

Flood Hazard Area Delineation Guidelines

Common Mistakes



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Prepared by



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Abbreviations and Acronyms

AOI	Area of Interest
BFE	Base Flood Elevation
cfs	Cubic Feet per Second
CMP	Corrugated metal pipes
DEM	Digital Elevation Model
EGL	Energy Grade Line
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FHAD	Flood Hazard Area Delineation
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
ft	Feet
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HGL	Hydraulic Grade Line
IEFAs	Ineffective Flow Areas
MHFD	Mile High Flood District
NFIP	National Flood Insurance Program
NLD	National Levee Database
NLFS	Non-Levee Features
PMR	Physical Map Revision
QA	Quality Assurance
QC	Quality Control
SWMM	Storm Water Management Model (EPA)
WSE	Water Surface Elevation
XS	Cross Section
RS	River Station (same as XS)
1D, 2D, 3D	One-Dimensional, Two-Dimensional, Three-Dimensional

Preface

Consultants should use this FHAD Common Mistakes document as a supplement to their QA/QC process. It aims to support the preparation of FHAD studies by:

- Communicating the District’s preferences for delivering work that meets a high standard of quality,
- Reducing review comments,
- Improving overall consistency and efficiency through the submittal and review process.

Why is this document necessary, given the availability of existing resources such as the User’s Manual, Hydraulic Reference Manual, FHAD Guidelines, FHAD Checklists, FEMA Guidance and Standards, and numerous other references supporting hydraulic studies?

While those resources provide comprehensive technical guidance, the FHAD Common Mistakes document serves as a collection of recurring issues observed across multiple FHAD reviews. These issues span modeling, mapping, final deliverables, and documentation. The primary purpose of this document is to provide a practical reference highlighting problems that are frequently overlooked, misunderstood, incomplete, or inconsistent, and to reiterate the District’s standard for delivering high-quality flood hazard data.

Producing high-quality data requires a rigorous and logical sequence, with each step building upon the last.

1. Collection of high-quality base information – including terrain, land use, survey data, and as-builts.
2. Accurate and complete model inputs – incorporating key inputs with a thorough understanding of the hydraulic model’s capabilities, assumptions, and limitations.
3. Sound engineering judgment – applying consistent decision-making based on accurate model inputs and proper model configuration, including selection of appropriate modeling methods, parameters, and simulation settings.
4. Clear and organized documentation – ensuring all analyses and files are labeled and structured logically, with accompanying notes to explain their purpose.
5. Transparency, Traceability, and Reproducibility – ensuring all modeling activities are well-documented and defensible by:
 - Providing clear justifications for adjustments, sensitivity analyses, model limitations, and the application of engineering judgment.
 - Referencing data sources, modeling decisions, and version control throughout all deliverables.
 - Bridging the gap between input data, model results, and final outputs to support transparency and scientific credibility.
6. Consistency across products – ensuring that FHAD tables, profiles, cross sections, and maps are consistent with each other and reflect the approved model results.
7. Quality assurance and peer review – ensuring modeling steps, mapping deliverables, and interpretation of results are internally reviewed and align with standards and guidance.

For ease of reference, the contents of this document are structured to align with the HEC-RAS model, flood profiles, hazard mapping, and FHAD Tables deliverables. **This is a living document that may be updated at any time to include additional details or to reflect new issues and user feedback. Please check back periodically for updated versions.**

I. FLOW DATA

a. Steady Flow Data

1. Inconsistent Flow Data and Unclear Profile Naming

One of the foundational elements of a sound hydraulic model is well-documented and consistent steady flow data. A common issue arises when the inflow values used in the steady flow file differ from those presented in the hydrology report, or when their origin is unclear.

To avoid confusion and ensure consistency, inflow values in the steady flow file should match those presented in the hydrologic analysis. If any adjustments are made, a clear rationale should be documented in the model description or supporting report. In addition, profile names should be descriptive and aligned with the terminology used in the hydrology report and plan names. Generic labels such as “Profile 1” or “Flow A” should be avoided, as they make interpretation and review more difficult.

Profile names should clearly reflect the event (e.g., 1% annual chance) and conditions (e.g., floodway, plus/minus) and follow a consistent naming convention. This improves traceability, reduces reviewer confusion, and ensures the model can be confidently integrated into the FHAD or FEMA PMR process. Table 1 provides a recommended naming convention for steady flow profiles and plan files.

Table 1. Recommended naming convention for steady flow events in plan and flow files

Event	Plan	Flow File
10%	10PAC	10PAC
4%	4PAC	4PAC
2%	2PAC	2PAC
1%	1PAC	1PAC
0.2%	0.2PAC	0.2PAC
1% Plus	1PACPlus	1PACPlus
1% Minus	1PACMinus	1PACMinus
1% Floodway	1PACFW	1PACFW

This practice enhances traceability, reduces confusion during review, and ensures the model can be confidently integrated into the overall FHAD or FEMA study. While MHFD’s current FHAD Guidelines may not formally prescribe a naming convention, adopting a consistent system such as the template above supports alignment with FEMA PMR DCS workflows and improves long-term model clarity.

2. Improper or Unsupported Downstream Boundary Conditions

A well-defined downstream boundary condition is critical for producing accurate water surface profiles in hydraulic modeling. If not properly defined, they can introduce errors that affect water surface profiles and model stability. Several recurring issues have been identified in practice, including:

- Placing the downstream boundary too close to hydraulic control, such as immediately downstream of a bridge, culvert, sharp bend, or weir. These locations can cause instability or abrupt changes in the water surface due to rapidly varying flow.
- Locating the boundary near a tributary confluence or grade break, where changes in slope or incoming flow can introduce complex hydraulic behavior not adequately handled by simple boundary assumptions.
- Defining boundaries in areas influenced by downstream backwater, such as from reservoirs, lakes, or tidal conditions. These settings require accurate tailwater elevation data or stage-discharge relationships, not assumptions.
- Using assumed normal depth slopes that are not supported by field data, such as applying a generic slope (e.g., 0.001 ft/ft) or selecting a value inconsistent with surveyed thalweg elevations or adjacent cross sections.
- Applying rating curves without sufficient supporting data, including undocumented gage records or transferring rating curves from unrelated locations without justification. This often results in misrepresenting site-specific flow conditions.
- Failing to evaluate the influence of the boundary condition on model results, which may lead to unrealistic drawdowns, profile distortions that extend upstream, or water surface elevations (WSEs) that deviate from expected hydraulic grade behavior.

To ensure stable and defensible results, the following practices are recommended when defining and evaluating downstream boundary conditions:

- Place the downstream boundary sufficiently far from the Area of Interest (AOI) to reduce artificial effects. Choose a hydraulically stable and uniform reach not immediately impacted by controls or flow transitions.
- When using a normal depth boundary, derive the slope from site-specific data, such as the thalweg gradient from surveyed cross sections. Avoid default values unless clearly justified and tested.
- Use rating curves only when supported by site-specific gage data or well-documented structure performance, and clearly cite all sources used in the model documentation.
- Conduct sensitivity testing by slightly varying the boundary condition (e.g., slope, tailwater elevation) to determine its impact on upstream results and verify model robustness.
- Visually inspect water surface profiles to confirm they behave hydraulically as expected: generally smooth, stable, and aligned with streambed slope in subcritical flow regimes.

3. Inappropriate Use or Omission of Internal Boundary Conditions

Internal boundary conditions such as lateral inflows, flow change locations, or junctions, are essential for routing flow properly in HEC-RAS models. Internal boundary conditions should be located at hydrologically meaningful locations such as tributary confluences, known inflow points, or areas with notable changes in land use, drainage patterns, or infrastructure. Flow inputs must align with the design hydrology and be clearly represented in the HEC-RAS model and supporting documentation. Common issues and best practices include:

- **Misaligned design points:** Applying flows derived from a downstream design point to an upstream location, without adjusting for differences in contributing drainage area, can result in overestimated flows, particularly when the referenced design point includes flow contributions from multiple sources beyond the local sub-basin.

- **Lack of documentation:** If a flow boundary does not correspond to a hydrologic design point, the model report or notes should explain the rationale for its location and describe how the flow was estimated or adjusted.
- **Unrepresented features:** Ensure all features referenced in the hydrology report such as ponds, stormwater outfalls, or storage basins are visibly represented in the HEC-RAS geometry.
- **Unclear boundary application:** Clearly apply the internal boundary condition in the model, using appropriate methods such as lateral inflows, stage boundaries, or rating curves.
- **Insufficient explanation of inputs:** Document the origin of all boundary conditions, including references to external models (e.g., EPA-SWMM), specific flow or stage values used, and any modeling assumptions.

HEC-RAS provides two options for defining internal boundary conditions for hydraulic controls: Set Changes in Water Surface and Energy Grade (WS and EG), and Rating Curve. The use of the “Headwater Check” with the rating curve option is recommended, as it helps prevent the model from producing drawdown profiles. Common issues that should be reviewed and addressed by modelers include:

- **Unrealistic drawdowns:** Computed drawdowns may indicate that the known water surface elevations or rating curves do not accurately reflect downstream conditions. Modelers should revisit and verify inputs and provide appropriate documentation.
- **Zero flow representation:** HEC-RAS does not allow zero flow. For events entirely contained within a closed drainage system, it is standard practice to assign a nominal flow value (e.g., 0.01 to 1 cfs) to represent dry conditions. This assumption should be clearly documented in the model description.
- **Incorrect water surface elevations at low flows:** At low flows, HEC-RAS may compute inaccurate water surface elevations at storm drain inlets or culverts due to the interaction between nominal flows and the Headwater Check setting. Modelers should be aware of this behavior and account for it during result interpretation.

b. Quasi-Unsteady Flow Data

1. Improper Use of Quasi-Unsteady Flow for Inflow Representation

Quasi-unsteady flow modeling can be a useful tool in certain applications, but it is often misapplied without proper justification. A common issue is using quasi-unsteady flow in situations where full unsteady modeling is more appropriate, such as in areas with rapidly changing flows, significant backwater effects, or critical storage (or several storages along the main channel). This can result in inaccurate flow routing and water surface profiles, particularly in dynamic or complex systems.

Quasi-unsteady flow should only be used when clearly supported by the project’s scope and objectives, where inflow changes are gradual and storage effects are minimal. The modeling report must explain why this approach was selected and demonstrate how it meets the hydraulic requirements of the study.

2. Inconsistent or Undocumented Inflow Hydrographs

In quasi-unsteady hydraulic models, inflow hydrographs are typically used to simulate gradual changes in flow over time. A typical error is using generic or overly simplified hydrographs that do not reflect the results of the hydrologic analysis. This can lead to inaccurate peak elevations, timing errors, or unrealistic conveyance through structures.

Inflow hydrographs used in quasi-unsteady models must represent the peak magnitude, general shape, and duration consistent with the hydrologic model results (e.g., CUHP, SWMM). Avoid oversimplified or generic hydrographs that misrepresent flow timing or volume, as this can distort structure performance and WSEs. While detailed routing isn't required, all hydrographs should be properly scaled, clearly labeled, and briefly documented in the report with source information and any assumptions noted.

c. Unsteady Flow Data

Accurate and well-documented inflow data are essential for reliable unsteady hydraulic modeling. The following key areas are commonly overlooked or misapplied, often leading to unrealistic results or revision requests. Modelers should carefully check each aspect during model setup and documentation.

1. Inflow Hydrographs Inconsistent with Hydrologic Modeling Results

A frequent issue is that inflow hydrographs do not match the hydrology report in terms of storm type, peak magnitude, duration, or timing. For example, a 100-year 3-hour storm might be used in the model when the hydrology report specifies a 24-hour event. Unit errors, such as using cfs/s instead of cfs, can also occasionally result in serious modeling errors.

To avoid this, all inflow hydrographs should be directly derived from the hydrologic model used in the study and should accurately reflect the intended event. Storm duration, return period, and peak timing must be preserved. Inflow files should be clearly labeled by event and location and cross-referenced with the hydrology report.

2. Missing or Mislocated Lateral/Tributary Inflows

A typical oversight is excluding tributary inflows, local drainage areas, or return flows, or placing them at incorrect river stations. This misrepresentation can lead to errors in flow distribution and water surface elevation calculations.

Another frequent issue is incorrect addition or subtraction of flow at junctions or diversion points, which can violate flow conservation principles and create unrealistic flow splits or volume inconsistencies.

All known inflows should be included at their correct geographic locations based on the hydrologic analysis. Tributary flows should reflect routed hydrographs or volume estimates consistent with contributing drainage areas. If any inflows are simplified, combined, or excluded, the rationale must be clearly documented in the modeling report and model notes.

3. Undocumented Timing Adjustments or Routing Assumptions

In some cases, inflow timing is manually shifted without explanation, which can cause unrealistic hydrograph shapes such as double peaks, excessive lag, or flow smoothing that doesn't match expected behavior.

To prevent this, inflow timing should follow travel times and routing outputs from the hydrologic model. If timing shifts or simplifications are necessary, they must be well documented and reviewed to ensure they do not distort the system's response or the interaction of multiple inflows.

4. Incomplete or Unverified Base Flow Conditions

Base flow is sometimes excluded or assigned without reference to observed conditions, which can lead to unrealistic results, especially in calibration events or dry-season simulations. When base flow is not appropriately represented, the model may produce zero depths or unreasonably low flows in the channel.

To improve accuracy, base flow should be derived from observed streamflow data, regional regression methods, or hydrologic model outputs. Include base flow where it is known to exist, and document the source and value in the steady or unsteady flow file and in the report.

5. Inconsistent Initial Conditions

Initial flow or stage conditions are sometimes left at default values or don't match the start of the inflow hydrographs. This can lead to early-time instabilities, inaccurate water surface elevations, or unrealistic volume storage in the system.

Initial conditions should be based on observed data or hydrologic estimates and should align with inflow hydrographs and known conditions at the event start. If flow or stage values are estimated, document the approach and verify that the model stabilizes early in the run.

II. GEOMETRIC DATA

a. River Centerline /Profile Baseline

The river centerline (also referred to as the profile baseline) is a foundational element in HEC-RAS modeling. It defines the primary flow path, determines reach lengths, influences channel slope, and controls cross section orientation. However, during reviews, several recurring issues have been observed such as misaligned thalweg paths, overcomplicated or angular linework, reversed digitization direction, and disconnected centerlines. These issues can lead to inaccurate reach lengths, unrealistic slopes, and misalignment of cross sections, all of which affect model stability and floodplain mapping accuracy.

This section provides guidance for establishing a reliable and hydraulically appropriate river centerline.

1. Thalweg Alignment

- **Centerline path:** The river centerline should follow the lowest ground elevations (thalweg) along the flow path and should be delineated using field surveys, topographic contours, and aerial imagery, in that order of priority.
- **Angular linework:** The river centerline should accurately reflect swift water movement through the channel. Ensure smooth alignment that reflects natural channel curvature and avoid sharp angles or abrupt directional changes.
- **Excessive vertices:** The polyline should be smoothed to reduce complexity, following a general guideline of no more than one vertex every 10 feet on average.
- **Excessively meandering centerline:** A two-foot contour interval is recommended as the basis for determining the thalweg alignment. An overly meandering centerline can increase downstream reach length, resulting in an artificial milder channel slope. This may lead to overly conservative flood hazard calculations and can complicate the placement of cross section cutlines, making it harder to maintain perpendicular orientation to the river centerline and flow direction in the floodplain.

- River centerline outside the surface flow area: The river centerline at an inline structure (e.g., inline detention, ponds, or diversions) should be reviewed with MHFD to determine the appropriate alignment across the structure, considering the outlet structure and overflow conditions.
- Long culverts or major storm sewers within a floodplain: When these features are present, the river centerline should be determined based on the following criteria and must be clearly noted in the description:
 - If the system has a 100-year capacity, the river centerline should follow the alignment of the long culverts or major storm drainage system.
 - If the system does not have a 100-year capacity and a significant surcharge occurs overland, the river centerline should follow the major surface flow path between the inlets and outlets. The culvert or storm system's capacity should be subtracted from the total surface flow to accurately represent the overland flow.
 - Clearly document in the report which alignment was used and why.
- Inconsistent centerline direction: Centerlines are sometimes digitized in the upstream direction, resulting in reversed reach lengths and profile stationing. This can cause confusion in cross section labeling and incorrect computation of flow direction. The river centerline should always be digitized from upstream to downstream. This ensures that HEC-RAS reach lengths, cross section stationing, and flow direction are correctly defined throughout the model.
- Disconnected centerline segments: In some cases, the centerline is broken into multiple segments or polylines, which can cause geometry import errors or confusion when assigning reaches and banks. Ensure the centerline is a single, continuous polyline per reach. Check for and remove unintended breaks or overlaps before importing into HEC-RAS.
- Unconnected tributary centerlines: Tributary centerlines are sometimes not connected to the main river reach in the geometry, which can cause routing errors, missing flow paths, or undefined junctions. This also creates confusion during review, especially if the tributary is part of the active flow network. If the tributary is being modeled, the centerline should connect directly to ("snap to") the main channel at the appropriate confluence point, and a junction should be defined in HEC-RAS. Even if the tributary is modeled in a different geometry or plan, the linework should still snap to the main river's pathbreak line to ensure continuity. If the tributary is not part of the active flow network, clearly note this in the geometry metadata or model report.

Figure 1 presents some examples of inaccurate thalweg alignments observed in previous reviews.

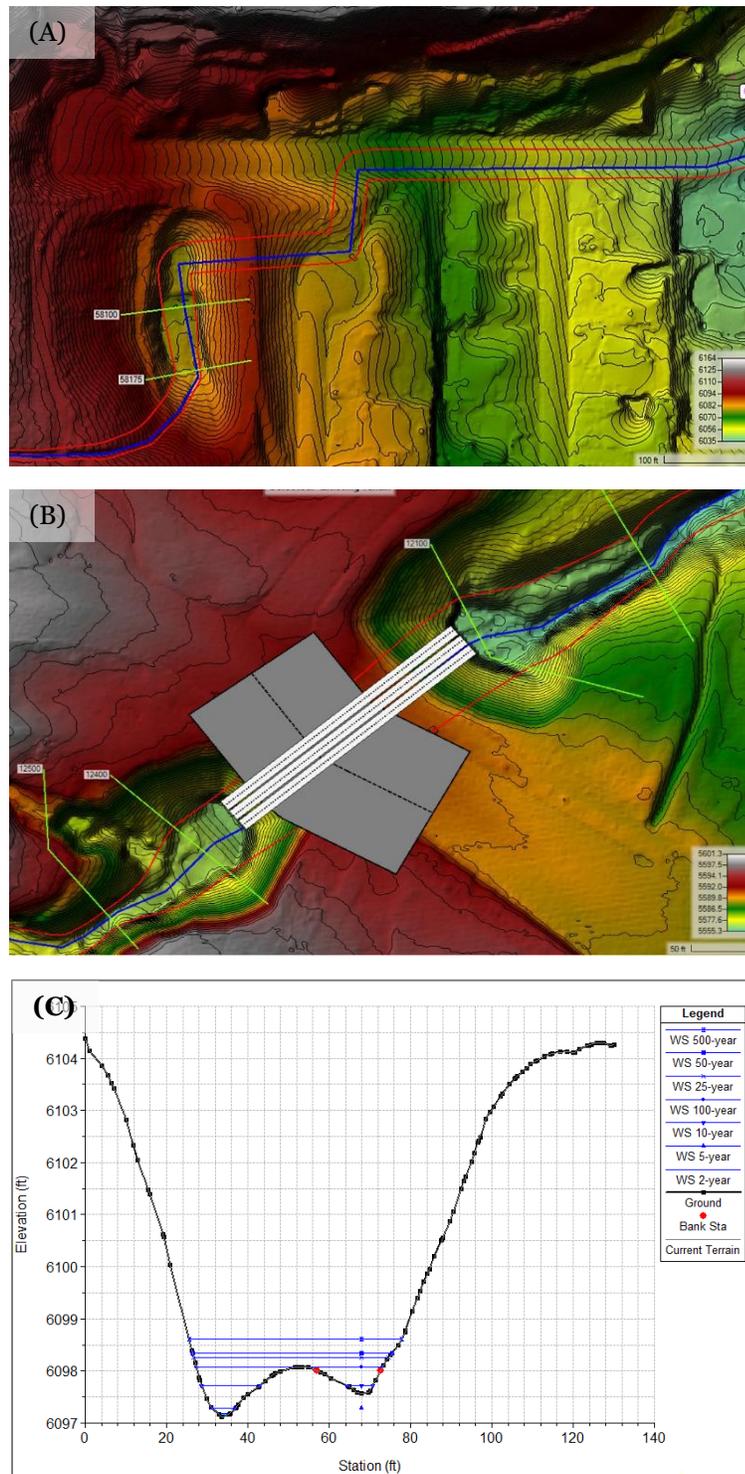


Figure 1. Examples of inaccurate thalweg alignment: (A) the river centerline crosses high ground without visible structures or supporting documentation, suggesting an inaccurate alignment, (B) the stream centerline is misaligned with the culvert layout and terrain; it enters through the right culvert but exits away from the center culvert, missing the lowest flow path, (C) the stream centerline does not follow the thalweg or channel invert.

2. Thalweg Adjustment

A natural thalweg may exhibit micro-scale undulation due to local sediment deposition and scour. However, for a large-scale floodplain analysis, the thalweg should generally slope downstream, allowing water to flow freely unless backwater effects from an adverse slope (or structure) are evident.

To ensure accurate hydraulic calculations, the thalweg should be adjusted to maintain a correct downstream slope. This can be achieved by removing low-flow water areas or correcting terrain irregularities based on interpolation from surveyed cross sections, structural data, and as-built information. Adjusting the channel slope requires modifying cross section geometries, but this must be done carefully, as channel geometry is a critical factor in floodplain hydraulics.

Sound engineering judgment should be applied to replicate the low-flow area using Digital Elevation Models (DEMs) and 2D/3D aerial imagery at the problematic reach and the nearby reaches. Field photographs and typical low-flow cross section measurements provide the most reliable source of information.

Figure 2 illustrates a few common mistakes in thalweg modification, including an unnatural channel geometry, excessive low-flow area, and adjusting the elevation across the entire cross section instead of focusing on the thalweg itself.

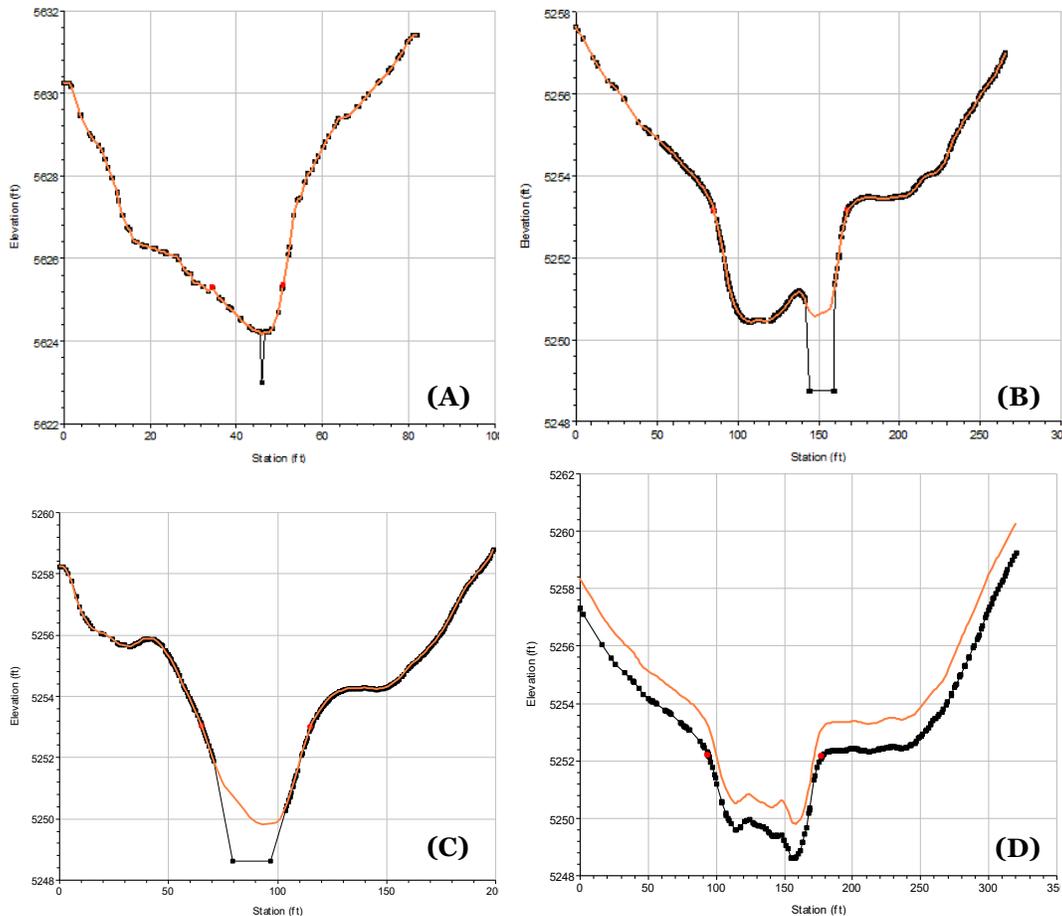


Figure 2. Examples of common mistakes in thalweg modification: (A) Unnatural channel geometry, (B) and (C) Excessive low flow area, (D) Elevation adjustment for the entire cross section.

b. Junction

Junctions represent the connection point between two or more reaches, typically where tributaries join the mainstem. Accurate junction setup is critical for preserving flow continuity, ensuring proper routing, and maintaining model stability. Several issues are commonly observed during reviews, ranging from incorrect length definitions to alignment and documentation problems. The following points outline key concerns and recommended practices.

1. Length Across the Junction

Lengths are often mistakenly measured from the confluence (where river centerlines join) to the upstream bounding cross sections. Instead, the length should be measured along the river centerline from the downstream bounding cross section to the upstream bounding cross section at the confluence. This ensures consistent flow path representation and accurate reach length calculations.

2. Flow Path Alignment

Tributary cross sections and river centerlines should be spatially aligned with the mainstem to ensure a smooth flow transition. Poor alignment between tributary and mainstem geometries may result in instability or irregularities in the water surface profile at the junction.

3. Cross Section Continuity

Cross sections at or near junctions should be placed with appropriate spacing. Overlapping or poorly spaced sections can introduce discontinuities, while excessive gaps may miss important hydraulic transitions near the junction area.

4. Naming and Documentation

Reaches and junctions should be clearly named to reflect their location and hydraulic function. Avoid generic names (e.g., "Reach 1", "Tributary 2") that do not communicate the model structure. Junction locations and assumptions should be clearly documented in the model notes and associated report.

c. Cross sections

Cross sections define the terrain geometry used for computing water surface elevations in HEC-RAS. Their alignment, spacing, and attribute consistency play a major role in the stability and accuracy of floodplain modeling. Several issues, including misaligned cutlines, unrealistic geometry, and insufficient spacing, are commonly observed during reviews and can result in distorted flood extents, unstable results, or misrepresented conveyance. The following guidance addresses key areas in cross section creation, providing recommendations based on recurring issues.

1. River Stations

River stations should be rounded to the nearest whole foot. If closely spaced cross sections require decimals, round to the nearest tenth of a foot. However, review densely spaced cross sections carefully, as they may be impractical for floodplain hydraulics analysis.

- Assign clear reach identification to cross section stations to ensure each cross section has a unique identifier in the hydraulic model.

2. Cross Section Alignments and Locations

- Avoid using vertical extensions or virtual walls at cross section endpoints to contain water. These features may misrepresent overbank flow and create artificial barriers. Instead, extend cross sections beyond the floodplain boundaries on both sides of the stream for the most extreme modeled event (typically the 0.2-percent-annual-chance or 1-percent plus flood).
- Cross section endpoints should not terminate at local high ground or a non-levee feature unless documented and justified with supplemental analysis.
- Cross sections should avoid intersecting tributaries and outfall structures. If unavoidable, apply the ineffective flow area to exclude these regions from contributing to conveyance.
- Avoid extending cross sections excessively beyond the floodplain boundaries, both vertically and horizontally.
 - Overly extended cross sections make editing inefficient, requiring constant zooming to see the details of the main channel.
 - Excessive vertical extension of cross section elevations reduces accuracy when using the Secant Method to calculate critical depth.
- Cross sections must be placed perpendicular to the main flood flow, which may require bending cutlines to accurately represent complex terrain or hydraulic controls at certain locations. When doing so, consider the following:
 - Limit vertices along cutlines to only those necessary to capture significant changes in terrain and flow conditions.
 - Ensure overbank water surface elevations are reasonable relative to river stationing. Cross section alignments in both left and right overbank areas must project reasonable water surface elevations that correspond to the river station along the mainstem.
 - Overbank reach lengths should be proportional to the river station spacing between cross sections.
 - Congested cross sections, which are densely spaced on only one side of the overbank should be carefully reviewed, especially in areas with rapid water surface changes.
 - Avoid excessive bending that artificially enlarges the conveyance area or misrepresents hydraulic connections between the mainstem and overbank areas, as this may require split-flow analysis or a 2D hydraulic model.
 - Use a series of cross sections with proper alignment spacing to ensure a gradual and smooth transition from significant hydraulic controls to normal cross sections.
 - In wide and gently sloping terrain, cross sections should not extend too far parallel to the contours, as this may unrealistically overestimate inundation areas where overland flow lacks the energy to reach. Flow exiting a sluice gate onto a flat surface can serve as a useful example, illustrating how cross sections in overbank areas should be bent to reflect realistic flow expansion and to more accurately limit inundation extents.

Figure 3 highlights issues with cross section alignment and spacing. Between XS 23200 and XS 22767, the model produces uneven overbank water surfaces, with the right overbank extending unrealistically. At XS 23200, the left overbank extends into a backwater area, which obviously does not correspond to the river station along the mainstem. This suggests misalignment with the main channel and may lead to overestimated flood extents. In addition, the congested spacing of XS 23517 and 23497 on the right overbank, along with the large gap between XS 23200 and XS 22860 also shows irregular spacing that does not follow the mainstem, further affecting model accuracy.

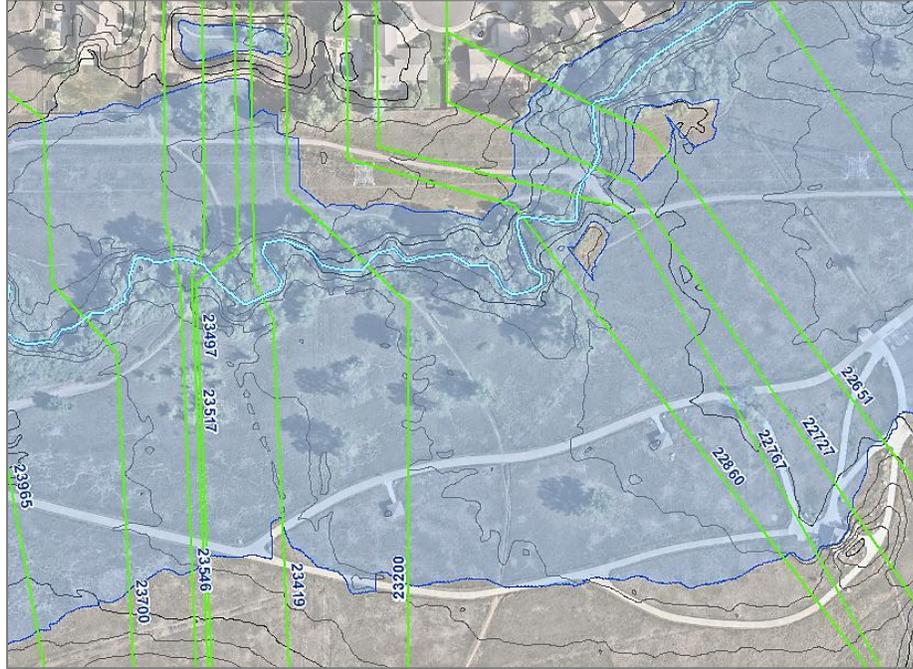


Figure 3. Examples of cross sections (XSs) with misaligned placement and orientation.

Figure 4 which includes the topographic figure and cross section plot, highlights a misalignment at XS 636. This misalignment causes the model to direct flow too far downstream, leaving the mainstem channel dry. Since HEC-RAS 1D does not inherently interpret terrain features, improper cross section orientation can result in the model routing flow through low-lying areas, as shown by the conveyance being shifted to a depressed region on the left side. In addition, A roadway crossing culvert is located upstream but is not included in the current model setup, which also contribute to the observed flow misalignment.

To address this issue, the culvert structure needs to be incorporated by defining appropriate upstream and downstream cross sections and cross sections 418 and 636 should be reoriented to align more perpendicularly with the main flow direction, taking into account the skew caused by the upstream structure. Additionally, the cross sections should be extended on both sides to better represent the primary flow path and fully capture the extent of the overbank and adjacent depressed areas.

To improve model resolution, one or two more cross sections should also be added between XS 219 and XS 418, where the channel geometry transitions from wide to narrow and back to wide. These additions will improve the definition of key hydraulic transitions, particularly when combined with the accurate placement of ineffective flow areas (IEFAs) in the depressed zones observed in this area.

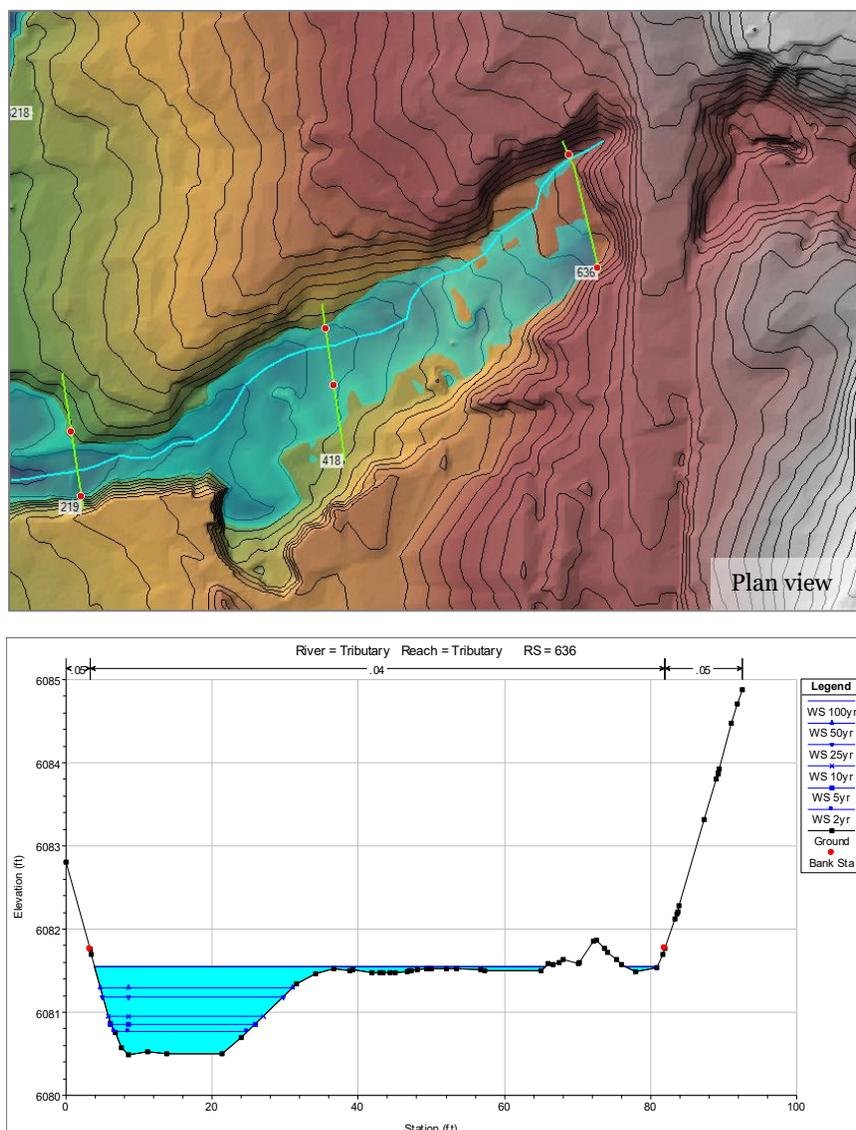
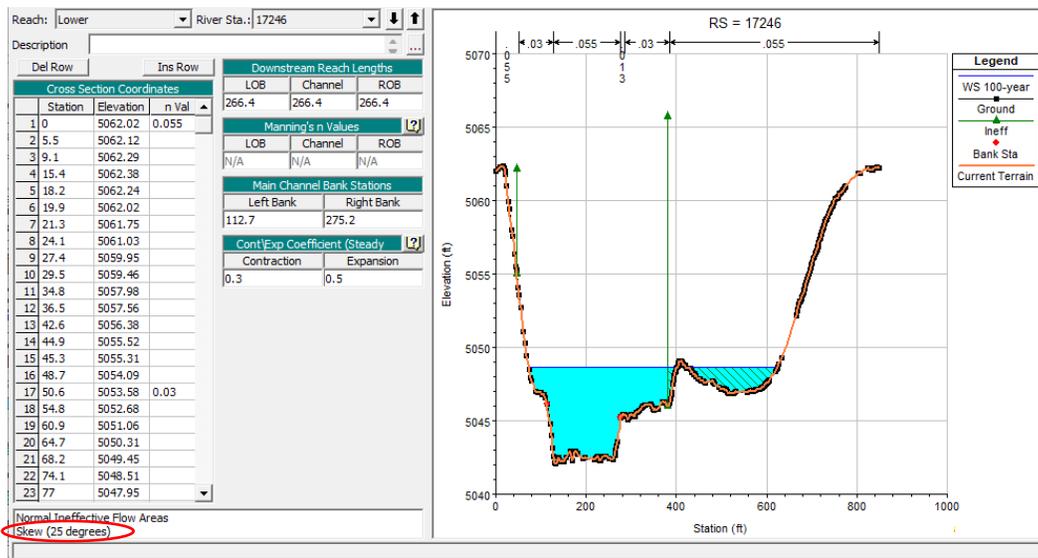


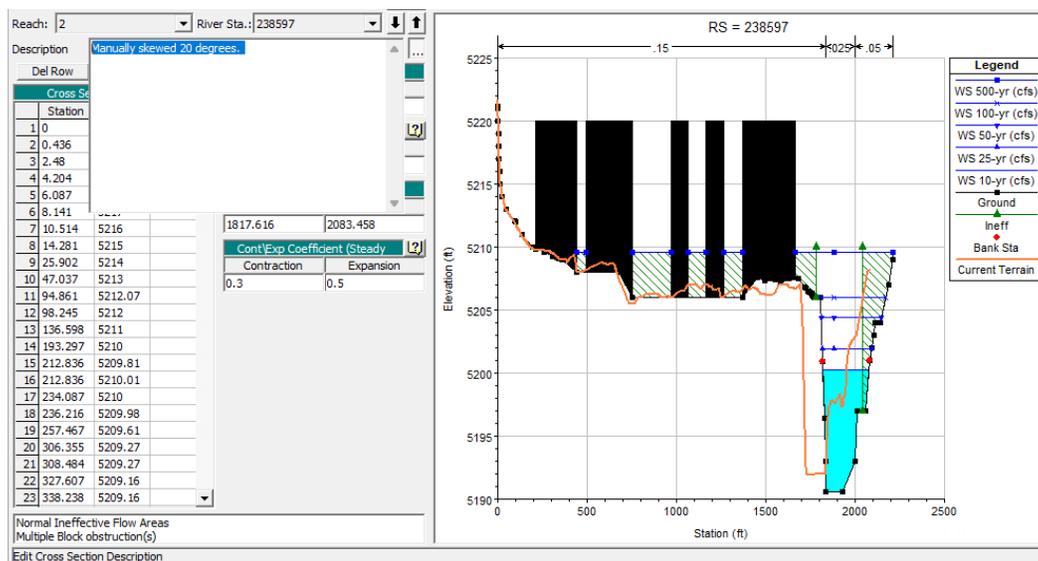
Figure 4. The cross section 636 misaligns, leaving the mainstem dry.

- Diagonal cross sections should be used only when necessary, as they can artificially increase the flow area and potentially underestimate flood hazards. To correct this, a skew angle should be applied in the cross section Data or Bridge/Culvert Data within the HEC-RAS hydraulic model. While a skew angle greater than 45-degree may occur, it should not be manually applied without a careful evaluation of the flow conditions around the crossing structures. In wide channels and floodplains, a large skew angle suggests that the flow may not fully turn, causing water to enter only portions of the cross structure at different stages of flow relative to the river centerline, rather than passing uniformly through the entire opening. If not properly accounted for in the model, such conditions can lead to hydraulic inefficiencies, inaccurate conveyance representation, or misestimation of upstream water surface elevations. This adjustment narrows the cross section geometry relative to the underlying terrain. Figure 5 and Figure 6 show examples of erroneously skewed cross sections.



Note: Current Terrain represents the ground cut along the cross section cutline.

Figure 5. The cross section geometry remains consistent with the terrain, even when a 25-degree skew is applied.



Note: Current Terrain represents the ground cut along the cross section cutline.

Figure 6. The cross section geometry is wider than the terrain, even when a 20-degree skew is manually applied.

- Insufficient cross sections to support detailed mapping:
 - Automated floodplain delineation can be a helpful tool for quickly assessing whether there are enough cross sections for detailed mapping. It may reveal areas of dry land that disconnect the floodplain or unnaturally bottlenecked sections between cross sections that are not supported by the terrain. This often indicates that the interpolated water surface elevations are inaccurate relative to the ground surface, likely due to missing or overlooked hydraulic controls (Figure 7 for example).

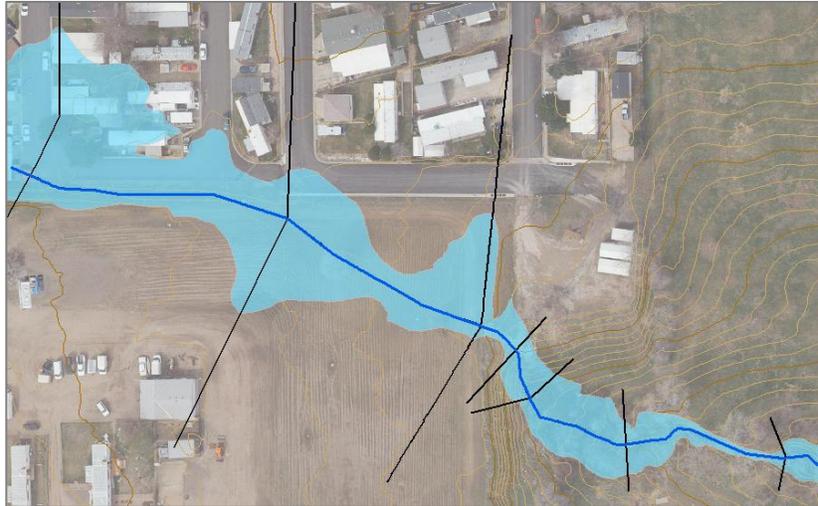


Figure 7. The relatively narrow floodplain top widths between the cross sections suggest that there may be an insufficient number of cross sections or a missing hydraulic control.

- When a stream centerline falls outside the automated floodplain delineation, it often indicates that there are not enough cross sections to accurately calculate water surface elevations or represent the curvature of the channel (Figure 8 as an example).

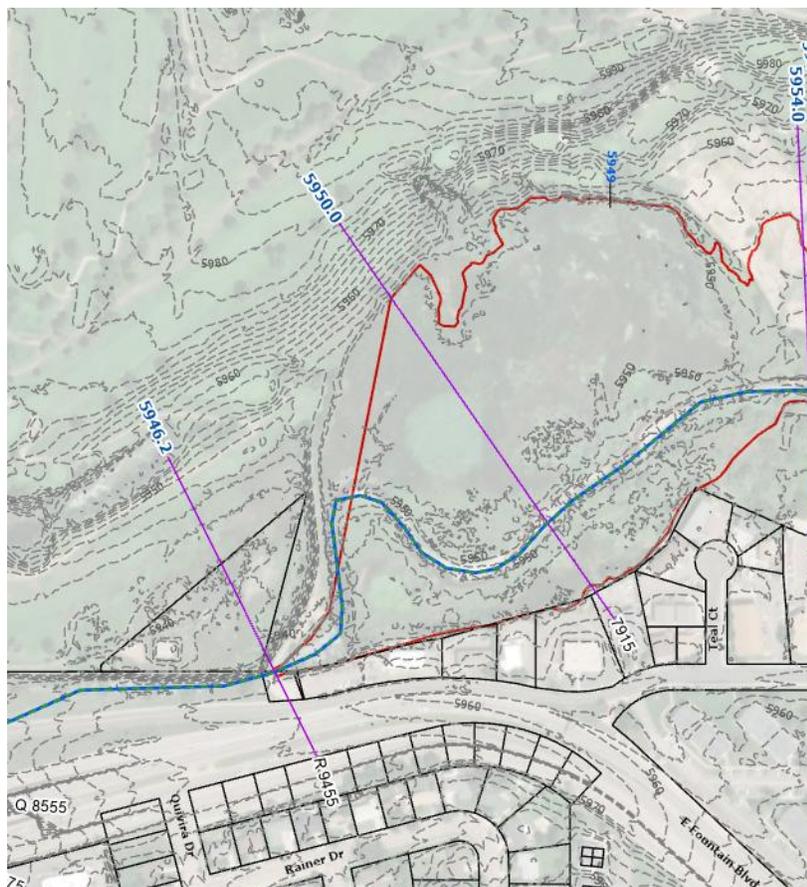


Figure 8. The stream centerline (in blue) falls outside the automated floodplain delineation (in red), indicating that there are not enough cross sections to represent the channel's curvature.

- Even in reaches where the channel geometry appears uniform, additional cross sections may be required at bends along a meandering reach to accurately capture changes in floodway path and floodplain interaction. While floodway boundaries can be interpolated from encroachment stations at each cross section using engineering judgment, this approach typically relies on linear interpolation, which may not reflect the true path of the floodway through curved reaches (
- Figure 9 as an example).

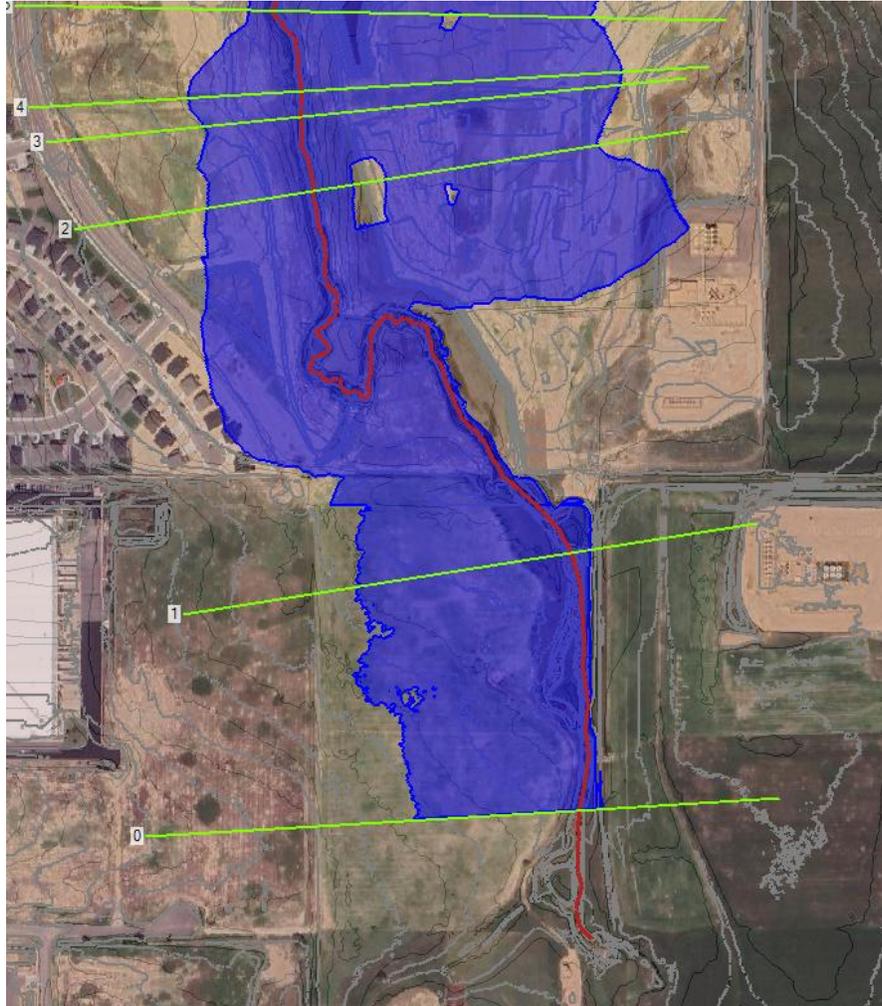


Figure 9. The channel centerline in this model is close to the floodplain edge due to the lack of cross sections in the meandering section of the reach.

3. Cross Section Coordinates

- It is recommended to start cross section stationing at zero from the left endpoint. Although HEC-RAS allows for any positive or negative station values, using a consistent zero-based approach improves clarity when aligning the cross section outline with its geometry. It also simplifies floodplain mapping and review by allowing floodplain extents to be measured directly from model output without the need to transpose station values.
- The cutline length should exactly match the cross section geometry coordinates. Any edits to the coordinates in the model should also be reflected in the cutline, and vice versa, to maintain consistency and ensure correct terrain slicing.

4. Downstream Reach Lengths

- Given the current technical capabilities for accurate modeling and mapping, the District requires an exact match between the topographic workmap and the hydraulic model, even though a tolerance of up to 5% of the map scale or 25 feet on a 1" = 500' floodplain map is technically allowable by FEMA standards.
- Unless the channel is straight and uniform, the left and right overbank reach lengths should differ from the main channel length and from each other. These values should reflect the natural meandering of the channel and be refined through modeling iterations. In reviews, we have observed that LOB and ROB lengths are incorrectly set to match the main channel reach length, even in meandering areas. This common error can result in unrealistic hydraulic behavior by misrepresenting overbank flow travel time and storage. Overbank reach lengths should reflect the natural flow paths and be refined based on terrain and modeling iterations. Figure 10 includes an example of inaccurate reach length.

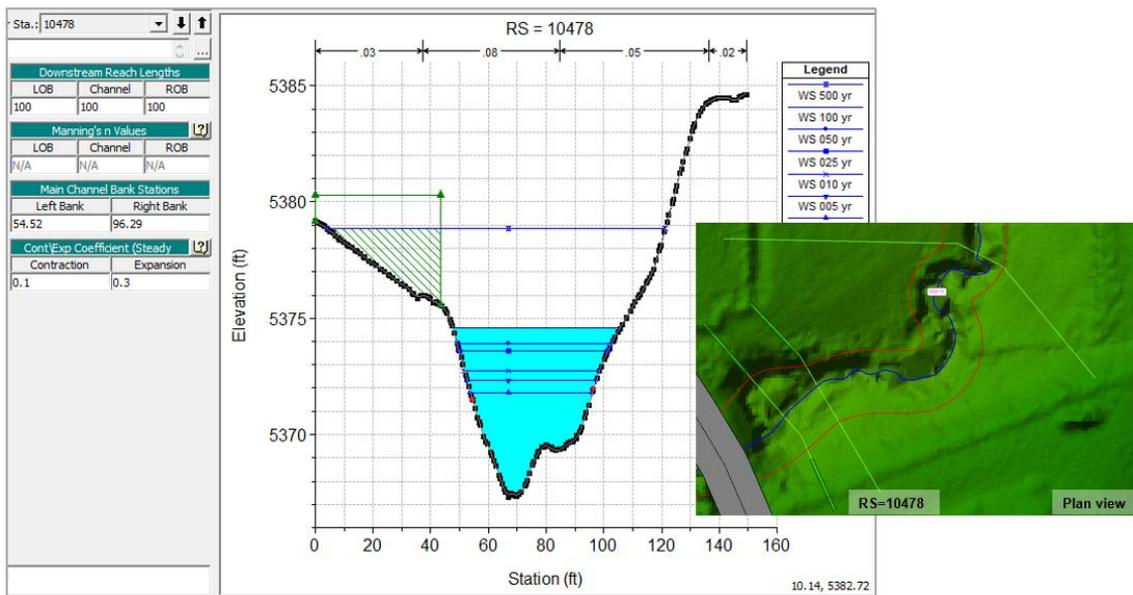


Figure 10. An example of a meander area is observed at XS 10478, where the overbank flow path lengths are the same as the main channel length.

- Reach lengths should be based on realistic overland flow paths derived from topography or contours, not simply measured as straight-line distances between cross sections.
- Zero or very short overbank lengths can result in model instability or incorrect delay in floodplain routing. In wide or gently sloped floodplains, ensure that overbank reach lengths are reasonable.
- Ensure overbank reach lengths are appropriately different from channel lengths when warranted by terrain.
- In steep or high-velocity channels, even small differences in reach lengths can cause noticeable changes in computed water surface elevations. This sensitivity makes it especially important to review and refine reach lengths near hydraulic controls, such as bridges and culverts, where accurate energy slope and head loss calculations are critical.
- In combined 1D/2D models, ensure that 1D reach lengths near 2D boundaries support a smooth hydraulic transition to avoid discontinuities or misrepresentations of energy slope.

5. Main Channel Bank Stations

Bank station locations should be placed approximately symmetrically around the low-flow area and above the channel thalweg in all hydraulic model plans. Ideally, bank stations should be located within the 1%-annual-chance (100-year) floodplain at a minimum to ensure consistent geometry for both floodplain and floodway modeling. While determining locations for the main channel bank stations, the following should be considered:

- Significant breaks of channel geometry, such as changes in slope, cross sectional shape, or width.
- Transitions in vegetation or surface roughness, especially where they influence Manning's n-values.
- It is preferred that changes in Manning's n values align with the bank stations when using horizontally varied n values.
- Bank stations should encompass the river centerline that reflects the primary flow path. In wide or braided channels, bank stations should define the primary conveyance path, while ineffective flow areas should be used to exclude disconnected or shallow areas from contributing to flow.
- Bank stations should account for potential floodway encroachment. Ideally, they should reasonably define the main flow area to ensure that:
 - Floodway encroachments do not extend beyond the bank stations' points.
 - Encroachments remain within the floodplain fringe, supporting a smooth and continuous floodway delineation, while maximizing allowable surcharge.
 - In wide or flat cross sections, placing bank stations too far out at grade breaks can overly constrain the floodway and reduce space for encroachment. In such cases, or in braided or complex floodplains, bank stations should define the primary conveyance path, while ineffective flow areas should be used to exclude disconnected or shallow areas from contributing to conveyance.
 - Maintain consistency across adjacent cross sections. Where channel geometry is relatively uniform, avoid sudden shifts in bank station placement that could affect floodway boundaries or cause mapping artifacts.
- Abrupt changes in the width between adjacent cross sections should be avoided to maintain consistency and ensure reasonable results.
- For 100-year capacity cross sections with vertical walls or precipitous channel banks, bank stations should be placed at the top of the channel rather than at the toe to ensure the friction losses caused by the steep banks are not underestimated. This is an allowable deviation from standard guidelines. During floodway analysis, care should be taken, as the floodway encroachment may need to extend inside the bank stations to align with the 100-year floodplain boundary. This special condition should be documented in the cross section description.
- Avoid placing bank stations too close together. Extremely narrow bank station spacing can create unrealistic low-flow channels, resulting in exaggerated velocities or water surface gradients.
- Use field photos and high-resolution aerial imagery to support bank placement, especially in areas with undefined banks, braided channels, or urban settings.

6. Manning's n Values (1D)

Accurate assignment of Manning's n values is essential for realistic flow modeling in HEC-RAS. Roughness coefficients represent surface resistance and vary based on factors such as vegetation,

land cover, channel material, and seasonality. Common oversimplifications or inconsistencies in roughness values can significantly impact computed water surface elevations, conveyance, and floodplain extent. The following are recurring issues and good modeling practices to address them:

- Overly simplified or generic Manning's n values: Often, Manning's n values are simplified or applied based on generic tables, without taking into account the specific channel conditions (e.g., roughness, vegetation, streambed material) at the site. This can lead to an inaccurate representation of flow behavior, especially in regions with complex terrain or high vegetation density. Use site-specific data where possible (e.g., field visits, aerial imagery, photos) or refer to past studies in the same region. For complex terrain, detailed calibration or sensitivity testing may be necessary. In all cases, lower Manning's n values should be used for the main channel, and higher values for overbanks unless site conditions indicate otherwise.
- Inconsistent Manning's n values along a cross section: Manning's n values may not be applied consistently within a cross section, especially where channel roughness changes abruptly between the channel, bank, and floodplain. Ensure that Manning's n values are correctly adjusted to account for changes in flow conditions across the cross section. Subdivide each cross section logically into low-flow channel, bank, and overbank zones. Apply roughness values that reflect each zone's characteristics. Transitions between zones should be gradual and reasonable to avoid artificial jumps in conveyance.
- Ignoring seasonality in vegetated areas: A common oversight is assigning Manning's n based on winter or dormant vegetation conditions, which may underestimate roughness during peak flow seasons. Assign roughness values in vegetated areas based on summer conditions, when vegetation is typically most dense. This reflects worst-case resistance scenarios and aligns with MHFD modeling preferences.
- Unrealistic low values in paved/developed areas: A common mistake is assigning overly low Manning's n values (e.g., 0.013) to urban surfaces such as parking lots or alleys, without considering real-world obstructions like vehicles, stockpiles, or debris.
 - MHFD recommends a minimum value of 0.02 for most paved urban areas unless the area is clearly clean and unobstructed. Use lower values (e.g., 0.013) only where justified (e.g., clean concrete channels, unimpeded flow).
- Mismatched Manning's n between model and report: A common issue is a lack of consistency between Manning's n values documented in the model and those described in the hydrology/hydraulics report. Ensure the roughness values used in the model match those stated in the report. Clearly document the source, methodology, or references used to assign the values to maintain transparency and defensibility.
- Not considering roughness between cross sections: While HEC-RAS computes conveyance based on individual cross sections, it does not directly account for resistance between them. This can lead to unrealistic flow behavior, especially in wide or complex floodplains where roughness conditions vary.
 - Roughness values should also reflect average conditions between cross sections, especially in complex floodplains.
 - In urban settings, a common mistake is placing cross sections along roadways and assigning only pavement roughness values. This approach can ignore adjacent vegetated areas, fences, or obstructions, leading to an underestimation of floodplain resistance.
 - In some cases, tighter spacing may be more appropriate than adjusting n values alone.

7. Contraction and Expansion Coefficients

- Contraction and expansion coefficients should be reviewed at cross sections where there is a significant change in velocity downstream. Sudden drops in water surface elevation may also signal underestimated expansion loss or geometry misrepresentation, requiring a coefficient or geometry adjustment.
- A common issue is only increasing the contraction and expansion coefficients at the bounding cross sections of a crossing structure. When using the standard four cross sections approach for modeling a structure, the coefficients should typically be increased at:
 - The two upstream cross sections, where the flow contracts entering the structure, and
 - The first downstream cross section, where the flow expands after exiting the structure.
- Ensure consistency across similar structures. Similar structures should generally use similar coefficient values unless a structural or geometric reason justifies a difference.
- When high coefficient values are used, engineering justification should be provided in the description of the corresponding cross sections.
- High coefficients may also be needed at natural transitions where there is an abrupt change in channel geometry, such as from a wide overbank to a narrow main channel, even if no structure is present. These transitions can cause significant energy losses due to flow contraction and expansion and should be reviewed carefully.
- Be cautious near junctions or bends. Overusing high coefficients in these areas can lead to exaggerated water surface variability or model instability.

8. Ineffective Flow Areas (IEFAs)

- A frequent issue is the lack of IEFAs in depressed overbank areas that don't actively convey flow (Figure 11 as an example). Use terrain and aerial imagery to identify low areas isolated from the main flow path and apply IEFAs to exclude them from contributing to conveyance.
- One common problem is placing IEFAs inside the main channel, which can cut off valid overbank flow. Ensure IEFAs reflect realistic flow paths and are not used where water would naturally convey flow during flood events.
- Another issue is abrupt or inconsistent IEFAs placement between cross sections, which may cause hydraulic instability or unexpected water surface elevation jumps. Maintain smooth transitions in IEFA stationing along the reach to support stable and continuous flow modeling.
- In some cases, IEFAs are included in the model without any explanation or supporting documentation. Clearly document IEFAs' assumptions in the model notes or report, including the reason for placement and how boundaries were determined.

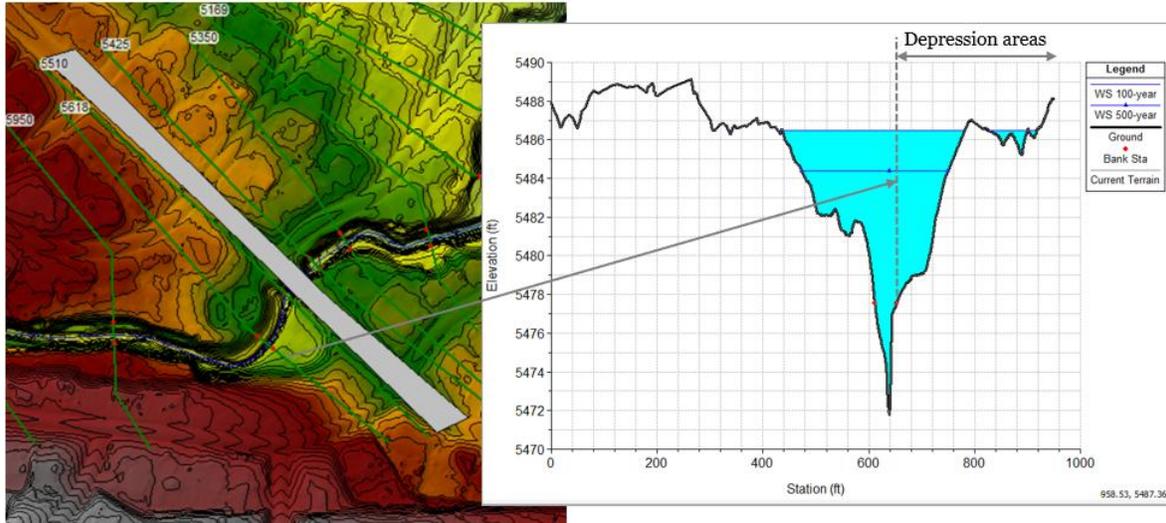


Figure 11. Example of missing IEFAs in depressed regions. IEFAs should be applied in areas where water does not naturally flow downstream to more accurately represent hydraulic behavior.

9. Rating curve

Rating curves are frequently used in HEC-RAS to define outflow conditions at culverts, storm drain outlets, junctions, or storage elements. When not properly developed or applied, they can produce unrealistic results, model instabilities, or routing inconsistencies. The following are common issues and recommended practices related to the rating curve, and they align with guidance provided in the Internal Boundary Conditions section.

- Use of default or auto-generated rating curves without review: A typical mistake is that default or auto-generated rating curves are used without verifying whether they reflect actual site conditions or expected flow behavior.

Always review these curves, especially for downstream boundaries, storage outlets, and lateral structures. Adjust them based on field data, survey points, or computed rating tables if available.

- Rating curve does not cover full headwater elevation range: The rating curve sometimes does not extend to cover the full range of expected headwater elevations in the model. This oversight can lead to truncated or flat outflow rates, especially during high-flow events, resulting in unrealistic storage behavior or instability; particularly for culverts, weirs, and outlet structures.

To avoid this, review the range of computed headwater stages for each event and ensure the rating curve spans that full range with appropriate flow values. Extend the curve conservatively if needed, and verify that transitions between flow regimes (e.g., weir to orifice, free to submerged) are captured.

- Rating curves that don't match hydraulic conditions: A rating curve may fail to capture important hydraulic behaviors such as submergence, drawdown, or tailwater effects. This can lead to unrealistic outflows, particularly at storm drain inlets, culverts, or internal boundary points.

To avoid this, ensure the rating curve accurately reflects the downstream hydraulic conditions. Use the "Headwater Check" option to prevent drawdown errors and improve model stability, especially at culvert or pipe outlets. Be cautious when applying rating curves at internal boundaries, they should align with the modeled control point, not be used generically. When

modeling dry systems, apply a nominal flow (e.g., 0.01–1 cfs) to avoid zero-flow errors and document this assumption in the model description.

- **Inconsistent rating curves between linked elements:** In storage routing or reservoir models, rating curves used for outlets and downstream boundaries are inconsistent, leading to mass balance errors or unrealistic flow routing.
Check for continuity between inflow, storage, and outflow rating relationships. Rating curves should be reviewed as a set to ensure they produce stable and physically reasonable routing behavior.
- **Lack of documentation for custom or user-entered rating curves:** Custom rating curves are entered without documentation of how they were developed—e.g., based on observed data, survey, or model output.
Include a brief explanation in the modeling report or geometry metadata on how rating curves were derived and validated (using reliable resources). If curves were adjusted for calibration purposes, explain the rationale.
- **Rating curve developed using incorrect units or vertical datum:** Sometimes, the rating curves are developed or imported using inconsistent units or a different vertical datum, often when using legacy data, scanned figures, or external references. This can result in vertical offsets, mismatched elevation-flow relationships, or unrealistic outflow behavior in the model.
To avoid this, confirm that all rating curve elevations are in the correct vertical datum used in the HEC-RAS model (e.g., NAVD88). If curves are developed from old references or local benchmarks, apply the appropriate datum conversion and document it in the report. Also, verify that units (e.g., ft, m, cfs) are consistent with project standards.

d. Bridges and Culverts

Bridges and culverts hydraulics are highly sensitive to modeling inputs, including the placement of the four standard cross sections, high and low chords, structure shape and dimensions, and ineffective flow areas. Accurate inputs and careful evaluation of outputs for reasonableness are critical for properly modeling bridges and culverts in HEC-RAS. The following clarifications address typical oversight identified during FHAD reviews.

1. Standard Four Cross Sections Used for Structure Modeling

- The standard four cross section approach, as defined in the HEC-RAS User’s Manual and Hydraulic Reference Manual, must be consistently applied when modeling bridges and culverts, even on prismatic channels.
- It is helpful to include the cross section numbering corresponding to the standard four cross sections in the description. This adds clarity and supports QA/QC efforts by ensuring accurate spacing between cross sections based on expected flow expansion and contraction near structures.
- This document emphasizes the importance of bounding cross sections 2 and 3 of the standard four. These are critical for accurately modeling bridges and culverts and should be placed as close to the structures as possible. However, their geometry must represent the natural channel, be located outside of road embankments and exclude any manmade structures. Please refer to the HEC-RAS manuals for additional guidance.
- Cross sections 2 and 3 should generally have similar start and end points. This consistency facilitates structure data inputs and helps reduce confusion and errors.
- The end points of cross sections 2 and 3 should tie into high ground, where appropriate. Excessive extension along the toe of the embankment should be avoided and reviewed carefully.

- Cross section alignments often fail to properly account for bridge and culvert skew. It is preferred to use cross sections that are parallel to each other and to the structure. Where skew is present, apply a skew angle to correct the unreal flow areas caused by skewed structures.
- Cross sections surrounding bridges or culverts are sometimes incorrectly skewed. Please refer to Section II.c.2. of this document for further details.
- Channel inverts should be reviewed and adjusted using structure surveys or as-built data, as terrain near structures may be inaccurate due to vegetation or base flow interference. If a scour hole is present in the survey, it should not be incorporated into the channel geometry. Any modifications should be documented in the description.
- When adjusting channel inverts near structures, please refer to Section II.a.2 of this document.
- Cross sections 2 and 3 should reflect natural channel conditions and must not be artificially modified to match the structure openings, a common misunderstanding in thalweg adjustment noted in FHAD reviews.

2. Ineffective Flow Areas (IEFAs)

Ineffective flow areas are among the most discretionary yet critical parameters significantly affecting floodplain hydraulics near crossing structures. They must be applied carefully to achieve a consistent flow conveyance between the main channel and floodplain during both low and high flow conditions. The following notes are based on recurring observations from multiple FHAD reviews and are intended to support consistent culvert modeling.

- Modelers are encouraged to thoroughly review Chapter 5 – Modeling Bridges in the HEC-RAS Hydraulic Manual for best practices.
- The “Permanent Ineffective Flow Area” option should be used only when appropriate – such as for areas obstructed by levees, floodwalls, or elevated roadways – with supporting engineering judgment clearly documented in the description.
- The Ineffective Flow Areas option uses station parameters to define the boundaries between active and inactive conveyance areas near structures under low-flow conditions. Common issues include misalignment with standard contraction and expansion rules, failure to consider appropriate distances, or lack of justification for atypical station placements.
- Ineffective Flow Area stations should be placed outside of the bank stations. If this is not feasible, the bank stations should be reviewed and adjusted as necessary, or engineering judgment should be clearly documented in the description.
- Ineffective Flow Areas are not required at cross sections 1 and 4. If they are deemed necessary, modelers should use an iterative approach to review and adjust the placement of these cross sections accordingly.
- The Ineffective Flow Areas option uses elevation parameters to transition a wetted area from inactive to active based on corresponding water surface elevations. This process involves a complex iterative procedure. For detailed guidance, please refer to the HEC-RAS Hydraulic Manual. The following considerations should be carefully evaluated when assigning ineffective flow area elevations.
 - At cross section 2, ineffective flow elevations should be set below the lowest high cord and above the low cord. An iterative approach should be used to determine appropriate elevations that activate the entire cross section under weir flow conditions at the crossing structures.

- Significant drawdowns often occur at cross section 2, primarily due to improperly assigned ineffective flow area elevations. Following the recommendation above has proven effective in eliminating drawdowns in most cases.
- At cross section 3, elevations should initially be set at the low point of the top-of-road (i.e., the lowest high chord) where weir flow is present. The elevations may require fine-tuning to ensure consistent flow computations. Under weir flow conditions, water typically overtops the entire length of the structure, and the full overbank area in the vicinity of the structure should be assumed to actively convey flow up to and over the structure.
- The recommendation above has also proven effective in resolving drawdown issues upstream of structures.
- Stepped ineffective flow areas may be needed to accurately represent obstructions caused by roadway embankments, particularly in cases with perched culverts or elevated road crossing where significant overbank flow occurs. These stepped ineffective areas should mimic the actual terrain profile and represent where water is physically obstructed from reentering the channel, helping to more realistically simulate how overbank flow interacts with the embankment. Figure 12 illustrates an example of stepped IEFAs.

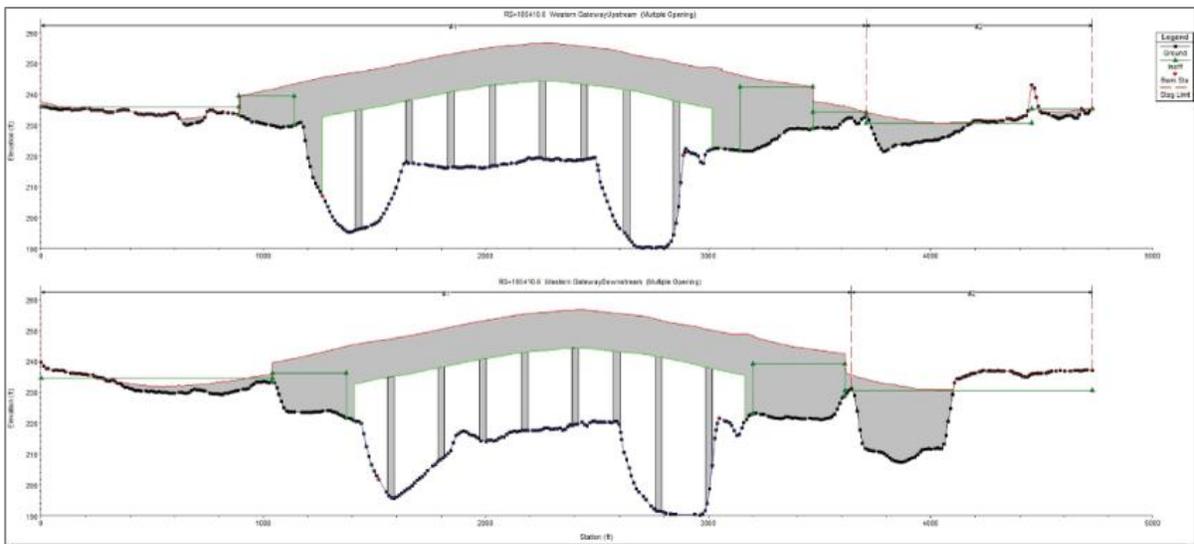


Figure 12. Illustration of stepped IEFAs as shown in a HEC-RAS screenshot of the Western Gateway/Route 5 Bridge over the Mohawk River in Rotterdam, New York (adapted from Suro et al., 2024).

3. Deck/Roadway Data

- Distance and width values are not only used to define the location of the bridge but are also critical parameters for applying the Energy Equation to compute energy losses through structures. For further guidance, please refer to the HEC-RAS Hydraulic Reference Manual.
- The alignments used for extracting the upstream and downstream high chord information must be included as part of the submittal for QA/QC purposes. The following points clarify common issues identified in FHAD reviews.
 - Misalignment with bounding cross sections: deck/roadway data must align with the bounding cross sections 2 and 3. The data should be projected perpendicularly to the cross sections to avoid distortion, particularly for skewed structures.

- Upstream alignment placement: The upstream alignment may be placed either at the upstream edge of the roadway or at the roadway median, which represents the most critical weir control cross section.
- Use of duplicated downstream data: For small crossing structures (e.g., narrow roadways or short culverts with uniform high cord conditions), duplicating the upstream deck/roadway data at the downstream side may be acceptable. In such cases, this approach often results in flat water surface profiles, which may be sufficiently accurate, as water surface elevation changes across the structure are expected to be minimal.
- Considerations for large structures: For larger structures—such as wide roadways or long culverts—the change in water surface elevation across the structure may be significant. In these cases, downstream deck/roadway data must be selected carefully to ensure a realistic water surface profile and proper flow transition across the crossing.
- The extents and elevations of fences, guard railings, New Jersey Barriers, and parapets at both the upstream and downstream ends should be included in the high cord data. If these features are excluded, a clear engineering justification must be documented in the description explaining why their inclusion is not necessary.
- The end points of the deck/roadway data must tie into the ground surface and extend across the full width of the cross sections. If this condition is not achieved, a clear explanation must be documented in the description. Figure 13 shows an example of insufficient deck/roadway data extents at the right overbank.

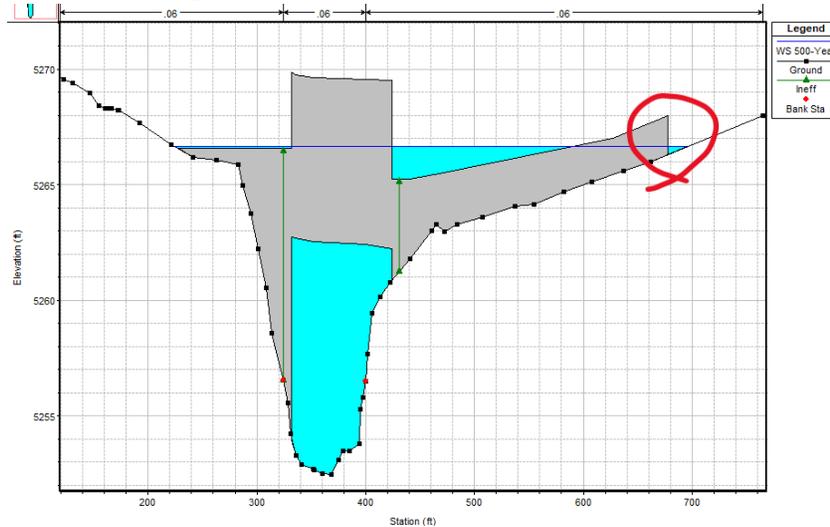


Figure 13. An example of insufficient deck/roadway data extents at the right overbank

- If the modeled floodwaters are fully contained within the bounding cross sections, but a virtual wall is used at the endpoints of the deck/roadway data (internal cross sections) to contain the water, both the bounding cross sections and the deck/roadway data must be expanded to fully encompass the highest flood event.
- Low chord and high chord elevations are critical parameters in bridge modeling. These values serve as flow threshold values that help the model determine flow conditions and select the appropriate equations for calculating water surface elevations at crossing structures. The following issues have been identified during multiple FHAD reviews.
 - Misuse of limited survey data: Survey data are sometimes underutilized or misinterpreted, resulting in high and low chord elevations that do not accurately represent the critical

hydraulic controls. In Figure 14, for example, only a single survey point at the center of the structure is used, leading to a flat or oversimplified structure profile and inaccurate representation of control elevations for pressure and/or weir flow. The red polylines in the example below illustrate the actual high chord and low chord based on the full set of survey data.

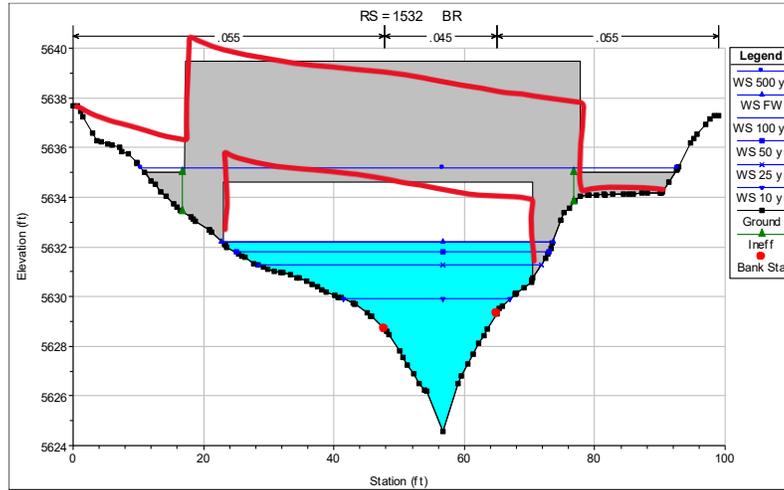


Figure 14. Example of misrepresenting bridge geometry due to limited survey data. A single centerline point was used to define the low/high chord, resulting in a flat profile. Red polylines show the correct elevation profiles based on all available survey points.

- Complex obstructions inside openings: Some structures contain complex internal features (e.g., structural beams) that cannot be accurately represented using the model's default settings. In these cases, engineers must manually adjust the opening dimensions to reflect the actual hydraulic conditions. Care should be taken to ensure that the low chord elevations remain consistent with the survey or as-built data.

4. Piers

Pier centerline stations are important as they affect the calculation of flow areas, obstruction loss, and energy dissipation within the bridge openings. HEC-RAS uses water surface elevations at the piers to calculate the reduction in conveyance due to pier obstructions. Inaccurate pier placement can distort the representation of conveyance and energy loss across the structure. If pier stationing is inaccurate, the program may overestimate or underestimate the submerged area impacted by the pier, especially under low-flow conditions or when the bridge opening is much larger than the modeled event. This can distort the representation of conveyance and energy loss across the structure.

- Pier centerline stations should be aligned perpendicularly to flow and geometrically centered between cross sections 2 and 3. Skewed pier placement should be avoided unless the structure is skewed and the modeling approach accounts for this.
- For structures with multiple piers, each pier should be modeled individually if possible. Spacing between piers should reflect actual field conditions or as-built plans.
- The width and shape (circular, rectangular, capsule) of each pier should be based on as-built drawings or survey data. Use appropriate shapes to reflect the pier's hydraulic behavior and surface area impacting flow.

- The sum of pier widths, gaps between piers, and bridge opening width should be consistent with the defined structure geometry. Discrepancies between pier geometry and bridge width can result in inaccurate flow area calculations.
- When pier geometry is not available or partially estimated, document the assumptions made regarding shape, spacing, and alignment in the model description. This is particularly important in older structures or inaccessible sites.

5. Sloping Abutment and/or Internal Bridge Cross Sections

- Vertical abutments can be defined as a part of the Deck/Roadway data.
- Sloping abutment data should be included when such features exist within the bridge opening, as they significantly affect flow patterns and contraction/expansion losses. Sloping abutments can be added using the “Sloping Abutments” option in the bridge editor.
- When complex geometry such as stepped abutments, trail underpasses or significant ground surface changes exists within the bridge opening and cannot be accurately represented using the sloping abutment option, the Internal Bridge Cross Sections Option should be used to define the bridge opening accurately.
- In the example below (Figure 15), the right channel bank appears to intrude into the bridge opening, even though the opening is actually clear within the structure. This issue may stem from the deck geometry not being properly projected to the bounding cross section, or from the structure’s placement near a channel bend. In such cases, the deck data should be adjusted to align more realistically with the channel geometry, or the Internal Bridge Cross Section option should be used to define accurate conditions within the bridge opening.

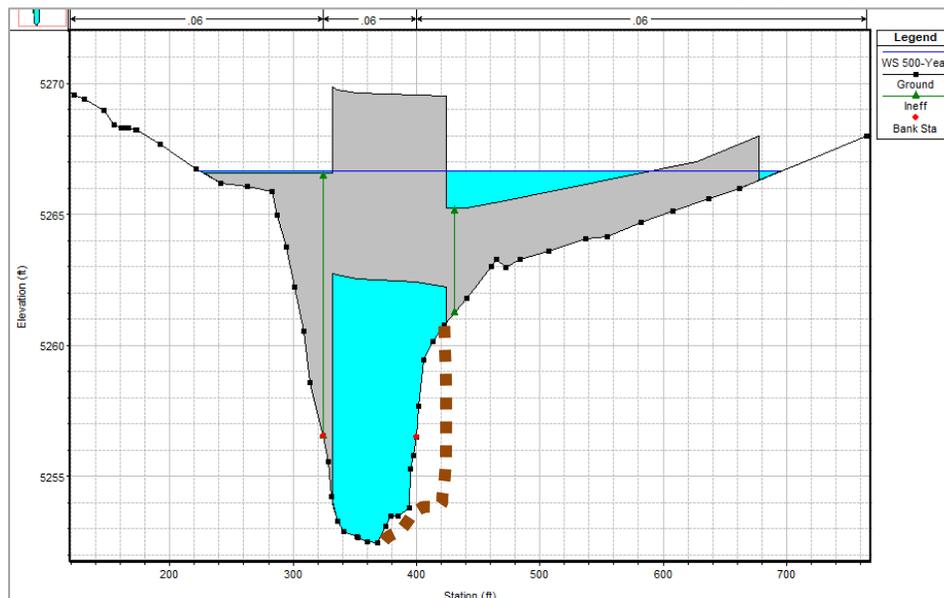


Figure 15. Example of a misaligned channel bank encroaching into the bridge opening due to inaccurate deck projection or structure placement. Although the actual opening is clear, the model geometry creates an artificial restriction.

- Internal bridge cross sections are strongly recommended when:
 - The structure crosses non-uniform terrain, such as a bend in the channel or sloping banks.
 - The deck alignment is significantly skewed relative to cross section orientation.

- There is a need to represent variability in low chord elevations or bridge soffit shape within the opening.
- Internal sections improve hydraulic accuracy by capturing changes in geometry that are not visible when only four bounding cross sections are used.
- Avoid relying solely on ineffective flow areas to compensate for misaligned abutments or irregular geometry. Where necessary, use internal cross sections to explicitly model flow restrictions caused by embankments or support structures.
- Cross section spacing between internal bridge sections and adjacent cross sections should be small enough to preserve energy losses but large enough to avoid numerical instability. For internal cross sections specifically (i.e., within the bridge opening), a typical spacing of 5 to 20 feet is recommended, depending on terrain complexity. This practice does not apply to the placement of bounding cross sections, which serve a different purpose in defining the contraction and expansion zones.
- If internal cross sections override the representation of natural banks (e.g., due to bridge placement across a slope or skewed terrain), ensure that their shape and elevation are still based on actual survey data or as-built conditions. Avoid artificially flattening, widening, or raising internal cross sections beyond what is supported by survey, as-built conditions, or terrain.
- All internal cross sections should be documented in the model description, with a summary of when and why they were used. Include cross section IDs and a reference to relevant profiles or figures if applicable.

6. Bridge Modeling Approach

- Low Flow Methods
 - When piers are present within bridge openings, both the Energy Equation and the Momentum Equation should be applied at a minimum. The higher of the two energy results should be used for the final output.
 - Avoid relying solely on the Energy Equation in the presence of piers or internal obstructions; Momentum or Yarnell methods may be required to account for additional energy losses.
 - The Yarnell Equation should only be used under Class A flow conditions, and only when the pier obstruction dominates the low flow hydraulics. A typical example is a railroad bridge with wooden piers, where eddy losses are dominant and flow remains within the piers' influence zone.
 - When applying the Yarnell method, confirm that conditions match the assumptions for Class A flow (e.g., subcritical flow, piers acting as primary restriction). Document the rationale for this selection in the Bridge/Culvert Data description.
- High Flow Methods
 - The preferred modeling approach is to use the Pressure and/or Weir Method, which is the default setting in the model.
 - When highly submerged conditions occur, the model will automatically switch to the Energy Equation. This ensures a realistic transition under overtopping or submerged flow regimes.
 - Engineers should confirm that the high chord and low chord elevations, as well as weir coefficients, are defined accurately to ensure appropriate switching between flow methods during simulations.
 - Any deviations from the standard low- or high-flow methods must be clearly documented in the Bridge/Culvert Data description.

- Check for flow method switching artifacts in profile plots or flow distribution outputs. Abrupt shifts in water surface elevation between low and high flow methods may indicate improper structure geometry or missing control elevations.
- Calibrate flow regime transitions using observed data (if available), particularly in FHAD studies where field observations or gage records exist. This helps validate that pressure/weir transitions occur at reasonable stages.

7. Culverts

- The preferred Solution Criteria for culvert hydraulics is “Computed Flow Control”. If an alternative option is selected, engineering judgment must be clearly documented in the description to justify its use and appropriateness.
- Culvert shapes and dimensions should be based on as-built drawings or surveyed data. The following points clarify common issues identified during FHAD reviews.
 - Crown elevation accuracy: Ensure that the crown elevation is accurate, as it is one of the several key geometric parameters influencing culvert hydraulics. While crown elevation plays a role in identifying control conditions (e.g., for weir or sluice gate flow at the inlet), the transition between inlet and outlet control also depends on tailwater conditions, culvert slope, length, roughness, and inlet geometry. Avoid oversimplifying by attributing flow control transitions solely to the crown elevation. Always verify elevation data with as-built drawings or surveys, and document any assumptions made during the modeling process.
 - Nonstandard culvert dimensions: Carefully investigate any deviations from standard industry shapes and dimensions. Surveyed data may be inaccurate due to factors such as sediment accumulation, scour, vegetation, partial blockage, or site access limitation. Always cross-reference multiple data sources when possible.
 - Special configurations: If a culvert has special configurations or existing conditions that cannot be modeled using the default HEC-RAS shapes and dimensions, engineering judgment should be used to determine an equivalent shape and dimension. In such a case, ensure the selected crown elevation matches the as-built or surveyed data.
 - Documentation of assumptions: All applications of engineering judgment must be clearly documented in the model description.
- The Chart Number and Scale Numbers should be selected based on the culvert’s inlet configuration. Refer to the HEC-RAS Hydraulic Reference Manual tables for appropriate values and select the combination that best matches field conditions.
- Distance to Upstream: The “Distance to Upstream” represents the distance from the culvert entrance to the upstream bounding cross section 2. This is typically different from the “Distance” parameter specified in the Deck/Roadway Data. Both should be reviewed for consistency with the physical layout.
- The entrance loss coefficient should be chosen according to the inlet configuration. Engineering judgment must be applied carefully when selecting this value, and the justification should be clearly documented in the model description. According to HEC-RAS Hydraulic Reference Manual, entrance loss coefficients should be calibrated whenever possible. The Tables shown in the manual are intended as guidelines, not absolute values.
- Manning’s n should be selected based on the culvert material. Any deviations from typical values, such as for internally lined CMPs, must be clearly documented in the model description.

- The use of the “Depth Blocked” parameter must be supported with a clear basis and calculation, if needed, and documented in the model description.
- Upstream and downstream invert elevations should be derived from as-built drawings or surveyed data. If an adverse culvert slope is identified, the data must be verified, and field reconnaissance should be conducted as needed. The condition must be clearly described and justified in the model description.
- Long culvert: In general, long culverts should not be modeled in HEC-RAS unless the following conditions are met:
 - The culvert is straight, with no bends, and maintains a uniform size and consistent slope along its entire length.
 - The culvert has sufficient capacity to convey all modeled flow events, as demonstrated by a detailed culvert hydraulics analysis.
 - If the culvert becomes surcharged, detailed water surface elevations along the overland flow path are not required, provided this is justified based on the surrounding land use conditions.
- Conspan culverts: Conspan culverts have become increasingly popular and are commonly used for drainage applications and pedestrian underpasses. While HEC-RAS can model Conspan structures, even if their span and/or rise are not in the predefined list, special attention is required. The following points address issues identified during FHAD reviews.
 - Modelers are strongly encouraged to review Chapter 6 – Modeling Culvert in the HEC-RAS Hydraulic Reference Manual to understand the capabilities and limitations of modeling Conspan culvert.
 - Modelers should ensure that the interpolated or scaled Conspan culvert geometry by HEC-RAS reflects the actual dimension of the structure.
 - Conspan culverts often contain pedestrian trails or other internal features. Modelers must assess the hydraulic impact of these obstructions and apply an appropriate modeling approach, rather than relying solely on the standard Conspan culvert routine.
- Unsteady flow modeling: For culverts modeled in unsteady flow simulations, ensure time step resolution is sufficient to capture flow transitions, especially under pressurized or outlet-controlled conditions. Use smaller time steps when headwater or tailwater conditions change rapidly.
- Tailwater conditions: Culvert performance is sensitive to downstream conditions. In flat terrain or urban settings, ensure the tailwater is accurately represented in the boundary condition or through downstream channel geometry.

8. Multiple Opening Analysis

- Flow should enter and exit each opening in a physically realistic manner, based on topography, conveyance capacity, and structure geometry. Inconsistent flow patterns can indicate errors in ineffective flow area setup, elevation data, or structure alignment.
- Use HEC-RAS flow distribution output: Review flow distribution tables or plots in HEC-RAS to confirm how flow is allocated between each opening under different flow conditions. Flow split percentages should match expected patterns based on channel alignment and invert elevations.
- Check for abrupt flow shifts: If flow switches abruptly between openings across flow ranges (e.g., 0% to 100% between events), review the ineffective flow areas, elevation controls, and structure geometry. This may indicate unstable transitions or poor elevation alignment.

- Use 2D modeling where appropriate: For very complex multiple-opening systems with braided overbank flow paths or significant interactions between openings, consider supplementing 1D modeling with 2D simulation or localized 2D breakout analysis for validation.
- Document flow assumptions clearly: Describe the flow distribution rationale in the model notes or report, especially if flow is intentionally directed to a primary opening (e.g., culvert vs. relief channel).

9. Skew Bridge/Culvert

- While skewed crossings with an angle up to 20 degrees showed no objectionable flow patterns under low flow conditions, the preferred modeling approach for FHAD studies is to apply the skew angle where appropriate.
- Floodplain hydraulics can become highly complex at skewed crossings. In certain cases, simply applying a skew angle may not address all hydraulic concerns. The modeler should evaluate all contributing factors — including flow direction, structure alignment, cross section orientation, and ineffective flow area placement — and focus on those that dominate floodplain hydraulics around the crossing structures. The selected modeling approach should prioritize accurate representation of base flood conditions (i.e., floodplain connectivity, flow paths, and energy losses) and must be approved by the District.

e. Inline Structure

Inline structures play a key role in controlling water surface profiles, flow transitions, and storage behavior. Inaccurate inputs or oversimplified assumptions can lead to instability, unrealistic backwater effects, or incorrect routing results. The following points outline common issues and how they should be addressed.

- A common issue is modeling inline structures using generic weir shapes without site-specific data. The structure shape, crest elevation, width, and control type should be defined based on field survey, as-built drawings, or design documentation. Generic parameters should only be used if justified by engineering judgment and clearly explained in the model description.
- Inline structures are sometimes modeled without accounting for tailwater effects, resulting in inaccurate flow conditions. When the tailwater can submerge the weir or gate, the tailwater influence must be considered. Use the submerged weir or outlet control options in HEC-RAS and verify that the rating curve or structure equations reflect downstream dependency.
- Bounding cross sections are often placed too far from the structure, leading to inaccurate energy losses. Cross sections immediately upstream and downstream of the structure should be placed close enough to capture head loss, backwater buildup, and elevation transitions. These sections must reflect natural terrain and exclude the structure itself.
- Inline reservoirs or detention structures are sometimes modeled without properly representing volume-elevation-storage relationships. Ensure the storage curve accurately reflects the available volume and validate routing behavior under unsteady flow. Check for realistic attenuation and delay of the inflow hydrograph through the structure.
- Model descriptions frequently lack sufficient documentation about the inline structure's function or assumptions. Clearly state whether the structure represents a dam, weir, gated control, drop, or other hydraulic feature. Include assumptions made for crest width, shape, control logic, and coefficients in the description.
- The rating curve used for the structure is often auto-generated and not reviewed for accuracy. Manually review or generate the rating curve, particularly for complex structures or those

affected by tailwater. Validate the curve against calculations, HY-8 results, or known operational behavior where available.

- Energy losses through the structure are often underestimated due to incorrect weir or gate coefficients. Use coefficients from reference tables that correspond to the structural material and flow condition. Adjust values based on field calibration or site-specific information when available.
- Flow is sometimes allowed through sections of the structure that should be blocked or inactive. For structures with gated or blocked openings, confirm that flow is restricted under appropriate stage conditions. Use the gated operation controls or adjust flow thresholds to accurately represent how the structure functions.
- An adverse slope or unnatural jump in the water surface upstream of the structure is sometimes caused by poor alignment or elevation errors. Review the upstream bounding cross section and terrain representation to ensure smooth transitions. Adjust cross section spacing or sample terrain more accurately around the structure footprint.
- Abrupt transitions at or near the structure can cause instability or unrealistic flow jumps. Avoid sharp elevation differences, vertical walls, or geometry gaps near the structure. Use interpolated terrain or additional cross sections to create smoother hydraulic transitions in both geometry and flow.

f. Lateral Structure

Lateral structures such as levees, overflow spillways, and embankments are critical for simulating flow exchange between channels and adjacent storage areas or floodplains. Accurate placement, elevation, and flow control assumptions are essential to represent overtopping, levee failure, or diversion flow paths. The following points identify common issues and recommended practices for lateral structure, levees, and split flow modeling.

1. Lateral Structure Setup and Geometry

- Inadequate extent: A common issue is that the lateral structure extent does not fully capture the most extreme modeled flood event, typically the 0.2-percent-annual-chance or 1-percent plus flood. The extent should be reviewed in plan view and supported by water surface profile comparisons.
- Overly detailed centerline tracing: Lateral structure centerlines are sometimes traced too closely along contour ridgelines, leading to artificially long weir lengths. The centerline of a lateral structure should be based on the best available terrain data and should accurately reflect the hydraulic control or crest of the spill location, while avoiding overly detailed tracing of contour ridges (zig-zag patterns) that could result in excessive weir length. Smooth, generalized alignment reduces unnecessary complexity while maintaining accurate flow paths.
- Missing crest elevation data: If embankment station and elevation data are not extracted from terrain along the centerline of the lateral structure, supporting information must be provided in the description of the corresponding lateral structures.
- Abrupt elevation changes: Sudden steps or depressions in the crest elevation can lead to unstable flow results. Unless specific features (e.g., notches) are present and documented, ensure a smooth and realistic elevation profile.
- Overestimated weir length and capacity: Long structures that convey flow only along certain segments should be broken into multiple parts with varying crest elevations. Ensure the modeled crest length reflects actual overtopping conditions.

2. Hydraulic Parameters and Connectivity

- **Unjustified weir coefficients:** The selected weir coefficient is not always appropriate for the terrain or structure type. The weir coefficient should be thoroughly reviewed and calibrated based on observed flows or known hydraulic behavior. Engineering justification must be provided in the description of the corresponding lateral structures to support the selected value.
- **Incorrect weir type:** Weir type is sometimes left as the default “broad crested” when a different shape is more appropriate. Review the site conditions and structure geometry to determine the correct weir type (e.g., broad crested, sharp crested, ogee). Select the type that best represents the physical behavior of the structure and adjust flow equations accordingly.
- **Missing flow linkages:** Flow entering or exiting the lateral structure is sometimes not properly linked to a storage area or adjacent 1D/2D system. Confirm that the lateral structure is connected to an appropriate storage area, 2D flow area, or separate river reach, and that the connection reflects actual overbank flow paths.

3. Levees and Non-Levee Features (NLFs)

- Clearly identify all levees and NLFs, especially those listed in the National Levee Database (NLD) or designated by the local community.
- Document critical levee attributes such as accreditation status, owner/maintenance responsibility, and hydraulic role.
- NLFs should be modeled using FEMA's Natural Valley approach unless a more appropriate method is documented and justified.
- Ensure all NLFs are correctly placed in the geometry and described in the report.
- Levees, especially those along reaches with floodways, must be modeled following FEMA's Levee Guidance.

4. Split Flow Modeling

Split flow occurs when a significant portion of the discharge follows a separate path from the main channel. In these cases:

- **Use distinct modeling elements:** Define separate reaches, cross sections, and alignment to clearly represent the split path.
- **Keep main channel discharge intact:** Do not reduce the main channel's flow to account for split flow. Instead, model the full flow in each path.
- **EGL/WSEL checks:** The energy grade line (EGL) or water surface elevation (WSEL) between the split flow paths should be within 0.5 ft at the upstream split point.
- **Include alternate flow plans:** If using flow splits to represent diversion paths, provide both “optimized” and “hard-wired” runs.

g. Storage Area

Storage areas are used to simulate volume-based routing, flood attenuation, and ponding behavior. They are often applied in detention basins, overbank floodplains, or other low-lying regions where flow temporarily accumulates. A proper definition of storage geometry, routing connections, and interaction with 1D/2D elements is essential for accurate hydraulic simulation. The following are common issues and how they should be addressed.

- A common issue (specifically in 1D models) is that ponding or floodplain storage areas are not defined at all, even when evident from terrain or floodplain behavior. When terrain or mapping clearly indicates backwater or ponding, modelers should define a storage area using the Storage Area feature in HEC-RAS. If not feasible, they should at a minimum use ineffective flow areas to represent temporary detention. This ensures the flood volume is correctly accounted for and prevents overestimation of flow capacity or channel velocities.
- Another typical error is that the storage area volume-elevation curve does not reflect actual site conditions. Storage volume should be based on survey, design drawings, or terrain-derived elevation-area data. Avoid using placeholder or flat curves unless supported by documentation and clearly marked as temporary in the model.
- Inflow and outflow connections to storage areas are often undefined or incomplete. All relevant inflows (e.g., lateral structures, 1D reaches, 2D flow areas) and outflows (e.g., outlets, culverts, spillways) must be defined to simulate realistic storage routing. Use connection types appropriate to the flow regime (e.g., weir, culvert, rating curve).

h. 2D Flow Area

2D flow areas are critical for simulating complex overland flow paths, ponding, flow splits, and spatially distributed hydraulic behavior in floodplains, alluvial fans, and urban areas. When improperly configured, 2D domains can introduce instability, unrealistic flood extents, or incomplete representation of flow dynamics. Below are issues identified across multiple studies, along with recommended approaches.

1. Terrain Coverage and 2D Domain Extent

- A common issue is that the 2D flow area does not cover the full extent of flooding, causing flows to leave the domain or be truncated. The 2D flow area should extend far enough to contain the entire 0.2%-annual-chance (500-year) floodplain, including flow paths that may not be evident during smaller events. Always check flood extents against terrain to ensure full coverage.
- Breaklines are often missing along key features such as roads, spillways, high ground, and canal banks. This can lead to unrealistic flooding, disconnected flow paths, and missed control points.
- Some terrain surfaces (elevation data) sometimes contain voids, flat spots, or incorrect elevations. Always QA/QC the terrain surface before mesh generation. Address holes, pits, or artifacts using interpolation or supplemental survey data to prevent unrealistic ponding or dry zones.

2. Mesh Resolution and Refinement

- The computational mesh is sometimes too coarse to capture hydraulic features or flow paths accurately. Mesh resolution should be refined near critical structures, flow splits, or narrow conveyance areas. To maintain terrain fidelity, use smaller cell sizes or break lines along roadways, channels, and embankments.
- In developed areas, breaklines are not consistently defined around buildings. This can result in poor representation of flow paths and unrealistic flood extents. Closely spaced buildings can be grouped within a single breakline, while large or hydraulically significant buildings should be outlined individually. However, applying breaklines around numerous buildings may generate small cells that exceed the terrain resolution or cause excessive computational load. In such cases, alternative approaches such as applying high Manning's n values to building footprints or modifying terrain directly may be more efficient and still provide a realistic

hydraulic representation. The choice of method should balance modeling accuracy, computational efficiency, and available data quality.

- Structures and crossings may appear within the floodplain without breaklines or refined mesh, misrepresenting their hydraulic impact. These features should be reviewed and represented using internal connections or refined mesh as appropriate.

3. Breaklines and Flow Connectivity

- Flow disconnections have been observed in several areas due to missing or misaligned breaklines, especially around roads, bridges, and small reaches outside the main channel. These disconnects lead to gaps in inundation mapping and poor flow continuity.
 - Missing or misaligned breaklines may also cause flow to improperly bypass hydraulic features, leading to underestimated upstream water surface elevations. Ensure breaklines align correctly to maintain realistic connectivity.
- Detention basins, spillways, and drop structures are often underrepresented in the terrain and not discussed in the modeling memo. Their hydraulic influence, whether flood control or overflow, should be considered and documented.
- If a feature such as a diversion canal is present but not included in the model, justification should be provided (e.g., negligible capacity during flood conditions, supported by owner communication or sensitivity analysis). Otherwise, it should be included using breaklines and appropriate connectivity.

4. Representation of Structures

- Levees and non-levee features are sometimes omitted or incorrectly aligned. Modeling assumptions related to levees should be clearly documented, and NFHL alignments should be checked against the model. Use FEMA Levee Guidance when determining how to represent accredited vs. non-accredited levees.
- Bridges, culverts, and road crossings within the study area, but outside the main reach, are often overlooked. Even if located on smaller reaches or tributaries, these structures can influence local flow behavior and should be modeled using internal connections or refined mesh geometry.
 - The appropriate modeling approach for these features should be discussed prior to modeling. The best modeling practice should be selected based on the project's goal and available resources.
- Flow control features like spillways, diversion canals, or drops are sometimes omitted without explanation. Their function (e.g., flow diversion, energy dissipation) should be reviewed, and their presence in the model confirmed.

5. Boundary Conditions and Hydrology Integration

- Boundary conditions are sometimes incomplete or undefined. Ensure that all inflows, outflows, and upstream/downstream boundaries are clearly specified and are tied to appropriate hydrographs, rating curves, or known flow conditions. Avoid "dry" boundaries unless intentional.
- Assumptions related to detention basin operation, negative discharges, or internal flow reductions are often undocumented. These should be explained, especially when affecting results across multiple locations.

- Flow reduction methods used in older 1D models (e.g., subtracting flow at a cross section) may not be appropriate in 2D. Carefully assess their effect on floodplain connectivity and flow distribution.

6. Manning's n Values and Roughness Mapping

- Uniform roughness values are sometimes applied across varying terrain types. This can lead to unrealistic floodplain behavior. Use land cover or high-resolution imagery to assign spatially varied Manning's n-values, and document your assumptions in the model metadata.

7. Hydraulic Instability and QA/QC

- Hydraulic results may show instability, including spiked velocities or sudden water surface changes. Instability is often caused by steep terrain, abrupt changes in elevation, or poorly aligned cell faces. Apply breaklines, smoothing, or cell face alignment to correct flow direction and energy gradients.
- Modelers sometimes rely only on automated mesh generation without verifying geometry near key features. Manually review mesh refinement around structures, bridges, embankments, or culvert outlets. Adjust cell sizes and orientations to maintain control geometry and prevent flow bypassing.
- Downstream flow disconnections or unrealistic transitions may stem from missing or mismatched boundary types or a lack of connectivity at road crossings, canals, or drainage structures.

8. Documentation and Transparency

- Modeling reports often lack discussion of key features such as levees, spillways, canals, or drop structures. All modeling assumptions related to these features, whether included or excluded, should be clearly documented with a rationale.
- Any omitted features (due to low impact, limited data, or operational status) should be justified, especially if noted in NFHL or other datasets.

9. Special Notes on Diversions and Floodplain Tie-ins

- Diversion canals should be evaluated for their hydraulic function: whether they carry flood flows, reduce WSEs, or divert excess volume. Their modeling treatment must align with FEMA guidance.
- All model BFEs tie-in within 0.5 foot to existing/effective study information, upstream and downstream including adjacent county/basin studies; Different models on different stream segments tie in within 0.5 foot; Model extents may need to be adjusted to ensure logical tie ins within 0.5 feet; Tie-in exceptions must be documented.

i. SA/2D Flow Areas Connection

SA/2D flow area connections are critical for allowing water to move between 1D elements and 2D flow domains. Improper or incomplete connections can result in poor representation of flood routing, water surface elevations, or floodplain exchange. The following outlines common issues and how they should be addressed.

- A common issue is that flow connectivity between 1D and 2D domains is not properly defined, leading to unrealistic water surface discontinuities. When linking a 1D river reach, lateral structure, or storage area to a 2D flow area, use SA/2D connection lines or lateral structures.

Ensure that the connection line geometry matches terrain elevations and includes proper flow control settings (e.g., weir, culvert, rating curve).

- Connection lines are sometimes placed correctly. Use best-available terrain data and field knowledge to position connection lines where flow interaction is expected. Match the crest elevation of the connection to the channel bank or levee opening to ensure realistic overtopping and routing.
- Elevation profiles along connection lines are often not reviewed or corrected, resulting in unrealistic flow paths. Always review the elevation vs. station profile along each connection line. Adjust elevations manually or interpolate using terrain to reflect true hydraulic features, such as road overtops, levee breaches, or berms.
- Manning's n-values along the connection line are not always specified or matched with adjacent terrain. Assign Manning's values along the connection line that are consistent with adjacent channel or floodplain conditions. Avoid abrupt roughness changes that can create artificial energy losses or instability.
- The flow direction between 1D and 2D areas is not visually validated. After running the simulation, use flow vectors, connection hydrographs, or mass balance summaries to confirm that flow is moving in the expected direction across the connection. Recheck elevations if reverse or stagnant flow appears.
- Flow exchange is sometimes unstable in unsteady models due to poor connection alignment or missing time step refinement. Ensure the time step is small enough to capture rapid flow exchange. For high-gradient or fast-routing connections, consider local refinement near the connection or reduce the global time step.

III. RUN

The Run configuration in HEC-RAS plays a critical role in the overall accuracy, clarity, and defensibility of a hydraulic model. It defines which flow files, geometry, and computational settings are used for simulations and therefore directly affects the outputs that inform floodplain mapping and regulatory decisions. Improper or inconsistent run setups can lead to errors, delays in the review process, and ultimately, unreliable results. This section summarizes common issues repeatedly observed during FHAD reviews and provides guidance to ensure best practices are followed in model setup and documentation.

a. Steady Flow Analysis

1. Multiple Profiles Run

- A recurring issue is that the default modeling settings have been modified without documentation and explanation in either the hydraulic model or the FHAD report. For floodplain hydraulic studies within the District's boundary, the default settings in the HEC-RAS program should be maintained. If any default settings have been revised, a clear justification should be included in the Plan Description and documented in the report
- Incomplete profile sets or unclear naming conventions are also common. Ensure that all required flood profiles (10-, 25-, 50-, 100-, 1%plus-, and 500-year events) are included and that plan and profile names are concise and descriptive to support review clarity.

2. Floodway Run

- One frequent mistake is using modeling settings that are inconsistent with those in the multiple profiles run. The best practice for creating a Floodway Run Plan is to use the ‘Save Plan As...’ function to duplicate the Multiple Profile Plan and then modify it into a floodway plan.
- A common issue is that the floodway profile is included in the Multiple Profile Plan. The District prefers separate plans for the base model and the encroachment model while using the same geometry. This approach improves model run time, simplifies model management, and prevents encroachments from being incorrectly assigned to other profiles.

b. Unsteady Flow Analysis

Unsteady flow modeling is essential for simulating time-varying flow conditions such as storm hydrographs, reservoir releases, or flood routing through complex terrain. While unsteady simulations are not currently used for regulatory mapping in FHAD studies, they may be employed to evaluate system performance, support design decisions, or analyze dynamic behavior during storm events. These simulations offer greater accuracy but also introduce additional risks for instability, unrealistic results, or mismatches between inputs and outputs. The following common issues and best practices apply to unsteady flow modeling used for non-regulatory analysis in FHADs.

- A common issue is that initial conditions do not align with the boundary conditions, resulting in unrealistic surges or instabilities at the start of the simulation. The initial water surface elevation should reflect base flow conditions, storage levels, or stage data that align with the upstream inflow and downstream tailwater assumptions. Avoid setting a dry model when inflow is already present.
- Inflow hydrographs are sometimes poorly defined, using coarse time intervals or values that do not reflect expected storm behavior. Hydrographs should be detailed enough to capture the rising limb, peak, and recession of the flow event. Use 15-minute to 1-hour intervals for typical storm events and validate that peak timing aligns with catchment response.
- Time step is too large or too small, causing either numerical instability or excessive run time. The computation time step should be chosen based on Courant conditions, geometry resolution, and flow velocities. Use the HEC-RAS stability diagnostic tool or trial-and-error to find the smallest stable time step without overburdening run times. Shorter time steps (e.g., 5–30 seconds) may be needed in steep terrain or rapidly varying flows.
- Abrupt lateral inflows (e.g., hydrographs from subbasins or tributaries) are added without smoothing or checking for model impacts. Sudden lateral inflows can create localized surging or backwater fluctuations. Apply hydrograph smoothing, ramping, or use intermediate storage areas to soften transitions.
- Flow routing behavior is not reviewed using flow distribution or storage plots. Always check flow hydrographs, velocity plots, and volume balance outputs to ensure the flow is routing properly through the system. If significant volume loss or gain is observed, revisit geometry, boundary conditions, or connection logic.
- Instabilities occur at bridges, culverts, or transitions due to rapid elevation or velocity changes. Review bridge/culvert time steps, ineffective area behavior, and storage damping options. Apply additional cross sections or adjust contraction/expansion coefficients as needed to stabilize flow transitions.
- Model shows unrealistic ponding, drying, or flooding in 2D areas during storm peaks.

- Review terrain for depressions or flat spots, validate boundary and connection conditions, and use small enough 2D cell sizes in critical areas. Breaklines and embankment enforcement can correct disconnected ponding zones.
- Unsteady flow plan descriptions lack documentation of settings and assumptions. Clearly state all important run parameters in the Plan Description, including initial conditions, hydrograph sources, time step, and any assumptions related to storage or gate operations.
- Use of HTAB parameters is inconsistent with terrain or flow behavior. Ensure the maximum flow and number of points in HTABs reflect expected flood conditions. Recompute HTAB curves if geometry or flow conditions change.
- Model convergence is not verified. Use output detail checks, velocity surface animations, and warning/error logs to ensure convergence is achieved and results are free of instabilities.

IV. Floodway

Floodway analysis is a system-based process that supports resilient floodplain management, risk reduction, and regulatory compliance. While the technical aspects of meeting natural rise and surcharge criteria are essential, it's important to take a broader perspective and ensure the floodway configuration supports the community and natural system as a whole. The floodway is a tool for sustainable planning and should reflect system hydraulics, not just isolated cross sections. Key concepts to keep in mind:

- A tool for communities: The floodway is not just a modeling output; it's a planning and regulatory tool that helps communities manage risk, guide development, and preserve natural floodplain functions.
- Floodway as a system: A floodway should be understood as a continuous, interconnected system that conveys flow efficiently during flood events. Its configuration should reflect the natural hydraulics of the river, not just what "fits" numerically.
- System-based configuration: During floodway modeling, ensure that the configuration aligns with the overall system behavior. Avoid abrupt or unrealistic transitions that may meet technical criteria but fail to represent the true flow dynamics.
- Floodway creep: Be mindful of "floodway creep", the gradual inward shift of floodway boundaries over time due to overly conservative or piecemeal modeling. This can reduce the effectiveness of the floodway and limit future floodplain management options.
- Floodplain preservation: A well-designed floodway supports the broader goal of preserving floodplain storage, habitat, and connectivity. It should balance hydraulic performance with environmental and community values.

Despite established guidance, several recurring issues are seen in floodway modeling that may affect accuracy or regulatory defensibility. These include:

- Floodway downstream boundary conditions are not adjusted to reflect the maximum encroachment scenario at the starting location.
- Floodway tie-in issues may occur at both downstream and upstream ends of the model. Ensure that the floodway boundary connects smoothly with the effective floodplain from adjacent studies or existing regulatory mapping, avoiding any visible gaps, overlaps, or misalignments at the model limits.

- Floodway encroachment stations are placed on dry land (outside of the 1% floodplain). This leads to overestimation of available conveyance and violates FEMA and District guidance. Encroachments must be located at or within the wetted overbank areas.
- Floodway encroachment stations are placed inside the bank stations. The floodway is intended to preserve flow through the main channel and adjacent overbank, encroachments inside bank stations reduce conveyance unrealistically and violate the definition of a floodway.
- Floodway top width includes islands. Consultants should discuss divided flow conditions with the District before initiating floodway modeling, especially when these conditions are hydraulically significant, particularly in urbanized areas where structures are closely located near the floodplain.
- Floodway surcharges exceed the allowable tolerance at the structure's internal cross sections but pass the check everywhere else. While surcharges may pass globally, check the bridge/culvert internal XS for exceedances and ensure any justification is clearly documented.
- Floodway encroachment is applied unevenly across asymmetrical floodplains without justification. When encroachment is greater on one side, document the rationale (e.g., levees, critical infrastructure, land use constraints).
- Encroachment spacing is too narrow, creating instability or unrealistic acceleration. In high-gradient areas, widen encroachments or refine geometry to avoid excessive velocity increases. MHFD also requires that the surcharge on the HGL in the encroached model remain below 0.5' to prevent excessive increases in velocity.
- Floodway includes areas of non-conveyance or fringe flow. Use velocity plots or ineffective flow designations to confirm that the floodway truly follows active conveyance paths.
- Floodway does not preserve the main flow corridor: Encroachments should not block or divert the core of the base flow. Use profile plots and velocity maps to confirm the floodway maintains its intended capacity.
- Between cross sections, floodway boundaries are interpolated from the encroachments at the bounding cross sections. However, in meandering channels – even when the geometry appears uniform – the river centerline may fall outside the interpolated boundaries. To address this, encroachment stations should be adjusted, or additional cross sections should be added at channel bends to better support accurate floodway interpolation.
- Floodway results are not supported with tables or visual QA: Include summary tables of encroachment stations, surcharge values, and widths. Visual floodway boundary checks in RAS Mapper are strongly recommended.

V. Flood Profiles

Flood profiles represent the longitudinal variation in water surface elevations along the modeled stream reach and are used to delineate floodplain boundaries. Drawdowns and profile discontinuities can result in mapping errors, misrepresent physical flow behavior, or indicate instabilities or modeling issues. All profiles should be carefully reviewed to ensure they reflect realistic and hydraulically defensible results.

a. Drawdowns

- Excessive drawdowns: A typical error is that flood profiles contain drawdowns exceeding 0.5 feet between adjacent cross sections, which may reflect unrealistic energy losses or modeling errors. Drawdowns on all flood profiles included in a study should be eliminated or reduced to less than 0.5 feet in the hydraulic model, using defensible modeling techniques that adhere to

sound hydraulic principles. The methods and engineering justifications used to address these drawdowns should be documented in the description at the corresponding cross sections.

- Mapping inconsistencies due to drawdowns: Uncorrected drawdowns result in inconsistencies between the hydraulic model and the floodplain mapping. All drawdowns must be mitigated in the final flood profiles. The same corrections should also be applied to the topographic workmap so that alignment between profile results and delineation products is maintained.
- Recommended modeling adjustments: To eliminate the drawdowns, the following parameters may be adjusted in the order of priority, as appropriate: Manning's n-values, ineffective flow areas (particularly around structures), contraction/expansion coefficients, and bank station locations.

The appropriate solution will depend on the specific site conditions. For instance, in highly developed urban areas, the presence of storm sewer systems and negative channel slopes may require a more tailored approach that incorporates additional field data and iterative testing.

b. Crossing Profiles

Crossing flood profiles, where water surface elevations from different frequency events intersect at the same location, can create confusion in interpretation, impact floodplain mapping, and raise concerns about model accuracy. These crossings are a common challenge when using a shared geometric model to compute flood elevations across multiple return periods. Whenever possible, profile crossings should be eliminated through model refinements. If crossings persist and are hydraulically justified, the rationale should be clearly documented, along with an explanation of why further adjustments are not feasible or necessary.

Several factors, acting independently or in combination, can lead to crossing profiles. These include:

- Complex channel or floodplain geometry
- Incorrect or inconsistent ineffective flow areas
- Abrupt changes in flow velocities or flow areas
- Inconsistent conveyance between the channel and floodplain across consecutive cross sections

Among these, inconsistent conveyance is often the primary contributor and should be carefully reviewed when attempting to eliminate crossing profiles. Ensuring smooth transitions in conveyance and maintaining hydraulic continuity between cross sections are key best practices.

VI. Flood Hazard Delineations

Stream channel boundaries or stream centerlines must be shown within the 1%-annual-chance floodplain. If a regulatory floodway is developed, the stream must also be shown within the mapped floodway boundaries. These delineations help clearly define the hydraulic context for floodplain mapping and regulatory coordination.

VII. FHAD Tables

a. Agreement Table

Instructions for completing the table and the required data format are provided in the FAHD Guidelines. The table can be expanded as needed to cover the full extent of the study area.

The Agreement Table is a QA/QC tool intended for use by the consultants during the development of detailed floodplain mapping. It should also be reviewed by project managers, the District and Communities to ensure consistency. Note that this table will not be included in the main FHAD report, as it serves as internal documentation. Instead, it will be included in the Technical Appendix. The following clarifications are provided to address common issues identified in FHAD reviews.

1. Reference locations (Column 1) should be provided, as they are helpful for orienting and identifying floodplain information.
2. Cross Section (Column 2) refers to the Cross Section River Station used in the hydraulic model, which may differ from the actual river station.
3. River Station (Column 3) represents the distance measured along the river centerline from a confluence or other significant reference point, formatted as 0+00.
4. The distance between Cross Sections (Map, Column 5) and Cumulative Distance (Map, Column 8) should reflect the measurement taken along the river centerline or profile baseline from the topographic workmap. These distances should not be calculated in the spreadsheet.
5. BFE (Profile, Column 19) should show the 100-year flood profile with corrected drawdowns.
6. Whole-foot BFEs between cross sections are no longer required as part of the final FHAD products. BFE Location (Column 21) is used to confirm the inclusion of additional BFEs where needed for clarity, such as near backwater areas, rapid water surface elevation changes, or confluences.
7. Comments and/or Explanations (Column 22) should provide description or justification for any discrepancies among model, map, or profile values at a given cross section. This column should also be used to document specific mapping issues, assumptions, supporting analyses and engineering judgements.

b. Floodplain and Floodway Data Table

Instructions for completing the table, along with the required data format, are provided in the FAHD Guidelines. The table may be expanded as needed to cover the full extent of the study area and is considered a formal component of the final FHAD mapping deliverables.

The Floodplain and Floodway Data Table is a component of the final mapping products and should align with the results from the final hydraulic model, flood profiles, and floodplain mapping.

The following clarifications address common issues that have been identified in FHAD reviews.

1. Reference locations should be included, as they are helpful for orienting and identifying floodplain information.
2. Cross Section (Column 2) refers to the Cross Section River Station used in the hydraulic model, which may differ from the actual river station.
3. River Station (Column 3) represents the distance measured along the river centerline from a confluence or other significant reference point, formatted as 0+00.
4. Significant digits should be applied according to the FHAD Guidelines.
5. **100-year water surface elevations (Column 13) must reflect the final flood profile, with all drawdowns corrected.**
6. **100-year floodplain width (Column 15) and floodway width (Column 19) should be based on measurements taken directly from the final mapping products.**

7. Note (Column 24) should be used to report typical mapping issues in an itemized format, helping to avoid overcrowding in the table.
8. Comment (Column 25) should be used to report specific mapping issues, assumptions, and engineering judgment that do not fall under typical mapping issues. This information often duplicates the content in Comments and/or Explanations (Column 22) of the Agreement Table and may also include additional details relevant to the final flood profiles and topographic floodplain mapping.

Resources

- Mile High Flood District (MHFD) (January 2022, April 2025 updated). Flood Hazard Area Delineation Guidelines.
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- Federal Emergency Management Agency (FEMA) (2020). Guidance for Flood Risk Analysis and Mapping Hydraulics: Two-Dimensional Analysis, Available at https://www.fema.gov/sites/default/files/documents/fema_hydraulics-two-dimensional-analyses.pdf, accessed July 2025.
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- FEMA (2020). Guidance for Flood Risk Analysis and Mapping: Profile Baseline Guidance, Available at https://www.fema.gov/sites/default/files/documents/fema_profile-baseline-guidance.pdf, accessed July 2025.
- Suro, T.P., Niemoczynski, M.J., and Boetsma, A. (2024). Development and calibration of HEC–RAS hydraulic, temperature, and nutrient models for the Mohawk River, New York: U.S. Geological Survey Scientific Investigations Report 2024–5005, 90 p., <https://doi.org/10.3133/sir20245005>

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