reviews

Once modeling, mapping, and consequences inputs are drafted, the assigned documentation team member performs a technical review of the report, involving the assigned team members from the disciplines to resolve comments as necessary. The technical review includes review of the consequences section based on content of the previously reviewed CTS worksheet and focuses on technical content accuracy. The technical reviewer will contact MMC members to modify the report language if an error is found. The assigned member will use the quality control checklist to verify correct information that was entered into the report. This serves as the initial MMC review of the report.

After the technical review has been completed, and the report is error free, the report is sent forward for management review. The management reviewer looks at the report holistically, and will make comments, if needed.

5.1.6 Report closeout

Report closeout procedures consist of a final technical edit and format review, then the Word document is printed as a portable document file (PDF). The documentation member will identify the completed report and CTS products as pre-IQR final in the project folder and notify the PM and MMC leads that the files are ready for district IQR.

5.1.7 District Independent Quality Review

There are two instances when the preCTS and HMCAS will be reviewed by the district. The first is during district model IQR, and the second is during district documentation/mapping IQR.

The preCTS worksheet with Facility Info tab complete is sent with the model geometry for model IQR. The district review comments received will be reviewed, and the report will be updated.

The district is notified once the pre-IQR draft report and map atlases are ready for district IQR. The pre-IQR draft report, final draft map atlas PDF, and data are posted to the model library for review by the district.

District map atlas and documentation IQR comments are uploaded to the COP SharePoint site and resolved by the MMC staff via input from the assigned team members from the disciplines as necessary. The final reviewed and approved copy of the report is reposted to the COP site by documentation. The documentation and map atlas are moved to the appropriate project folder on the Dam Safety ProjectWise server upon project completion.

SECTION 6—MAPPING

This section discusses the process to develop inundation maps based on model outputs delivered by the modeling production team member. All steps are performed by the mapping production team members unless otherwise noted.

Map production should be performed for both dam breach inundation maps (DBIM) and non-breach inundation map (NBIM) atlases.

6.1 Review Hydraulics and Hydrology and Consequence Models

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

6.1.1 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.

6.1.2 Data, Report, and Model

Review the modeling data to include consequence analysis and HEC-RAS models, model output data, and reports to verify that the data meets the checklist requirements for data inclusion and that the data meet the data structure requirements.

6.1.3 Request Additional Information (if needed)

If additional data are needed, the GIS/mapping team member should request additional data from the assigned modeler for the study dam. Common missing elements are required model scenarios and model time steps.

6.1.4 Put Data in the Appropriate Location

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

6.2 Model Data Dissemination

The mapping technical lead verifies that all necessary model data are organized in MMC file share. The data is also viewable through the MMC data viewer, which results in the following for the study area:

- Model data layers are loaded within the MMC geodatabase.
- Floodplain time series data is reloaded if necessary.
- The map viewer and web applications are updated with the latest model data.

6.3 Mapping Data Preparation

The mapping production team develops and customizes datasets for use in all MMC Production Center maps. Detailed steps for preparing the mapping data can be found in Appendix 4.1.5. Most steps are performed for any model that is to be mapped.

6.3.1 Create Working Geodatabase

Create a new empty file geodatabase within the mapping folder called "Inundation_study_area_name.gdb." This geodatabase stores all the data for use in the individual map series (see Appendix 4.3.1 for file schema information).

6.3.2 Create Inundation Areas for Mapping

Use the breach inundation areas for MH and NH scenarios included in the model output to create inundation polygons for the mapping process (see Appendix 4.1.5). Include the non-breach inundation areas for MH and IH scenarios if the NBIM atlas series is to be produced. The GIS/mapping team members will store the inundation polygons in the working geodatabase for map production.

Any major edits made to inundation areas during the mapping process should be reviewed with the modeler and modeling team lead.

6.3.3 Create Map Grids

Determine the mapping scales for the study area. Most of the study areas will use standard grids for use at a scale of 1:31,680 (1 inch=½ mile) and detail grids for use at a scale of 1:15,840 (1 inch=¼ mile) for use in densely populated areas. The number of grids to map is determined by the extent of the maximum breach scenario, plus upstream area to be mapped if the UNIM atlases are to be produced. Non-breach inundation scenario mapping may be limited to upstream mapping of the elevated pools, or upstream in conjunction with downstream non-breach inundation.

A national standard grid layer for use at 1:31,680 and a detail grid layer for use at 1:15,840 are maintained by the mapping technical lead. The mapping production team will create custom map grids based on existing national map grids when standard scales are not appropriate.

The map grids will be used as the sheet index for map production.

6.3.4 Create Sheet Numbering Draft Map

Use the standard sheet number guidelines in Appendix 4.1.5 to draft a preliminary map. This map should be sent to the mapping technical lead for review and approval before sheet numbering is considered final. In some cases, the mapping technical lead will review the sheet numbering schema with the district DSPM for the study area.

6.3.5 Create Flood Info Points

The output datasets for hydraulic models should include raster datasets for peak time, WSE and depth information. A point in each sheet should be used to display the peak time, depth and elevation information for the sheet.

6.4 Cover Page Development

All MMC Production Center projects will include a cover page to identify the study dam and location for each specific project. The cover page will be developed based on the information and standards set in Appendices 4.1.5 and 4.1.7. Inundation atlases are generated for dam breach and non-breach inundation scenarios. Non-breach inundation scenario mapping may be limited to upstream mapping of the elevated pools, or upstream in conjunction with downstream non-breach inundation.

The cover page will be provided to GIS/mapping team members in PowerPoint format and will serve as the standard for all study areas. Update the information in the title block for the assigned study area according to Appendix 4.1.5.

A photo of the dam is required for placement on the cover of the map atlas and model report. The following step will likely be completed by the MMC documentation lead during initial setup of the flood inundation modeling and consequence assessment report, during the initial phase of the project while pre-model GIS development is performed. The mapping team member should begin by checking the project's folder in MMC Team SharePoint to determine if a project photo has been selected. The intent is for the same project photo to be used on the cover of the report and the covers of the map atlases. If a photo has not yet been selected, the mapping team member will contact the documentation production lead to request a photo. Update the cover page template according to Appendix 4.1.5.

6.5 Map Notes Pages

Map notes pages will be created according to Appendix 4.1.5. Information shown on map notes pages should reflect the information and values located in the CTS worksheet located on the MMC Team SharePoint project folder.

6.6 Standard Map Sheet Development

The mapping team member incorporates modeling output into a standard sheet template for inclusion in the final map product, according to Appendices 4.1.5, 4.1.6, and 4.1.7. Mapping for upstream inundation will use the same templates and procedures but will only be included in the non-breach inundation atlas series.

6.6.1 Sheet Template

Verify that all elements in the .aprx file for standard sheets match existing graphic standards documented in Appendix 4.1.7.

6.6.2 Data Sources

Set the inundation layer data sources in the .aprx file to the appropriate study dam feature classes, according to Appendix 4.1.6. Verify that basemap data layers are sourced correctly.

6.6.3 Data Validation

Check the NID for data placement outliers. The location of the features will be verified based on the most current aerial imagery available.

In situations where data must be altered, the data will be changed in the local copy, and all changes will be documented accordingly.

6.6.4 Data Frame Properties

Set the data frame scale and the coordinate system in the .aprx file for the study area. All map sheet data frames will use the Universal Transverse Mercator (UTM) coordinate system as specified in Appendix 4.1.5. Study areas that intersect multiple UTM zones should have individual tabs within the .aprx files created for each applicable UTM zone.

6.6.5 Create Map Series

Create a map series using Data Driven Pages.

6.6.6 Source Linked Text

Source text elements in the .aprx file to the standard sheet grid layer fields for text that dynamically updates during map series production.

6.6.7 Annotation

Create annotation for applicable data layers. Edit annotation according to guidelines in Appendices 4.1.5 and 4.1.7.

6.7 Detail Map Sheet Development

Detail sheet development follows the same process for standard sheets; however, it uses the detail sheet .aprx template. Detail sheets are developed for areas where a large scale is needed due to high feature density (e.g., metropolitan areas).

6.8 Sheet Index Map Development

The mapping production team member creates a location reference map for the study area in accordance with Appendices 4.1.5, 4.1.6, and 4.1.7. The numbering scheme shall ensure that all corresponding dam breach inundation map (DBIM) and NBIM map sheets have the same sheet number. If a downstream non-breach inundated area is to be included, NBIM map sheets should be produced to cover the entire extent of corresponding DBIM map sheets to the point downstream where non-breach inundated areas are constrained in the channel. This will eliminate confusion that would result if NBIM map sheets with no non-breach inundated area were omitted from the set.

6.8.1 Map Template

Sheet index map .aprx files are maintained by the mapping technical lead. The mapping production team member will determine an appropriate scale for the sheet index map based on the inundation area and information in Appendix 4.1.5.

6.8.2 Data Sources

Set the layer data sources in the .aprx file to the appropriate feature classes according to Appendix 4.1.6. Verify that basemap data layers are sourced correctly.

6.8.3 Data Frame Properties

Set all data frame scales and extents based on the size of the standard sheet grid. Set the coordinate systems in the .aprx file to the UTM coordinate system as specified in Appendix 4.1.5.

For study areas that intersect multiple UTM zones, set the coordinate system as the UTM zone containing the majority of standard sheets.

6.8.4 Annotation

Create annotation for applicable data layers. Edit annotation according to guidelines in Appendix 4.1.5.

6.9 Critical Infrastructure Lookup Table Page Development

Every standard sheet in a dam breach inundation atlas that has critical infrastructure points in the depth grid will have a corresponding lookup table. Critical infrastructure lookup tables are not currently developed for non-breach inundation.

If a printed map atlas was opened on a tabletop with a depth map sheet on the right, or front side of the pages, the arrival map sheet would be on the left, and the critical infrastructure lookup table would be in the back of the atlas, like an appendix. The critical infrastructure lookup tables contain information that references the data in the map on the corresponding map sheet. Critical infrastructure lookup tables contain the structure type, name, address, inundation depth, peak time, and peak elevation for each affected critical infrastructure point within the associated standard sheet. If there are more critical infrastructure points affected than can fit on one sheet an ellipsis will appear at the bottom of the table.

6.9.1 Critical Infrastructure Lookup Tables

Use ESRI ArcGIS Pro and the MMC Utilities Toolbar to process data to create the critical infrastructure lookup tables from the information in Appendix 4.1.5 and according to the standards set in Appendix 4.1.7.

6.10 Export to Portable Document File

All MMC Production Center projects will have .pdf files created for the inundation atlas assembly. All files will be created according to Appendices 4.1.5, 4.1.7, and 4.3.7.

6.10.1 Export Cover Page

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

6.10.2 Export Map Notes Pages

Use ESRI ArcGIS Pro to export both pages to .pdf documents.

6.10.3 Export Standard and Detail Sheets

Use the series export function within Data Driven Pages to export each map sheet to .pdf documents.

6.10.4 Export Sheet Index Map

Use ESRI ArcGIS Pro to export the index map to a .pdf document.

6.10.5 Export Critical Infrastructure Lookup Table Pages

Use ESRI ArcGIS Pro to export the critical infrastructure lookup table series to a .pdf document.

6.11 Map Atlas Development

The map atlas is a consolidated mapping product of all the mapping outputs. See Appendices 4.1.5 and 4.1.7 for information on the contents of the inundation atlas.

Standard and detail sheets and critical infrastructure pages are all exported as stand-alone .pdf files. The files will be stored individually and be combined into the inundation atlas. The file naming and storage

parameters described in Appendix 4.1.5 should be followed for all .pdf files. Individual pages should be maintained in full-resolution and optimized formats. The full-resolution files should be used to generate the combined inundation atlas .pdf file.

6.11.1 Combine Pages

Use the Atlas Builder tool on the MMC Utilities Toolbar to combine .pdf files into inundation atlases as in Appendix 4.1.5.

6.11.2 Optimize .pdf Files

After saving a full-resolution version of the map atlas, use the optimization tool in Adobe Acrobat Professional to reduce the file size of the inundation atlas for Web delivery. Use Appendix 4.1.5 to reference best practices to optimize the .pdf map book.

The mapping production team member will need to send both optimized and full-resolution versions of the .pdf files to the mapping technical lead for distribution and archival purposes.

6.12 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 GIS/mapping team member. All products are then provided for mapping technical lead review using the MMC file share.

6.12.1 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 4.3.7 and 4.3.8.

6.12.2 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, and all comments are provided to the mapper for edits. The .pdf inundation atlas is submitted for a second-round review where it will be cleared for MMC and District IQR in most cases. In some cases, additional rounds of technical lead review are necessary. The technical lead review is tracked in the schedule database by the task mapping complete. Once all review comments are resolved, the task is complete.

6.12.3 Update Mapping Product

The mapping production team member updates the map series based on comments from the mapping reviewers. The inundation atlas is then re-created 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 4.1.5 to finalize the .pdf product.

6.13 Develop KMZ Files

If requested by the district and at the district's expense, the mapping team can develop KMZ files.

Use Google Earth Pro to convert the vector modeling data layers 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.

6.14 Load Data into Modeling, Mapping, and Consequences Geodatabase (Draft)

Load the data from the mapping portion of the project into the consolidated geodatabase for display in the MMC Production Center web map application.

6.15 Final Reviews: Modeling, Mapping, and Consequences and District Independent Quality Review

The district the dam is located in will be offered the opportunity to review all MMC products. The mapping team lead coordinates with the district Dam Safety Officer and Dam Safety Program Manager to schedule and begin the review. The .pdf inundation atlas and documentation is sent to the district for review. All district IQR map atlas and documentation comments will be recorded and responded to within the MMC COP SharePoint site.

District review comments are provided to the MMC and addressed by the modeling, mapping, or consequence team members as appropriate. Once final review is complete and all issues have been addressed, the MMC member converts the suffix of the year root folder name in the MMC file share from **Year-Draft** to **Year-Final**. The study area is migrated from the draft product MMC geodatabase and map viewer to the final product MMC geodatabase and map viewer. Once the study area has been migrated from draft to final the District Review Products task in the schedule database is complete.

SECTION 7—EXTERNAL DELIVERABLES

This section summarizes the products available at the end of an MMC study, the review steps undertaken during the production process, and USACE policy and guidance for product handling and dissemination.

7.1 Modeling, Mapping, and Consequences Products

MMC Production Center deliverables produced using this SOP document are listed below and are accessible from the servers as noted.

7.1.1 Modeling, Mapping, and Consequences External SharePoint Site

The MMC external SharePoint site is known as the MMC COP SharePoint site (<https://usace.dps.mil/sites/KMP-MMC>).

- Comment/response database for district IQR of MMC products.
- Comment/response database for MMC SOP.
- MMC study status summary for each assessment.
- Links to online maps for each dam (MMC FIM viewer).
- MMC quarterly status report.
- Geospatial metadata—Federal Geographic Data Committee (FGDC) metadata for features in the following MMC databases. Further discussion of metadata is available in Section 3.6.
 - Pre-model database
 - Model results database
 - Mapping database

7.1.2 Flood Inundation Mapping

- Final modeling data layers.
- Final inundation mapping data layers.
- Inundation atlas map sheets and profiles (PDF format).

7.1.3 Corps of Engineers Dam and Levee Safety ProjectWise

- Consequences Model Deliverables. A complete consequences model with all scenarios and input shapefiles are included in the final deliverable.
- GIS Modeling Deliverables. GIS modeling deliverables will include files and data used in interfacing GIS data with the HEC-RAS model. Final GIS deliverables will include final maps, DEMs used in creating models, supplemental ground surface data, pre-HEC-RAS geodatabases, pre-HEC-RAS GIS export files used in model creation, post-HEC-RAS export files, post-HEC-RAS geodatabases, and any additional shapefiles used in modeling.
- Model Deliverables. The final model deliverable contains the final model with the file structure as specified in this manual.
- Reference Material. The reference material deliverable is to contain all materials used in model development. All data supporting the model should be included. This data may be, but is not limited to the following:
 - Existing district models
 - Data collected from the district
 - Hydrology data
 - POR data

- Breach worksheets
 - Consequences Toolbox
 - Water control manual.
- Report Deliverable. A report is developed for each MMC Production Center model developed. The report is intended to summarize dam conditions, assumptions, and difficulties, as well as HEC-RAS model results.
 - Report
 - CTS worksheet
 - Handoff PowerPoints
 - PWP
- Review Deliverable. This delivery will contain all review comments and correspondence pertaining to the model. These comments should contain a response from the modeler. The review checklist should be utilized for model review.
- Consequence output files and reports.
- Mapping file geodatabase, output files, KMZ files for Google Earth (if procured by the district), and PDF map products.

7.2 Review Process Summary

This section lists the review steps that are performed as part of the SOP. Internal MMC reviews and external reviews are described in detail within Section 5. District IQR is the last step in the review process. District coordination begins with the initial request to complete the MMC Kickoff Meeting Checklist and continues with model review and the final District IQR.

7.2.1 Internal (Modeling, Mapping, Consequences, Documentation) Review

- Pre-model GIS data review—Mapping team member
- Pre-model GIS data review—Modeling lead
- Model interim review—Modeling assigned reviewer
- Model compliance review—Modeling assigned reviewer
- Model final review—Modeling lead
- Consequences model technical review (QC)—Consequences team lead
- Consequences QA review—Consequences branch chief
- Model data consistency review—Mapping team member
- Report internal review—Documentation technical reviewer
- Report internal review—Documentation management reviewer
- Mapping internal review—Independent mapping team member
- Mapping initial—Mapping technical lead
- Report final internal review—Documentation production lead
- Quarterly Quality Review—Program Manager/Director

7.2.2 External Review

- Model district IQR—District POC
- Mapping/Documentation District IQR—see below

7.2.3 District Independent Quality Review

District IQR is performed in two phases. First, the district is provided with an opportunity to review the hydraulic model once it is substantially complete and before development of consequences and mapping products begins. The second phase of district IQR occurs once all consequences, mapping, and

documentation products are complete and is the last step before formally closing out of a project. District IQR gives the district responsible for operating the project an opportunity to review the MMC products for adherence to the MMC SOP and to make final comments on questions or concerns with the products as the district begins to incorporate the MMC materials into local products such as EAPs. District comments are crucial to the MMC—addressing these comments improves the quality of USACE products and the processes and procedures used to develop them. The MMC commonly responds to district IQR comments with:

- Concurrence—Editing products to address the comment.
- Concurrence—Logging the comment and deferring the edits to a future study (such as an upcoming Issue Evaluation Study (IES) or PA).
- Concurrence—Adjusting the MMC SOP to ensure similar issues do not occur in future studies.
- Providing information to further explain MMC procedures and assumptions.

During the first phase of IQR the district should review the model and provide comments on issues that could affect consequences or mapping results. During the second phase of IQR the district should focus on the inundation map atlases, as their contents are the end result of the MMC production process, and they are to be incorporated into EAPs. Other topics to be considered during this final review include:

- Consistency of consequences results—understanding that results reported by MMC will be refined during dam safety risk assessments.
- Completeness of the inundation modeling and consequence assessment report—does it serve as a good summary of methods, assumptions and results that can be used by others in the future to evaluate and refine the models?
- Completeness of products and documentation—are all files present, located in correct folders, and properly named? Is there sufficient documentation, including documentation of reviews?
- Are model results reflected in the map atlases (inundated areas and flood elevation and timing information/profiles) consistent with district input provided during the prior district review of the model?

7.3 Data Handling

The MMC is responsible for maintaining and managing MMC products. Districts are responsible for data dissemination to external stakeholders. The MMC will not disseminate products to external stakeholders except in extraordinary circumstances with either the concurrence of or at the request of a DSPM or DSO (district, division, or USACE).

MMC products are finalized via resolution of comments received in the reviews discussed above. The district DSO and DSPM are notified via email once products have been finalized. Final products are available to the district for download via CEDALS. Upon receipt of the transmittal memo further dissemination of the data to other stakeholders becomes the responsibility of the dam safety community (district, division, or USACE). The district is primarily responsible for determining the proper use and distribution of the data, including dissemination to local governments or emergency response agencies in accordance with current USACE policy on release of information.

GLOSSARY

Active Storage Water Elevation (feet). Maximum reservoir water surface obtained when the reservoir is fully utilized for all purposes, including conservation and flood storage. This elevation represents the highest elevation obtained under normal regulated operating conditions. This water surface elevation corresponds to the top of active storage level.

Antecedent Pool Level. The initial reservoir pool level associated with a model run.

Banklines (Pertaining to HEC-River Analysis System [HEC-RAS]). A Geographic Information System (GIS) shapefile that represents where banks are located along a particular river reach.

Bathymetric Data. Underwater topography of oceans, seas, or other large bodies of water.

Blocked Obstructions (Pertaining to HEC-River Analysis System [HEC-RAS]). Areas within cross sectional flow areas that are blocked from containing water in a particular cross section.

Breach Progression (Pertaining to HEC-RAS). The progression in which dam embankment material is removed from the structure due to dam breach.

Centerline (River Centerline). Water surface course centerlines for a waterway defined by digitizing centerlines atop a contiguous imagery source. Centerlines begin from the confluence upstream to the dam at a 1:15,000 scale.

Conversion Points. Nationwide point features containing interpolated values at point locations. Conversion points contain the elevation difference between National Geodetic Vertical Datum of 1929 (NGVD29) and North American Vertical Datum of 1988 (NAVD88). This point shapefile can be used to update raster value fields. See the National Geodetic Survey website for additional information: <http://www.ngs.noaa.gov/>.

Consequences. Potential loss of life or property damage caused by floodwater released at the dam or by waters released by partial or complete dam breach. Consequences also include effects of inundation upstream of the dam on property located around the reservoir.

Consequence-based Top Screening (CTS). CTS methodology is used to quickly identify dam projects whose breach or disruption could trigger significant consequences. CTS allows the dam's sector to establish common methods, assumptions, and measures to consistently quantify diverse types of consequence elements across the sector.

Critical Infrastructure. Defined in the U.S. Patriot Act as those systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters.

Cross Section. An elevation view topography formed by passing a plane through the topography perpendicular to the axis.

Dam Safety Action Classification. A dam classification system created by U.S. Army Corps of Engineers dam safety professionals to group dams that exhibit certain characteristics for potential safety concerns.

Depth Damage Curves. A relationship between water depth and the associated economic damages.

Depth-Percent Damage Curve. A relationship between water depth at a damaging property (e.g., structure or vehicle) and the associated damage. The value of the property is multiplied by the percentage corresponding to the flood depth at the property to make the damage estimate.

Depth-Direct Dollar Damage Curve. A relationship between water depth at a damageable property (e.g., structure or vehicle) and the direct (actual) dollar damage value. A percentage of property is not applied when direct dollar damage curves are used.

Depth Grid. Depth raster datasets that represent the depth (elevation) to the water table encountered throughout the inundation area.

Design Memorandum. Notes or plans corresponding to a design.

Design Water Elevation (feet). Maximum level pool reservoir water surface elevation, including surcharge, that a dam is designed to withstand excluding any allowance for freeboard. This water surface elevation corresponds to the maximum storage. Same as “design water level” in the Federal Emergency Management Agency (FEMA) Federal Guidelines for Dam Safety – Glossary of Terms, April 2004.

Drainage Area (square miles). Surface area that drains to a particular point (in this case, the dam) on a river or stream. Same as data field 33 in the National Inventory of Dams, Version 4.0, April 2008.

Emergency Action Plan (EAP). A plan of action to be taken to reduce the potential for property damage and loss of life in an area affected by a dam breach or large flood.

Emergency Planning Zone (EPZ). An area or areas with potentially unique overall evacuation effectiveness such as warning time, evacuation preparedness, community awareness, and the types of flood warning systems available.

Duration Exceedance Elevation. Elevation in a reservoir that is equaled or exceeded a certain percentage of the time. Example: 10-percent exceedance duration elevation for a particular reservoir is equaled or exceeded only 10 percent of the time.

External Deliverables. Deliverables produced during and from the MMC Production Center’s production cycle that are to be considered final end products for the intended customer.

Flood Storage (acre-feet). Storage space in the reservoir exclusively allocated for regulation of flood inflows. This storage space includes the increment of storage volume between the top of conservation storage and top of active storage.

Flow Path. The center-of-mass of a particular flow area within a model cross section.

Formation Time (Pertaining to Dam Breach). The amount of time between the instant and a significant uncontrolled flow of water leaves the dam due to breach to the time breach formation is complete.

Geodatabase. A geodatabase is a collection of geographic datasets of distinct types held in a common file system folder, a Microsoft Access database, or a multi-user relational database (such as Oracle, Microsoft SQL Server, or IBM DB2).

Hillshade Creation. The hillshade surface area is generated from the 10-meter digital elevation model (DEM). Hill shades are primarily used to identify changes to topology or to approximate topology.

Historical Maximum Pool Elevation (feet). The highest elevation attained in the reservoir since construction.

Hydrograph Routing. The act of accounting for inflow and outflow rates, water storage characteristics, and losses for a particular river reach or reservoir.

Ineffective Flow Areas (Pertaining to HEC-RAS). Areas within a cross section representing floodplain flow that do not convey water downstream.

Inflow Design Flood (IDF). The flood in the design of a dam and its appurtenant works particularly for sizing the spillway and outlet works, and for determining the maximum temporary storage and height of dam requirements.

Inline Structures (Pertaining to HEC-RAS). A physical feature that generally lies perpendicular to flow and impounds water (such as a dam). Water may be routed through or over this structure.

Intermediate High Pool (IH). An unsteady flow simulation for non-breach and breach scenarios is modeled for the IH pool water level. The starting reservoir pool will correspond to the initial elevation used for MH. Reservoir inflow will be a scaled IDF hydrograph. The scaled hydrograph will be developed by trial and error. Gate operation procedures from the latest water control manual will be applied to the hydrograph routing. The IH scenario corresponds to an elevation that would occur in an unusual event, specifically an elevation that corresponds to a maximum peak discharge approximately halfway between the maximum TAS discharge and the lower of the maximum MH or TOD pool discharge. It does include some surcharge storage and will likely result in a significant increase in discharge above downstream channel capacity based on the physical properties of the project and/or operation procedures from the latest WCM.

Intermediate Low Pool (IL) An unsteady flow simulation for non-breach and breach scenarios will be modeled for an IL pool elevation. Starting reservoir pool will correspond to the NN pool elevation. Reservoir inflow will be a scaled IDF hydrograph. The scaled hydrograph will produce downstream peak discharges approximately halfway between the maximum NN peak discharge and the maximum NPC peak discharge. Gate operation procedures consistent with the latest WCM will be applied to the hydrograph routing. The IL scenario is obtained under normal regulated operating conditions. Depending on the navigation dam, this scenario may or may not be associated with a flood event.

Internal Deliverables. Deliverables created during the MMC Production Center production cycle and disseminated between team leads and/or team members.

Interpolated Cross Sections (Pertaining to HEC-RAS). A cross section within the model geometry that is created from an interpolation of the ground surface data for the cross sections immediately upstream and downstream.

Lateral Structures (Pertaining to HEC-RAS). A physical feature that generally lies parallel to flow. Water may be routed through or over this structure.

Life Loss Estimates (Life Loss). Estimate of potential life loss using approved life loss estimating methodology. May be for individual breach modes, or total for specified loading scenario.

Loading Conditions. The reservoir pool level corresponds to a particular dam outflow event.

Manning's "n" Values. A scale of relative roughness pertaining to stream channels and overbank areas and used in Manning's equation.

Maximum Flood Control Elevation (feet). The highest elevation of flood control storage.

Maximum High Pool (Type of Condition). An unsteady flow simulation for non-breach and breach scenarios will be modeled for the maximum high pool water level. The maximum high pool event will be defined by the inflow design flood.

Maximum Operating Pool. The highest elevation achieved in the reservoir under normal operating conditions. This represents the upper limit or top of active storage.

Maximum Storage (acre-feet). Total storage space in the reservoir below the design water elevation. This storage space includes surcharge, flood, conservation, inactive, and dead storage. Maximum storage is determined based on a level pool assumption excluding any allowance for freeboard or wedge storage due to sloping water surface. This measurement is the same as data field 30 in the National Inventory of Dams, Version 4.0, April 2008.

Minimum Operating Water Elevation (feet). The lowest elevation the reservoir is drawn down to under normal operating conditions excluding any special provisions for drought operations. This water surface elevation corresponds to the bottom of active storage. This measurement is the same as “minimum operating level” in the FEMA Federal Guidelines for Dam Safety, April 2004.

Model Geometry (Pertaining to HEC-RAS). A representation of the physical features that influence flow in a particular modeled reach.

Navigation Pool Channel Capacity (NPC). An unsteady flow simulation for non-breach and breach scenarios will be modeled for the navigation pool with discharges equal to the downstream channel capacity. Starting reservoir pool will correspond to the normal navigation (NN) pool elevation. Reservoir inflow will be a scaled IDF hydrograph. The scaled hydrograph will be developed to produce a peak pool equal to the NPC loading. Gate operation procedures from the latest WCM will be applied to the hydrograph routing. The NPC scenario corresponds to the highest elevation which can be obtained under normal regulated operating conditions that allow releases equal to the downstream channel capacity. This scenario may or may not be associated with the occurrence of a flood event.

Normal High Pool (Type of Condition). An unsteady flow simulation for non-breach and breach scenarios will be modeled for a normal high-water level, the 10-percent duration exceedance. Starting reservoir pool will correspond to the 10-percent duration exceedance pool elevation. Reservoir inflow will be a constant inflow hydrograph as required to produce the 10-percent duration exceedance pool under normal gate operations. Gate operation procedures consistent with the latest water control manual will be applied to the hydrograph routing. Consequence analysis will include damage and LL estimates. A consequence analysis simulation for the non-breach condition is not necessary if non-damaging releases result from the normal high pool event.

Normal Navigation Pool (NN). An unsteady flow simulation for non-breach and breach scenarios will be modeled for a NN pool level under normal operating conditions. Starting reservoir pool will correspond to the NN pool elevation. Reservoir inflow will be a constant inflow hydrograph as required to produce the NN pool under normal gate operations. Gate operation procedures consistent with the latest WCM will be applied to the hydrograph routing. This scenario represents a normal pool condition. This scenario is not associated with the occurrence of a flood event.

Normal Water Elevation (feet). Maximum reservoir water surface elevation obtained when the reservoir is fully utilized for conservation purposes (e.g., municipal and industrial water supply, industrial water supply, irrigation, hydroelectric power generation, navigation, etc.) excluding flood and surcharge. This water surface elevation corresponds to the top of conservation storage level.

Normal Storage (acre-feet). Total storage space in the reservoir below the normal water elevation excluding any flood or surcharge storage. This storage space includes conservation, inactive, and dead

storage. This amount of storage space corresponds to the top of conservation storage level for dams with seasonal variations. This measurement is the same as data field 31 in the National Inventory of Dams, Version 4.0, April 2008.

Population at Risk (PAR). For dam safety risk assessments, it is the population subject to risk from flooding; usually documented in numbers of persons at risk. Previously referred to as threatened population.

Dam Portfolio Risk Assessment. A tool for prioritizing structural and non-structural measures for reducing dam safety risks across a group of dams. A dam portfolio risk assessment can also be used to prioritize further investigations and analyzes and to give a basis for the evaluation of other dam safety activities (e.g., monitoring and surveillance, inspections, and emergency planning).

Portfolio Risk Management. A risk-informed approach for improved management of dam safety for a portfolio of dams in the context of the owner's business.

Stage Damage. The relationship of damage to a range of flood stages at a structure or the aggregated values of damage-by-damage categories for a range of stages at some form of index location, such as a LifeSim Common Computation Point.

Storage. The retention of water or delay of runoff either by planned operation, as in a reservoir, or by temporary filling of overflow areas, as in the progression of a flood wave through a natural stream channel. Definitions of the specific types of reservoir storage are as follows:

- **Active Storage.** The volume of the reservoir that is available for some use such as power generation, irrigation, flood risk management, water supply, etc. The bottom elevation is the minimum operating level.
- **Dead Storage.** The storage that lies below the invert of the lowest outlet. This type of storage cannot readily be withdrawn from the reservoir.
- **Flood Surcharge.** The storage volume between the top of the active storage and the design water level.
- **Inactive Storage.** The storage volume of a reservoir between the crest of the invert of the lowest outlet and the minimum operating level.
- **Live Storage.** The sum of the active and inactive storage.
- **Reservoir Capacity.** The sum of the dead and live storage of the reservoir.

Storage Area Connectors (Pertaining to HEC-RAS). A physical feature that lies between two HEC-RAS storage areas over which water may be routed.

Storage Curves (Pertaining to Reservoir Storage). A relationship between reservoir pool elevation and corresponding storage volume.

Streambed Elevation. The lowest elevation of the original natural ground surface (prior to dam construction) along the centerline axis of the dam. This elevation is typically located where the original stream channel intersects the centerline axis.

Study Area. An estimated inundation area created by GIS from buffering the centerline to create the 10-meter digital elevation model (DEM) for pre-model GIS process.

Surface Area (acres). The surface area of the impoundment at normal water elevation (normal storage). This measurement is the same as data field 32 in the National Inventory of Dams, Version 4.0, April 2008.

Thalweg. The middle of the main channel of a waterway.

Top of Active Storage (Type of Condition). An unsteady flow simulation for non-breach and breach scenarios will be modeled for the top of active storage water level. Starting reservoir pool will correspond to the normal operating pool elevation. Reservoir inflow will be a scaled PMF or reservoir design flood hydrograph. The scaled hydrograph will be developed by scaling the available hydrograph using trial and error to produce a peak pool equal to the top of active storage elevation. Gate operation procedures from the latest water control manual will be applied to the hydrograph routing. Consequence analysis will include damage and LL estimates. A consequence analysis simulation for the non-breach condition is not necessary if non-damaging releases result from the top of active storage event.

Top of Active Storage Elevation (feet). The reservoir elevation is attained if the reservoir is fully utilized for all project purposes (i.e., power generation, irrigation, flood risk management, water supply, etc.). The pool elevation that, if exceeded, would result in significant increase in discharge based on the physical properties of the project and/or operation procedures from the latest water control manual.

Two-Dimensional Model. The MMC Production Center standard for two-dimensional (2D) modeling is HEC-RAS 2D. HEC-RAS 2D is a finite volume hydraulic model that can simulate channel flow and unconfined overland flow.

Unsteady Flow Modeling. Hydraulic modeling involves routing a hydrograph through a system.

USACE Dam Safety Program. The USACE Dam Safety Program effectively attempts to apply the utmost care and competence to every aspect of dam design, construction, operation, and maintenance.

Warning Time. The difference in time between the warning issuance and flood arrival times.

Water Control Manual. Document containing pertinent information pertaining to a dam and or reservoir. It may include construction plans, operational procedures, and duration exceedance curves.

LIST OF ACRONYMS AND ABBREVIATIONS

1D	one-dimensional
2D	two-dimensional
CAR	Consequences Assessment Report
CEDALS	Corps of Engineers Dam and Levee Safety Database
CIPR	Critical Infrastructure Protection and Resilience Program
COP	Community of Practice
CTS	consequence-based top screen
CUI	Critical Unclassified Information
DEM	digital elevation model
DBIM	dam breach inundation map
DHS	Department of Homeland Security
DM	design memorandum
DSO	dam safety officer
DSPM	dam safety program manager
DSPMT	Dam Safety Program Management Tool
DSS	data storage system
DVD	digital video disc or digital versatile disc
EAP	Emergency Action Plan
EGM	Economic Guidance Memorandum
EPZ	Emergency Planning Zone
ESRI	Environmental Systems Research Institute
FEMA	Federal Emergency Management Agency
FGDC	Federal Geographic Data Committee
FIS	flood insurance studies
FSA	Farm Service Agency
FTP	file transfer protocol
GIS	geographic information systems
HAZUS	Hazards US (Geodatabase data from FEMA)
HEC	Hydrologic Engineering Center
HEC-HMS	Hydrologic Modeling System
HEC-RAS	River Analysis System
H&H	hydraulics and hydrology
HH&C	hydrology, hydraulics, and coastal engineering
HMCAS	Hydraulic Modeling and Consequences Summary

HTML	hypertext markup language
IDF	inflow design flood
IES	Issue Evaluation Study
IH	intermediate high
IL	intermediate low
IQR	independent quality review
IWR	Institute for Water Resources
KML	keyhole markup language
KMZ	keyhole markup (file), zipped
LiDAR	light detection and ranging
MH	maximum high
MMC	Mapping, Modeling and Consequences Production Center
MXD	map document files
NAV	navigation
NAVD 88	North American Vertical Datum of 1988
NED	National Elevation Dataset
NBIM	non-breach inundation map
NGVD 29	National Geodetic Vertical Datum of 1929
NH	normal high
NHD	National Hydrography Dataset
NID	National Inventory of Dams
NL	normal low
NLD	National Levee Database
NN	normal navigation
NPC	navigation pool channel
NWK	U.S. Army Corps of Engineers, Kansas City District
NWS	National Weather Service
OHS	Office of Homeland Security, U.S. Army Corps of Engineers
PAI	protective action initiation
PAR	population at risk
PDF	portable document format, a file extension from Adobe Systems
PDT	project delivery team
PMF	probable maximum flood
POC	point of contact
POR	period of record

PWP	project work plan
RA	risk assessment
RMC	Risk Management Center
SOP	standard operating procedures
SPRA	Screening Portfolio Risk Assessment
SS	security scenario
TAS	top of active storage
TIN	Triangulated Irregular Network
TOD	top of dam
UOC	USACE Operations Center
UNIM	upstream non-breach inundation map
USACE	U.S. Army Corps of Engineers
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VDF	volume duration frequency
WCM	water control manual
WS	water surface

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