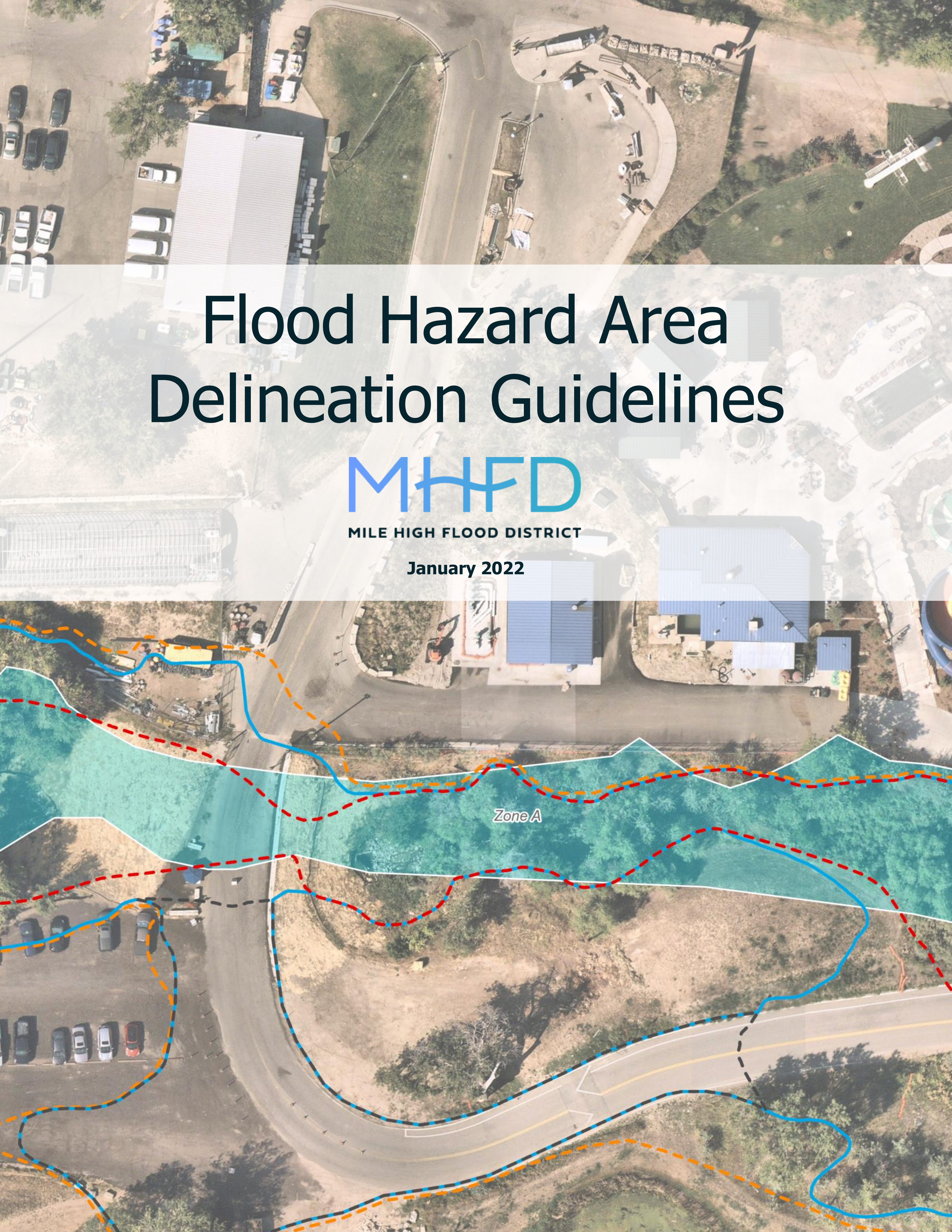
Flood Hazard Area Delineation Guidelines

MHFD

MILE HIGH FLOOD DISTRICT

January 2022



Contents

Figures

Tables

Appendix

Abbreviations and Acronyms

BFE	Base Flood Elevation
CAD	Computer-Aided Design
cfs	Cubic Feet per Second
DEM	Digital Elevation Model
DRCOG	Denver Regional Council of Governments
EGL	Energy Grade Line
EPA	U.S. Environmental Protection Agency
FBS	Floodplain Boundary Standard
FEMA	Federal Emergency Management Agency
FHAD	Flood Hazard Area Delineation
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
FP/FWDT	Floodplain and Floodway Data Table
fps	Feet per Second
ft	Feet
GIS	Geographic Information System
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HGL	Hydraulic Grade Line
LC	Low Chord
LiDAR	Light Detection and Ranging
LOMR	Letter of Map Revision
MDP	Major Drainageway Plan
MHFD	Mile High Flood District
NFIP	National Flood Insurance Program
OSP	Outfall Systems Plan
PMR	Physical Map Revision
QA	Quality Assurance
QC	Quality Control
sq ft	Square Feet
SWMM	Storm Water Management Model (EPA)
TOR	Top of Road
WSEL	Water Surface Elevation
XS	Cross Section

Revision Descriptions

January 2022	The January 2022 revision of the Flood Hazard Area Delineation (FHAD) Guidelines has been modified to update references and supporting documents, reorganize the explanations of the deliverables to parallel the FHAD review steps, and update expectations for FHAD deliverables and quality assurance/quality control procedures.
August 2017	The August 2017 revision of the FHAD Guidelines has been modified to specify geographic information system (GIS) deliverable requirements, as well as updated FHAD Submittal Requirements.
January 2015	The January 2015 revision of the FHAD Guidelines has been modified to clarify deliverables mainly for the drawings, report content, and technical documentation.
June 2012	The June 2012 revision of the FHAD Guidelines has been modified to mainly address clarification of deliverables. Section 1 emphasizes the inclusion of both Report and Technical Appendix Checklists. Copies of the Checklists and the Agreement Table are provided with the Urban Drainage and Flood Control District (MHFD) Vendor Agreement. Section 2 clarifies digital file requirements for both the hydrologic and hydraulic analyses. Section 3 clarifies Flood Map and Flood Profile components, and includes more emphasis on use of the Comment column contained in the Floodplain and Floodway Data Table. Section 4 regarding Submittal Requirements had been extensively revised to address three separate submittal phases for the FHAD documentation. Section 5 includes minor clarification to required Quality Control and Error-Checking information. The Appendix now includes the top-width example figures (previously included in the report text).

THIS DOCUMENT WAS PREPARED BY:

Moser & Associates Engineering
Icon Engineering
Mile High Flood District
Jacobs Engineering Group Inc. (Technical Editor)

1.0 Introduction and Purpose

The Flood Hazard Area Delineation (FHAD) Guidelines were written to offer guidance and direction for consultants developing FHAD studies. The guidelines cover the development and review processes, and specify the materials to be included in the interim and final FHAD submittals. These FHAD Guidelines also include references to Federal Emergency Management Agency (FEMA) standards and guidance to ensure a smooth transition for the deliverable into the next phase of mapping.

1.1 Referenced Documents

The FHAD Guidelines reference several documents that, when used in conjunction with these guidelines, offer important information for those developing the FHAD. The following information should be consulted routinely throughout the study:

- **Submittal Form and Checklists—**The FHAD Submittal Form, the FHAD Report Checklist, and the FHAD Deliverables Checklist identify the information that is required for submittals. The FHAD Submittal Form identifies the supporting documentation required for submittals, and the FHAD Deliverables Checklist and FHAD Report Checklist identify the digital deliverables included with a finalized FHAD Report. These documents are provided in each Vendor Agreement with the Mile High Flood District (MHFD). The contents of the FHAD Report are discussed further in **Section 4**.
- **Common Mistake Examples—**To expedite the submittal and review process, MHFD has compiled a list of common mistakes that have been identified during FHAD reviews. This information may assist consultants in their QA/QC process, and it is recommended that a FHAD study is checked against this list prior to submittal. This document can be found on MHFD's website (https://mhfd.org/services/floodplain-management/).
- **Agreement Table—**The Agreement Table is an error-checking tool to be completed by the consultant. It will also be used during submittal review by MHFD to ensure that there is good correlation between the hydraulic model, spatial data, flood profiles, and Floodplain and Floodway Data Table (FP/FWDT). The Agreement Table is also included in the Vendor Agreement with MHFD. Use of the Agreement Table is discussed in more detail in **Section 3.2.5**.
- **FHAD Tools**—The FHAD Tools are a set of geographic information system (GIS) tools created specifically for MHFD FHAD reviews. These tools provide a quick visual representation of some Hydrologic Engineering Center's River Analysis System (HEC-RAS) inputs and outputs. The tools are run by MHFD, but consultants are also encouraged to use these tools for quality assurance (QA)/quality control (QC). This manner of review is highly encouraged. The FHAD Tools can be downloaded from the MHFD website (https://mhfd.org/services/floodplain-management/).
- **FHAD Layer Formatting—**The final data deliverables for each FHAD must be provided in a specific format to ensure that each individual FHAD provides data that can be accumulated into larger datasets. Interim reviews do not require processing data into this symbology; only the final deliverables must be put in this format. A FHAD layer package that generates the symbology automatically and a template geodatabase that specifies the appropriate data schema can be downloaded from the MHFD website (https://mhfd.org/services/floodplain-management/).

- **FEMA Technical References and Guidance Documents**—FEMA has published many documents and references to ensure that each deliverable is uniform and has the required information to ensure that a seamless transition between mapping partners takes place. These documents are updated frequently; check the FEMA website for the most up-to-date version of the guidelines (https://www.fema.gov/flood-maps/guidance-reports/guidelines-standards).

1.2 FHAD Development in Support of Physical Map Revisions

The objective of FEMA's Physical Map Revision (PMR) process is to perform partial countywide updates for the regulatory flood hazard data impacting several Flood Insurance Rate Map (FIRM) panels and the corresponding Flood Insurance Study (FIS). This allows MHFD to submit completed FHAD studies to become FEMA regulatory products, allowing local flood hazard information to be reflected on the FIRM and FIS. The process also provides the opportunity to incorporate Letter of Map Revisions (LOMRs), that have become effective since the last FIRM revision, into the revised and republished FIRMs. Because of MHFD's Cooperating Technical Partner (CTP) Agreement with FEMA Region VIII, PMRs are typically processed through FEMA (subject to available regional funding) with MHFD's assistance. MHFD assists with National Flood Insurance Program (NFIP) Community coordination and resolution of any comments throughout the PMR process. More information on MHFD's floodplain management services can be found at https://mhfd.org/services/floodplain-management/.

While MHFD has requirements specific to FHADs, some comments and requirements provided during the FHAD process are intended to expedite the PMR process. Some FHAD review comments may appear trivial, but addressing these issues at the FHAD stage has a positive impact on completing the PMR process in a timely fashion. Deliverables and comments informed by the PMR process include the following:

- Hydraulic profile adjustments
- FP/FWDTs
- Flood hazard delineations and other data deliverables

1.3 Hydrology Requirements

While not every FHAD study includes a hydrologic study or update, FHAD hydrology is typically based on existing infrastructure and future land use conditions (i.e. future conditions hydrology). For the PMR process, FEMA's FIRM hydrology requirements may differ from the FHAD. FIRM hydrology is typically based on existing infrastructure and existing land use conditions (i.e. existing conditions hydrology).

MHFD's CTP Agreement with FEMA defines the hydrologic basis for FHAD and FIRM hydraulic models within the District's boundary for different circumstances, summarized in **Table 1.1**:

- If the future conditions hydrology is less than 130 percent of the existing conditions hydrology, the basis of the FHAD and FIRM hydraulic models should be based on the future conditions hydrology.
- If the future conditions hydrology exceeds 130 percent of existing conditions hydrology, the FHAD hydraulic model may be based on existing or future conditions hydrology, at the discretion of MHFD. If it is determined through consultation with FEMA that the FIRM must be based on the existing conditions hydrology, MHFD may direct the consultant to develop a FIRM based on the existing

conditions hydrology, which may be considered an additional Scope of Services. The difference in hydrology shall be clearly documented in the FHAD Report. The supporting documentation for a FIRM will follow the same FHAD Report and FHAD Deliverables Checklists included with the MHFD Vendor Agreement. In addition, the consultant should discuss the approach to the 500-year peak discharges with MHFD.

- As a possible exception, FEMA may consider a request to use future conditions hydrology even if the future conditions hydrology exceeds 130 percent of existing conditions hydrology, if the future conditions Base Flood Elevations (BFEs) are within 0.5 foot of the existing conditions BFEs.

Table 1-1. FIRM versus FHAD Hydrology Requirements

Future Conditions Scenario	Basis for FHAD Hydraulic Model	Basis for FIRM Hydraulic Model
Within 130 percent of Existing Conditions	Future Conditions	Future Conditions
Exceeds 130 percent of Existing Conditions	Future or Existing Conditions	Existing Conditions
Exceeds 130 percent of Existing Conditions, Future Conditions BFEs within 0.5 foot of Existing Conditions BFEs	Future Conditions	Future Conditions

Note: In the table, "Existing Conditions" refers to existing condition hydrology; "Future Conditions" refers to future condition hydrology.

Hydrology for the FHAD may be baseline hydrology (existing infrastructure and future land use conditions) from an approved MHFD parallel study, such as a Major Drainageway Plan (MDP) or an Outfall Systems Plan (OSP), unless as specified above. The 500-year hydrology may need to be developed for the FHAD, since it is not required in either the MDP or OSP. If the baseline hydrologic analysis is performed as part of the FHAD, it must be completed in accordance with MDP or OSP requirements for the 10-year, 25-year, 50-year, 100-year, and 500-year events. All pertinent electronic files and additional calculations used for the hydrologic analysis must be provided as supporting documentation. This includes spatial data (for example, shapefiles) for the drainage basins, attributed with the required basin information, as well as information on existing facilities, such as capacity, rating curves, and maintenance activities. If available, include the Maintenance Site Plan and the name of the local official responsible for maintenance of any regional detention facilities that have a Maintenance Site Plan. Files should be consistent with the FHAD Deliverables Checklist.

Existing regional detention facilities that have been accounted for in the FHAD hydrology must be clearly identified. Topographic work maps should include the 100-year Water Surface Elevation (WSEL), 100-year volume, and peak 100-year discharges (inflow and outflow). Documentation for all existing regional detention facilities incorporated into the FHAD hydrology must include a sketch/drawing/description of the outlet structure for the existing facility, a corresponding stage versus discharge rating curve for that outlet structure (that is not exceeded in the latest version of the U.S. Environmental Protection Agency's (EPA's) Storm Water Management Model (SWMM), and a stage versus volume rating curve for the facility (preferably with a grading plan). This information should be included in Appendix B of the FHAD Report (Hydrologic Analysis).

The baseline hydrology must have MHFD written approval prior to submittal of any FHAD hydraulic analysis.

2.0 FHAD Review Process

The FHAD review process is separated into multiple steps. The goal of a stepped approach, as opposed to one submittal of all products, is to reduce the number and length of reviews and reduce rework required for all deliverables.

Five separate submittal steps are required for the FHAD review process:

Step 1—Hydraulic Models
Step 2—Floodway Model
Step 3—Flood Hazard Delineations
Step 4—Final Review
Step 5—Final Submittal

FHAD studies typically cover large drainage areas, contain many crossings and structures, and can have complex flow paths. It is important for consultants to communicate issues to MHFD early in the process. The earlier a problem can be discussed, the less likely rework or changes will be needed.

Multiple iterations are likely necessary when reviewing the hydraulic and floodway models. To reduce the number of iterations, MHFD will provide comments through a brief letter (to address general comments) and a spatially referenced GIS file (for detailed and specific comments). The GIS comments also provide a space for the consultant to provide responses upon resubmittal. **Consultants shall provide responses to both the comment letter and the GIS comment file with each resubmittal.**

When completing a FHAD model, the consultant should ask themselves the following questions:

- Do the models capture all critical floodplain controls and potential flood risks?
- Do the models accurately represent the stream hydraulics within an acceptable level of risk/error?
- Do the models represent the most reasonable, conservative scenario for the regulatory storm event?
- Are modeling approaches applied consistently throughout the model? If not, what are the exceptions and why are they necessary?
- Do the inputs to this model vary in a consistent and reasonable manner?
- Is the engineering judgment used to make complicated modeling choices sound, and is supporting information provided to support these choices?
- Does the model information (both inputs and outputs) represent a spatially accurate hydraulic model? Can this information be used by local governments as a tool to protect people and property and regulate land use and development?
- Do the models provide accurate and sufficient base flood elevations backed by physical cross sections at the proximity of insurable structures, especially, where the base flood elevations change rapidly?

An overview of requirements for each submittal step is listed in the FHAD Submittal Form in the Vendor Agreement. The FHAD Submittal Form highlights the items that will be reviewed with each submittal. Each submittal is intended to build on the previous submittal; the consultant should coordinate with the MHFD Watershed Manager prior to submittal. The five steps of the review process are described in the following sections.

2.1 Step 1 – Hydraulic Models

Figure 2-1. Step 1 - Hydraulic Models

Prior to any submittal for Step 1, the baseline hydrology must have MHFD written approval prior to submittal of any FHAD hydraulic analysis.

With each Hydraulic Models submittal, MHFD will perform a technical review of the hydraulic models for the storm events as stated in the MHFD Vendor Agreement. **MHFD must approve the Hydraulic Models (Step 1) and the Floodway Model (Step 2) in writing prior to beginning the Flood Hazard Delineations (Step 3).**

While Step 1 focuses on the HEC-RAS model itself, MHFD will extract cross section and stream centerline information from HEC-RAS and review it spatially in GIS. This portion of the review ensures the hydraulic model is spatially accurate. **A georeferenced HEC-RAS model with sufficient descriptions, a projection file, and the digital elevation model (DEM) of topography used for the study should be provided with Step 1 submittals**. Models that have not been appropriately georeferenced will be returned before the review is started.

The description boxes in HEC-RAS models are an underutilized but valuable area to explain and document pertinent information about the model. For example, the overall HEC-RAS project description should contain the HEC-RAS version used to complete the analysis, the date the model was completed, the horizontal and vertical datums used for the model, and contact information for the consultant and modeler. The HEC-RAS plan description can provide a short explanation of what that model was used for (for example, floodplain development, floodway development, optimization, supporting calculations, and so forth). Cross section descriptions can contain information such as flow changes, or identify changes to base topography from LOMRs. Structure descriptions should note the corresponding structure number from the structure survey and street name, if applicable. An example is provided in **Figure 2-2**.

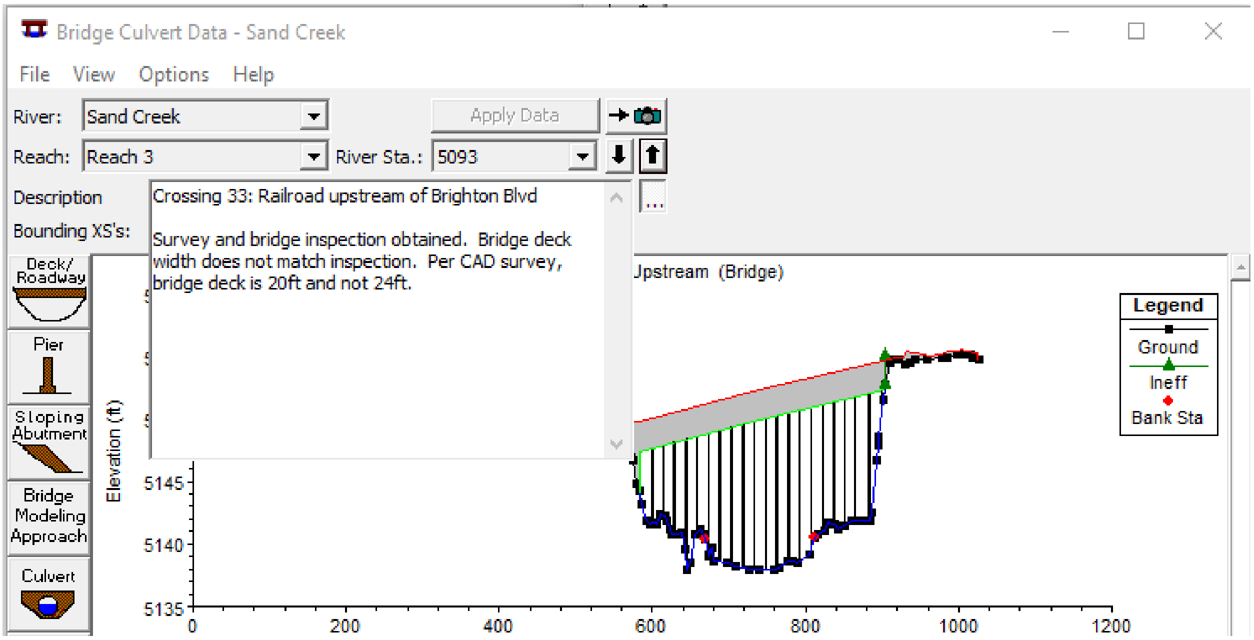


Figure 2-2. Using the HEC-RAS Description Boxes

The Hydraulic Models submittal needs to include any supplemental documentation or analysis that supports the hydraulic model, if this information applies. For example, this information could include description of, and reference to, other accepted hydraulic models and calculations, detention outlet structure information, or rating curves.

2.1.1 Step 1 Review

The following items are required for Step 1 submittals:

- An electronic submittal of the FHAD Report: Section 1 – Background Information (complete), Section 2 – Hydrologic Analysis (complete), and Section 3 – Hydraulic Analysis (partially complete) documenting completed portions of the model and providing discussion of decisions or assumptions made, to be expanded upon with each step of the review process (explained in more detail in **Section 4**)
- Brief response addressing the previous comment letter items (if resubmittal)
- GIS comment file with response sections completed (if resubmittal)
- A georeferenced HEC-RAS model and associated projection file
- Any supplemental information (other accepted hydraulic models, rating curves, and so forth) if such information applies
- DEM of topography used (see **Section 4.4.2** for more information)
- Electronic submittal of all items documented on the FHAD Submittal Form

The following Step 1 items require MHFD discussion and written approval before proceeding with Step 2:

- Stream centerline alignment and cross section placement
- Split flow areas

- The need for two alignments for different storm events, if low flow and flood flow paths differ substantially

While the above list represents the required submittal items, supplemental information that a consultant may use to complete their model should be provided with the submittal. For example:

- GIS files used to determine HEC-RAS inputs (such as Manning's n shapefiles)
- Informational files (such as building footprints and aerial photography)
- As-built information
- Site visit documentation

Once MHFD has completed a Step 1 review, consultants are urged to schedule a meeting and/or call to review the comments prior to proceeding with revisions.

The review of the HEC-RAS model in Step 1 will focus on the following information:

- *Compare HEC-RAS peak flow discharges to hydrology information.* Where HEC-RAS flows do not match hydrology in magnitude or location, an explanation should be provided within the FHAD Report.
- *Evaluate accuracy of plan form.* It is important to resolve any issues with the stream centerline and cross section alignments, as well as the coverage of cross sections, early on. MHFD will check that the stream centerline follows the channel thalweg, not just the path of the flood. Cross sections should be perpendicular to the stream centerline (outside of skew from structures) and topography to prevent overestimation of cross sectional area. Cross sections should be properly spaced to represent structures, contraction and expansion, and significant changes in topography. Cross sections shall be laid out in the simplest format possible that captures all flood risk accurately and appropriately. Additional detail is needed in complicated areas, such as confluences and split flows. If a reasonably simple cross section format cannot be followed, additional reaches or analysis may be needed. **Any questions on alignment for the stream centerline/stationing need to be resolved with MHFD prior to beginning the hydraulic analysis.**
- *Evaluate accuracy of hydraulic model inputs.* The consultant may be asked to provide justification for ranges of, and spatial changes in, Manning's n values; location of obstructions; ineffective flow areas; bank stations; contraction and expansion values; and boundary conditions. Proactive supporting information is encouraged where useful.
- *Evaluate flow splits.* Flow splits can be difficult to model accurately and may require some discussion and input from the local government and MHFD. The consultant should ensure that the geometry of any lateral structures is accurate and that the profile is extended to upstream and downstream high ground so that all events are contained within the structure geometry. **When lateral structures are present, the HEC-RAS model should include plans for both optimized and hard-wired flow runs.** Optimized models will indicate where additional flow change locations may be required outside of the impacts of hydrology.
- *Evaluate non-levee features.* Any berm-like features encountered within the model should be discussed with MHFD to determine a modeling approach in line with current FEMA guidance. **The modeling approach should be discussed early and approved by the local governments and MHFD.**

- *Compare hydraulic structures to structure survey.* MHFD will contract with a surveyor to complete an inventory of bridges, culverts, crossings, and drops within a study area. The elevations and geometry determined in this survey must be used to model hydraulic structures in HEC-RAS. **QA/QC should be completed to ensure the structure survey has been incorporated prior to submittal to MHFD. Doing so will greatly reduce review time and number of submittals required for Step 1.**
- *Compare HEC-RAS model inputs to spatial representation in GIS.* While there are no specific GIS products required in this step, HEC-RAS inputs such as reach lengths, cross section cut line lengths, junction lengths, and overbank lengths will be reviewed for spatial accuracy.

2.1.2 Hydraulic Model Requirements

The FHAD hydraulic analysis shall be based on existing infrastructure and future land use conditions hydrology. The hydraulic analysis utilizes the standard step-backwater method and the most recent version of HEC-RAS, or another method approved in writing by MHFD. The hydraulic model should utilize a subcritical analysis unless there is a justifiable reason to use a mixed flow or super-critical flow analysis. **If one of the latter analyses is preferred, the approach must be approved by MHFD first.** The HEC-RAS model shall be spatially georeferenced. Special conditions, such as major flow splits, may require modeling additional hydraulic reaches based on stakeholder consensus. Other conditions may require additional hydraulic calculations to support data used in the hydraulic model.

All pertinent electronic files and additional calculations used in the hydraulic analysis must be provided as supporting documentation for each formal submittal. For HEC-RAS, these will typically include the project (.prj) file with each plan clearly identified. All files used to analyze pertinent plans in the project must also be included. Each submittal should include clear descriptions accompanying the HEC-RAS model to identify the contents of each project file (.prj) and individual plan file (.p0#) with corresponding geometry file (.g0#) and flow file (.f0#) identifying each file's contents and purpose. The version of HEC-RAS used to complete the analysis should be included, as well. These descriptions can be provided within the files themselves, or as a readme document appended to the HEC-RAS model.

Typically, there are two submitted HEC-RAS hydraulic plans for the FHAD: a plan for the multiple-profile analysis (10-, 25-, 50-, 100-, and 500-year discharges), and a separate plan for the floodway determination. Alternatively, flow and geometry files can be set up such that all profile analyses and the floodway analysis are completed in one plan. If this is the case, the flow file must be set up such that the floodway run, then the 100-year discharge run, are the first two events, respectively. **A floodway model is required any time there is a designated floodway – even if the floodway is equal to the floodplain (such as confined within a design channel).**

2.1.3 Boundary Conditions

Downstream boundary conditions are a required input for all subcritical flow, mixed flow, and supercritical flow analyses; thus a downstream boundary condition must be determined for any FHAD study. Several options are available within HEC-RAS, but at a minimum the following should be considered:

- For a partial stream study, known water surface elevations shall be used for the downstream boundary conditions when available. If known water surface elevations are not available, the downstream boundary shall start at a control structure or use a normal depth calculation. **Before**

using this method, the choice should be verified with MHFD.

- For a tributary study, a normal depth calculation shall be used for the downstream boundary condition, unless a coincident peak condition is determined to be appropriate. If using coincident peaks, known water surface elevations for the receiving stream's equivalent storm events should be used. This method of determining the downstream boundary condition is most consistent with FEMA's guidance (see **Section 1.1** Referenced Documents for more information on FEMA guidance).
- It should be noted that previous studies within the MHFD boundary have used a known WSEL equivalent to the 10-year storm event of the receiving stream as the downstream boundary condition for all storm events in the study reach. If updating a previous study, this downstream boundary condition should also be evaluated and warrants discussion with MHFD.

2.1.4 Stream Alignment

Stream alignment (or profile baseline) is the line that determines the flood location and the flood profile. The stream alignment should follow the channel thalweg or invert. It is important that the length of the channel along the alignment shown in the Flood Hazard Figure and the flood profile matches the channel length used in the HEC-RAS hydraulic model. The stream alignment should generally depict the flood flow path and follow the alignment of the stream bed based on best available information (in many cases, the contours and surface used in the base map). **Any questions on alignment for the stream centerline/stationing must be resolved with MHFD prior to beginning the hydraulic analysis.**

If there are two or more possible flow paths along a drainageway, a consensus must be reached on which flow path will be considered dominant (and the basis for the main drainageway stream alignment and stationing). Stream alignments and stationing typically need to follow the surface flow path for floodplain mapping. For example, if there is a minor storm sewer under a development but the majority of the flood flow will be on the surface, then the stream alignment and stationing need to follow the surface flow path regardless of the minor storm sewer alignment. Significant overtopping of roadway crossings may also warrant alignment consideration.

When a large percentage of the discharge follows a distinctly separate flow path than the main channel, a split floodplain (with a distinctive alignment, modeling reach, cross section locations, flood profiles, and so forth) may be required. The split flow floodplain delineation will be determined using the split flow discharge. In some situations, the main channel floodplain delineation will still be determined based on the total discharge (that is, do not reduce the main channel discharge to account for the split flow). When determining the floodway delineation, if the total discharge cannot be confined to the main channel within the 0.5-foot floodway criteria, a separate, split floodway may be required. **Please discuss split flow areas with MHFD before analyzing split flows.**

In a few cases, the low-flow channel may be very sinuous with little flow capacity, and the overbanks would convey the majority of the flood flows. With this situation, the channel alignment (or profile baseline) may be different from the stream bed, and the modeled length of the flood flow path between cross sections may be different (most likely shorter) than the stream bed length between cross sections. **Before deciding that the sinuosity of the low-flow channel is considered to be so extreme that separate alignments (both a stream alignment and profile baseline alignment) will be required for the more frequent events (10-year and 50-year) versus the major storm events**

(100-year and 500-year), the consultant must obtain approval from MHFD and the local governments.

The use of a separate profile baseline for flood flows (that is, 100-year and 500-year events) has a significant impact on the products required for the FHAD. In addition to the stream alignment that follows the channel bed on the topographic work map, the corresponding HEC-RAS hydraulic model and resulting water surface profiles for the more frequent events (that is, the 10-year and 50-year events) must be provided. Additionally, the following items must be included:

- The profile baseline must be shown and clearly labeled on the topographic work map in addition to the stream alignment (and include relative stationing).
- Channel distances between cross sections in the HEC-RAS hydraulic model must match those along the profile baseline for the 100-year and 500-year events.
- A separate geometry file for the HEC-RAS hydraulic model will be required to reflect the profile baseline distances for the 100-year and 500-year events (instead of one geometry file for all storm events).
- A separate plan will need to be included in the HEC-RAS model, specifically for the 100-year and 500-year events (instead of one plan for all storm events).
- A separate water surface profile will need to be provided (for the 100-year and 500-year events) that reflects the stationing and relative distances between cross sections along the profile baseline (instead of one profile for all storm events).

One outcome of using the stream alignment for all storm events in the FHAD hydraulic model would be the potential to overestimate the upstream water surface in some reaches with high sinuosity due to additional friction losses accounted for along the stream alignment. The HEC-RAS model, however, already compensates for the differences in channel and overbank reach lengths by using a discharge-weighted reach length between cross sections based on the discharges conveyed in the main channel and left and right overbank segments for a given reach along the drainageway.

All stationing for a given drainageway will use continuous stream stationing from the confluence with the receiving stream regardless of jurisdictional boundaries and increase going upstream. This means that Station 0+00 for the main drainageway will be at the confluence with the receiving stream's thalweg regardless of the downstream limit of the study area. All drainageways in the study need to have a unique station-numbering sequence. For tributaries to the main drainageway, if stationing starts at 0+00 for the tributary at the confluence with the main drainageway, then there must be clear reach identification associated with the cross section stations provided in all models and tables that will result in a unique identifier for each cross section used in the hydraulic model.

2.1.5 Cross Sections

Cross sections should be placed along the waterway in a manner that reflects the topography of the channel, depicting changes in stream cross section geometry, and changes in channel slope and energy such that the geometry and hydraulic roughness vary gradually. Cross sections should accurately represent crossings and drop structures. Because MHFD communities are committed to maintaining crossings, it is appropriate to assume hydraulic structures are free of blockages and debris. Cross sections should be placed to not cross other cross sections on the same flooding source and cross the entire 500-year floodplain. The locations and orientation of all cross sections used in the hydraulic model should be shown on the Flood Hazard Figure. Locations of cross section lines on the Flood Hazard Figure along the stream alignment (or profile baseline) must correspond to the cross section location on the flood profiles. In general, for hydraulic flood models in urban areas with consistent geometry, the distance between cross sections should be in the range of 200 to 400 feet, in accordance with the MHFD Urban Storm Drainage Criteria Manual (https://mhfd.org/resources/criteria-manual/). Cross sections should fully contain all storm events, unless adjacent to a split flow, lateral structure, or otherwise appropriate and accepted by MHFD.

Distances between cross sections measured along the stream centerline, as defined in **Section 2.1.1**, must agree with corresponding distances shown on the water surface profiles to within the maximum tolerance specified on the Agreement Table (**Section 3.2.5**).

HEC-RAS cross section plots of each crossing (culverts and bridges) shall be included in Appendix C of the FHAD Report. This information should include the structure's location, station, dimensions, material, and elevations of the invert, low chord, road elevation, and if appropriate, any other features that would obstruct flow, such as guardrails, curbs, or other features.

2.2 Step 2 – Floodway Model

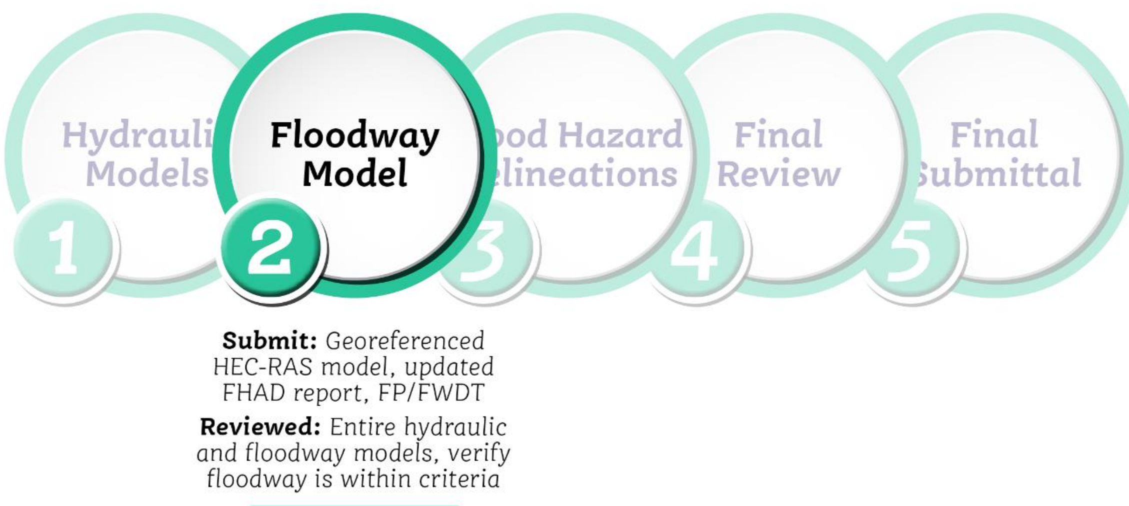


Figure 2-3. Step 2 - Floodway Model

Each Floodway Model submittal shall include all approved items from the previous submittal. Approval of the Hydraulic Models (Step 1) and Floodway Model (Step 2) must be received prior to Flood Hazard Delineation (Step 3).

While this step is focused on review of the Floodway Model, comments provided may require adjustment to the Hydraulic Models. Such comments will not result in reverting to Step 1, but the Hydraulic Models may need to be resubmitted to demonstrate comments have been addressed.

A floodway is a tool to assist the local government in managing development within floodplains and their associated increase in flood risk. With MHFD's acknowledgement, the consultant should coordinate with the impacted local government prior to floodway model development to ensure the floodway meets their needs, transitions smoothly to adjacent floodway models, and considers the nature of the effective floodway along restudied streams.

The FHAD Report should be updated with a section explaining the approach used for the Floodway Model, and note any adjustments needed in the hydraulic models. Understanding the location of encroachments placed to create the floodway is important to the Step 2 review. **A georeferenced HEC-RAS model with sufficient descriptions and a projection file should be provided with each submittal in Step 2**.

MHFD will utilize the FHAD Tools to extract encroachments and floodway extents from the HEC-RAS model to review the information spatially. The consultant should verify that encroachments are placed appropriately. It may be helpful to complete this QA/QC by running the FHAD Tools before submitting.

The floodway should be developed based on WSEL and energy grade line (EGL) elevation surcharges. The floodway should also be without consideration of backwater from confluences unless a coincident peak analysis warrants it. In addition, new or revised floodway data must match any effective floodways at the limits of the study, with encroachments matching where they are available from the effective model.

In some areas, the floodway should equal the floodplain. There should be no additional encroachment for a floodway along stream reaches where the following conditions exist:

- A 100-year channel has been constructed
- There has already been fill in the floodplain up to a previously published floodway limit
- There is an online regional detention pond with a 100-year flood pool (the floodway should match the 100-year flood pool)
- A corridor has already been established through the development process (that is, maintenance eligible reach)
- Floodplain preservation is being implemented

There is a risk of floodway creep where the *cumulative* encroachment within a floodplain reach exceeds the maximum allowable WSEL rise. If a stream has already experienced encroachment due to development and has been re-evaluated through a LOMR, re-establishing a new floodway through that reach may effectively double the permitted flood elevation increase.

The floodway is based on the principle that the area chosen for the regulatory floodway is designed to carry the waters of the base flood within the allowable surcharge requirement. Therefore, in most cases the floodway should not include ineffective flow areas that are a part of the mapped floodplain. In addition, this statement also implies that the channel is fully contained within the floodway. In the case where an online detention facility and ineffective flow area exist (for example, at an outlet structure), the approach to have the floodway equal to the floodplain takes precedence.

Typically, an equal conveyance-reduction method is used to establish the first attempt at the regulatory floodway. Modification can then adjust the encroachment as needed to meet criteria and better reflect circumstances along the stream. Then, the final HEC-RAS model submitted to MHFD must be saved as a Method 1 floodway, where the exact location of the encroachment stations is specified for each individual cross section.

Negative surcharges are a common problem when developing the Floodway Model. The process provided below should be followed when evaluating and resolving negative surcharges. When setting encroachments, follow these primary directives:

- The floodway top widths should be less than or equal to the active (effective) flow top widths.
- Where possible, avoid including high ground and/or islands within the floodway.
- Use a consistent approach to modeling the floodway within a given reach (that is, all cross sections are floodway equal to the floodplain or all have encroachments). Isolated cross sections using a different approach should be avoided, if possible.
- Provide a reasonable and smooth floodway transition throughout the model.

The following example (**Figure 2-4**) provides an explanation of the allowable encroachment.

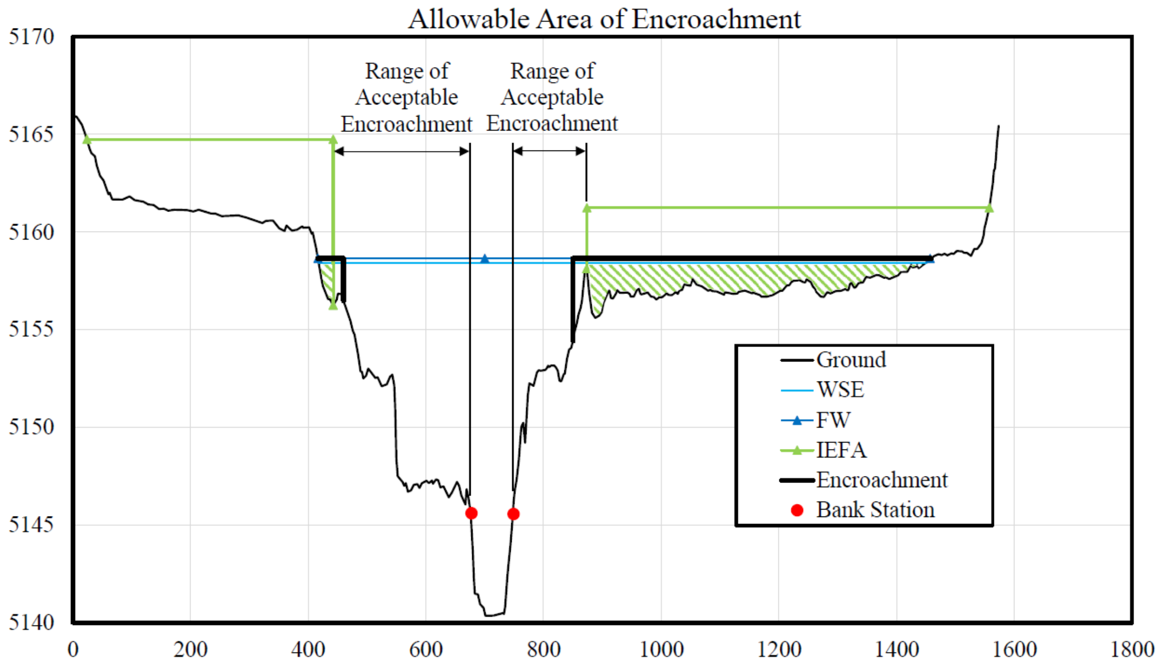


Figure 2-4. Allowable Area of Encroachment

If the floodway encroachment results in negative surcharges, attempt to resolve the issues in the following order:

1. Negative surcharge values may be caused by excessive encroachment, errors in the bridge modeling, or insufficient encroachment at or downstream of the cross section with the negative surcharge. Negative surcharges in one cross section may be influenced by cross sections much farther downstream than adjacent cross sections, so it is important for modelers to try all efforts to revise **floodway configurations,** not just individual cross sections that are in error.
2. When efforts to eliminate negative surcharges within the model have been exhausted, set the floodway encroachments in accordance with the primary objectives above. Negative surcharges between 0 and -0.04 foot will be deemed acceptable. However, explanations must be provided in the Comments Column of the FP/FWDT.
3. If all other efforts to eliminate negative surcharges greater than -0.04 foot within the model have been exhausted, the no-encroachment approach can be used at isolated, problematic cross sections.

Documentation of the reasoning to allow the negative surcharge or reasoning to use the no-encroachment approach should be clearly documented within the FHAD on the FP/FWDT.

4. If significant negative surcharges persist, these issues should be discussed with MHFD before finalizing the floodway model and FHAD. These issues must also be documented within the FHAD.

If the floodway delineation will eliminate a flow split from the main channel, thereby increasing the main channel discharge and corresponding WSEL, there may only be a limited additional encroachment, or possibly no further floodway encroachment allowed along the main channel reach. **It is advised to consult with District staff before beginning floodway analyses to verify areas of potentially limited encroachment. This will minimize unnecessary modeling efforts associated with this process.**

Before beginning the floodway analysis, **the consultant should discuss the Floodway Model approach before creating the Floodway Model.**

2.2.1 Step 2 Review

The following items are required for Step 2 submittals:

- Brief response addressing the previous comment letter items
- GIS comment file with response sections completed
- An electronic submittal of Section 3 – Hydraulic Analysis (updated) of the FHAD Report
- A completed FP/FWDT
- Electronic submittal of all items documented on the FHAD Submittal Form
- All revised items from the previous submittal

Once MHFD has completed a Step 2 review, it may be necessary to conduct a meeting and/or call to review the comments that require discussion.

The review of the HEC-RAS models in Step 2 will focus on the following information:

- *Evaluate the logic of the floodway model approach.* Consider the local government's needs during floodway development. The 0.5-foot maximum allowable rise should be targeted assuming a reasonable floodway top width and transition are achieved. The floodway should not prohibit existing land uses from any renovation or improvement or unnecessarily hinder any future development. Where local governments have adopted a regulatory floodway, the new study must use the configuration of the adopted floodway to the extent practical to compute floodway data along restudied streams.
- *Evaluate the accuracy of the floodway model approach.* Encroachments and effective flow areas should not contract or expand rapidly unnecessarily.
- *Check that the floodway equals the floodplain, where appropriate.*
- *Evaluate the accuracy of the floodway model surrounding split flows.* When determining the floodway delineation, if the total discharge cannot be confined to the main channel within the 0.5-foot floodway criteria, a separate, split floodway will likely be required. Exceptions, while rare, may occur.
- *Compare the discharges, boundary conditions, and geometry of floodplain and floodway models.*

These inputs should be identical between plans.

- *Compare the FP/FWDT to HEC-RAS models for accuracy and verify that surcharge values meet criteria.* **The FP/FWDT should be reviewed by the consultant before submittal to MHFD.** This QA/QC should confirm that no hydraulic grade line (HGL) or EGL surcharges are greater than 0.50 foot, or less than 0.00 foot (if possible), which would eliminate most of the comments from MHFD in this step.

2.3 Step 3 – Flood Hazard Delineations

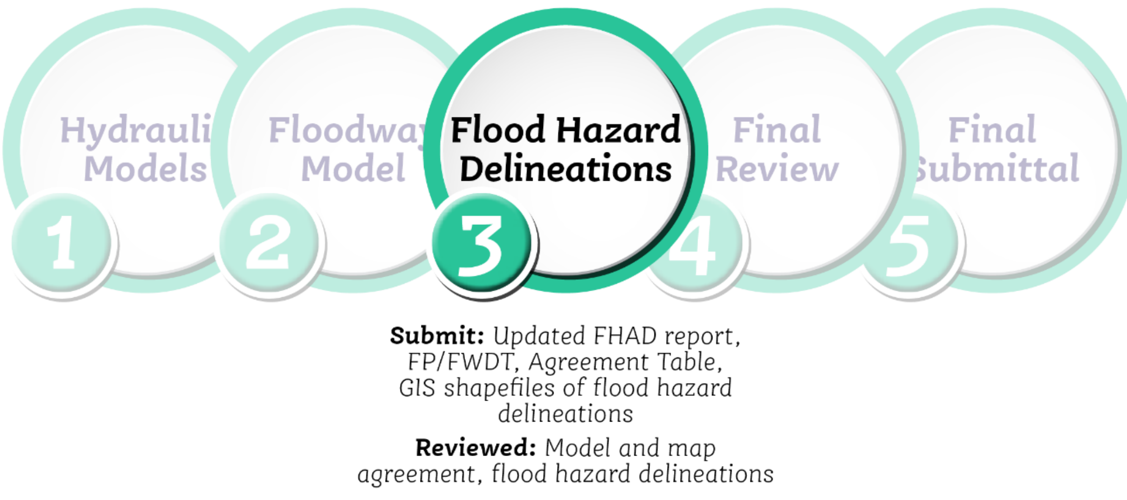


Figure 2-5. Step 3 - Flood Hazard Delineations

The Flood Hazard Delineations submittal is provided to MHFD and all other stakeholders and shall include all approved items from the previous submittals outlined in **Section 2.1** and **Section 2.2**. **Approval of the delineations for the 100-year floodplain, 500-year floodplain, floodway, and corresponding Agreement Table (Step 3) shall be received prior to the development of final FHAD deliverables (Step 4).**

Once the HEC-RAS models from Steps 1 and 2 have been reviewed and updated, work on Step 3 deliverables can begin. The goal of this step is to translate the HEC-RAS results into spatial deliverables by interpolating WSELs from each cross section to create flood hazard delineations. This step should not require adjustments to the HEC-RAS models, but some comments may need to be addressed.

The FHAD Report should be updated with a section explaining the results of the floodplain and floodway delineations, and note any adjustments needed from the HEC-RAS models. Some programs may generate auto-delineated floodplains, but these results alone are typically not sufficiently accurate.

Delineations should be reviewed by the consultant prior to submittal. The consultant can provide their cross section and centerline shapefiles used for delineation purposes, but they should check that these shapefiles accurately represent the HEC-RAS model. MHFD uses several different methods for review of Step 3, including the FHAD Tools and FEMA's Floodplain Boundary Standard (FBS) (FEMA, latest version). Information on FHAD Tools and an overview of FBS is provided in the Referenced Documents,

Section 1.1. In addition, the Agreement Table provides a tabular check of these results. The Agreement Table should be completed, checked, and submitted in Step 3.

2.3.1 Step 3 Review

The following items are required for Step 3 Submittals:

- Brief response addressing the previous comment letter items
- GIS comment file with response sections completed
- A completed Agreement Table
- Separate GIS shapefiles for each flood hazard delineation
- Draft Flood Hazard Figure (explained in more detail in **Section 4**)
- Electronic submittal of all items documented on the FHAD Submittal Form
- All revised items from the previous submittal

The review of the flood hazard delineations in Step 3 will focus on the following information:

- *Compare HEC-RAS model with Agreement Table and FP/FWDT*. Model values in each table should match HEC-RAS results precisely. Map values should match GIS precisely. **Any significant differences between map and model values for a given cross section should be explained in the Comments Column of the FP/FWDT.**
- *Verify HEC-RAS cross sections are properly located spatially.* If the wrong version of the cross section shapefile is used, delineations may be incorrect. **If this issue is identified by the reviewer, the submittal may be returned before a full review is completed.**
- *Verify flood hazard delineations follow topographic information.* Delineations should project reasonable WSELs across the floodplain and smoothly cross contours according to the results of the HEC-RAS models. Delineations should cross contours at the interpolated BFEs and should not repeatedly cross between contours or increase in elevation downstream without supporting evidence from model results.

2.3.2 Flood Hazard Boundaries

The 100-year floodplain boundaries shall be delineated to depict the flood elevations from the HEC-RAS analysis. If the 500-year floodplain is required by the scope of work, it shall be provided with the same accuracy as the 100-year floodplain. The 100-year floodplain boundaries should be continuous through bridges with 100-year capacity, but not continuous through culverts that have 100-year capacity. Any overtopping, potential spills into a canal or ditch, or other water bodies should be identified with notes on the Flood Hazard Figure.

Floodway boundaries for the 0.5-foot rise floodway (if required by the scope of work) shall be delineated to depict the results of the floodway analysis. Where no additional encroachment for a floodway along a stream reach is warranted as described in **Section 2.2**, the floodway is equal to the floodplain. Where this occurs, the condition shall be noted in the FP/FWDT.

The flood hazard boundary supported by a hydraulic model should extend across the entire width of the inundated area without separating the shallow flooding areas at the floodplain fringes. If a reach is experiencing 100-year shallow flooding, additional supporting calculations will be required to document the depth of flow, and **the shallow flooding area shall be included in the 100-year floodplain delineation**. In addition to including this area within the 100-year floodplain, a separate, shallow flooding-only delineation shall be provided. Shallow flooding areas have an average depth less than 3 feet. Isolated areas of very shallow flooding (less than 6 inches) outside of the main channel may be removed from the flood hazard delineation during mapping cleanup after discussion with MHFD. **Shallow flooding zones with an average depth greater than 1 foot may be acceptable on a case by case basis but should be discussed with MHFD because this approach does not provide BFEs for future regulation.** The average depth, rounded to the nearest whole foot, shall be included in the attribute table of the shallow flooding shapefile and annotated on the Flood Hazard Figure. Averaged depth values cannot be rounded down (that is, if the average flooding depth is 1.2 feet, the annotated value is 2 feet). The corresponding delineation must be distinguishable from the 100-year floodplain.

Where there are existing on-site detention facilities adjacent to the channel, the HEC-RAS model top width ("Top Width" value) reflects the top width of the wetted cross section including the ineffective flow area within the detention pond. While the ineffective flow area covering the detention facilities is not accounted for in the FP/FWDT, **the detention facility areas need to be shown as 100-year floodplain** at least up to the 100-year WSEL in the adjacent cross section along the channel.

Ensure that the GIS delineation of the flood pool for existing detention facilities coincides with the EPA SWMM hydrology model results (that is, ponding depth, surface area and/or volume, and so forth). Documentation for all existing regional detention facilities incorporated into the FHAD hydrology needs to include the following:

- A sketch/drawing/description of the outlet structure for the existing facility
- A corresponding stage versus discharge rating curve for the outlet structure (that is not exceeded in the EPA SWMM model)
- A stage versus volume rating curve for the facility (preferably with a grading plan)
- A Maintenance Site Plan for the facility
- The local official responsible for maintenance

This information should be included in Appendix B of the FHAD Report (Hydrologic Analysis).

2.3.3 Base Flood Elevations

BFEs shall be shown at all cross section locations and supplemented with BFE lines between cross sections, as needed. Placement of additional BFE lines are discussed in this section. **It is advised to consult with MHFD staff before placement of additional BFE lines.** FEMA's *Guidance for Flood Risk Analysis and Mapping – Mapping Base Flood Elevations on Flood Insurance Rate Maps* (FEMA, latest version) provides the following recommendations to help determine BFE spacing:

- The 100-year BFE shall be shown on cross section lines. These BFEs should be rounded to the tenth of a foot. Rounded values should either be performed based on three decimal places or determined in the model results.
- Additional BFEs shall be placed at inflection points not already captured by cross sections, or as needed in areas of backwater, ponding, complex flow areas, overflow areas off the profile baseline, or other areas as needed, based on engineering judgment. These BFEs should be rounded to the tenth of

a foot. Note that the need for supplemental BFEs could be an indicator that additional cross sections are warranted.

- BFEs must be shown at appropriate locations to allow map users to accurately interpolate flood elevations both horizontally and vertically. This information shall match the WSELs shown on the flood profiles.
- Minimize overcrowding of BFEs.

If it is determined that additional BFEs are needed beyond those shown at cross section locations, the BFE lines shall be drawn perpendicular to the direction of floodwater flow. BFEs must cross perpendicular to the stream alignment, and extend completely across the 100-year floodplain, snapping to the floodplain boundary. BFEs should tie into the intersection of the floodplain boundary with the corresponding topographic location. BFEs should never cross over a cross section line.

2.4 Step 4 – Final Review

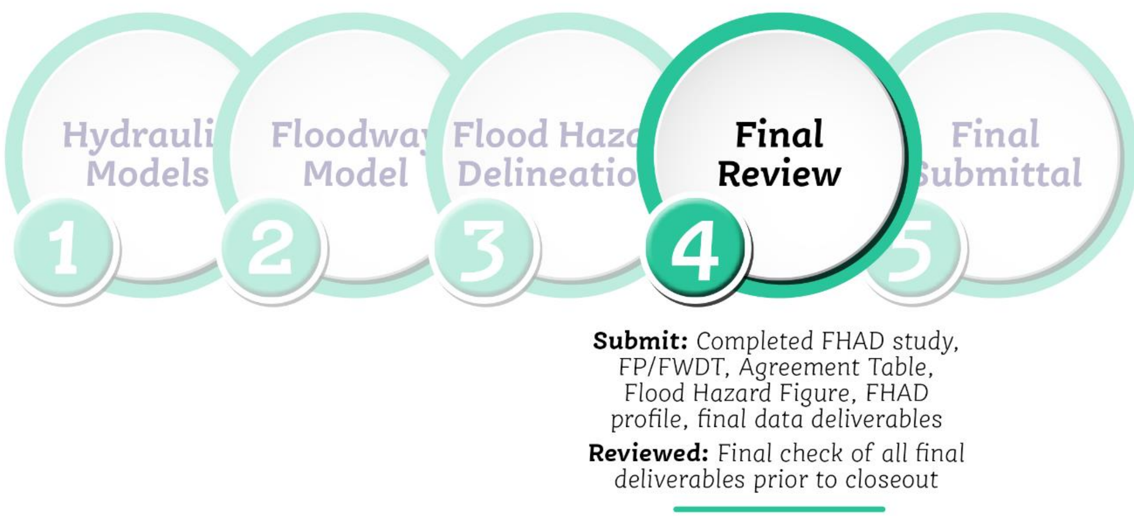


Figure 2-6. Step 4 - Final Review

Once the hydraulic models and mapping have been approved, the full FHAD submittal (Final Review) shall be provided to MHFD and all other stakeholders. **Step 4 is expected to be a final review. The goal of this step is to provide one final set of comments that are addressed in the subsequent Final Submittal (Step 5).**

Step 4 is primarily focused on ensuring all information matches across deliverables. The submittal will be reviewed for consistency, accuracy of results, and that all technical data deliverables have been created using the format and attributes as requested.

In addition, the profile output from HEC-RAS (using RASPLOT) should be provided. It is an important piece of supporting information to document for incorporation into the PMR. This deliverable will require output with appropriate adjustments to the profile as necessary (see **Section 2.4.2**).

If the consultant disagrees with any of the comments provided in this step, these items should be discussed prior to submittal of Step 5. The goal is to have no additional comments on a Step 5 submittal.

2.4.1 Step 4 Review

The following items are required for Step 4 submittals:

- Brief response addressing the previous comment letter items
- GIS comment file with response sections completed
- A completed FHAD Report containing all three sections
- A completed Flood Hazard Figure
- A completed profiles figure
- All final data deliverables in the final format and schema

The Final Review in Step 4 will focus on QA/QC of the following information:

- *Compare the HEC-RAS model with the Agreement Table and FP/FWDT*. Model values should match HEC-RAS results precisely. Map values should match GIS precisely. **Any significant differences between map and model values for a given cross section should be explained in the Comments Column of the FP/FWDT.**
- *Complete a final review of the FHAD Report*. Important modeling decisions and information supporting the FHAD should be provided.
- *Review the HEC-RAS Flood Profile deliverable*.
- *Verify accuracy of technical deliverables*. GIS files provided will be reviewed to ensure they match the results of the model.

2.4.2 Flood Profiles

Flood profiles can be generated using RASPLOT, which automatically uses FEMA's standard profile layout described in Section 7 of the FIS Report Technical Reference (FEMA, latest version). However, some manual adjustments may be required to adjust the HEC-RAS results to better represent the WSEL. These adjustments (such as impacts from drawdowns and backwater) should be incorporated into the final deliverable, as needed, and the deliverable is typically submitted as a computer-aided design (CAD) file. The delivered CAD files must be compatible with AutoCAD 2014 or later and include the .dwg file, and pertinent associated files such as external references, data shortcuts, and so forth.

Flood profiles should be developed for the storm events specified in the scope of work. The profiles depict the flood elevation at each cross section. The digital profiles should be one continuous profile. Flood profiles should be oriented with stationing increasing from left to right.

Units

Units for all distances and elevations should be in feet.

Grid and Scale

The flood profile layouts are to be created to minimize the number of sheets. The printed map size is not to exceed 36 inches by 120 inches, but should be no smaller than 11 inches by 17 inches. If multiple sheets are necessary because the maximum map size would be exceeded, clearly indicate match lines between the multiple sheets to indicate breaks, and provide a key map on each sheet.

The digital profiles shall be plotted on a grid. Note that flood profiles must be oriented with the downstream end on the left side of the sheet regardless of the Flood Hazard Figure orientation.

The horizontal scale of the profile should match the horizontal scale of the Flood Hazard Figure. Vertical grid lines should be spaced every 0.5 inch on the printed flood profile. Label the major vertical grid lines with the stations that correspond to the stations along the stream centerline in the Flood Hazard Figure.

The minimum vertical scale is 1"= 10'. Major horizontal grid lines should be spaced every 0.5 inch on the printed flood profile with minor horizontal grid lines representing every 1 foot of vertical elevation. Label the horizontal grid lines with elevations at 10' intervals. Elevation labels should be repeated at least every 10 inches on the printed flood profile. For exceptionally steep drainageways, consult with MHFD on reducing the vertical scale.

Profile Lines

Flood profiles are to include lines for the thalweg (typically stream bed, or profile baseline) and WSELs for the storm events specified in the scope of work. Different line types should be used to differentiate the profiles. Flood profiles should be checked to ensure that the flood profile lines do not intersect or cross each other. Drawdowns are typically manually eliminated from the flood profiles. FEMA provides guidance on these issues in Section 3.2 of *Guidance for Flood Risk Analysis and Mapping – Flood Profiles* (FEMA, latest version).

Cross Sections

Each cross section should be represented by a symbol (consistent with the symbol on the Flood Hazard Figure) and the cross section number at the station that matches the cross section location on the stream centerline alignment. Cross section symbols should be a consistent distance from the flood profile lines to facilitate capturing pertinent data when printing a select area of the profiles.

Structures

Bridges, culverts, and other hydraulic structures should be illustrated on the profile to depict the open area and length of the structure along the profile. For bridges, the top of road (TOR) and low chord (LC) are to be represented by the conventional symbol (I), where TOR is represented by the upper horizontal bar, LC by the lower bar, and the center of the structure by the vertical bar. For culverts, use the culvert linework typically output by HEC-RAS.

Feature Appearance and Layer Conventions

Flood Profile features should be formatted in accordance with **Table 2-1**. Line styles (patterns, dashes, and so forth) should be applied to the feature objects, and not drawn in. Annotation and leader lines must be on separate layers from geographic data.

Labels

Label the flood elevation lines and the stream alignment line on the profile. Label jurisdictional boundaries, tributary and receiving stream confluences, and structures with the street name or other identifier with vertical text near the appropriate station. Vertical labels are typically placed above the flood profile, but may be placed below the stream alignment if the allowable paper space requires it. Label the peak discharges (10-year and 100-year minimum) at appropriate locations along the profile. Also label the study limits.

Table 2-1. Flood Profile Feature Appearance and Layer Conventions (AutoCAD/RASPLOT)

Feature	Layer Name	Appearance	Other
0.2% Annual Chance Flood	500-PROFILE	Green, solid line	Label
1% Annual Chance Flood	100-PROFILE	Red, long dash - short dash - short dash line	Label
2% Annual Chance Flood	50-PROFILE	Blue, long dash - short dash line	Label
10% Annual Chance Flood	10-PROFILE	Magenta, short-dashed line	Label
Stream Bed	PROF_BASLN	Red, solid line with two stream bed symbols	Label
Cross Section Text	XSTXT	White	
Cross Section Symbol	XS-HEX	White, closed polygon	
Structures	STRUCTURES	Bridges: Conventional I-symbol with upper bar TOR, and lower bar LC, and vertical bar center of structure; Culverts: gray-shaded polygon	
Grid Lines	GRID	White line	
Text (Stationing, elevations, hydraulic structures; pertinent peak discharges)	TXT-PROFILE	White	
Limit of Study	STUDYLIMIT	White, thick solid line	

Additional Flood Profile Components

Flood profiles should include the following information:

- FHAD study name (consistent with the Flood Hazard Figure drawing's title, typically, "Flood Hazard Area Delineation, <u>Name of Drainageway</u>")
- Date of FHAD (month and year)
- Horizontal and vertical scale (**Section 2.4.2**), and vertical datum
- Legend including symbology for flood profile lines and cross section symbols
- Consultant's information
- Match lines and key map if more than one flood profile is produced

2.4.3 Final Data Deliverables

While GIS files exported from HEC-RAS are appropriate during review, the finalized deliverables will require more detail and effort. The following guidelines provide the requirements for these deliverables. **Because MHFD conducts many FHAD studies completed by different consultants, it is important that final deliverables are prepared in a consistent format so that the data can all be used collectively. Naming conventions, attributes, and attributes types should all be followed exactly.**

The final data deliverables for the Step 5 submittal will include specific attributes, attributes types, and styles that can change with time. The layer package specifying symbology and empty geodatabase specifying the schema to be used for final data deliverables can be downloaded from the floodplain management page of MHFD's website (https://mhfd.org/services/floodplain-management/). As deliverables change, these tools should be updated to produce accurate, consistent deliverables. Please confirm that the version available to use is the most recent. **This information should be specified with and included in each MHFD Vendor Agreement, after discussion with District staff to verify the appropriate form of data deliverables is being provided.** The typical data deliverables included with each FHAD are listed below:

- Stream Centerline and Stationing
- Cross Sections
- Insurable Structures
- Hydraulic Structures
- Flood Hazard Delineations (floodplains, floodway, and shallow flooding)
- BFEs (optional)

2.5 Step 5 – Final Submittal

Figure 2-7. Step 5 - Final Submittal

The most important piece of the Final Submittal is ensuring that all FHAD information as approved in Step 4 has been organized in the final folder structure. The finalized FHAD Report will be provided in the format specified in the FHAD Report Checklist. The final deliverables will be provided in the format and structure specified in the FHAD Deliverables Checklist.

The following items are required for Step 5 submittal:

- Electronic submittal of all items documented on the checklists in the Vendor Agreement

3.0 QA/QC and Error-Checking

QC and QA are important processes and are expected to be completed by the consultant prior to each submittal to MHFD. One of the most important steps of review by MHFD will be to confirm that the results provided match across models and deliverables. If a submittal appears to contain many errors and it is suspected that QA/QC has not been completed, MHFD may return the submittal to be checked and updated before an official review takes place.

3.1 Quality Assurance

QA is the portion of the review process completed by the consultant prior to each submittal to MHFD. The goal of this process is to provide confidence in the accuracy and validity of the content provided. Depending on how far along the FHAD development may be, there are several items to check for prior to making a submittal to MHFD. Several of these items are listed in **Table 3-1**. Please ensure that QA has been performed **by a registered Professional Engineer** before submitting products to MHFD for review.

Table 3-1. FHAD Quality Assurance Items

All data and hydraulic models provided shall be spatially referenced.
The stream centerline delineation follows the thalweg, unless otherwise approved by MHFD for special circumstances.
Cross sections are oriented perpendicular to the flow and stream centerline (or profile baseline).
Cross section orientation is left to right facing downstream; bank stations are below the 100-year WSEL.
Floodplain delineation is based on subcritical hydraulic analysis results.
Existing online detention facilities that were accounted for in the hydrologic analysis are to remain unencroached to the flood pool elevations.
Clearly identify both the upstream and downstream study limits on the topographic work map.
Verify for a given cross section that the WSEL is the same on both sides of the plotted floodplain.
Verify that the cross section identifications and locations used in the hydraulic model are consistent with those shown on the topographic work map and water surface profile.
Make sure that an existing regional detention facility has been accounted for in the hydraulic model to produce consistent results for all storm events modeled (that is, actual geometry for outlet structure, rating curve, boundary condition, known WSEL, and so forth). Verify that the existing detention facility is reflected in the resulting water surface profile from the hydraulic model results.
Verify whether overtopping occurs at roadways or railroad crossings along the drainageway, and make sure the water surface profile and topographic work map clearly indicate if overtopping occurs.
Make sure that floodplain delineations downstream of overtopped crossings are representative of the hydraulic conditions (especially since the hydraulic model will not reflect the impacts of overtopping at downstream cross sections).
Make sure that the EGLs and/or WSELs between any two split flow segments are within 0.5 foot at the upstream end (breakout point).
Shallow flooding areas shall be included within the 100-year floodplain delineation.

Table 3-1. FHAD Quality Assurance Items

No future detention facilities are to be shown on the topographic work maps for the FHAD. These proposed facilities are to be shown in the related master planning documents for the drainageway.
Make sure that relative top widths make sense (that is, the floodway top widths are not greater than the floodplain top width at a given location).
Use consistent significant digits for the values in the FP/FWDT and Agreement Table.
Note differences in floodplain or floodway top widths between the hydraulic model results and the topographic work map delineations in the FP/FWDT.
Verify floodway results have WSEL and EGL surcharges that meet criteria.
Even though the 500-year floodplain is not the official regulatory floodplain, the delineations for this floodplain need to be mapped to a reasonable accuracy (that is, the 500-year delineation on the topographic work map needs to reflect the hydraulic model results).
Eliminate crossing water surface profiles between the multiple storm events used along a given drainageway (or provide a logical explanation of why it was or was not changed).
Review the RASPLOT output for each profile, especially near long crossings. RASPLOT may show a horizontal profile drawn level from the upstream WSEL. Review and determine if the plotted profile should be adjusted to better represent the drawdown on the downstream side of these structures.

3.2 Quality Control

The following QC tools and guidance are provided to support the QA process.

3.2.1 Checklists

The FHAD Report Checklist identifies the information that is required for FHAD studies. A copy of the FHAD Report Checklist should accompany the Final Review and the Final Submittal.

The completed FHAD Deliverables Checklist shall be included with the Final Review and the Final Submittal. The FHAD Submittal Form shall be included with all submittals to document what needs to be submitted and what has been approved.

3.2.2 cHECk-RAS

cHECk-RAS is a program developed by FEMA to verify the validity of an assortment of parameters found in the HEC-RAS hydraulic modeling program. The cHECk-RAS tool and information regarding its use can be found at https://www.fema.gov/flood-maps/tutorials/check-ras.

3.2.3 FHAD Tools

The FHAD Tools are a set of GIS tools created specifically for MHFD FHAD reviews. These tools provide a quick visual representation of some HEC-RAS inputs and outputs. Some of these tools may aid the consultant in QA/QC prior to submittals. A summary of the current version of each tool is provided in **Table 3-2**. The FHAD Tools can be downloaded from MHFD's website (https://mhfd.org/services/floodplain-management/), including a file that provides guidance and steps for correctly executing the tools.

Table 3-2. FHAD Tools Overview

FHAD Tool	Purpose
All Geo Reviews	Reads ineffective flow area, obstruction, and n-value inputs from HEC-RAS geometry (.g##) and overlays visual representations on cross sections (.shp)
BFE Tool	Reads WSEL and cumulative downstream reach length HEC-RAS outputs (.csv) and places traditional (1-foot interval) BFEs along channel alignment (.shp)
Plot RAS Cross Section Extents	Reads left and right extents HEC-RAS outputs (.csv) and displays two-point representations of extents (.shp) at each cross section. Can be used for WSEL for any event, bank stations, effective flow, or values with left and right extents.
Top Width Check	Delineation check that clips cross sections (.shp) to extents of flood hazards (.shp). Additional calculation in attribute table provides map values for flood hazard top widths. Used to verify values in FP/FWDT and Agreement Table.
XS Location Test	Downstream reach length check that reads reach length HEC-RAS outputs (.csv) and places a test line (.shp) to represent each cross section along the channel alignment (.shp). This result can be overlaid with the cross sections (.shp) to verify HEC-RAS downstream reach lengths and map representation of cross sections agree.

3.2.4 Floodplain and Floodway Data Table

The FP/FWDT lists information at each cross section for the floodplains and floodways studied. Floodway data are required even when the model flows are confined within a well-defined channel. Floodway data values reported in the table will be taken from the floodway hydraulic model. A notation in the Comments Column of the FP/FWDT should be added whenever the floodway is equal to the floodplain. **Table 3-3** shows the required and optional information that should be included in the table.

Table 3-3. Floodplain and Floodway Data Table Contents

Item	Location	Content to Add
Study Name	Top Center	Table #, FHAD Study Name
Reach	Row Heading	River/Reach (Repeat at each River/Reach break)
Reference Location	Column 1	Location or other identifier (street, structure, confluence, and so forth)
River Station	Column 2	Station along stream alignment
Cross Section	Column 3	Cross section ID from hydraulic model
Thalweg Elevation (ft)	Column 4	Profile baseline stream bed elevation
Peak Flow (cfs) (storm events from Vendor Agreement)	Columns 5-9	Peak Flow data from hydraulic model for 10-, 25-, 50-, 100-, and 500-year storm events, or as otherwise specified by Vendor Agreement
WSEL (ft) (storm events from Vendor Agreement)	Columns 10-14	Flood WSEL from hydraulic model for 10-, 25-, 50-, 100-, and 500-year storm events, or as otherwise specified by Vendor Agreement
100-Year Floodplain Width (ft) and EGL (ft)	Columns 15-16	Total floodplain width as defined below, and the EGL for the 100-year storm event

Table 3-3. Floodplain and Floodway Data Table Contents

100-Year Floodway: Floodway WSEL (ft) EGL (ft) Width (ft) Area (sq ft) Velocity (fps)	Columns 17-21	100-year, 0.5-foot floodway WSEL, total top width of mapped floodway including high ground and ineffective flow area, flow area of the entire cross section including ineffective flow area (Area), and the average velocity of flow in the total cross section (Vel Total)
Δ HGL and EGL (≤ 0.5' HGL/EGL and no negative surcharge)	Columns 22-23	Change in HGL and EGL. Difference between the floodway WSEL and 100-year floodplain WSEL, and between the floodway EGL and the 100-year EGL. Use the Prof Delta WS and Prof Delta EG from HEC-RAS Output Table.
Note	Column 24	Use to note specific details or how the values may differ from the hydraulic model and reason for the difference (see **Table 3-5**)
Comments	Column 25	For unique or special characteristics or conditions, or other supplemental information to the typical conditions specified in Column 24
Footnotes	Below table	Additional notes or a way to note specific details for particular cross sections (see **Table 3-5**)

ft = feet
fps = feet per second
sq ft = square feet

Beginning with Step 2, each submittal is to be accompanied by a completed FP/FWDT.

Please limit values within the FP/FWDT to reasonable significant digits. Provide discharges to the nearest whole cubic foot per second (cfs), top widths to the nearest whole foot, areas to the nearest whole square foot, velocities to the nearest tenth of a foot per second, and elevations to the nearest hundredth of a foot from HEC-RAS output given to the thousandth of a foot. For example, if the HEC-RAS WSEL is 5200.145, the BFE shown in the Agreement Table should be 5200.15. Surcharges should maintain the same number of significant digits as elevations – to the nearest hundredth of a foot.

This information should be included as Appendix D of the FHAD Report. An example of the required significant digits is provided in **Table 3-4**.

Table 3-4. Required Significant Digits

Flow (CFS)	WSEL (Feet)	EGL (Feet)	Width (Feet)	Area (Sq Feet)	Velocity (FPS)	HGL Surcharge (Feet)	EGL Surcharge (Feet)
(8)	(13)	(18)	(19)	(20)	(21)	(22)	(23)
100	5100.10	5000.50	1000	50	5.5	0.00	0.00

Additional Data Descriptions and Information

Thalweg Elevation (ft) - Defined as the minimum channel elevation. In HEC-RAS, "Min Ch El" is the minimum channel elevation.

Peak Discharge (cfs) - Defined as the peak flood flow (as specified in the MHFD Vendor Agreement) for the given storm event. In HEC-RAS, "Q Total" is the total flow in the cross section.

WSEL (ft) - Defined as the flood WSEL for the given storm event. In HEC-RAS, "W.S. Elev" is the calculated water surface from the subcritical flow regime for steady flow computations.

100-Year Floodplain Width (ft) - Defined as the total width of the floodplain as shown on the Flood Hazard Figure, regardless of islands (whether mapped or not) and other obstructions. When this value is different from results in the hydraulic model, note it in the Comments Column of the FP/FWDT and state why. The total top width can be calculated by using HEC-RAS's "Sta W.S. Lft" and "Sta W.S. Rgt" output values. Since the floodplain and floodway values in the MHFD FHAD typically reflect the total width of the floodplain/floodway regardless of ineffective flow, islands, and other obstructions, a note should be added to the Comments Column of the FP/FWDT to indicate what is included. These notations will be helpful in explaining discrepancies in future FIS updates, since the Floodway Data Table in the FIS reports active top width instead. See the top width examples in **Appendix A**.

An exception to this rule would be for areas where existing on-site detention facilities are located adjacent to the main channel. For these areas, the floodplain top width shown in the FP/FWDT adjacent to the detention facilities needs to reflect the top width for actual conveyance without the ineffective flow area (this would typically be the "Top Width Act" HEC-RAS output).

Note that for FHAD studies, islands are not typically mapped (shown as high ground) in the floodway. Also note that islands within a floodplain or floodway must be treated on a case-by-case basis and the consultant should coordinate with MHFD when islands occur within the floodplain or floodway limits for further guidance.

EGL Elevation (ft) - Defined as the EGL for a given storm event. In HEC-RAS, "E.G. Elev" is the calculated water surface from the subcritical flow regime for steady flow computations.

Floodway Elevation (ft) - Defined as the floodway WSEL with encroachments that cause either the HGL or EGL to rise up to 0.5 foot.

Floodway Width (ft) - Defined as the total floodway width (regardless of islands and other obstructions, or ineffective flow area) with encroachments that cause either the HGL or EGL to rise to an allowable maximum of up to 0.5 foot. Refer to the definition of 100-Year Floodplain Width for additional information on reporting and mapping widths.

Floodway Area (sq ft) - Defined as the flow area of the entire cross section including ineffective flow. In HEC-RAS, this is the "Area" variable. When different from results in the hydraulic model, note it in the Comments Column of the FP/FWDT and state why. For cross sections with adjacent detention facilities, this value may end up being the "Area Channel" or "Flow Area" value.

Floodway Velocity (feet per second [fps]) - Defined as the average velocity of the flow in the total cross section. In HEC-RAS, this is the "Vel Total" variable. For cross sections with adjacent detention facilities, this value may end up being the "Vel Chnl" value.

Discrepancies between Table Values and HEC-RAS Model

The values published in the FP/FWDT must match the Flood Hazard Figure (within acceptable tolerances), but there may be situations where flood hazards do not match the top width of the HEC-RAS output. For instance, a rapid change in geometry, such as the downstream side of an overtopped roadway, may result in the floodplain delineation differing from the HEC-RAS output. Or a floodplain delineation line around a small island may be omitted to simplify the floodplain limits. In these situations, it is imperative that the discrepancy be well-documented. Record the reason for the discrepancy in the Comments Column of the FP/FWDT and further describe it in the text of the FHAD Report.

Table 3-5 lists several examples of standard comments used to describe or explain discrepancies between the hydraulic model, water surface profile, and topographic work map values that can be used in the FP/FWDT (**Section 3.2.4**) and Agreement Table (**Section 3.2.5**). In addition, other comments may be more appropriate to describe the situation occurring at a given cross section.

Table 3-5. Example Comments for the FP/FWDT and Agreement Table

Floodway Equal to Floodplain
Floodplain top width includes high ground or obstruction, and ineffective flow area.
Floodway top width includes high ground or obstruction, and ineffective flow area.
Floodway top width includes high ground or obstruction.
Floodplain top width includes ineffective flow area.
Floodway top width includes ineffective flow area.
Adjacent on-site detention pond.
Island located within 100-year floodplain not shown because it falls within the floodway.
Roadway overtopping of "Street Name," top width adjusted for Flood Hazard Figure delineations.
Floodplain delineation includes ineffective flow area not reflected in the hydraulic model.
Top width includes flow from upstream cross section in the left overbank (LOB), right overbank (ROB), or both.
WSEL is influenced by backwater effects.

3.2.5 Agreement Table

The Agreement Table serves as a QC and error-checking tool to ensure that data and results for the Flood Hazard Figure, flood profiles, FP/FWDT, and HEC-RAS models agree. **Note that the allowable tolerance for floodplain and floodway widths is within either 5 percent of the map scale or 25 feet for a 1":500' FIRM.** If discrepancies exist, the reasons for any valid discrepancies can be noted in the Comments Column of the FP/FWDT. **Table 3-6** lists the required and optional information that should be included in the table. Beginning with Step 3, each submittal is to be accompanied by a completed Agreement Table. The Agreement Table will not be included in the study, but will be included in the Final FHAD deliverables to accompany the final hydraulic model files.

The Agreement Table lists every cross section and compares the distances between cross sections, the cumulative distance, floodplain and floodway top widths, WSELs, and an indication of whether the BFE lines have been located correctly relative to the adjacent cross sections and water surface profile (this is typically an "ok" or "yes" once verified by the consultant). The allowable differences between the map, profile, and table are listed at the bottom of the Agreement Table, and check columns are provided to give a visual indication of values that do not meet tolerances.

Please limit values within the Agreement Table to reasonable significant digits. Provide distances and top widths to the nearest foot. BFEs should be rounded to the tenth of a foot from HEC-RAS output given to the thousandth of a foot. For example, if the HEC-RAS WSEL is 5200.145, the BFE shown in the Agreement Table should be 5200.1.

Table 3-6. Agreement Table Contents

Colum n	Contents
1	Reference Location–Specify the River/Reach and, if needed, a location or other identifier like streets, structures, or other physical features.
2	Cross Section–The cross section number/identifier used in the hydraulic model (that can sometimes differ from the actual river station). If the cross section identification is consistent with the actual river station along the stream alignment then this could also be used to reference previous FHAD cross section identifications or FIS cross sections. Start at the downstream cross section and work upstream.
3	River Station–Actual station along the stream alignment corresponding to the cross section.
4 - 6	Distance between XS (ft)–Relative distance from cross section to the next downstream cross section in feet. Column 6 checks to see if model and map values are within 5%.
7 - 9	Cumulative Distance (ft)–Relative distance from cross section to origin of the profile baseline in feet. Column 9 checks to see if model and map values are within 5%.
10 - 13	Floodplain Width (ft)–The total floodplain top width at the cross section including high ground and/or ineffective flow areas in feet; however when an on-site detention facility exists adjacent to the main channel, this value will only reflect the top width for active conveyance without the ineffective flow area (this would typically be the Top Width Act value in HEC-RAS). Column 13 checks to see if model and map values are within 25 feet, and Column 15 checks to see if they are within 5%.
14 - 17	Floodway Width (ft)–The total floodway top width at the cross section in feet. This can include high ground and ineffective flow areas. Column 16 checks to see if model and map values are within 25 feet and Column 17 checks to see if they are within 5%.
18 - 20	BFE (ft)–The 100-year water surface elevation for the cross section to the nearest tenth of a foot. Column 20 checks to see if model and profile values are within 0.5 foot.
21	BFE Loc–This is a verification that the BFE line plotted on the topographic work map is located correctly based on the corresponding water surface profile near the cross section.
22	Comments and/or Explanations–A description and/or reasoning for any discrepancies between values from the model/map/profile that occur at the cross section (see **Table 3-5** for Example Comments for the Floodplain and Floodway Data Table).

3.2.6 Common Mistake Examples

To expedite the submittal and review process, MHFD has compiled a list of common mistakes that have been identified during FHAD reviews. This information may assist consultants in their QA/QC process, and it is recommended that a FHAD study is checked against this list prior to submittal. This document can be found on MHFD's website (https://mhfd.org/services/floodplain-management/).

4.0 FHAD Report and Flood Hazard Figure

The FHAD Report has two basic components. The first component is the three-part text discussion of the study process that provides the reader with background information, discusses the hydrology (typically existing infrastructure and future land use conditions), and explains the hydraulic analysis used in the study. While one overall study is provided for the FHAD, the three sections are maintained separately, since they may be updated individually, outside of the FHAD process. The second part of the FHAD Report consists of the technical appendices provided within the FHAD Deliverables folder structure.

The engineering information in the FHAD Report should be presented in an organized fashion for use in development of MDP updates, road and bridge planning and design, design of channel modifications, and design of flood control structures.

The following is a brief outline of the FHAD Report and Appendices:

Section 1 Supporting Information and Background Data

Section 2 Hydrologic Analysis

Section 3 Hydraulic Analysis

FHAD Report Section 1 (Supporting Information and Background Data) Technical Appendix

FHAD Report Section 2 (Hydrologic Analysis) Technical Appendix

FHAD Report Section 3 (Hydraulic Analysis) Technical Appendix

Detailed descriptions of what is to be provided in each of these components, in addition to required figures and tables, are addressed later in this section, as well as in the MHFD Vendor Agreement and FHAD Report Checklist.

All deliverables will be provided in the specified folder structure for the Final Submittal (Step 5), and will include all final hydrologic and hydraulic models and supporting calculations used for the FHAD. Please refer to the FHAD Deliverables Checklist.

The following sections provide additional direction for specific portions of the FHAD Report.

4.1 FHAD Report Section 1: Supporting Information and Background Data

The first portion of the FHAD Report provides high-level information in regard to the study area. This portion of the study should be completed with each FHAD study. This document is meant to be concise with a majority of the information collected in a group of tables. It is expected that this section of the study would be completed with the first submittal for Step 1. The required information for this section is provided in the FHAD Report Checklist.

4.2 FHAD Report Section 2: Hydrologic Analysis

The second portion of the FHAD Report provides information pertinent to the hydrologic analysis. This portion of the study should only be completed when hydrology for the study area is being updated. If an existing hydrologic study is being used or the hydrology is being updated through another means (that is, a concurrent MDP), this section should not be completed. Instead, that information will be referenced in the Hydraulic Analysis portion of the overall FHAD Report. It is expected that this section of the study would be completed with the review of hydrologic models and updated as needed. The required information for this section is provided in the FHAD Report Checklist.

4.3 FHAD Report Section 3: Hydraulic Analysis

The third portion of the FHAD Report provides information pertinent to the hydraulic analysis. This portion should be completed with each FHAD Report. This section provides the majority of information associated with the FHAD and should include all key engineering decisions made for the hydraulic and floodway models. It is expected that this section would be completed alongside those models and updated in parallel to the FHAD review steps discussed in the previous sections. The required information for this section is provided in the FHAD Report Checklist.

4.4 Flood Hazard Figure

Digital topographic work should be provided in GIS format, unless MHFD authorizes a different format in advance of the submittal. If the Flood Hazard Figure files are created with CAD, they must be converted to GIS data and delivered in MHFD’s geodatabase format (example provided by MHFD) with the Final Submittal.

4.4.1 Map Projection

A major aspect of transportability of mapping or survey files to a GIS is horizontal and vertical positioning on the earth. Mapping data must be controlled to a grid or geographic projection and referenced to horizontal and vertical datums. These positional references are established prior to the surveying process. Survey control is expressed in the form of horizontal and vertical position plotted on a geographic projection or control grid (State Plane). All planimetric and topographic features must be collected/compiled and referenced to this survey control.

Data deliverables shall be delivered in Colorado State Plane Central, with the most recent version of the North American Datum of 1983 (NAD83) horizontal datum in US feet, and North American Vertical Datum of 1988 (NAVD88) vertical datum. The mapping source and projections shall be documented in the FHAD Report.

4.4.2 Base Mapping and Topography

MHFD will provide a base map package at the beginning of each study, based on the expected extents of the study. The package will include all information discussed below, if available. **At the beginning of each study, the consultant should discuss these items, their extents, and the preferred GIS software version in which the information should be provided.** If additional area or data are desired, please discuss with MHFD staff. If modifications are required for the base map DEM and/or contours, incorporating this updated survey information should follow guidance from MHFD staff. If the consultant would like to include additional information as base map data, this can be discussed and included, as well. Any additional topographic information must be certified by a registered professional engineer or a licensed land surveyor, represent the bare earth terrain, and represent the best available data.

Base mapping should show all current features, streets, railroads, airfields, and so forth. All streets and roads within or near the floodplain shall be shown and labeled. There must be adequate planimetrics to distinguish major features and impacts related to the flood hazard information. The information shown in **Table 4-1** is in addition to the submittal data defined previously.

Some information, such as major confluences, streams adjacent to but not included in the study, or other pertinent features located in or directly adjacent to the flood hazard area, should be labeled on work maps by the consultant. This information does not necessarily need to be associated with any spatial data deliverable if it can be seen clearly from the aerial imagery.

Table 4-1. Base Mapping

Data	Source[3]
Existing Ground Contours (Differentiating major and minor contours) [1]	DRCOG Light Detection and Ranging (LiDAR)
Three-Dimensional Surface Data (DEM)	DRCOG LiDAR
Aerial Imagery	Nearmap Imagery
Jurisdictional Boundaries	DRCOG Municipalities
Effective Flood Hazard Delineations for Receiving Streams and Tributaries	FEMA National Flood Hazard Layer
Planimetrics (i.e. Building Footprints)	DRCOG Regional Planimetric Data
Hydrologic Features (i.e. Facilities, Canals, Flood Control Structures) [2]	National Hydrography Dataset
Streets, Roadways, and Other Transportation Features [2]	ESRI Transportation Service

[1] Major Contours will be a minimum of 10-foot intervals.
[2] Data layers will be provided, if available. If not available, consultant should label major features.
[3] Data provided will be the most up-to-date version available.

4.4.3 Units

Units for all distances and elevations are in feet.

4.4.4 Map Scale and Size

The Flood Hazard Figure and flood profiles must be at the same horizontal scale. The minimum printed scale of the Flood Hazard Figure is 1" = 200'. This is the scale used for MHFD review. The horizontal scale should be illustrated by a bar scale and text stating the print scale (for example, 1" = 200'). The orientation of the printed Flood Hazard Figure should be horizontal. The north arrow on the Flood Hazard Figure should always point to the left, top, or right of the sheet and never toward the bottom or bottom corners.

Note that flood profiles must be oriented with the downstream end on the left side of the sheet regardless of the Flood Hazard Figure orientation. **Section 2.4.2** provides more information on flood profiles.

Layouts for the Flood Hazard Figure and flood profiles should be created so that sheet counts are minimized. Printed maps should not exceed 36 inches by 120 inches and be no smaller than 11 inches by 17 inches. If multiple sheets are necessary because the maximum map size would be exceeded, clearly indicate match lines between the multiple sheets to indicate breaks and provide a key map on each sheet.

4.4.5 Feature Appearance and Layer Conventions

In the printed Flood Hazard Figure, features shall be formatted in accordance with **Table 4-2**. As mentioned in **Section 2.4.3**, the layer package for the flood hazard symbology can be downloaded from the floodplain management page of MHFD's website (https://mhfd.org/services/floodplain-management/). Confirm that the version available to use is the most recent. This layer package can be used to automatically generate the symbology. Instructions on using the geodatabase and layer package are included at the MHFD link above. Priority should be given to producing a readable hard copy in grayscale. Appropriate line symbology and line weights should be used.

Table 4-2. Flood Hazard Layer Symbology*

Feature	Feature Type	Layer Name	Appearance (RGB Values)	
Cross Sections	Line	Cross_Section	Black, solid line	
BFE (if applicable)	Line	BFE	Red (255, 0, 0), solid line	
Stream Centerline	Line	Stream_Centerline	Blue (0, 77, 168), solid line	
Centerline Stationing	Line	Stationing		
Insurable Structures	Polygon	Insurable_Structure	Red outline, 45-degree hatch fill	
Culverts, Bridges, Other Structures	Polyline	Hydro_Struct	Black, solid line	
Areas Revised by Previous LOMRs; Limits Should Match LOMR Reference	Polygon	LOMR	Black outline, 45-degree hatch fill	
Major Contours	Line	Contours	Brown (164, 121, 22), 1.2 point	
Minor Contours	Line	Contours	Brown (221, 168, 64) 0.40 point	

* See **Section 4.4.2** for base map requirements.

4.4.6 Additional Flood Hazard Figure Components

The Flood Hazard Figure should include the following information:

- FHAD study name (consistent with the flood profile drawing's title; typically, "Flood Hazard Area Delineation, [Name of Drainageway]")
- Date of FHAD (month and year)
- North arrow and scale (**Section 4.4.4**)
- Legend including symbology for cross sections, floodplain and floodway boundaries, BFEs, stream centerline, hydraulic structure symbols, and contours
- Information about mapping source including the date, horizontal datum, and vertical datum
- Consultant's information
- Match lines and key map if more than one Flood Hazard Figure is produced

5.0 References

CH2M HILL (CH2M). 2006. *Specification for Electronic Submittal of FHAD and Master Plan Documents in PDF Format*. (2nd ed.). August.

*Federal Emergency Management Agency (FEMA). Latest Version. Flood Insurance Study (FIS) Report Technical Reference – Preparing FIS Reports.

*Federal Emergency Management Agency (FEMA). Latest Version. *Guidance for FEMA's Risk Mapping, Assessment and Planning, Guidance: Floodplain Boundary Standards (FBS)*. November. Available at https://www.fema.gov/media-collection/guidance-femas-risk-mapping-assessment-and-planning

*Federal Emergency Management Agency (FEMA). Latest Version. *Guidance for FEMA's Risk Mapping, Assessment and Planning, Guidance: Mapping Base Flood Elevations on Flood Insurance Rate Maps*. December. Available at https://www.fema.gov/media-collection/guidance-femas-risk-mapping-assessment-and-planning

*Federal Emergency Management Agency (FEMA). Latest Version. *Guidance for FEMA's Risk Mapping, Assessment and Planning, Guidance: Profile Baseline*. December. Available at https://www.fema.gov/media-collection/guidance-femas-risk-mapping-assessment-and-planning

*Federal Emergency Management Agency (FEMA). Latest Version. *Guidance for FEMA's Risk Mapping, Assessment and Planning, Hydraulics: One-Dimensional Analysis*. November. Available at https://www.fema.gov/media-collection/guidance-femas-risk-mapping-assessment-and-planning

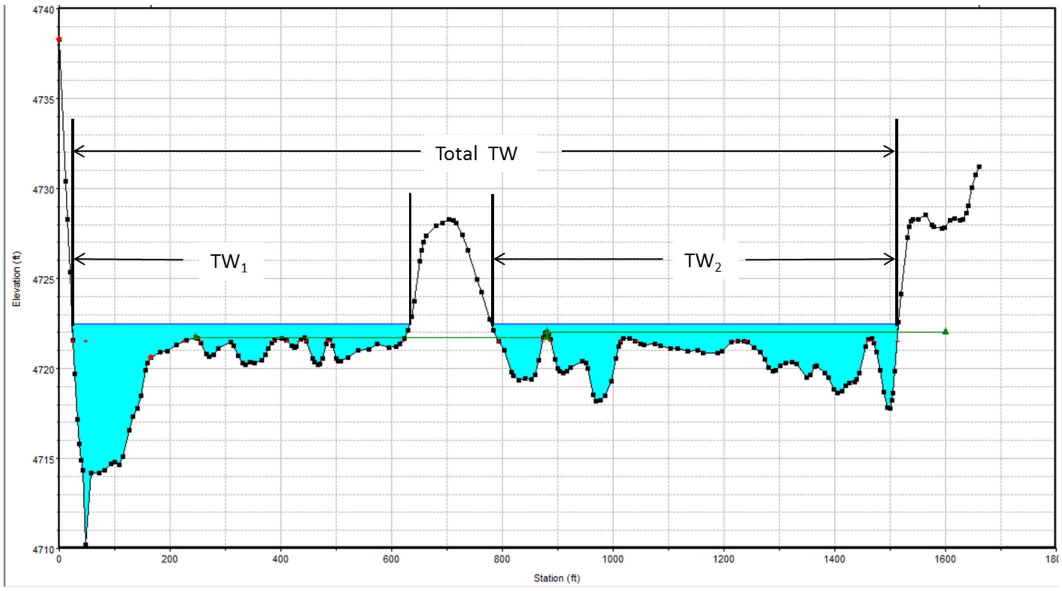
U.S. Environmental Protection Agency (EPA). Storm Water Management Model, Latest Version. https://www.epa.gov/water-research/storm-water-management-model-swmm.

*FEMA guidance documents are updated regularly. These references should always be reviewed to ensure the latest guidance document is being referenced.

Appendix A
Top Width Examples

Legend: Effective Flow Area: Ineffective Flow Area:

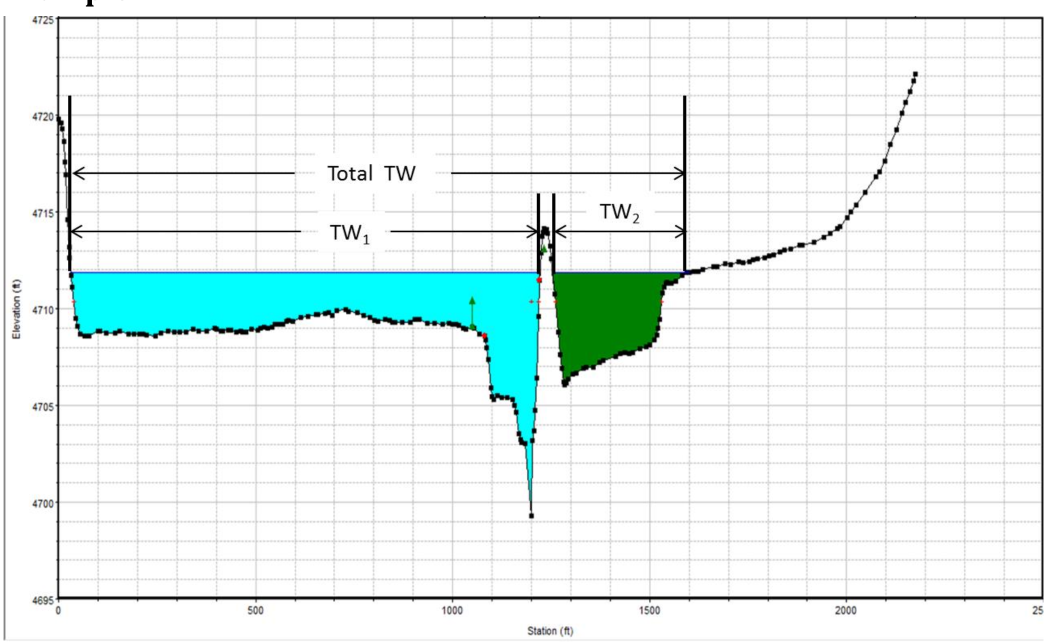
Example 1:



Total Top Width includes high ground (islands)

Actual Top Width = $TW_1 + TW_2$

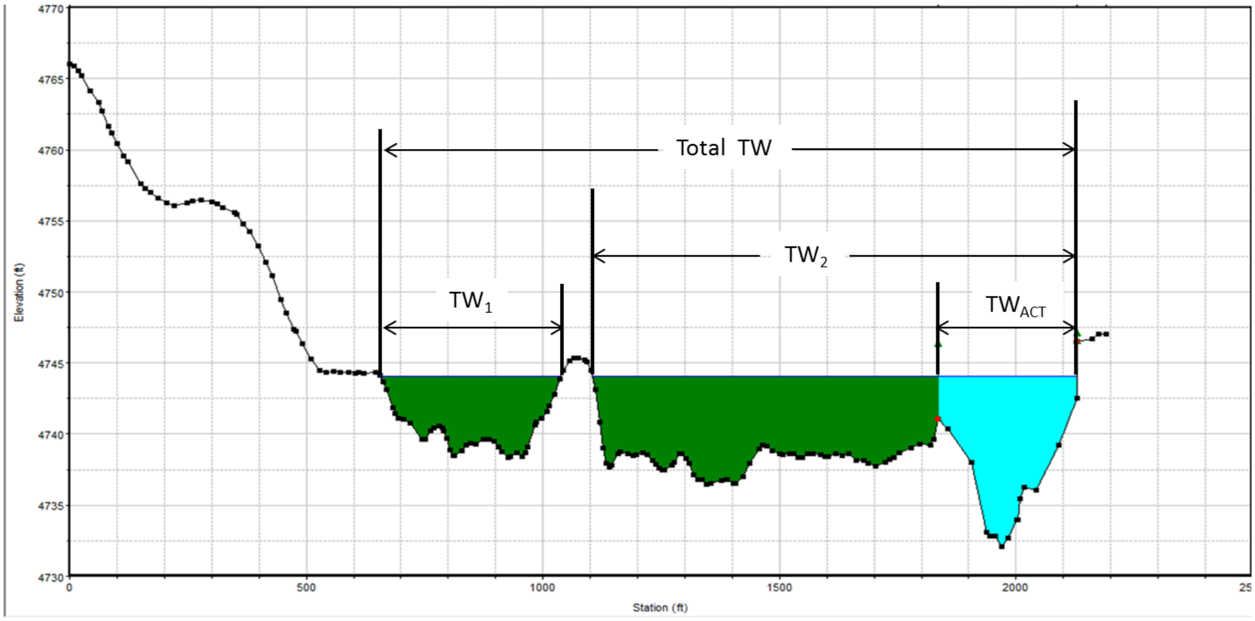
Example 2:



Total Top Width includes high ground and ineffective flow area (TW_2)

Actual Top Width = TW_1

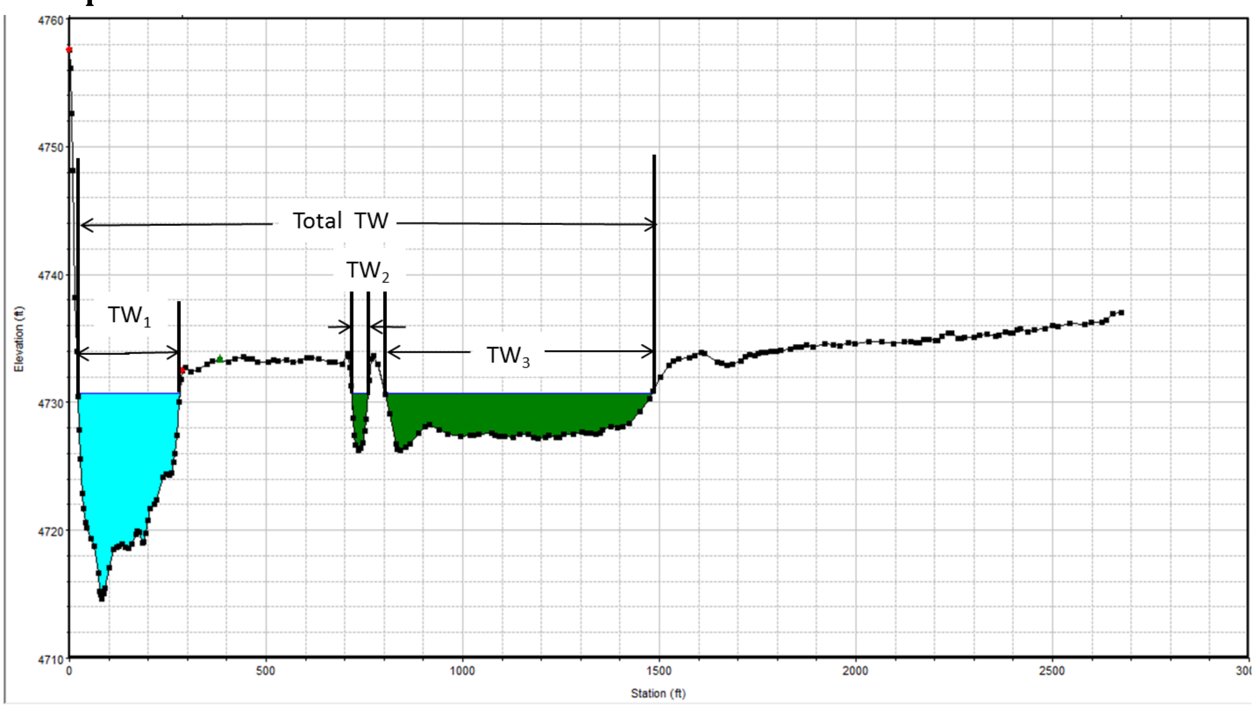
Example 3:



Total Top Width includes high ground and ineffective flow areas.

TW_1 could be an adjacent on-site detention pond. TW_2 includes the Actual Top Width and an ineffective flow area.

Example 4:



Total Top Width includes ineffective flow areas and high ground

Top Width = TW1 + TW2 + TW3